

# **Block\_3\_IA North Central\_2020\_D20 Lidar 2020 Final Report**

Report Produced for U.S. Geological Survey

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Submitted From:

**Aerial Services, Inc.**

6315 Chancellor Dr.

Cedar Falls, IA 50613

319.277.0436

Submitted to:

**U.S. Geological Survey**

1400 Independence Road

Rolla, MO 65401

573.308.3810

## Contents

<b>Overview</b> .....	5
Project team.....	6
Survey area .....	6
Date of survey .....	6
Coordinate reference system .....	7
Lidar vertical accuracy.....	7
Project deliverables.....	8
Project tiling footprint.....	8
Project Area Elevation Model .....	9
<b>Aerial Surveys International, LLC LiDAR Acquisition Details and System parameters</b> .....	10
Lidar System parameters .....	11
<b>Calibration Report</b> .....	12
Acquisition Control .....	12
Airborne GPS Kinematic.....	12
Generation and Calibration of Laser Points (raw data) .....	12
<b>Boresight and Relative Accuracy</b> .....	18
<b>Final Calibration Verification</b> .....	19
Between Swath Relative Accuracy (DZ Orthos).....	22
Within Swath Relative Accuracy (Intraw swath) .....	23
Horizontal Alignment/Calibration Check (Rooftops/Planar Surface Profiles) .....	24
<b>SurvTech Solutions LiDAR Acquisition Details and System Parameters for Iowa North Central</b> .....	25
Lidar System parameters .....	26
<b>Calibration Report</b> .....	27
Acquisition Control .....	27
Airborne GPS Kinematic.....	27
Generation and Calibration of Laser Points (raw data) .....	27
<b>Boresight and Relative Accuracy</b> .....	34
<b>Final Calibration Verification</b> .....	35
<b>LiDAR Quality Control Reporting</b> .....	38
Overview .....	38
Between Swath Relative Accuracy (DZ Orthos):.....	40

Within Swath Relative Accuracy (Intraswath): .....	40
Horizontal Alignment/Calibration Check (Rooftops/Planar Surface Profiles): .....	41
<b>DATA CLASSIFICATION AND EDITING.....</b>	<b>43</b>
LiDAR Qualitative Assessment .....	45
<b>VISUAL REVIEW .....</b>	<b>45</b>
Data Voids .....	45
Bridge Removal Artifacts.....	46
Culverts .....	47
Dirt Mounds .....	48
Flightline Ridges .....	49
Dam and Lock system .....	50
FORMATTING .....	50
<i><b>LiDAR Positional Accuracy.....</b></i>	<i><b>51</b></i>
BACKGROUND .....	51
SURVEY VERTICAL ACCURACY CHECKPOINTS .....	51
VERTICAL ACCURACY TEST PROCEDURES .....	60
VERTICAL ACCURACY RESULTS.....	61
HORIZONTAL ACCURACY TEST PROCEDURES .....	61
<i><b>Breakline Production methodology.....</b></i>	<i><b>62</b></i>
Breakline Qualitative Assessment.....	62
Feature Definition .....	62
Inland Streams and Rivers.....	62
Inland Ponds and Lakes.....	62
Islands .....	62
Bridge Breaklines .....	62
<i><b>Intensity Imagery Production &amp; Qualitative Assessment .....</b></i>	<i><b>63</b></i>
INTENSITY PRODUCTION METHODOLOGY .....	63
INTENSITY QUALITATIVE ASSESSMENT.....	63
<i><b>DEM Production &amp; Qualitative Assessment .....</b></i>	<i><b>64</b></i>
DEM PRODUCTION METHODOLOGY .....	64
DEM QUALITATIVE ASSESSMENT.....	64
DEM VERTICAL ACCURACY RESULTS .....	65

<b><i>Appendix A: List of Delivered LAS File.....</i></b>	<b>66</b>
<b><i>Appendix B: Aerial Surveys International, LLC Mission GPS and IMU Processing Report .....</i></b>	<b>173</b>
<b><i>Appendix C: SurvTech Solutions Mission GPS and IMU Processing Report .....</i></b>	<b>201</b>

## Overview

This task order is for a spring/summer 2020 leaf-off lidar survey to be collected over a primary Defined Project Area (DPA) in the state of Iowa of approximately 19,737 square miles, including the counties of: Boone, Buena Vista, Butler, Calhoun, Carroll, Cerro Gordo, Clay,, Dallas, Dickinson, Emmet, Floyd, Franklin, Greene, Grundy, Guthrie, Hamilton, Hancock, Hardin, Howard, Humboldt, Jasper, Kossuth, Marshall, Mitchell, Osceola, Palo Alto, Pocahontas, Polk, Sac, Story, Tama, Webster, Winnebago, Worth and Wright. This project will support the National Resources Conservation Service (NRCS) high resolution elevation enterprise program, the Iowa Department of Agriculture and Land Stewardship (IDALS) Iowa Flood Plain program, and the 3DEP mission. Block 3 of North Central Iowa was planned for the acquisition, processing, and derivative products of lidar data to be collected at an QL2 aggregate nominal pules spacing (ANPS) of  $\leq 0.71$  meters. Approximately 6132 square miles of Block 3 referred to as Block\_2\_IA North Central\_2020\_D20 Lidar 2019 was acquired in the spring of 2020 with one flight flown in the spring of 2021. Block 3 Iowa North Central project area consists of 10 Iowa counties; Carroll, Greene, Guthrie, Boone, Dallas, Story, Polk, Marshal, Jasper, and Tama. The condition of the ground was good during the collection of the survey.

Acquisition of the IA North Central DPA was broken out to three subcontractors in the following manner.

Contractor	Number of Flight Days	Square Miles Flown
Aerial Surveys, International	15	$\sim 12,411$
SurvTech Solutions	4	$\sim 2,889$
TAC	13	$\sim 4,437$

Table 1: Subcontractor Days of Flight and Square Miles Flown

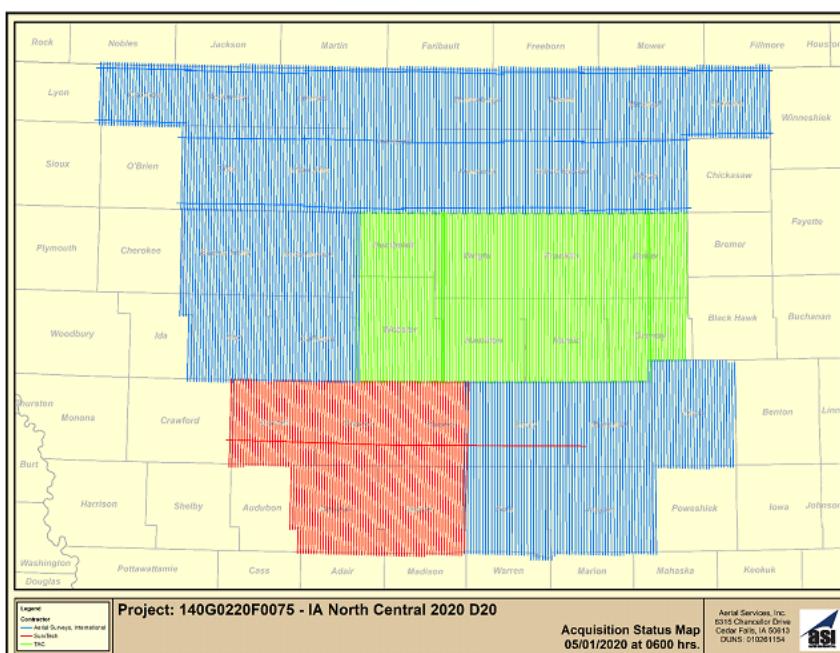


Figure 1: Iowa North Central DPA Subcontractor Breakout

The LiDAR data for Block 3 Iowa North Central was processed and classified according to project specifications. Detailed breaklines, bare earth Digital Elevation Models (DEMs), and Intensity Images were produced for the Block 3 Project area. Data was formatted into tiles with each tile covering an area of 1000 meters by 1000 meters. A total of 16,106 LAS files, 16,105 DEMs, and 16,105 Intensity Images were produced for the project, encompassing the Block 3 Project area of approximately 6132 square miles and formatted into 16,106 total tiles. Block w4140n4593 is a sliver tile containing 2 LAS points. Block w4140n4593 is less than 1 meter at its widest part, therefore no DEM, or DSM could be produced for this Block.

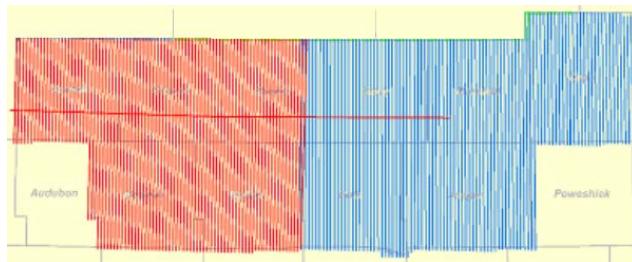


Figure 2: Block 3 Iowa North Central Breakout

## Project team

Aerial Services, Inc. (ASI) served as the prime contractor for this project. In addition to project management, ASI was responsible for LAS filtration of the entire Block 3 Project area. ASI also performed bare earth cleanup of 3243 square miles of the Block 3 Project area. ASI produced the LiDAR products; Digital Elevation Model (DEM) production, Intensity Image production, and quality assurance for the entire Project area. Subcontractor: Aerial Surveys International, LLC (ASU) was responsible for LiDAR acquisition and calibration of approximately 3243 square mile area of the Block 3 Project area. Subcontractor: Michael Baker International collected hydro for 3243 square miles of the Block 3 Project area. Subcontractor: SurvTech Solutions was responsible for LiDAR acquisition and calibration of approximately 2889 square mile area of the Block 3 Project area. SurvTech also performed ground edit and hydro collection for that area. All follow-on processing was completed by the prime contractor.

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

## Survey area

The project area addressed by this report falls within the Block 3 Iowa North Central project area consists of 10 Iowa counties; Carroll, Greene, Guthrie, Boone, Dallas, Story, Polk, Marshal, Jasper, and Tama.

## Date of survey

LiDAR acquisition for Block 3 Iowa North Central was conducted between the dates of April 16, 2020 to April 27, 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:** Universal Transverse Mercator (UTM) Zone 15 North.

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

**Geoid Model:** Geoid12B

## Lidar vertical accuracy

For the Block 3 IA North Central project, the tested RMSEz of the classified LiDAR data for checkpoints in non-vegetated terrain equaled 0.041 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 0.081 meters compared with the 0.196 meter specification.

For the Block 3 IA North Central project, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to 0.086 meters, compared with the 0.294 meter specification.

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

100 % of Totals	# of Points	RMSEz NVA (m)	NVA-Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	105	0.041	0.081	-0.010	-0.010	0.832	0.040	-0.130	0.19	5.664

Table 2: Block 3 IA North Central Non-vegetated Vertical Accuracy (NVA) results.

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

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	103	0.04	0.079	-.008	-0.10	1.112	0.040	-0.120	0.190	6.233

Table 3: Block 3 IA North Central unclassified Calibrated Vertical Accuracy NVA results.

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

## Project deliverables

The deliverables for the project are listed below.

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

## Project tiling footprint

16,106 tiles, 16,106 LAS files, 16,105 DEM tiles, 16,106 Intensity Image tiles were delivered for the project. Each tile's extent is 1000 meter by 1000 meter. (See Appendix A for a complete listing of delivered tiles.)

Block 3 IA North Central project

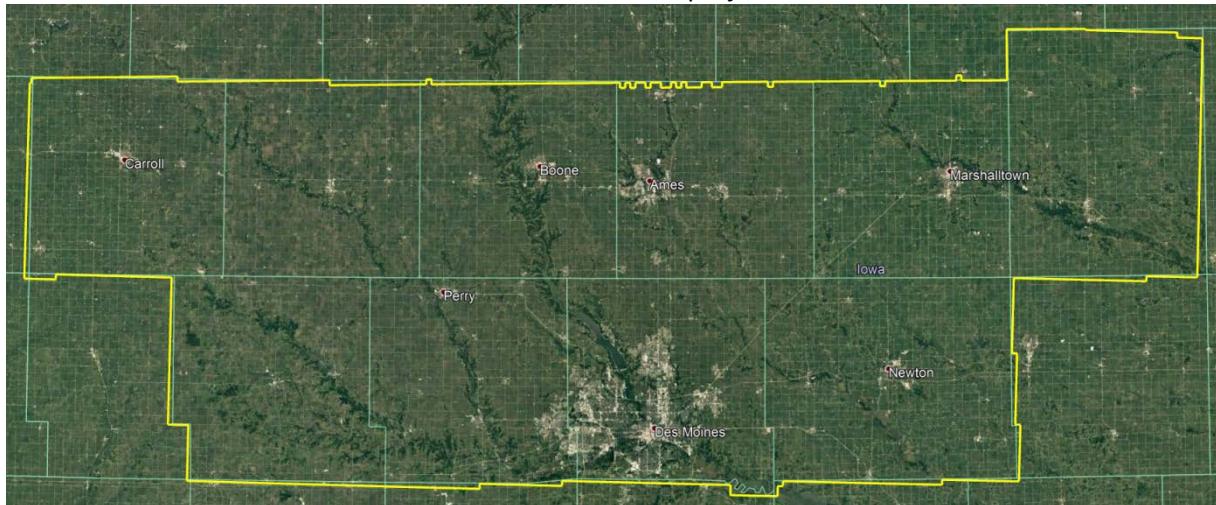


Figure 3: Block 3 IA North Central project Area of Interest

## Project Area Elevation Model

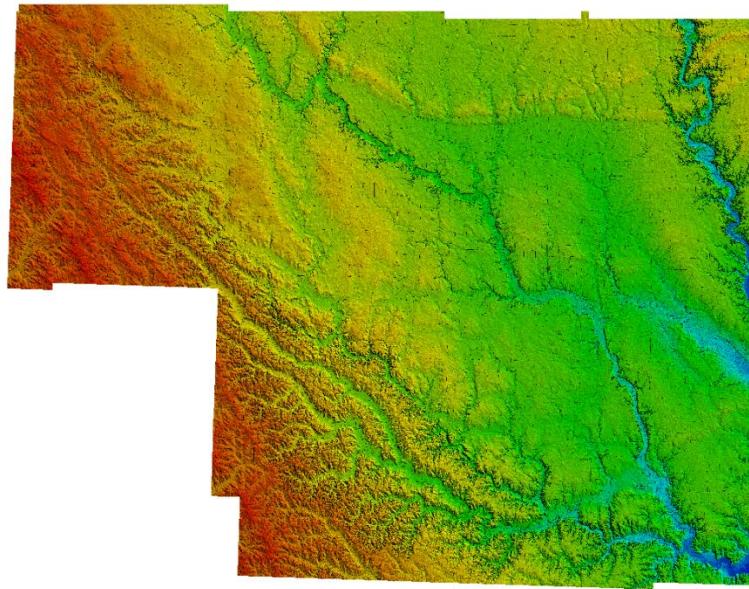


Figure 4: Western section of Block 3 IA North Central project Elevation DEM

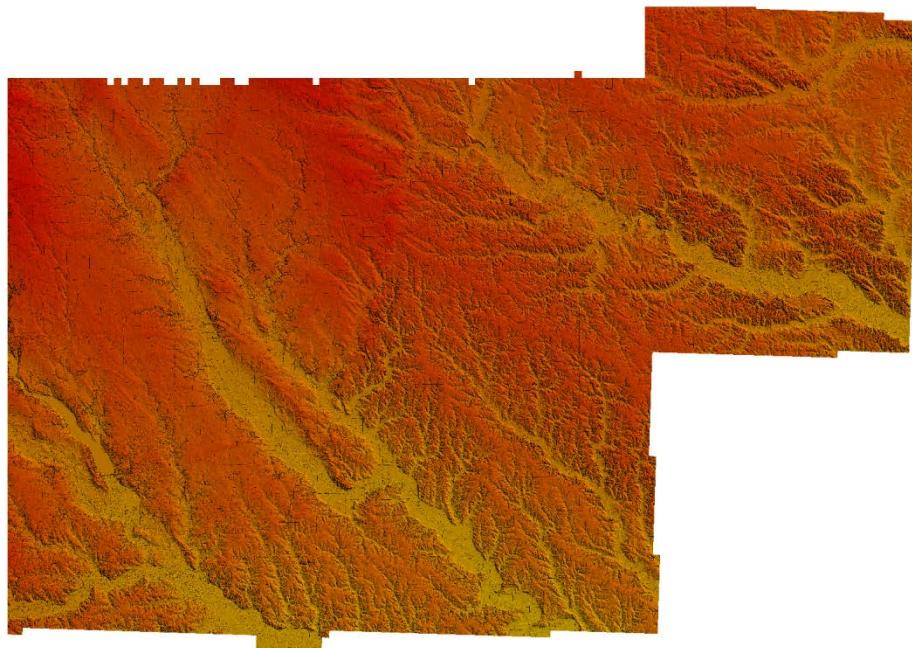


Figure 5: Eastern section of Block 3 IA North Central project Elevation DEM

## ***Aerial Surveys International, LLC LiDAR Acquisition Details and System parameters***

Aerial Surveys, International (ASU) served as Sub Contractor for the Block 3 IA North Central project area and preformed the LiDAR Acquisition and Calibration for Iowa counties; Story, Marshall, Jasper the majority of Polk and approximately ¼ of Boone .

The following image is of the Planned Flight Line Overview for the 13 counties of Block 3 IA North Central project area.

**Figure 6: ASU Block 3 IA North Central planned flight line overview**

Aerial Surveys International, LLC planned 380 passes for the entire IA North Central project area as well as a series of cross flightlines for quality control during processing and are not included in delivery. Of the 380 passes Aerial Surveys International, LLC collected 103 passes for the Block 3 IA North Central project area. 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 FMC Flight Management Suite flight design software for direct integration into the aircraft flight navigation system.
  - Planned flight lines; flight line numbers; and coverage area.
  - Lidar coverage extended beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables. A buffered AOI was provided by ASI.
  - All airspace was coordinated and any controlled or restricted areas were pre coordinated and approval granted from the airspace owner.

## Lidar System parameters

Aerial Surveys International, LLC operated a Cessna 310 (Registration N7516Q) and a Cessna 402 (Registration N2JJ), both equipped with an Optech Galaxy Prime LiDAR system during the collection of this task order. Data was acquired between April 16, 2020 and April 27, 2020.

Item	Parameter
System	Optech Prime
Maximum Number of Returns per Pulse	7
Nominal Pulse Spacing (single swath), (m)	0.67
Nominal Pulse Density (single swath) (ppsm), (m)	2.21
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.67
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.21
Altitude (AGL meters)	2300
Approx. Flight Speed (knots)	160
Total Sensor Scan Angle (degrees)	46
Scan Rate (hz)	63
Scanner Pulse Rate (kHz)	400
Did the Sensor Operate with Multiple Pulses in The Air? (MPiA) (yes/no)	Yes
Beam Divergence (mRADs)	0.25 (1/e)
Nominal Swath Width on the Ground (m)	1953
Swath Overlap (%)	30
Computed Down Track spacing (m) per beam	0.69
Computed Cross Track Spacing (m) per beam	0.69

Table 4: ASU Lidar System Parameters

## Calibration Report

### Acquisition Control

Aerial Surveys International, LLC (ASU) conducted the survey using Applanix PPRTX for processing the GPS/IMU data. Trimble CenterPoint® RTX™ is a proprietary GPS, GLONASS, BeiDou, and QZSS enabled technology that provides high-accuracy GNSS positioning worldwide without the use of traditional local base stations or a VRS network. By combining real-time data from a global reference station infrastructure with innovative positioning and compression algorithms, Trimble RTX technology computes centimeter-level positions based on satellite orbit and clock information.

### Airborne GPS Kinematic

Airborne GPS data was processed using POSPac MMS 8.4 GNSS-aided inertial post-processing software suite. Flights were flown with a minimum of 6 satellites in view ( $13^{\circ}$  above the horizon) and with a PDOP of better than 4.

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.

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

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

Subsequently the mission points are output using LMS Pro, initially with default values from LMS Pro 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.

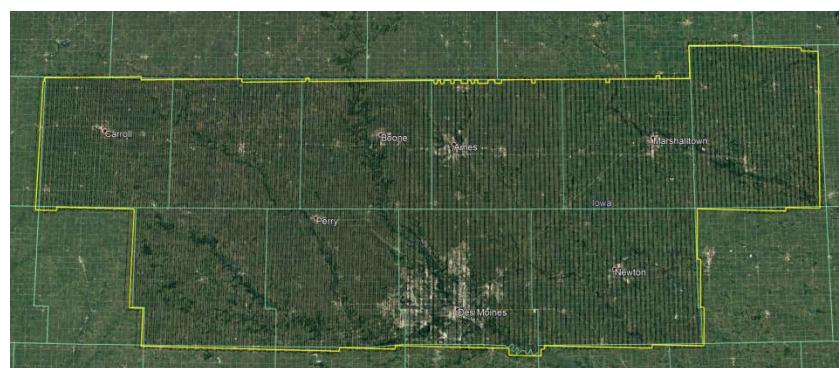


Figure 7: Block 3 IA North Central project Lidar swath coverage.

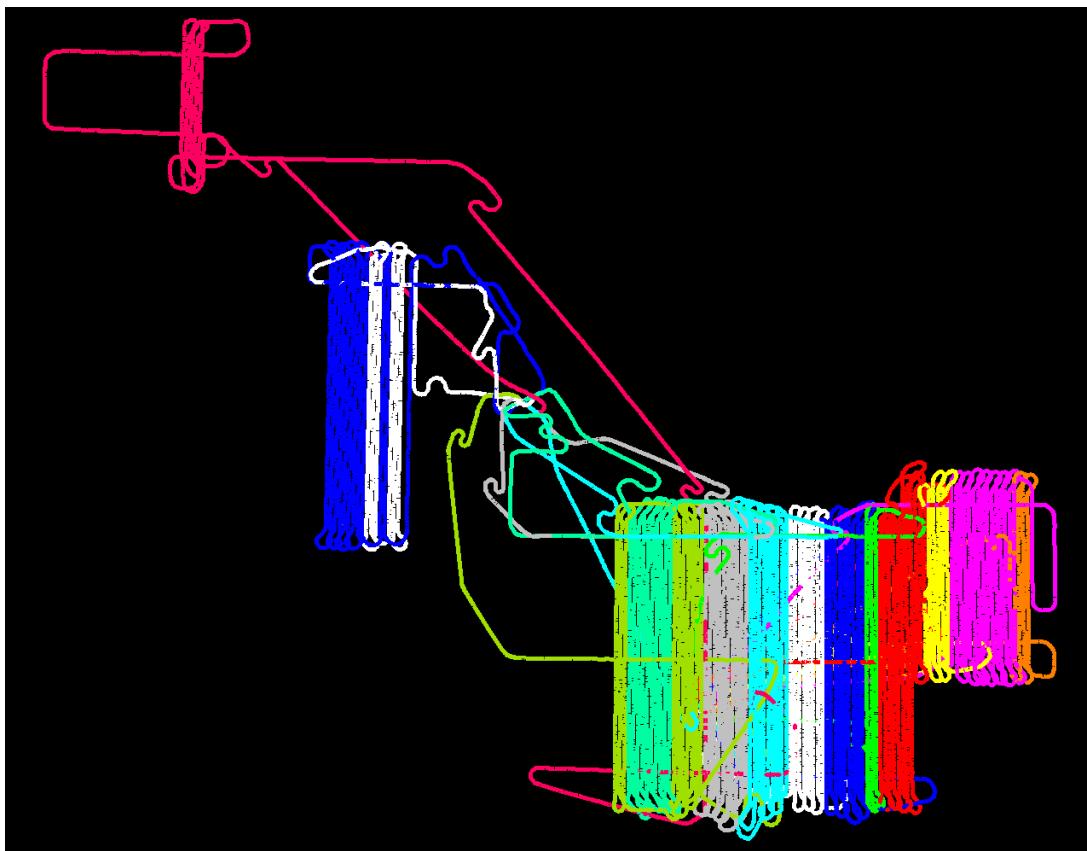


Figure 8: ASBlock 3 IA North Central project Combined project SBET

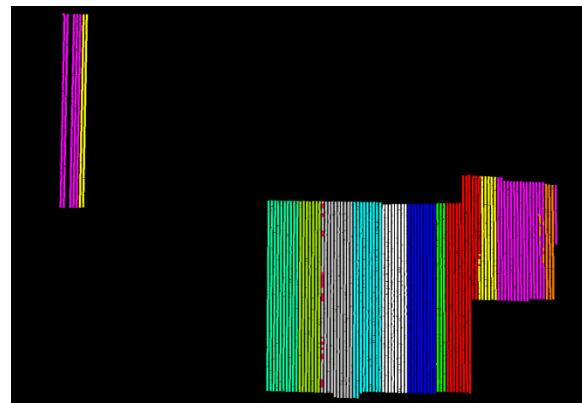


Figure 9: shows the combined trajectory of the flightlines by mission over Block 3 IA North Central project area.

The table below is a listing of Flightlines and corresponding, Lift\_ID, Date, Point Source ID, Scanner, and adjusted GPS Start and End times.

Name	Lift_ID	Date	PT Source ID	Scanner	Start Time	End Time
20200418_152710	20200418_F1_SN386	2020-04-18	1100	project	271258830.3	271259868.7
20200418_154836	20200418_F1_SN386	2020-04-18	1101	project	271260116	271261188.9
20200418_161001	20200418_F1_SN386	2020-04-18	1102	project	271261401.1	271262454.8
20200418_163133	20200418_F1_SN386	2020-04-18	1103	project	271262692.6	271263722.9
20200418_165230	20200418_F1_SN386	2020-04-18	1104	project	271263950	271265048.6
20200418_171503	20200418_F1_SN386	2020-04-18	1105	project	271265303.4	271266342.5
20200418_173629	20200418_F1_SN386	2020-04-18	1106	project	271266589.1	271267692.7
20200418_175843	20200418_F1_SN386	2020-04-18	1107	project	271267922.9	271268943.3
20200418_181943	20200418_F1_SN386	2020-04-18	1108	project	271269183.3	271270278.1
20200418_184324	20200418_F1_SN386	2020-04-18	1109	project	271270604.1	271271630.5
20200419_151813	20200419_F1_SN386	2020-04-19	1113	project	271344693	271345698.6
20200419_153946	20200419_F1_SN386	2020-04-19	1114	project	271345986.5	271347114.7
20200419_160137	20200419_F1_SN386	2020-04-19	1115	project	271347297.3	271348291.5
20200419_162246	20200419_F1_SN386	2020-04-19	1116	project	271348565.8	271349671.7
20200419_164421	20200419_F1_SN386	2020-04-19	1117	project	271349861.4	271350876.2
20200419_170439	20200419_F1_SN386	2020-04-19	1118	project	271351079.4	271352175.7
20200419_172626	20200419_F1_SN386	2020-04-19	1119	project	271352386.2	271353400.6
20200419_193140	20200419_F2_SN386	2020-04-19	1120	project	271359899.7	271360992.9
20200420_014333	20200420_F1_SN386	2020-04-20	1127	project	271382212.5	271383370.7
20200420_020624	20200420_F1_SN386	2020-04-20	1128	project	271383583.9	271384597.8
20200420_022746	20200420_F1_SN386	2020-04-20	1129	project	271384866.1	271386010.8
20200420_025011	20200420_F1_SN386	2020-04-20	1130	project	271386211	271387238.1
20200420_031140	20200420_F1_SN386	2020-04-20	1131	project	271387500.2	271388651.4

20200420_033427	20200420_F1_SN386	2020-04-20	1132	project	271388867.2	271389901.6
20200420_035707	20200420_F1_SN386	2020-04-20	1133	project	271390226.8	271391358.7
20200420_041913	20200420_F1_SN386	2020-04-20	1134	project	271391553.2	271392608.1
20200420_044044	20200420_F1_SN386	2020-04-20	1135	project	271392843.8	271393973.5
20200421_113852	20200421_F1_SN386	2020-04-21	1136	project	271504331.9	271505377.3
20200421_120314	20200421_F1_SN386	2020-04-21	1137	project	271505793.9	271507114.8
20200421_122930	20200421_F1_SN386	2020-04-21	1138	project	271507369.5	271508371.5
20200421_125507	20200421_F1_SN386	2020-04-21	1139	project	271508907.4	271510104.3
20200421_131854	20200421_F1_SN386	2020-04-21	1140	project	271510334	271511351.9
20200421_134055	20200421_F1_SN386	2020-04-21	1141	project	271511655.4	271512830.3
20200421_140344	20200421_F1_SN386	2020-04-21	1142	project	271513023.7	271514024.8
20200421_142442	20200421_F1_SN386	2020-04-21	1143	project	271514282.3	271515443.9
20200421_144730	20200421_F1_SN386	2020-04-21	1144	project	271515649.6	271516656.3
20200426_144935	20200426_F1_SN386	2020-04-26	1198	fill-in	271947774.6	271948796.6
20200426_150936	20200426_F1_SN386	2020-04-26	1199	fill-in	271948976	271950026
20200427_011158	20200427_F2_SN386	2020-04-27	1205	fill-in	271985117.7	271986171
20200427_015313	20200427_F2_SN386	2020-04-27	1207	fill-in	271987593.1	271988648.3
20200427_023430	20200427_F2_SN386	2020-04-27	1209	fill-in	271990069.7	271991107.9
20200416_141901	20200416_F1_SN442	2020-04-16	2108	project	271081941.5	271082562.5
20200416_143307	20200416_F1_SN442	2020-04-16	2109	project	271082786.9	271083410.8
20200416_144719	20200416_F1_SN442	2020-04-16	2110	project	271083638.9	271084263.9
20200416_150120	20200416_F1_SN442	2020-04-16	2111	project	271084479.6	271085118.3
20200416_151537	20200416_F1_SN442	2020-04-16	2112	fill-in	271085337.2	271085815.4
20200418_134911	20200418_F1_SN442	2020-04-18	2113	project	271252950.9	271253274.4
20200418_135746	20200418_F1_SN442	2020-04-18	2114	project	271253466.4	271254096.4
20200418_141208	20200418_F1_SN442	2020-04-18	2115	project	271254327.6	271254962.9
20200418_142640	20200418_F1_SN442	2020-04-18	2116	project	271255199.8	271255823.4
20200418_144118	20200418_F1_SN442	2020-04-18	2117	project	271256077.8	271256715.1

20200418_145537	20200418_F1_SN442	2020-04-18	2118	project	271256936.7	271257559
20200418_150947	20200418_F1_SN442	2020-04-18	2119	project	271257787.5	271258441.9
20200418_152418	20200418_F1_SN442	2020-04-18	2120	project	271258658.2	271259284.2
20200418_153829	20200418_F1_SN442	2020-04-18	2121	project	271259508.8	271260166.2
20200418_155304	20200418_F1_SN442	2020-04-18	2122	project	271260384.2	271261013.5
20200418_160719	20200418_F1_SN442	2020-04-18	2123	project	271261239.1	271261890.5
20200418_162202	20200418_F1_SN442	2020-04-18	2124	project	271262121.7	271262767
20200418_163640	20200418_F1_SN442	2020-04-18	2125	project	271262999.6	271263639.2
20200418_165043	20200418_F1_SN442	2020-04-18	2126	project	271263843	271264480.3
20200418_170442	20200418_F1_SN442	2020-04-18	2127	project	271264682.4	271265340.4
20200418_171827	20200418_F1_SN442	2020-04-18	2128	project	271265506.9	271266172.5
20200418_193057	20200418_F2_SN442	2020-04-18	2129	project	271273456.9	271274139.2
20200418_194531	20200418_F2_SN442	2020-04-18	2130	project	271274331.1	271274992.9
20200418_195950	20200418_F2_SN442	2020-04-18	2131	project	271275189.9	271275851.8
20200418_201333	20200418_F2_SN442	2020-04-18	2132	project	271276012.7	271276676.4
20200418_202805	20200418_F2_SN442	2020-04-18	2133	project	271276884.8	271277555.8
20200418_204648	20200418_F2_SN442	2020-04-18	2135	fill-in	271278007.9	271278244.1
20200419_124610	20200419_F1_SN442	2020-04-19	2136	fill-in	271335570	271336109
20200419_130439	20200419_F1_SN442	2020-04-19	2137	project	271336679	271337351.8
20200419_131926	20200419_F1_SN442	2020-04-19	2138	project	271337565.6	271338258.7
20200419_133323	20200419_F1_SN442	2020-04-19	2139	project	271338403.3	271339601.2
20200419_133323	20200419_F1_SN442	2020-04-19	2139	project	271338403.3	271339601.2
20200419_135714	20200419_F1_SN442	2020-04-19	2140	project	271339834.1	271341045.7
20200419_142151	20200419_F1_SN442	2020-04-19	2141	project	271341311.3	271342502
20200419_144520	20200419_F1_SN442	2020-04-19	2142	project	271342719.6	271343769
20200419_150555	20200419_F1_SN442	2020-04-19	2143	project	271343954.9	271344971.7
20200419_152606	20200419_F1_SN442	2020-04-19	2144	project	271345165.7	271346207
20200419_154649	20200419_F1_SN442	2020-04-19	2145	project	271346409.2	271347438.9

20200419_160729	20200419_F1_SN442	2020-04-19	2146	project	271347649.3	271348695.5
20200419_184413	20200419_F2_SN442	2020-04-19	2147	project	271357053.4	271358084.4
20200419_190455	20200419_F2_SN442	2020-04-19	2148	project	271358294.9	271359315.2
20200419_192508	20200419_F2_SN442	2020-04-19	2149	project	271359508.1	271360538.6
20200419_194635	20200419_F2_SN442	2020-04-19	2150	fill-in	271360794.7	271360968.6
20200421_120141	20200421_F1_SN442	2020-04-21	2160	project	271505701.3	271507094.5
20200421_122949	20200421_F1_SN442	2020-04-21	2161	project	271507389	271508418.5
20200421_125138	20200421_F1_SN442	2020-04-21	2162	project	271508697.7	271510025
20200421_131726	20200421_F1_SN442	2020-04-21	2163	project	271510246.1	271511271.1
20200421_133957	20200421_F1_SN442	2020-04-21	2164	project	271511597.2	271512867
20200421_140404	20200421_F1_SN442	2020-04-21	2165	project	271513043.5	271514066.8
20200421_142527	20200421_F1_SN442	2020-04-21	2166	project	271514327.4	271515579.2
20200421_144939	20200421_F1_SN442	2020-04-21	2167	project	271515779	271516772.7
20200421_151003	20200421_F1_SN442	2020-04-21	2168	project	271517003	271518233.1
20200421_172860	20200421_F2_SN442	2020-04-21	2169	project	271525339.8	271526548.9
20200421_175148	20200421_F2_SN442	2020-04-21	2170	project	271526707.8	271527736.3
20200421_181245	20200421_F2_SN442	2020-04-21	2171	project	271527964.6	271529164.3
20200421_183602	20200421_F2_SN442	2020-04-21	2172	project	271529362.5	271530367.4
20200421_185628	20200421_F2_SN442	2020-04-21	2173	project	271530587.8	271531732.2
20200421_191828	20200421_F2_SN442	2020-04-21	2174	project	271531908	271532944.8
20200421_193908	20200421_F2_SN442	2020-04-21	2175	project	271533148.5	271534255.7
20200421_200050	20200421_F2_SN442	2020-04-21	2176	project	271534450.4	271535478.8
20200427_005146	20200427_F2_SN386	2020-04-27	1204	fill-in	271983905.5	271984945.9
20200427_021354	20200427_F2_SN386	2020-04-27	1208	fill-in	271988834.2	271989887.4

Table 5: Block 3 IA North Central ASInt Project flightline by Mission

## Boresight and Relative Accuracy

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

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

For this project, the specifications used are as follows (derived from LiDAR base specification 2.1, QL2):  
Relative accuracy (smooth surface repeatability)  $\leq 6$  cm maximum differences within individual swaths and  $\leq 8$  cm RMSDz between adjacent and overlapping swaths.

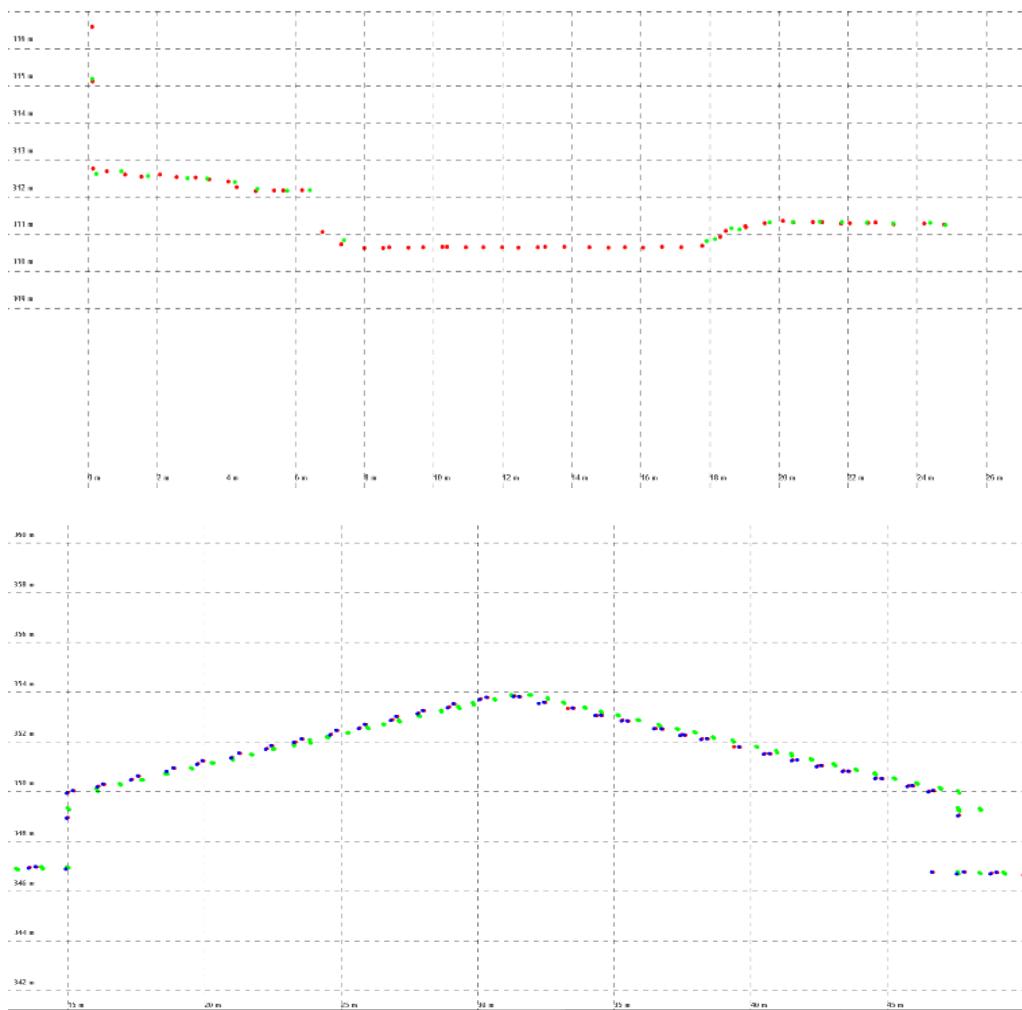


Figure 10: Profile views showing correct roll and pitch adjustments

## Final Calibration Verification

Prairie Engineers conducted the survey throughout the area of interest. 41 Ground control points (GCPs) were used to test the accuracy of the calibrated swath data. These 41 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 figure below. Surveyed ground control points (GCPs) and the accuracy results from testing the calibrated swath data against the GCPs is provided in the Tables below. Ground control points (GCPs) vertical accuracy results no further adjustments to the swath data were required based on the accuracy results of the GCPs.

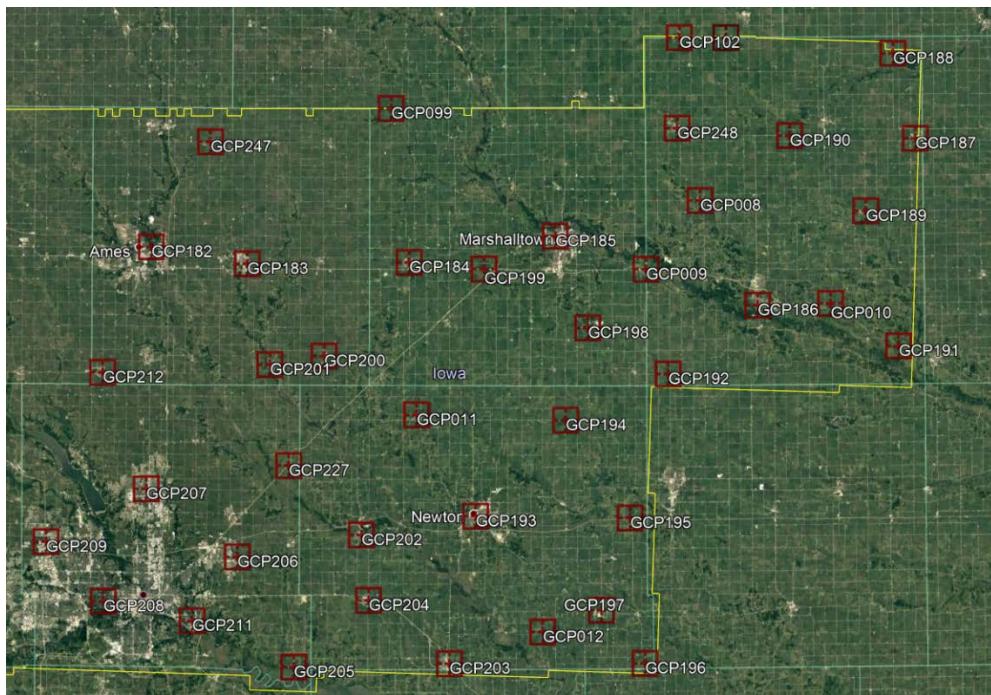


Figure 11: surveyed Ground Control Point Locations

Point ID	NAD83 (2011 adj) UTM Zone 15 N		NAVD88 (Geoid 12B)		Dz (M)
	Easting X (M)	Northing Y (M)	Z-Survey (M)	Z-LiDAR (M)	
GCP008	526814.470	4660182.990	280.130	280.150	0.020
GCP009	519282.580	4650654.240	269.590	269.590	0.000
GCP010	545003.920	4645900.820	253.470	253.460	-0.010
GCP011	487346.040	4630527.680	306.320	306.300	-0.020
GCP012	504855.420	4600414.780	271.370	271.380	0.010
GCP099	483837.650	4672985.600	312.460	312.450	-0.010
GCP102	523965.700	4682784.020	302.450	302.440	-0.010
GCP103	530456.210	4682786.080	311.580	311.520	-0.060
GCP182	450412.980	4653857.770	272.030	272.010	-0.020
GCP183	463797.400	4651478.050	305.670	305.680	0.010
GCP184	486324.560	4651638.030	326.000	325.990	-0.010
GCP185	506662.620	4655247.220	284.260	284.270	0.010
GCP186	534824.500	4645680.890	250.510	250.490	-0.020
GCP187	556895.800	4668823.440	293.810	293.820	0.010
GCP188	553795.690	4680632.800	303.660	303.650	-0.010
GCP189	549931.740	4658760.030	267.120	267.100	-0.020
GCP190	539331.650	4669189.330	294.450	294.460	0.010
GCP191	554511.060	4640016.130	248.720	248.720	0.000
GCP192	522343.570	4636146.010	306.210	306.200	-0.010
GCP193	495532.430	4616475.260	291.410	291.390	-0.020
GCP194	508069.860	4629763.310	312.400	312.370	-0.030
GCP195	517030.380	4616203.730	299.950	299.930	-0.020
GCP196	519102.290	4596037.750	272.970	272.940	-0.030

GCP197	513032.220	4603421.020	277.900	277.870	-0.030
GCP198	511168.610	4642545.540	293.440	293.420	-0.020
GCP199	496741.320	4650713.620	318.510	318.450	-0.060
GCP200	474483.690	4638693.060	305.150	305.080	-0.070
GCP201	466930.710	4637508.690	268.540	268.540	0.000
GCP202	479633.900	4613895.090	251.220	251.170	-0.050
GCP203	491869.010	4596038.320	276.740	276.740	0.000
GCP204	480628.940	4604830.820	280.320	280.350	0.030
GCP205	470181.640	4595564.260	245.600	245.590	-0.010
GCP206	462351.430	4610871.170	285.550	285.540	-0.010
GCP207	449666.680	4620310.700	299.540	299.560	0.020
GCP208	443637.75	4604711.33	297.18	297.19	0.010
GCP209	435654.53	4612979.58	290.84	290.81	-0.030
GCP211	456014.85	4602012.28	238.83	238.88	0.050
GCP212	443632.49	4636468.07	316.21	316.16	-0.050
GCP227	469524.77	4623505.35	258.67	258.65	-0.020
GCP247	458678.35	4668405.11	311.17	311.17	0.000
GCP248	523640.14	4670194.31	300.72	300.72	0.000

Table 6: Block 3 IA North Central surveyed ground control points (GCPs).

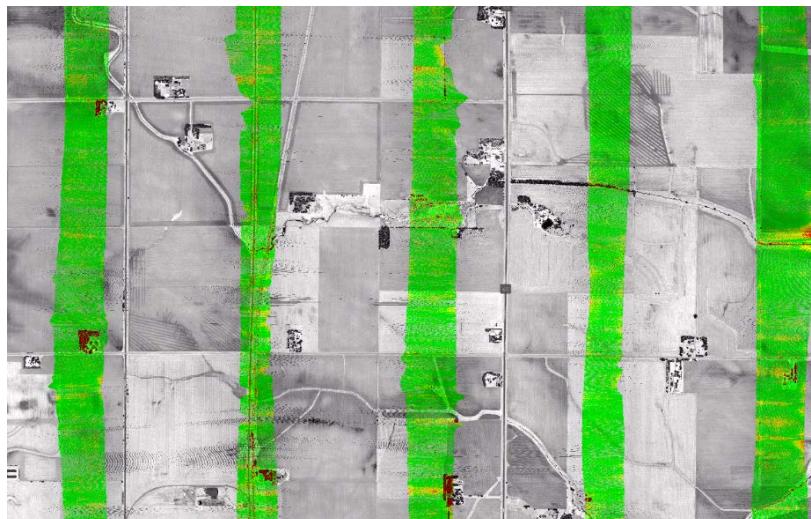
This project meets Ground Control Vertical Accuracy  $\leq 19.6$  cm at the 95% confidence level based on RMSEz  $\leq 10$  cm  $\times 1.9600$ .

100 % of Totals	# of Points	RMSEz NVA (m)	NVA-Non-vegetated Vertical Accuracy ((RMSEz $\times 1.9600$ ) m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
GCP	41	0.027	0.053	-0.011	0.010	-0.249	0.025	-0.070	0.050	0.625

Table 7: Block 3 IA North Central Ground Control Vertical Accuracy (GCP) results.

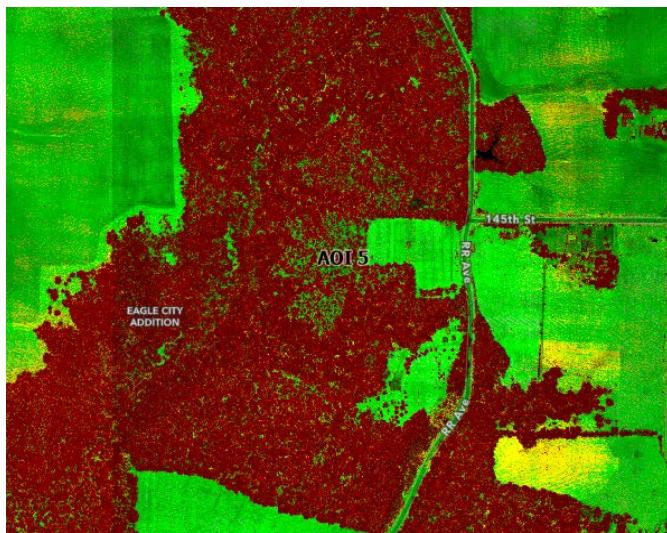
## Between Swath Relative Accuracy (DZ Orthos)

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



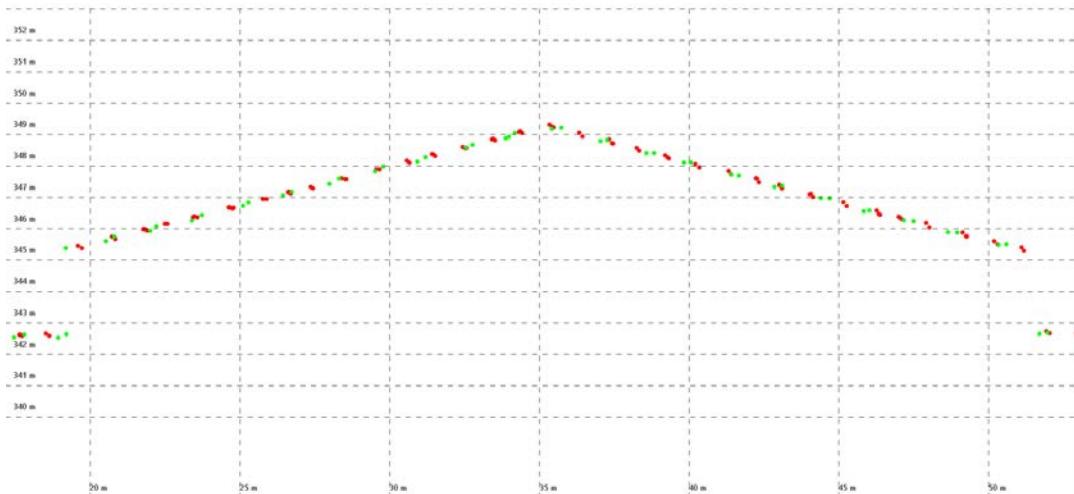
## Within Swath Relative Accuracy (Intraswath)

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



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

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

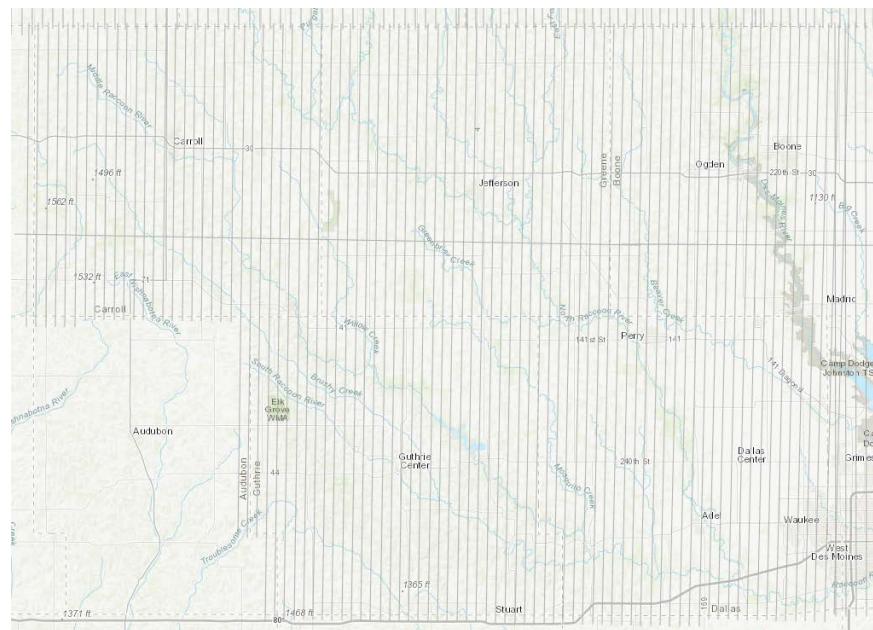


See Appendix B: For Aerial Surveys International, LLC GPS and IMU Processing Reports

## ***SurvTech Solutions LiDAR Acquisition Details and System Parameters for Iowa North Central***

SurvTech Solutions served as a Sub Contractor for the Block 3 IA North Central project and preformed the LiDAR Acquisition and Calibration for Iowa counties; Carroll, Greene, Guthrie, Dallas, a sliver of Polk and approximately ¾ of Boone.

The following image is of the Planned Flight Line Overview for the 8 and 2 partial counties of Block 3 IA North Central project area.



## Lidar System parameters

SurvTech Solutions operated a Cessna 401 (Registration N41GD) equipped with an Optech Galaxy Prime Lidar system during the collection of this task order. Data was acquired between April 18, 2020 and April 21, 2020.

Item	Parameter
System	Optech Galaxy Prime
Altitude (AGL meters)	2286
Approx. Ground Speed (kts)	150
Laser Firing Rate (kHz)	400
Swath width (m)	1894
Swath Overlap (%)	30%
Line Spacing (m)	1300
Pass heading °	North-South
Field of View °	45
Computed Down Track spacing (m) per beam	0.61
Computed Cross Track Spacing (m) per beam	0.67
Average point spacing (m)	0.64
Point density at Nadir	2.42
Points per meter <sup>2</sup> (m)	2.74
Scan Pattern	Sawtooth

Tabel #: SurvTech Soutions LiDAR system parameters

## Calibration Report

Point clouds are output using Optech's LMS. The initial point generation for each mission calibration is verified within LMS for calibration errors. If significant calibration errors are observed within the mission; the internal sensor misalignments are calculated. The data is then regenerated with the new solution and is validated internally once again to ensure quality.

Relative accuracy and internal quality are checked using Terramatch, as well as, BayesMap-StripAlign, in which points from all lines are observed and compared. Vertical differences between ground surfaces of each line are displayed. Rasters are generated on filtered tiles to model Dz between adjacent lines. Inter-swath accuracy is tested to the <.08m standard specified in the base spec. Data are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

## Acquisition Control

SurvTech Solutions conducted the survey which provided the established base stations used to control the lidar acquisition for USGS Iowa North Central area. The coordinates of the base stations are provided in the table below. These stations are continuously running by the state of IOWA which is the IARTN.

Name	NAD83(2011) Deg Min Sec		Ellipsoid Ht (GRS80, m)
	Latitude	Longitude	
IACA	42-04-40.01012	-94-54-40.40128	366.0066
IAJE	42-01-16.06223	-94-22-55.43946	303.9157
AIDM	41-39-27.16598	-93-35-48.11477	255.7855

Table 8: Base stations used to control lidar acquisition for the Project.

## Airborne GPS Kinematic

Airborne GPS data was processed using PosPac MMS 8.4. Flights were flown with a minimum of 8 satellites in view (10° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 80km.

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

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

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

The initial points for each mission are inspected for flight line errors, flight line overlap, slivers or data holidays, point data minimums or issues with the LiDAR unit or GPS. Data collected by the LiDAR unit is reviewed for completeness, acceptable density and errors or corrupted values. Intra-swath repeatability

is tested to meet the <.06m standard specified in the base spec. In addition, all GPS data, aircraft trajectories, mission information and ground control files are reviewed. On a project level, a supplementary coverage check is carried out to ensure data voids unreported by Field Operations are not present.

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.

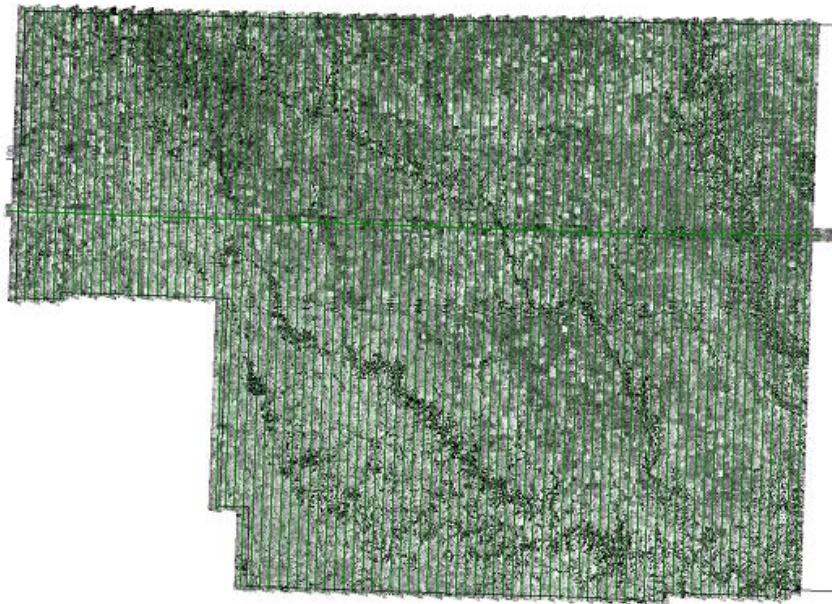


Figure 12: SURVTECH LiDAR swath output showing complete coverage

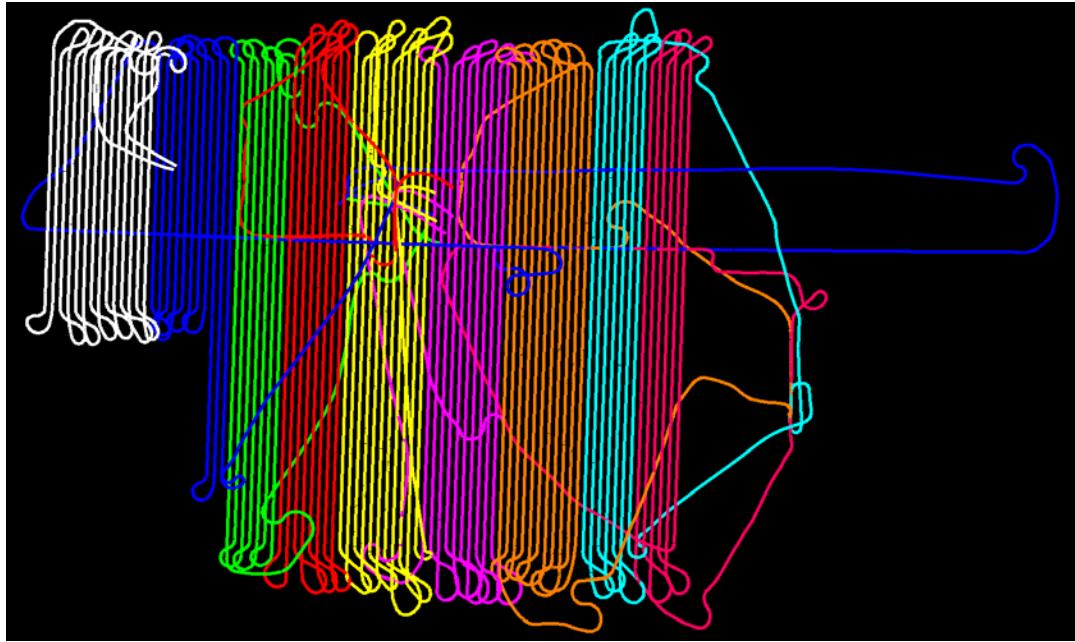


Figure 13: SURVTECH Block 3 IA North Central project Combined project SBET

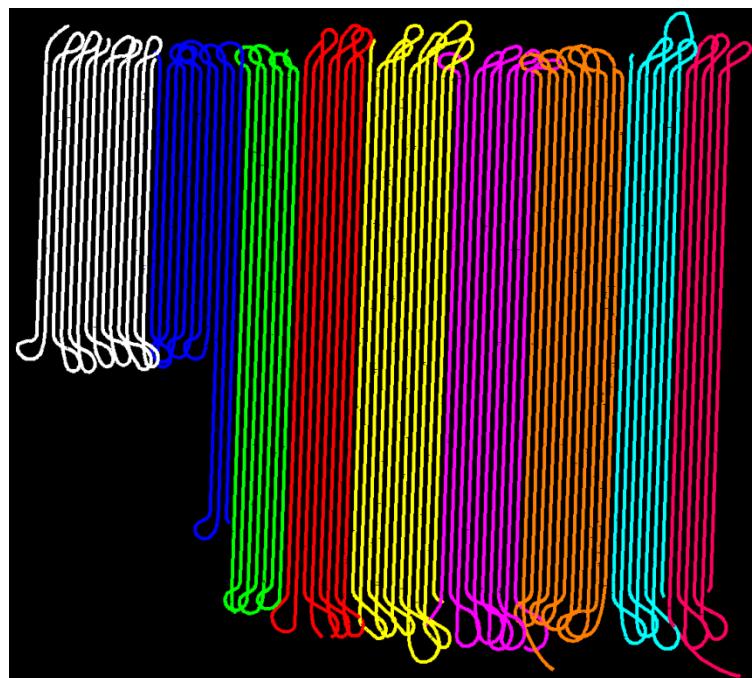


Figure 14: SURVTECH combined trajectory of the flightlines by mission over Block 3 IA North Central project area.

The following table is a listing of Flightlines and corresponding, Lift\_ID, Date, Point Source ID, Scanner, and adjusted GPS Start and End times.

Name	Lift_ID	Date	PT Source ID	Scanner	Start Time	End Time
20200418_175931	0200418_F1_SN5060413	2020-04-18	10001	project	271267971.2	271268763.4
20200418_181243	0200418_F1_SN5060413	2020-04-18	10101	project	271268763.4	271269447.5
20200418_182408	0200418_F1_SN5060413	2020-04-18	10201	project	271269447.5	271270201.7
20200418_183642	0200418_F1_SN5060413	2020-04-18	10301	project	271270201.7	271270941.9
20200418_184902	0200418_F1_SN5060413	2020-04-18	10401	project	271270941.9	271271684
20200418_190124	0200418_F1_SN5060413	2020-04-18	10501	project	271271684	271272390.2
20200418_191330	0200418_F1_SN5060413	2020-04-18	10601	project	271272410.2	271273122.3
20200418_192522	0200418_F1_SN5060413	2020-04-18	10701	project	271273122.4	271273828.5
20200418_193709	0200418_F1_SN5060413	2020-04-18	10801	project	271273828.5	271274558.7
20200418_194919	0200418_F1_SN5060413	2020-04-18	10901	project	271274558.7	271275252.8
20200418_200053	0200418_F1_SN5060413	2020-04-18	11001	project	271275252.8	271275957
20200418_201237	0200418_F1_SN5060413	2020-04-18	11101	project	271275957	271276685.2
20200418_202445	0200418_F1_SN5060413	2020-04-18	11201	project	271276685.2	271277379.3
20200418_203619	0200418_F1_SN5060413	2020-04-18	11301	project	271277379.3	271278045.5
20200419_123802	0200419_F1_SN5060413	2020-04-19	11401	project	271335082.2	271335734.3
20200419_124854	0200419_F1_SN5060413	2020-04-19	11501	project	271335734.3	271336446.5
20200419_130046	0200419_F1_SN5060413	2020-04-19	11601	project	271336446.5	271337138.6
20200419_131219	0200419_F1_SN5060413	2020-04-19	11701	project	271337138.6	271337840.8
20200419_132401	2200419_F1_SN5060413	2020-04-19	11801	project	271337840.8	271338534.9
20200419_133535	0200419_F1_SN5060413	2020-04-19	11901	project	271338534.9	271339237.1
20200419_134717	0200419_F1_SN5060413	2020-04-19	12001	project	271339237.1	271339929.3
20200419_135849	0200419_F1_SN5060413	2020-04-19	12101	project	271339929.3	271340637.4
20200419_141037	0200419_F1_SN5060413	2020-04-19	12201	project	271340637.4	271341707.7
20200419_142828	0200419_F1_SN5060413	2020-04-19	12301	project	271341707.7	271342767.9
20200419_144608	0200419_F1_SN5060413	2020-04-19	12401	project	271342767.9	271343726.1

20200419_171803	0200419_F2_SN5060413	2020-04-19	12501	project	271351883.3	271353077.6
20200419_173758	0200419_F2_SN5060413	2020-04-19	12601	project	271353077.6	271354273.8
20200419_175754	0200419_F2_SN5060413	2020-04-19	12701	project	271354273.8	271355472.1
20200419_181752	0200419_F2_SN5060413	2020-04-19	12801	project	271355472.1	271356652.4
20200419_183732	0200419_F2_SN5060413	2020-04-19	12901	project	271356652.4	271357880.7
20200419_185801	0200419_F2_SN5060413	2020-04-19	13001	project	271357880.7	271359076.9
20200419_191757	0200419_F2_SN5060413	2020-04-19	13101	project	271359076.9	271360273.2
20200420_013145	0200419_F3_SN5060413	2020-04-19	13201	project	271381505.1	271382749.4
20200420_015229	0200419_F3_SN5060413	2020-04-19	13301	project	271382749.4	271383985.7
20200420_021306	0200419_F3_SN5060413	2020-04-19	13401	project	271383985.7	271385236
20200420_023418	20200419_F3_SN5060413	2020-04-19	13501	project	271385258	271386532.3
20200420_025532	20200419_F3_SN5060413	2020-04-19	13601	project	271386532.3	271387798.6
20200420_031639	0200419_F3_SN5060413	2020-04-19	13701	project	271387798.6	271389072.9
20200420_033753	0200419_F3_SN5060413	2020-04-19	13801	project	271389072.9	271390335.2
20200420_035855	0200419_F3_SN5060413	2020-04-19	13901	project	271390335.2	271391553.5
20200421_035721	0200420_F1_SN5060413	2020-04-20	14001	project	271476641.1	271477887.4
20200421_041807	0200420_F1_SN5060413	2020-04-20	14101	project	271477887.4	271479257.7
20200421_044058	0200420_F1_SN5060413	2020-04-20	14201	project	271479257.7	271480510
20200421_050150	0200420_F1_SN5060413	2020-04-20	14301	project	271480510	271481886.3
20200421_052446	0200420_F1_SN5060413	2020-04-20	14401	project	271481886.3	271483172.6
20200421_054613	0200420_F1_SN5060413	2020-04-20	14501	project	271483172.6	271484536.9
20200421_060857	0200420_F1_SN5060413	2020-04-20	14601	project	271484536.9	271485889.2
20200421_063129	0200420_F1_SN5060413	2020-04-20	14701	project	271485889.2	271487333.6
20200421_065534	0200420_F1_SN5060413	2020-04-20	14801	project	271487333.6	271488651.9
20200421_071732	0200420_F1_SN5060413	2020-04-20	14901	project	271488651.9	271490044.2
20200421_074044	0200420_F1_SN5060413	2020-04-20	15001	project	271490044.2	271491182.5
20200421_123024	0200421_F1_SN5060413	2021-04-21	15101	project	271507424.2	271508774.5
20200421_125255	0200421_F1_SN5060413	2021-04-21	15201	project	271508774.5	271509928.8

20200421_131209	0200421_F1_SN5060413	2021-04-21	15301	project	271509928.8	271511323.1
20200421_133523	0200421_F1_SN5060413	2021-04-21	15401	project	271511323.1	271512497.4
20200421_135457	0200421_F1_SN5060413	2021-04-21	15501	project	271512497.4	271513877.7
20200421_141758	0200421_F1_SN5060413	2021-04-21	15601	project	271513877.7	271515112
20200421_143832	0200421_F1_SN5060413	2021-04-21	15701	project	271515112	271516494.3
20200421_150134	0200421_F1_SN5060413	2021-04-21	15801	project	271516494.3	271517730.6
20200421_152211	0200421_F1_SN5060413	2021-04-21	15901	project	271517730.6	271519142.9
20200421_154543	0200421_F1_SN5060413	2021-04-21	16001	project	271519142.9	271520339.2
20200421_181730	0200421_F2_SN5060413	2021-04-21	16101	project	271528250.4	271529684.7
20200421_184125	0200421_F2_SN5060413	2021-04-21	16201	project	271529684.7	271530863
20200421_190103	0200421_F2_SN5060413	2021-04-21	16301	project	271530863	271532143.2
20200421_192223	0200421_F2_SN5060413	2021-04-21	16401	project	271532143.2	271533313.5
20200421_194153	0200421_F2_SN5060413	2021-04-21	16501	project	271533313.5	271534565.8
20200421_200246	0200421_F2_SN5060413	2021-04-21	16601	project	271534565.8	271535774
20200421_202254	0200421_F2_SN5060413	2021-04-21	16701	project	271535774.1	271537074.3
20200421_204434	0200421_F2_SN5060413	2021-04-21	16801	project	271537074.3	271538300.6
20200421_210501	0200421_F2_SN5060413	2021-04-21	16901	project	271538300.6	271539622.9
20200421_212703	0200421_F2_SN5060413	2021-04-21	17001	project	271539622.9	271540871.2
20200421_214751	0200421_F2_SN5060413	2021-04-21	17101	project	271540871.2	271542109.5
20200421_235936	0200421_F3_SN5060413	2021-04-21	17201	project	271548775.5	271550021.8
20200422_002022	0200421_F3_SN5060413	2021-04-21	17301	project	271550021.8	271551320.1
20200422_004200	0200421_F3_SN5060413	2021-04-21	17401	project	271551320.1	271552642.4
20200422_010402	0200421_F3_SN5060413	2021-04-21	17501	project	271552642.4	271553970.7
20200422_012611	0200421_F3_SN5060413	2021-04-21	17601	project	271553970.7	271555285
20200422_014805	0200421_F3_SN5060413	2021-04-21	17701	project	271555285	271556553.3
20200422_020913	0200421_F3_SN5060413	2021-04-21	17801	project	271556553.3	271557703.6
20200422_033142	0200421_F4_SN5060413	2021-04-21	17901	project	271561502.2	271562904.5
20200422_035505	0200421_F4_SN5060413	2021-04-21	18001	project	271562904.5	271564172.8

20200422_041613	0200421_F4_SN5060413	2021-04-21	18101	project	271564172.8	271565403.1
20200422_043643	0200421_F4_SN5060413	2021-04-21	18201	project	271565403.1	271566651.4
20200422_045731	0200421_F4_SN5060413	2021-04-21	18301	project	271566651.4	271567903.7
20200422_051824	0200421_F4_SN5060413	2021-04-21	18401	project	271567903.7	271569023.9

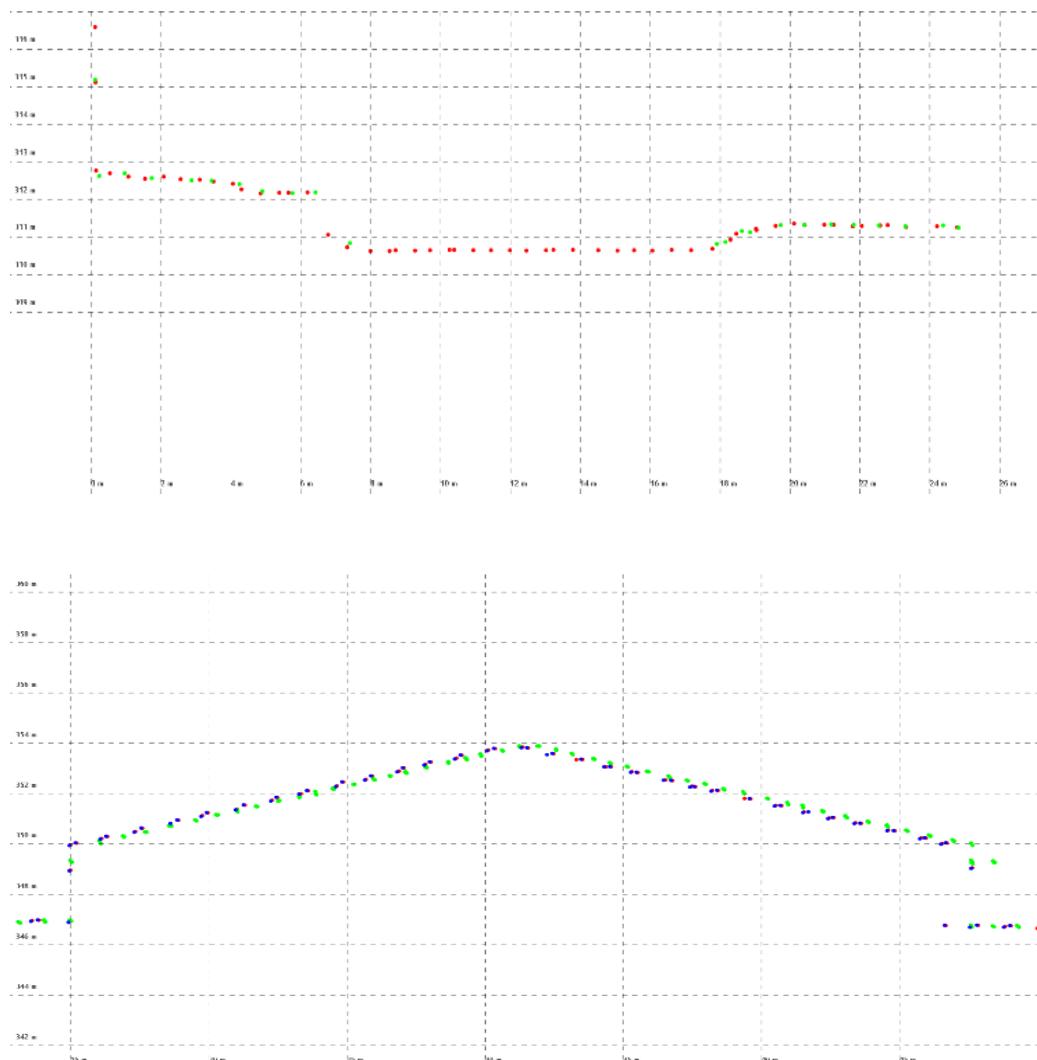
Table 9: SURVTECH Block 3 IA North Central ASInt Project flightline by Mission

## Boresight and Relative Accuracy

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

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

For this project, the specifications used are as follows (derived from LiDAR base 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.



Profile views showing correct roll and pitch adjustments

## Final Calibration Verification

Prairie Engineers conducted the survey throughout the area of interest. 38 Ground control points (GCPs) were used to test the accuracy of the calibrated swath data. These 38 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 following figure Surveyed ground control points (GCPs) and the accuracy results from testing the calibrated swath data against the GCPs is provided in the following tables. Ground control points (GCPs) vertical accuracy results; no further adjustments to the swath data were required based on the accuracy results of the GCPs.

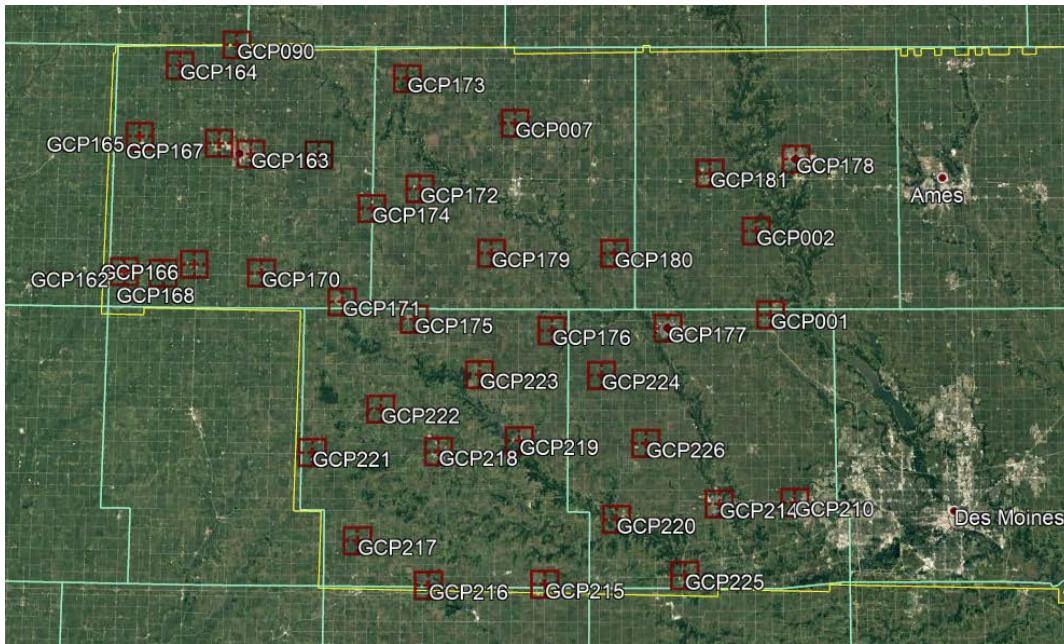


Figure 15: surveyed Ground Control Point Locations

Point ID	NAD83 (2011 adj) UTM Zone 15 N		NAVD88 (Geoid 12B)		Dz (M)
	Easting X (M)	Northing Y (M)	Z-Survey (M)	Z-LiDAR (M)	
GCP001	423155.310	4634123.420	323.060	323.110	+0.050
GCP002	421246.960	4646311.770	323.650	323.670	+0.020
GCP007	386059.940	4662583.990	327.670	327.640	-0.030
GCP090	344987.640	4674783.880	387.260	387.280	+0.020
GCP162	328724.870	4641625.980	415.490	415.550	+0.060
GCP163	347178.990	4658608.650	375.270	375.270	+0.000
GCP164	336594.220	4671842.610	421.050	421.100	+0.050

GCP165	330773.210	4661456.890	438.110	438.120	+0.010
GCP166	338988.850	4642558.650	441.340	441.350	+0.010
GCP167	342515.840	4660247.530	382.000	382.040	+0.040
GCP168	334460.700	4641316.790	454.070	454.110	+0.040
GCP169	357204.860	4658331.210	378.230	378.210	-0.020
GCP170	348867.320	4641163.720	393.390	393.500	+0.110
GCP171	360695.740	4636803.570	357.930	357.920	-0.010
GCP172	372062.640	4653140.850	360.290	360.300	+0.010
GCP173	370197.300	4669422.930	348.630	348.630	+0.000
GCP174	365029.200	4650355.630	357.570	357.570	+0.000
GCP175	371207.500	4634153.880	339.420	339.450	+0.030
GCP176	391281.490	4632220.550	319.070	319.080	+0.010
GCP177	408193.360	4632377.670	293.360	293.350	-0.010
GCP178	427252.930	4656772.720	345.260	345.100	-0.160
GCP179	382519.220	4643587.870	341.510	341.520	+0.010
GCP180	400475.700	4643323.060	326.670	326.700	+0.030
GCP181	414598.110	4654849.940	332.900	332.890	-0.010
GCP210	426203.290	4607088.910	314.780	314.800	+0.020
GCP214	415305.520	4607010.860	274.400	274.360	-0.040
GCP215	389989.630	4595904.360	368.950	368.890	-0.060
GCP216	373214.200	4595959.310	379.000	379.040	+0.040
GCP217	362961.990	4602436.580	439.340	439.370	+0.030
GCP218	374712.300	4615025.540	333.180	333.250	+0.070
GCP219	386435.260	4616439.950	330.350	330.360	+0.010

GCP220	400410.120	4605015.990	295.120	295.070	-0.050
GCP221	356393.970	4615118.940	428.810	428.820	+0.010
GCP222	366331.750	4621238.170	349.280	349.250	-0.030
GCP223	380703.180	4626009.840	356.630	356.610	-0.020
GCP224	398439.490	4625674.640	321.020	320.980	-0.040
GCP225	410179.790	4596917.980	330.800	330.710	-0.090
GCP226	404790.900	4615807.930	301.520	301.460	-0.060

This project meets Non-vegetated Vertical Accuracy (NVA)  $\leq$  19.6 cm at the 95% confidence level based on RMSEz  $\leq$  10 cm  $\times$  1.9600.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA- Non-vegetated Vertical Accuracy ((RMSEz $\times$ 1.9600) Spec = .196m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
GCP	38	0.047	0.092	0.001	0.010	-0.909	0.048	-0.160	0.110	2.748

Table 10: Ground control points (GCPs) vertical accuracy results

## ***LiDAR Quality Control Reporting***

### **Overview**

SurvTech Solutions conducted the evaluation of calibrated data for USGS Iowa South Central to ensure that the swath lidar has been calibrated and produced to meet the required specifications in the Scope of Work (SOW). This review includes verifying the calibration and final formatting of the swath data. Between swath relative accuracy, horizontal alignment, and LAS statistics were reviewed. Results of this review are provided below.

LiDAR Calibration Review			
Requirement	Description of Check	Yes / No	Additional Comments
Review Adjustment Parameters	Examine magnitude and types of corrections applied (POSPac) for outliers or issues.	Yes	
Review against control	Calculate offset between control and lidar points. These statistics include RMSE, standard deviation, mean, min/max. Report magnitude of bias shift made, or report if no shift applied.	Yes	
Run DZ Orthos	Create difference rasters (DZ orthos) and review for any artifacts.	Yes	
Run intraswath Check	Create intraswath difference rasters and review for artifacts	Yes	
Run and review quantitative interswath check	Create statistics showing the alignment swath-swath (e.g. Measure Match report)	Yes	
Spot check cross sections	Draw cross sections on roofs and open areas throughout the project to check horizontal and vertical alignment. Include example cross sections in this report	Yes	

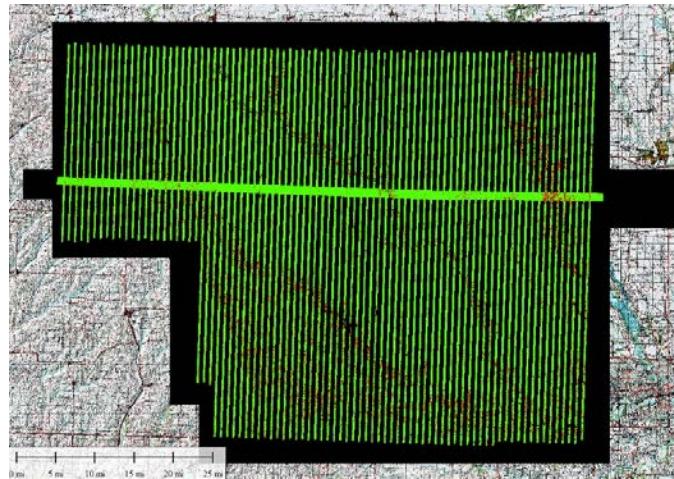
Formatting Checks			
Requirement	Description of Check	Pass/ Fail	Additional Comments
Swaths are in v1.4 formatting	Swaths are in LAS v1.4 as required by the project.	Pass	
Classification set to 0	All classes should be set to class 0. If any classes are set, or flags are set (withheld, synthetic, etc) please describe what these classes/flags are denoting.	Pass	
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number)	File Source IDs are correctly assigned	Pass	
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps are Adjusted GPS time and Global Encoding field is correctly set to 17	Pass	
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values are 16-bit	Pass	
Point Source IDs must be	Point Source IDs are assigned and match the	Pass	

populated and should match the File Source IDs	File Source IDs		
Scan angle values must be within expected range	Verify scan angle statistics for angles that are significantly above or below expected ranges	Pass	
Channels are merged and channel bit set	If the processing software outputs multiple LAS per swath for a single sensor, these should be merged into a single LAS file. Additionally, the scanner bit and user byte should be set to the scanner numbers. (e.g. 1 for channel 1)		None Applicable.
Scan Direction and Edge of Flightline Flags Set Correctly	The scan direction flag should be set to 0 for rotating mirror systems, and 0/1 for oscillating mirror systems. The edge of flightline flag should be set for all systems.	Pass	

Lidar Calibration Deliverables			
Requirement	Description of Deliverable	Included?	Additional Comments
Calibrated LAS Swaths	Examine magnitude and types of corrections applied (either Bayesmap or TerraMatch TMS) for outliers or issues.	Yes	
Terrascan TRJ Files	.trj files for each swath delivered. These trajectory files need to match the LAS swath spatially, temporally (correct time system), and have identical flightline numbering	Yes	
Calibration Adjustment Reports	Files that contain information on the adjustments applied. This at a bare minimum must include what parameters are being solved for. Ideally these include all the values being applied to the data. An example from the TerraMatch workflow would be to include all .TMS files applied.	Yes	
Calibration Control Reports	Calculate offset between control and lidar points. These statistics include RMSE, standard deviation, mean, min/max. Report magnitude of bias shift made, or report if no shift applied.	Yes	
Calibration Control Shapefile	Provide shapefile of calibration control points	Yes	
Relative Accuracy Statistics	Quantitative statistics showing relative alignment of swath-swath	Yes	
DZ Ortho Rasters	DZ raster's showing alignment between swaths (interswath)	Yes	

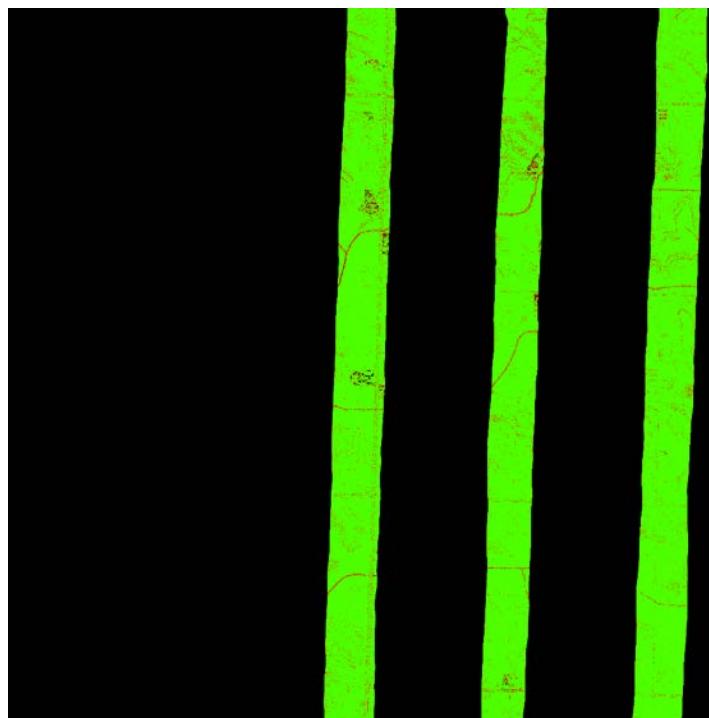
### **Between Swath Relative Accuracy (DZ Orthos):**

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



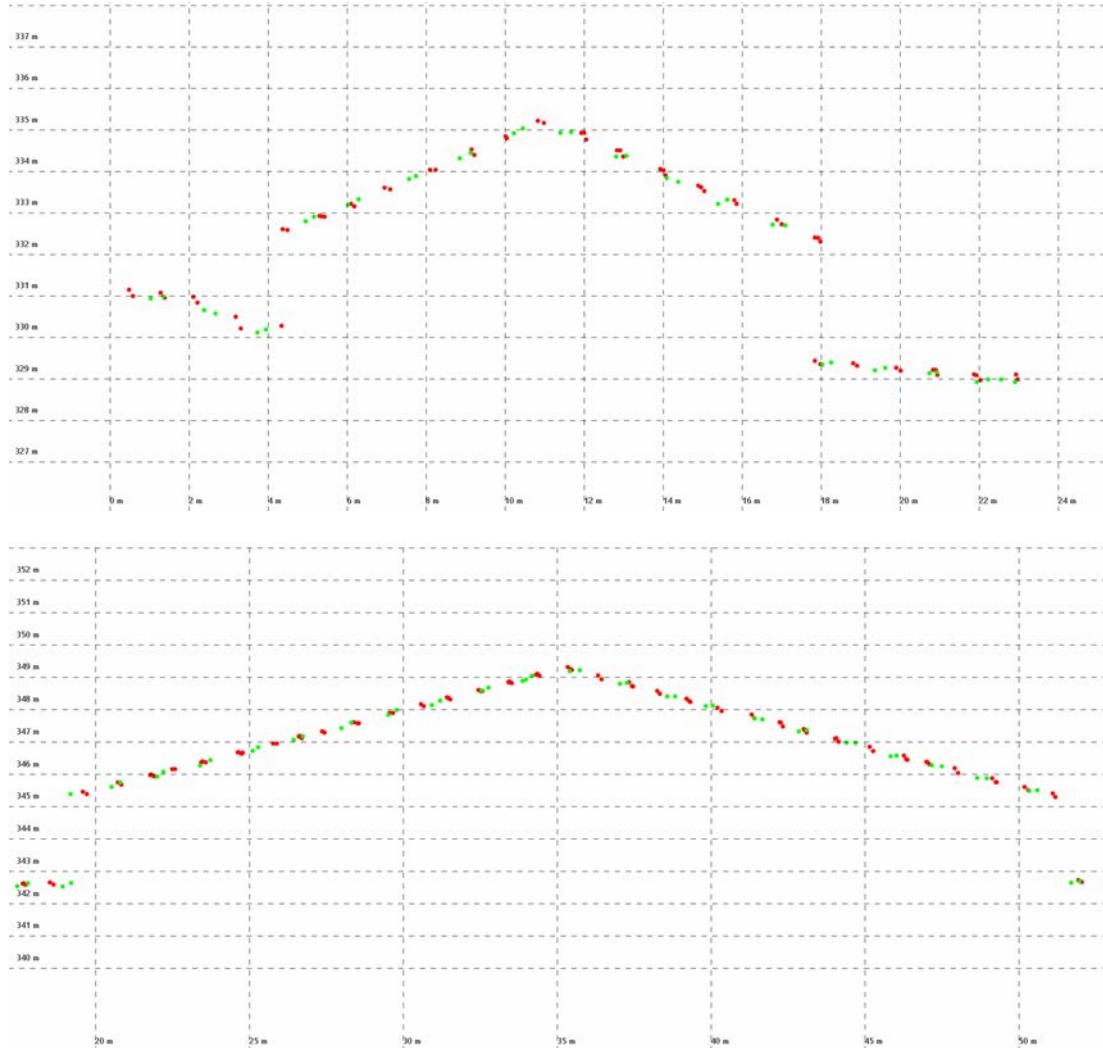
### **Within Swath Relative Accuracy (Intraswath):**

Intra-swath relative accuracy was reviewed and passes specification. All flight lines were reviewed to confirm intra-swath within 8 cm (green) of each other on flat plainer surfaces. Areas colored red are where differences greater than 8 cm exist. Red areas are expected in vegetated and sloped areas as this is an assessment only of hard surface repeatability.



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

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



See Appendix C: For SurvTech Solutions GPS and IMU Processing Reports

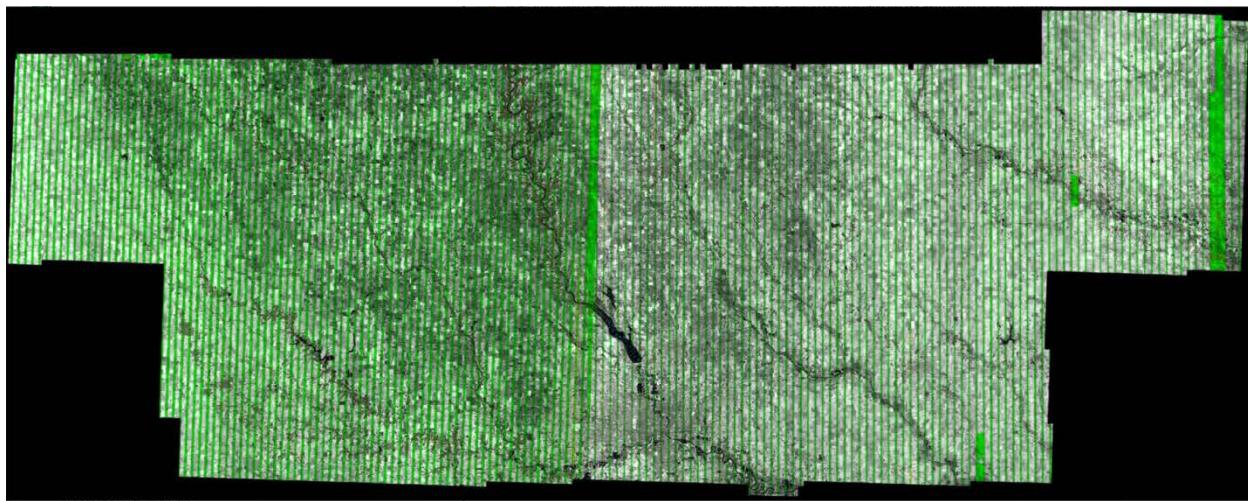


Figure 16: Block 3 IA North Central Project Delta-z raster image.

## DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, ASI utilized TerraScan software for data processing. The acquired 3D laser point clouds, in LAS binary format, were imported into the project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

In TerraScan surface models for each tile was created to examine the ground classification. ASI analysts visually reviewed the ground surface model for artifacts left in the ground classification. These artifacts consist of vegetation, buildings, and bridges that were still present in the ground after initial processing. ASI analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that errant points are removed from the ground classification. Bridge decks are manually classified to class 17. After the ground classification had been completed, the dataset was processed through a water classification routine that utilized breaklines compiled by the Prime and Subcontractor to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, ground points that are within 2x NPS or less of the hydrographic features are moved to class 20 ignored ground, due to breakline proximity. Overage points are then identified in TerraScan and used to set the overlap bit for those points. The withheld points identified during the classification routine are used to set the withheld bit. The LiDAR tiles were classified to the following classification schema:

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

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

This project consists of 60,042,226,001 lidar points the table below shows the total number of points for every class.

Project Count by Class		
Class 1	Processed, unclassified	6606864990
Class 2	Bare-earth ground	34653127546
Class 7	Low Noise	111541867
Class 9	Water	101114260
Class 17	Bridge Decks	3405725
Class 18	High Noise	507433022
Class 20	Ignored_Ground	3498777
Class Overlap 1	Overlap Processed, unclassified	7685232206
Class Overlap 2	Overlap Bare-earth ground	10237780852
Class Overlap 7	Overlap Low Noise	6835969
Class Overlap 9	Overlap Water	1697036
Class Overlap 17	Overlap Bridge Decks	1273270
Class Overlap 18	Overlap High Noise	101923198
Class Overlap 20	Overlap Ignored_Ground	758849
Class Withheld 1	Withheld Processed, unclassified	3617778
Class Withheld 2	Withheld Bare-earth ground	14573552
Class Withheld 7	Withheld Low Noise	2400
Class Withheld 17	Withheld Bridge Deck	6126

Class Overlap Withheld 1	Overlap Withheld Processed, unclassified	310922
Class Overlap Withheld 2	Overlap Withheld Processed, ground	1226075
Class Overlap Withheld 17	Overlap Withheld Bridge Deck	527
Class Overlap Withheld 18	Overlap Withheld High Noise	1054
Project Total Count		60042226001

Table 11: By Class Point Count.

## LiDAR Qualitative Assessment

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

## VISUAL REVIEW

The following sections describe common types of issues identified in LiDAR data and the results of the visual review for Block 3 IA North Central 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. Blocks; w3500n4674, w3520n4674, w3530n4674, w3540n4674 and w3550n4674 which are located along the northeastern edge of Block 3 contain void patches from the adjacent Aerial Survey International flights located in the center section of the Iowa Northcentral project area. These Blocks did not contain full coverage from either Aerial Survey International or SurvTech Solutions, so both sources had to be used to create full block coverage. No unacceptable voids are present in the Block 3 IA North Central 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).

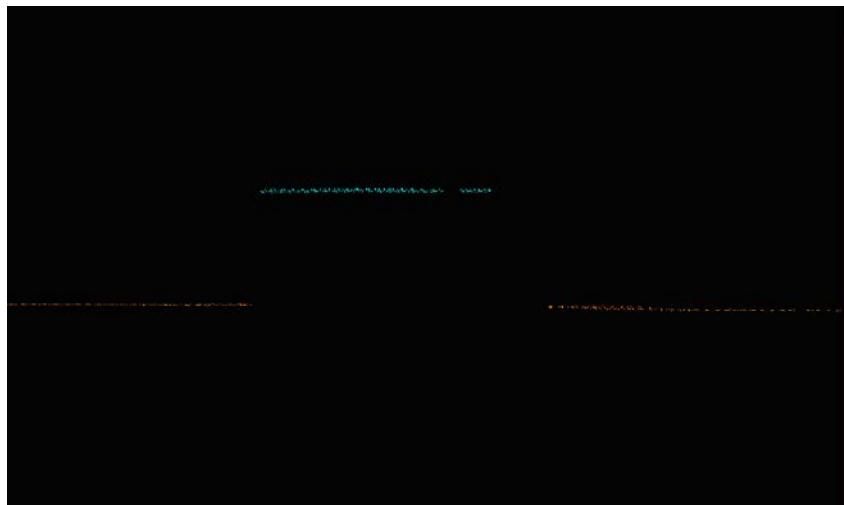


Figure 17: Profile view of a classified bridge deck (blue) and ground (orange).

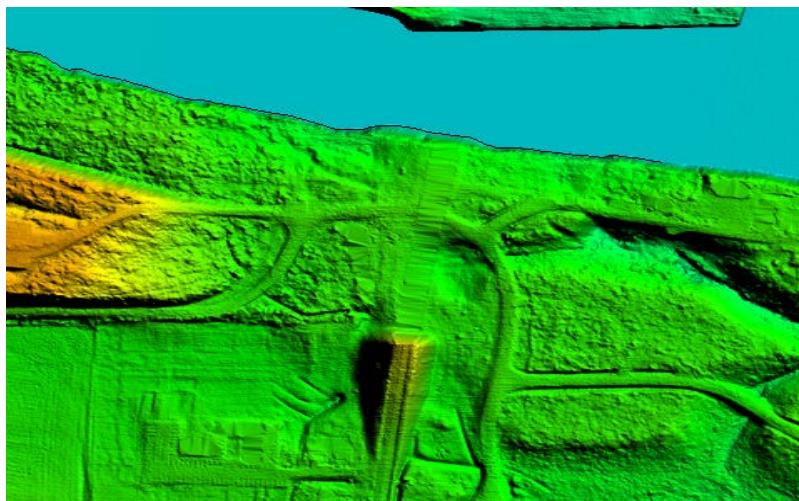


Figure 18: DEM with bridge removed from surface model.

### 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.

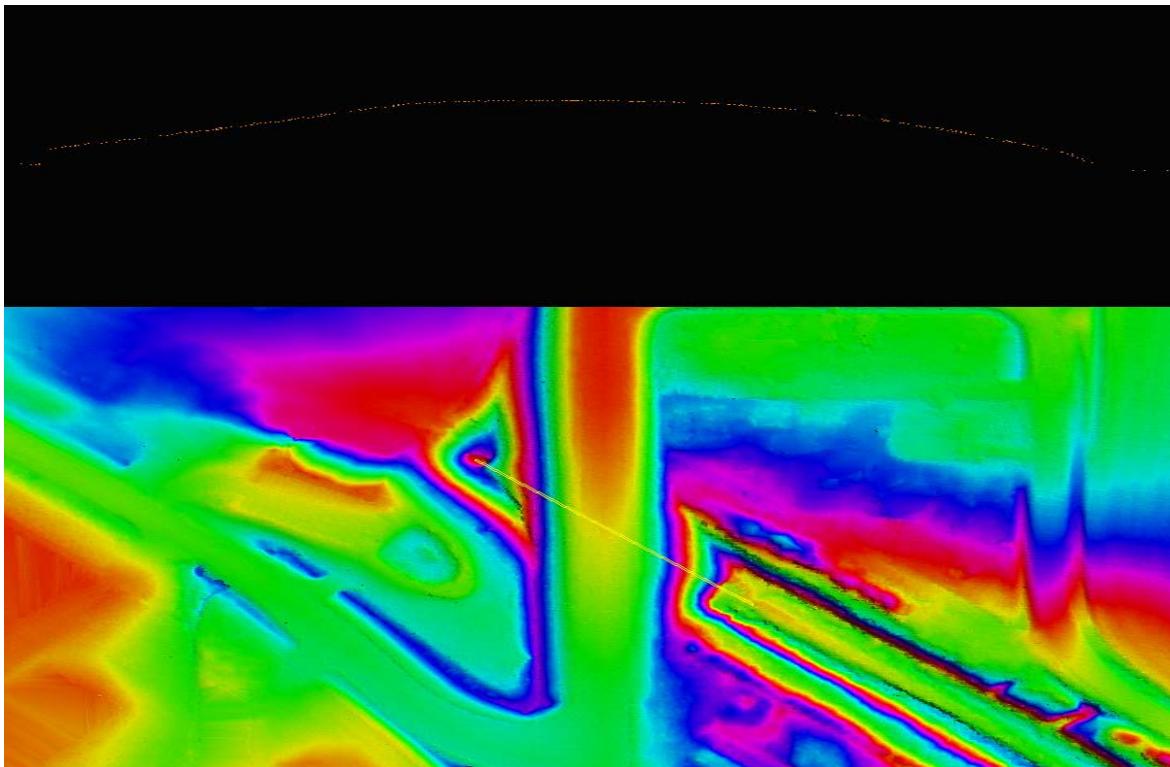


Figure 19: Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

### 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.

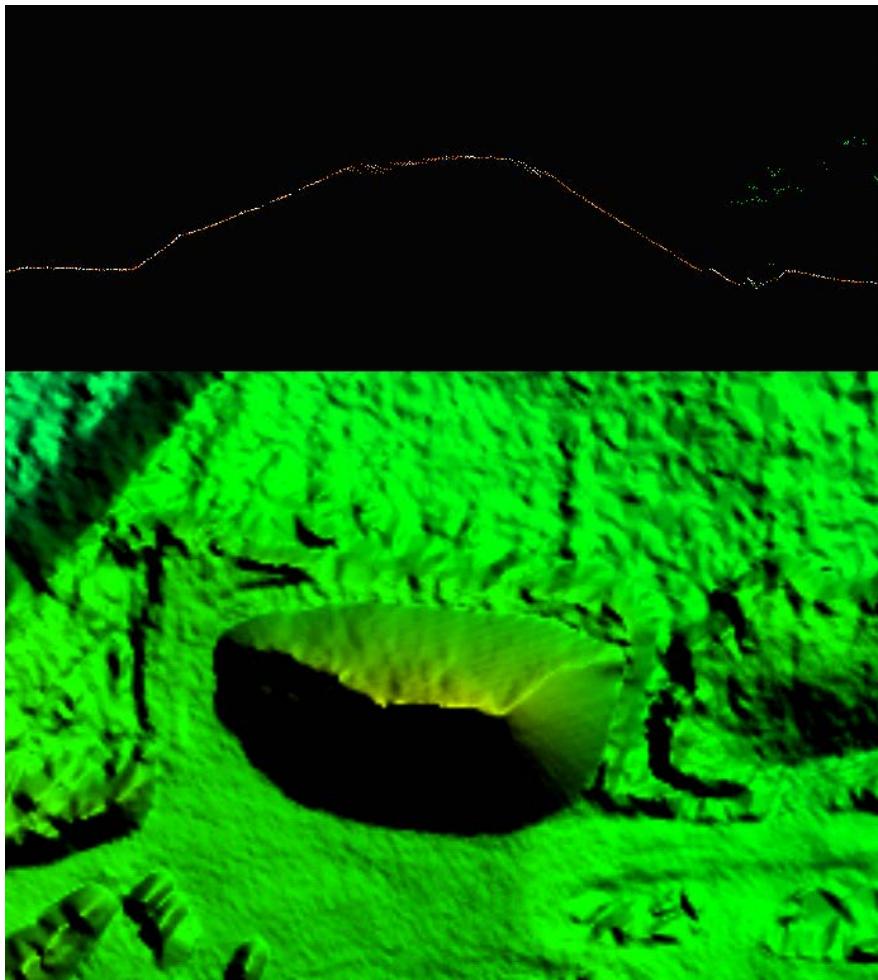


Figure 20: Profile with the points colored by class (unclassified points are white, ground points are orange) is shown on the right and a DEM of the surface is shown to the left. These features are correctly included in the ground classification.

## 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.

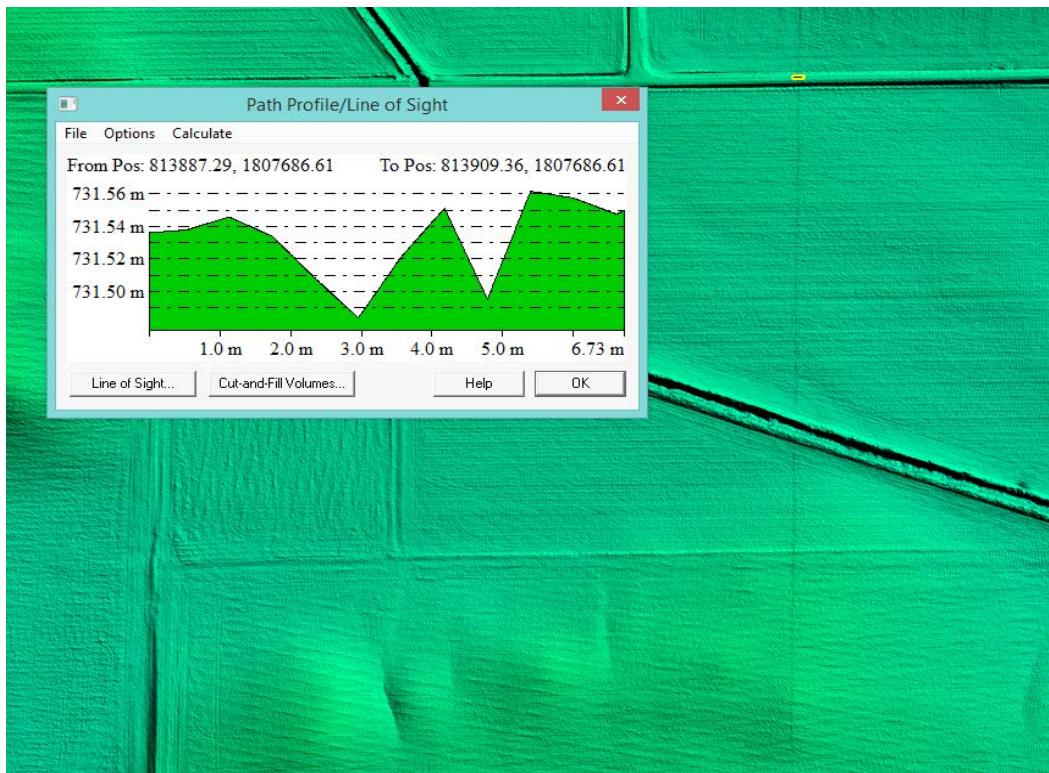


Figure 21: The flight line ridge is less than 8 cm. Overall; the Block 3 IA North Central project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.

### 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 Block 3 IA North Central Lidar project area.

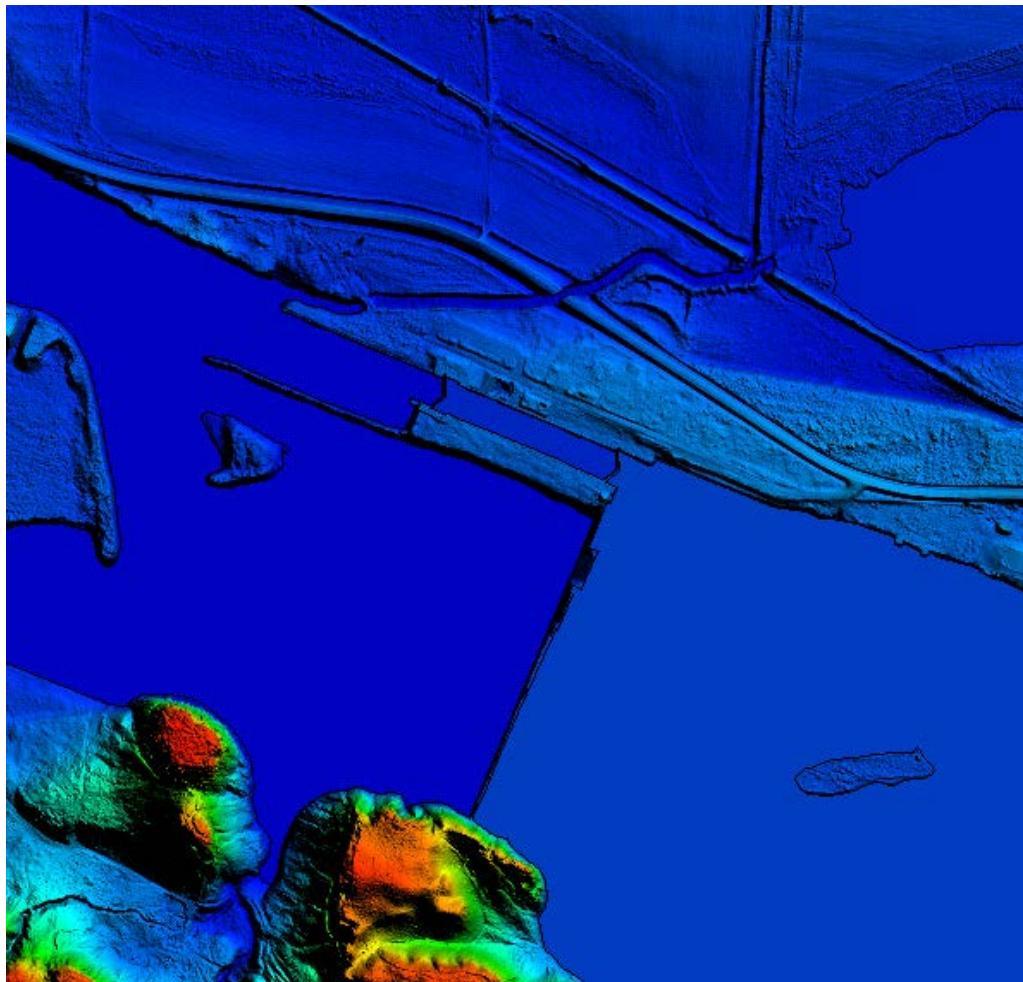


Figure 22: DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.

## FORMATTING

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

## ***LiDAR Positional Accuracy***

### **BACKGROUND**

ASI quantitatively tested the dataset by testing the vertical accuracy of the LiDAR. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. The nature of lidar data makes it difficult to assess absolute horizontal accuracy as one would with imagery or compiled planimetric data. Guidance on how absolute horizontal accuracy can be estimated and reported based on the error budget of the instrumentation and operational parameters can be found in ASPRS (2014). The horizontal accuracy of each lidar project shall be reported using the form specified by the ASPRS (2014).

### **SURVEY VERTICAL ACCURACY CHECKPOINTS**

For the vertical accuracy assessment of Block 3 IA North Central project, one hundred five check points were surveyed. All of those check points are located within bare earth/open terrain (105 NVA points). Please see provided survey report which details and validates how the survey was completed for this project. Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the "dispersed method" of placement. All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) UTM Zone 15 North	NAD83 (2011) UTM Zone 15 North	NAVD88 (Geoid12B)
	Easting (M)	Northing (M)	Elevation (M)
NVA108	423490.960	4635702.270	325.120
NVA234	530579.490	4661031.280	306.570
NVA256	523957.430	4681198.790	321.160
NVA257	537535.790	4678066.770	285.850
NVA258	544582.380	4678965.040	282.190
NVA259	553775.750	4675013.830	301.580
NVA260	557265.880	4668943.300	296.710
NVA261	544645.610	4670920.590	285.610

NVA262	534548.290	4669205.590	294.240
NVA263	549220.140	4658878.490	268.760
NVA264	535251.980	4646090.970	261.190
NVA265	523340.070	4669918.800	314.620
NVA266	550320.780	4641010.770	238.970
NVA267	507238.230	4650112.980	302.170
NVA268	507977.830	4661657.110	285.940
NVA269	517630.100	4636486.910	314.320
NVA270	507727.740	4618350.010	271.770
NVA271	503251.090	4643540.510	310.330
NVA272	499887.490	4670600.830	305.900
NVA273	483879.640	4663375.270	309.260
NVA274	486461.860	4651583.170	325.550
NVA275	491449.430	4643423.450	318.820
NVA276	352175.700	4656495.970	365.240
NVA277	336723.690	4672098.220	417.680
NVA278	344941.090	4673211.080	377.090
NVA279	344674.810	4660708.160	404.610
NVA280	359017.700	4671279.210	334.450
NVA281	328745.690	4641510.020	415.500
NVA282	336514.500	4652306.430	413.230
NVA283	326435.450	4660166.390	411.840
NVA284	339252.530	4639622.460	422.150
NVA285	360800.710	4636801.910	357.590

NVA286	386077.980	4652601.210	324.420
NVA287	377847.520	4668274.590	338.800
NVA288	396398.180	4668896.070	336.690
NVA289	365195.900	4656981.800	336.110
NVA290	372063.610	4653236.610	360.150
NVA291	364933.840	4643854.850	356.690
NVA292	379454.820	4643616.600	345.140
NVA293	388448.250	4641853.200	328.260
NVA294	397113.960	4648192.680	328.450
NVA295	405241.430	4654582.460	308.770
NVA296	408567.370	4662265.770	335.890
NVA297	386536.560	4637078.070	334.920
NVA298	415904.300	4668749.040	338.670
NVA299	427095.990	4657217.490	346.380
NVA300	434248.410	4668518.220	335.660
NVA301	425760.010	4664644.740	353.690
NVA302	414634.970	4654850.480	333.220
NVA303	448541.340	4649912.350	280.750
NVA304	438920.050	4652574.020	321.360
NVA305	450864.580	4670724.880	306.210
NVA306	442311.500	4668505.500	314.480
NVA307	432424.210	4646233.710	336.020
NVA308	404991.570	4637634.870	311.670
NVA309	447172.420	4661397.540	302.700

NVA310	462548.280	4652406.690	305.900
NVA311	458665.350	4668573.900	313.860
NVA312	458487.420	4658587.720	309.090
NVA313	468119.320	4668346.800	331.660
NVA315	450294.380	4638355.980	311.020
NVA316	466772.840	4637470.030	265.440
NVA317	474401.510	4658484.260	332.610
NVA318	475948.440	4639425.530	312.410
NVA319	499953.740	4658395.420	271.850
NVA320	506433.710	4629772.550	289.190
NVA321	519413.210	4620509.010	292.430
NVA322	518121.570	4603038.990	249.040
NVA323	498272.360	4613992.440	289.510
NVA324	495170.800	4629802.880	272.280
NVA325	491561.020	4595379.270	277.660
NVA326	493378.830	4611184.190	268.030
NVA327	479601.380	4614156.270	242.750
NVA328	476295.340	4623945.190	255.490
NVA329	461221.630	4612660.260	293.370
NVA330	446065.980	4596658.030	286.270
NVA331	428770.590	4603327.960	313.690
NVA332	470139.750	4595543.590	246.970
NVA333	448335.340	4620245.890	298.170
NVA334	435598.610	4630117.900	291.490

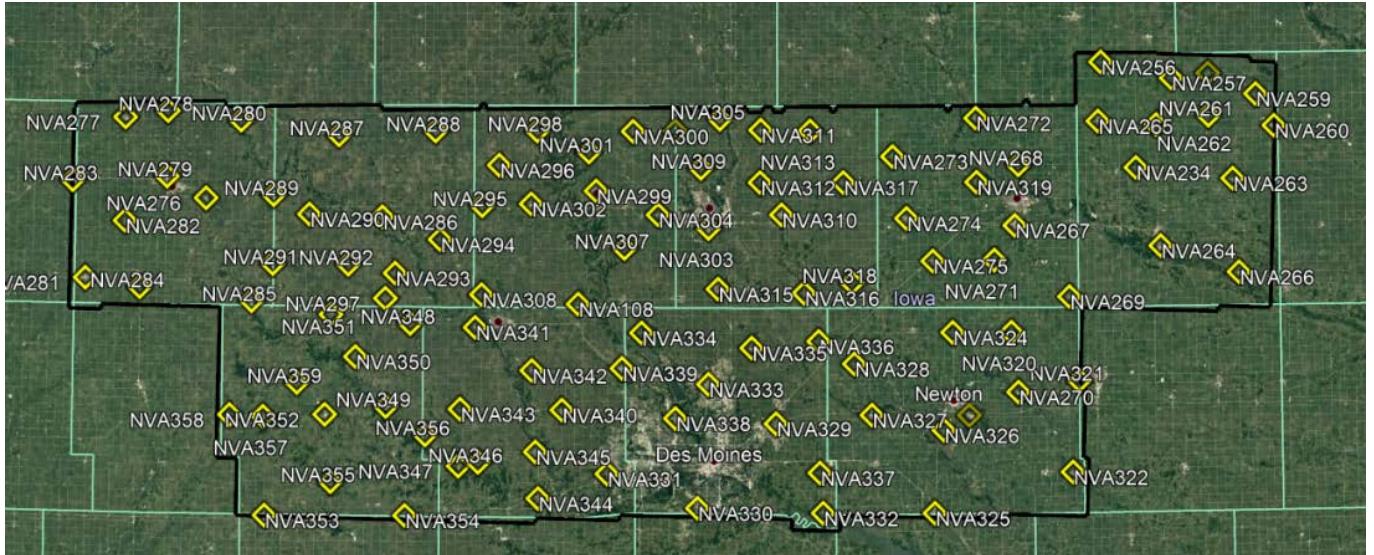
NVA335	456669.130	4627095.030	295.280
NVA336	469496.100	4628272.620	292.730
NVA337	469571.480	4603206.530	275.950
NVA338	441964.990	4613797.630	254.370
NVA339	431805.330	4623399.800	270.150
NVA340	420233.420	4615541.670	320.040
NVA341	403721.390	4631409.470	308.490
NVA342	414515.730	4623108.090	319.710
NVA343	400716.930	4615848.740	312.440
NVA344	415523.470	4598722.720	294.170
NVA345	415083.170	4607603.830	273.330
NVA346	404053.680	4605687.110	289.060
NVA347	400271.640	4605007.330	295.470
NVA348	391261.200	4632242.310	319.090
NVA349	386439.460	4616450.040	330.170
NVA350	380706.460	4626003.680	356.770
NVA351	376074.430	4634084.710	356.020
NVA352	374711.500	4615025.020	333.180
NVA353	362919.470	4595866.350	447.540
NVA354	389919.300	4595649.580	368.370
NVA355	375696.730	4602192.940	394.780
NVA356	393948.940	4610993.250	342.820
NVA357	362839.230	4614741.440	418.600
NVA358	356397.650	4615119.080	428.730

NVA359	369402.170	4621145.460	372.680
VVA117	525398.820	4678890.510	322.520
VVA119	451599.860	4670186.950	296.050
VVA120	427464.110	4649486.150	332.320
VVA121	426938.410	4658697.870	345.720
VVA122	448401.670	4656883.420	275.010
VVA123	449696.940	4638401.630	313.260
VVA124	474229.810	4651564.310	313.750
VVA125	486979.420	4662206.150	290.760
VVA126	507698.120	4656778.280	264.530
VVA127	523324.800	4670292.790	303.730
VVA128	526200.610	4660229.450	272.460
VVA129	545017.370	4671172.380	270.360
VVA130	556994.180	4680090.660	291.650
VVA131	545535.820	4678976.560	273.890
VVA132	556272.470	4668655.500	285.700
VVA133	534984.940	4644250.460	248.010
VVA134	550206.920	4641536.880	238.230
VVA135	540007.030	4655014.950	301.630
VVA136	507497.240	4650087.530	302.770
VVA137	491574.150	4642949.910	313.820
VVA138	517923.630	4636204.580	314.810
VVA139	513050.830	4621369.010	267.490

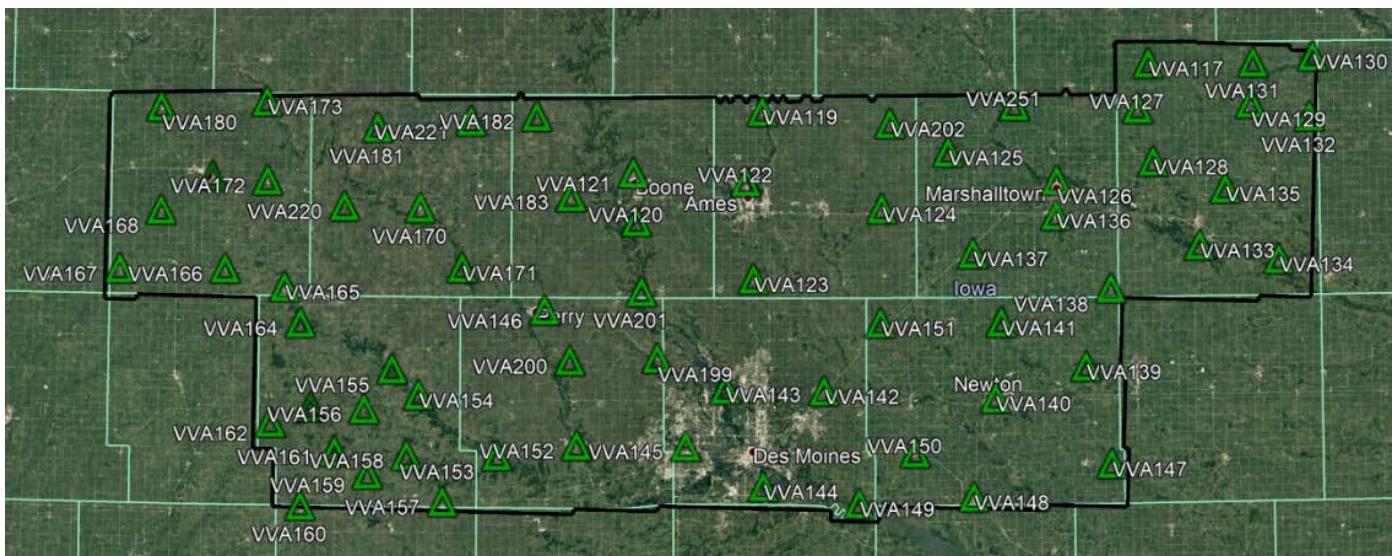
VVA140	495728.080	4615467.250	278.940
VVA141	496912.360	4629845.470	273.640
VVA142	462995.470	4617055.870	297.450
VVA143	444179.740	4617544.480	280.380
VVA144	451263.350	4598992.920	249.930
VVA145	436522.930	4606786.760	259.480
VVA146	409829.920	4632826.240	296.570
VVA147	517903.160	4602856.600	261.990
VVA148	491460.480	4596737.960	280.620
VVA149	469555.800	4595615.030	248.720
VVA150	480338.280	4605181.830	282.410
VVA151	473867.230	4629882.340	253.690
VVA152	415726.340	4607083.870	270.610
VVA153	400453.820	4605239.150	305.430
VVA154	385616.150	4616892.730	332.620
VVA155	380586.220	4621888.420	334.420
VVA156	375162.220	4614343.380	324.520
VVA157	389965.140	4596588.210	350.480
VVA158	383188.970	4605439.750	314.600
VVA159	375680.050	4601893.990	386.390
VVA160	362748.180	4596058.220	445.670
VVA161	369402.650	4606294.190	416.690
VVA162	357177.130	4611870.880	427.590
VVA163	364930.250	4614750.450	380.100

VVA164	363121.070	4630781.820	340.820
VVA165	360137.380	4637639.390	363.860
VVA166	348751.410	4641255.260	382.250
VVA167	328513.920	4641430.520	406.950
VVA168	336542.730	4652537.090	420.890
VVA169	346475.490	4658961.040	376.840
VVA170	386226.440	4652473.360	327.820
VVA171	394124.860	4640989.120	293.970
VVA172	357032.850	4657937.360	374.110
VVA173	357035.540	4672926.660	329.050
VVA180	336756.860	4672183.970	414.650
VVA181	378177.530	4667767.420	337.200
VVA182	408598.540	4669626.330	346.380
VVA183	415060.070	4654302.380	331.980
VVA199	431223.750	4623506.300	270.660
VVA200	414542.870	4623190.230	318.720
VVA201	428324.530	4636170.220	262.070
VVA202	475944.670	4667714.640	315.530
VVA220	371725.87	4652916.06	357.45
VVA221	396065.22	4668806.32	337.58
VVA251	499710.99	4670957.14	308.08

Table 12: Block 3 IA North Central project LiDAR Validation Checkpoints.



**Figure 23: Location of Block 3 IA North Central LiDAR NVA Checkpoints**



**Figure 24:** VVA Checkpoints were located in Block 3 IA North Central

## 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 Block 3 IA North Central project, vertical accuracy must be 19.6 cm (0.64 ft) or less based on an RMSEz of 10 cm (0.33 ft)  $\times 1.9600$ . VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Block 3 IA North Central Lidar project VVA standard is 29.4 cm (0.96 ft) based on the 95th percentile.

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

Table 13: Acceptance Criteria.

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

1. Prairie Engineers 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	105	0.081	
VVA	67		0.086

Table 14: Tested NVA and VVA.

## HORIZONTAL ACCURACY TEST PROCEDURES

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

## ***Breakline Production methodology***

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

## **Breakline Qualitative Assessment**

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

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

## **Feature Definition**

### **Inland Streams and Rivers**

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

### **Inland Ponds and Lakes**

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

### **Islands**

Permanent island 4046m<sup>2</sup> (1 acre) or larger were delineated within all water bodies. Breaklines have been delivered in PolygonZ format in the final GDB

### **Bridge Breaklines**

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

## *Intensity Imagery Production & Qualitative Assessment*

### **INTENSITY PRODUCTION METHODOLOGY**

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

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

### **INTENSITY QUALITATIVE ASSESSMENT**

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



Figure 25: Intensity Image example.

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

### **DEM PRODUCTION METHODOLOGY**

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

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

### **DEM QUALITATIVE ASSESSMENT**

ASI performed a qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained proper referencing information.

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

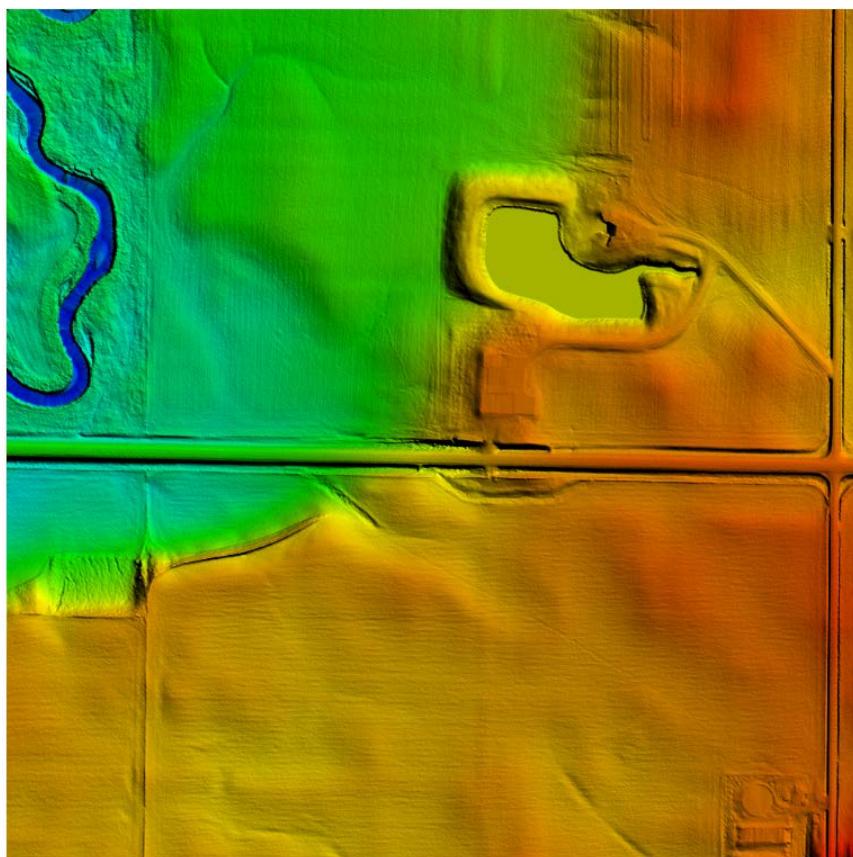


Figure 26: Block 3 IA North Central project bare earth DEM

## DEM VERTICAL ACCURACY RESULTS

The same 103 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.

Table 15; 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	105	0.082	
VVA	67		0.101

Table 15: DEM vertical accuracy summary

DEM datasets were tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 0.042 meters with a 0.083 meters accuracy at 95 % confidence level. Actual VVA accuracy tested 0.101 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 Block 3 IA North Central project satisfies the project's pre-defined vertical accuracy criteria.

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

w3250n4635	w3260n4666	w3280n4637
w3250n4636	w3260n4667	w3280n4638
w3250n4637	w3260n4668	w3280n4639
w3250n4638	w3260n4669	w3280n4640
w3250n4639	w3260n4670	w3280n4641
w3250n4640	w3260n4671	w3280n4642
w3250n4641	w3260n4672	w3280n4643
w3250n4642	w3260n4673	w3280n4644
w3250n4643	w3270n4635	w3280n4645
w3250n4644	w3270n4636	w3280n4646
w3250n4645	w3270n4637	w3280n4647
w3250n4646	w3270n4638	w3280n4648
w3250n4647	w3270n4639	w3280n4649
w3250n4648	w3270n4640	w3280n4650
w3250n4649	w3270n4641	w3280n4651
w3250n4650	w3270n4642	w3280n4652
w3250n4651	w3270n4643	w3280n4653
w3250n4652	w3270n4644	w3280n4654
w3250n4653	w3270n4645	w3280n4655
w3260n4635	w3270n4646	w3280n4656
w3260n4636	w3270n4647	w3280n4657
w3260n4637	w3270n4648	w3280n4658
w3260n4638	w3270n4649	w3280n4659
w3260n4639	w3270n4650	w3280n4660
w3260n4640	w3270n4651	w3280n4661
w3260n4641	w3270n4652	w3280n4662
w3260n4642	w3270n4653	w3280n4663
w3260n4643	w3270n4654	w3280n4664
w3260n4644	w3270n4655	w3280n4665
w3260n4645	w3270n4656	w3280n4666
w3260n4646	w3270n4657	w3280n4667
w3260n4647	w3270n4658	w3280n4668
w3260n4648	w3270n4659	w3280n4669
w3260n4649	w3270n4660	w3280n4670
w3260n4650	w3270n4661	w3280n4671
w3260n4651	w3270n4662	w3280n4672
w3260n4652	w3270n4663	w3280n4673
w3260n4653	w3270n4664	w3280n4674
w3260n4654	w3270n4665	w3290n4635
w3260n4655	w3270n4666	w3290n4636
w3260n4656	w3270n4667	w3290n4637
w3260n4657	w3270n4668	w3290n4638
w3260n4658	w3270n4669	w3290n4639
w3260n4659	w3270n4670	w3290n4640
w3260n4660	w3270n4671	w3290n4641
w3260n4661	w3270n4672	w3290n4642
w3260n4662	w3270n4673	w3290n4643
w3260n4663	w3270n4674	w3290n4644
w3260n4664	w3280n4635	w3290n4645
w3260n4665	w3280n4636	w3290n4646

w3290n4647	w3300n4658	w3310n4669
w3290n4648	w3300n4659	w3310n4670
w3290n4649	w3300n4660	w3310n4671
w3290n4650	w3300n4661	w3310n4672
w3290n4651	w3300n4662	w3310n4673
w3290n4652	w3300n4663	w3310n4674
w3290n4653	w3300n4664	w3320n4636
w3290n4654	w3300n4665	w3320n4637
w3290n4655	w3300n4666	w3320n4638
w3290n4656	w3300n4667	w3320n4639
w3290n4657	w3300n4668	w3320n4640
w3290n4658	w3300n4669	w3320n4641
w3290n4659	w3300n4670	w3320n4642
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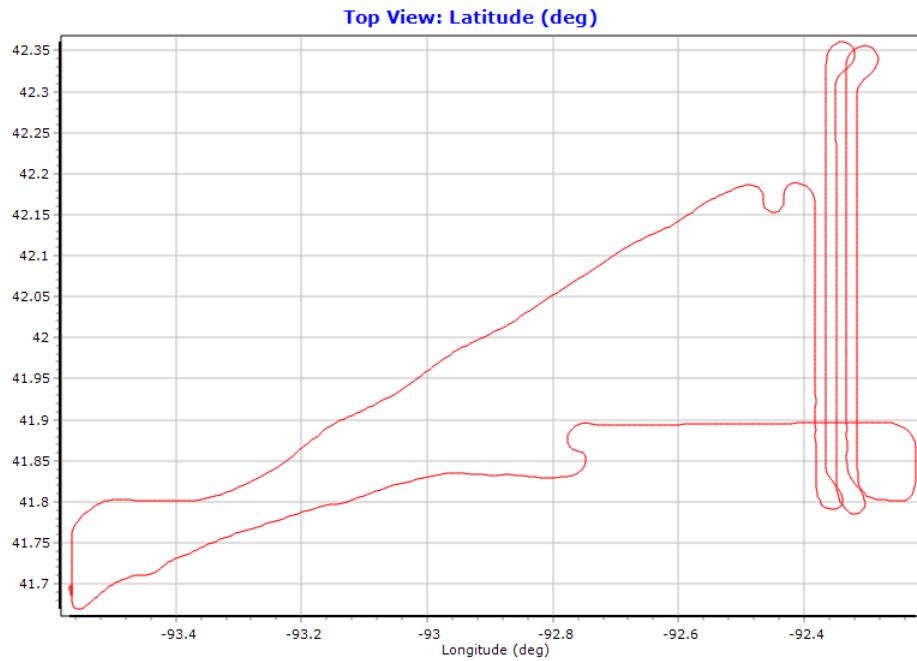
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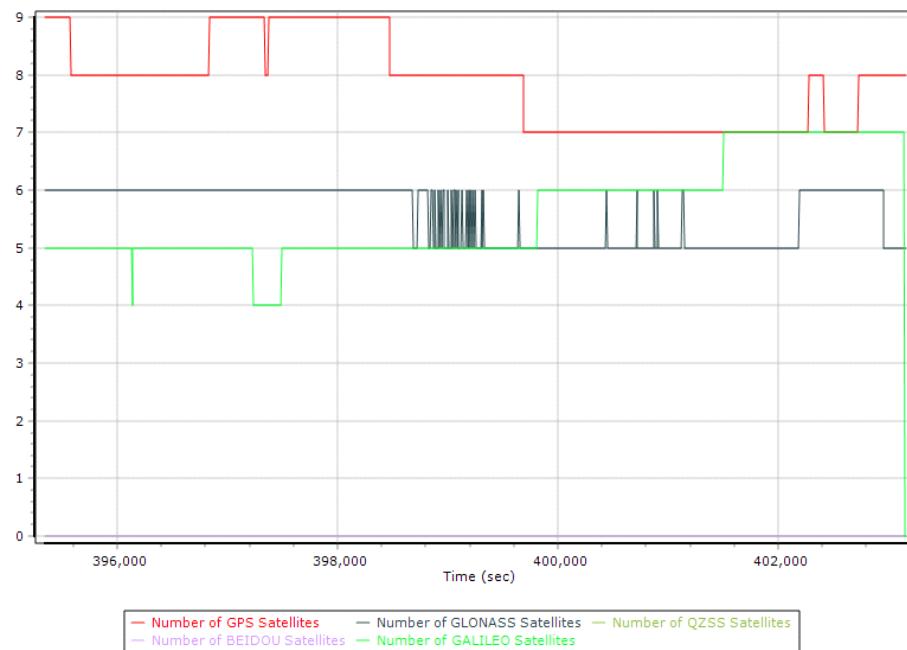
## Appendix B: Aerial Surveys International, LLC Mission GPS and IMU Processing Report

South\_041620A\_10-442.docx QC Report - 4/07/2021 14:11:41  
Smoothed Trajectory Information

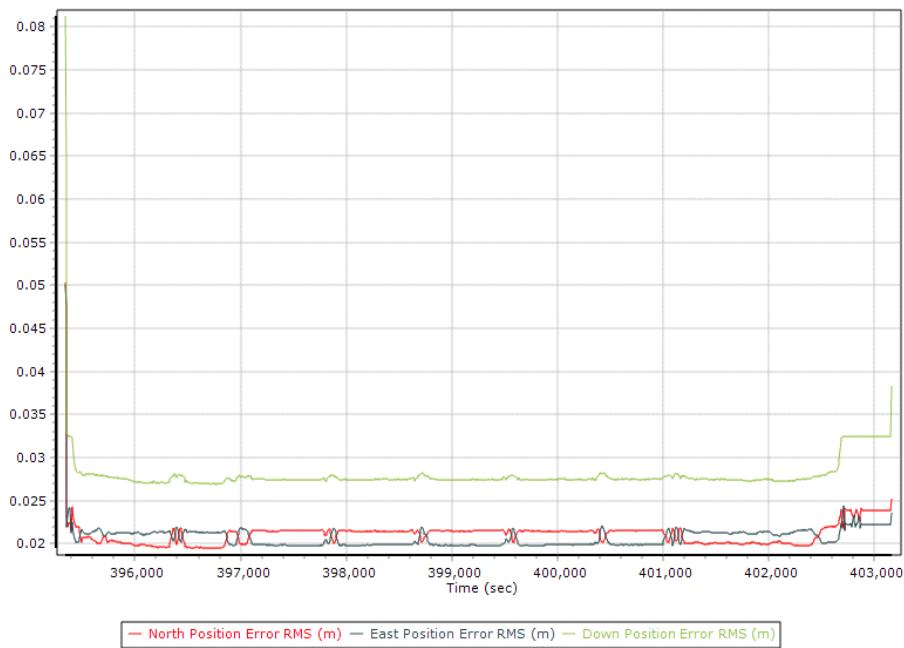
### Top View



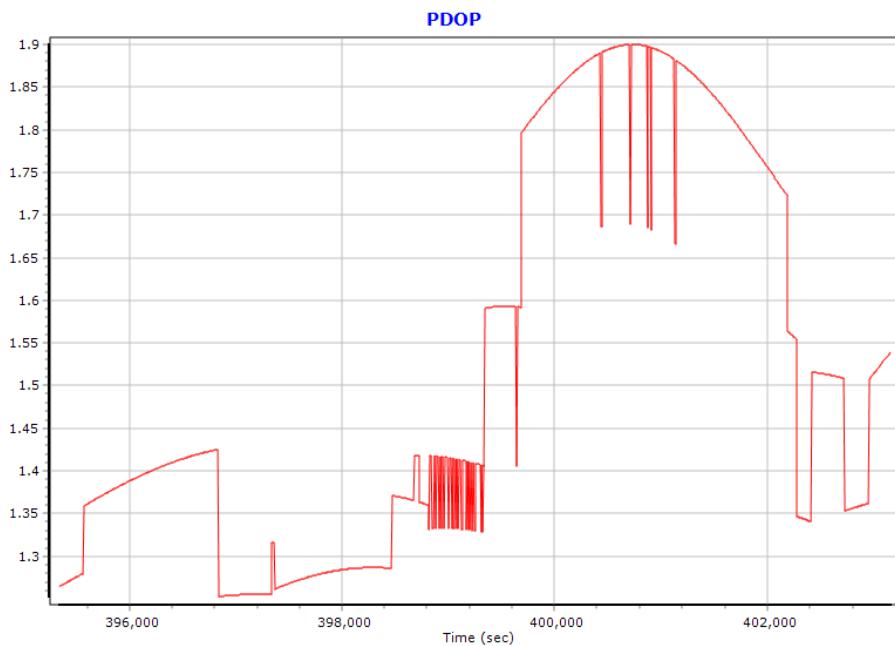
### Number of Satellites



### Forward/Reverse Separation

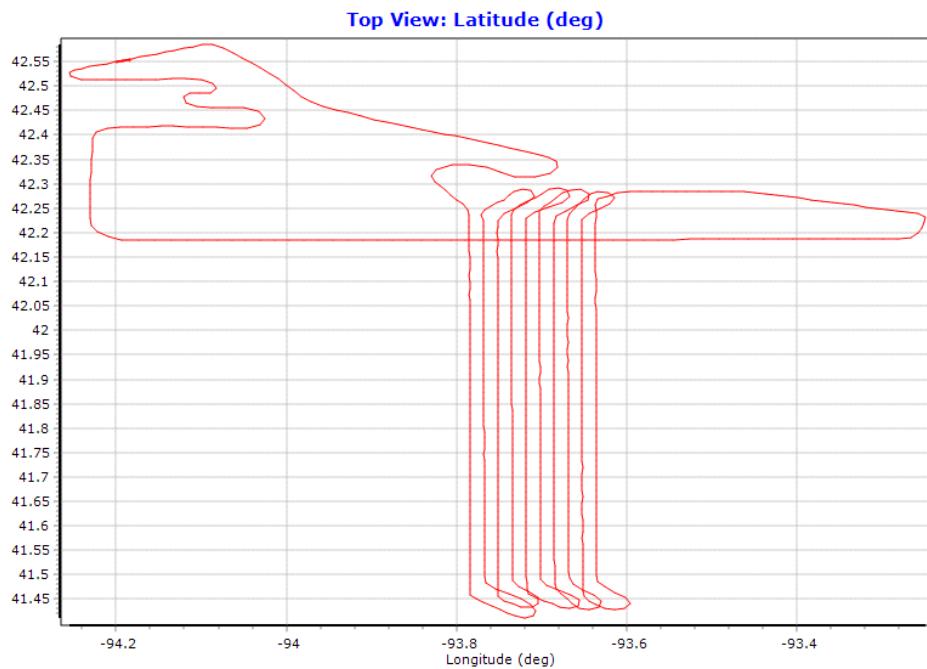


### PDOP

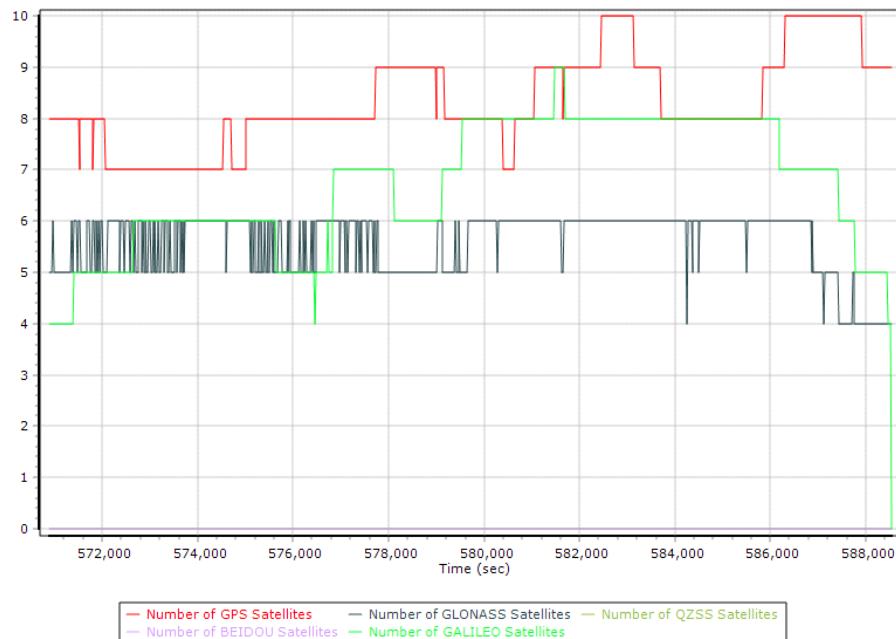


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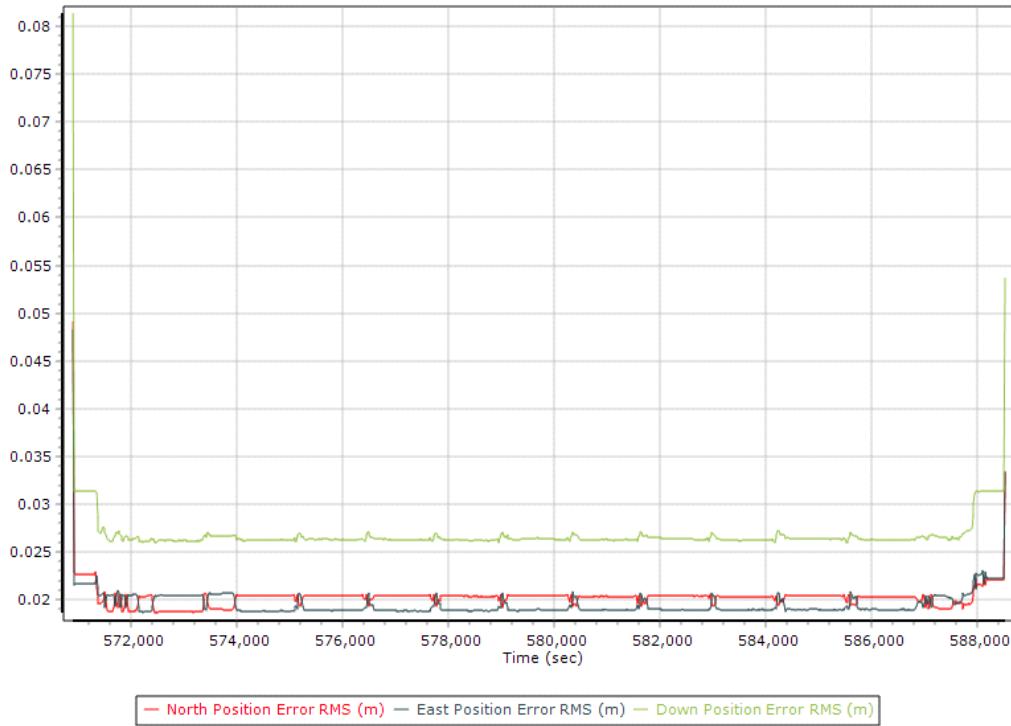
### Top View



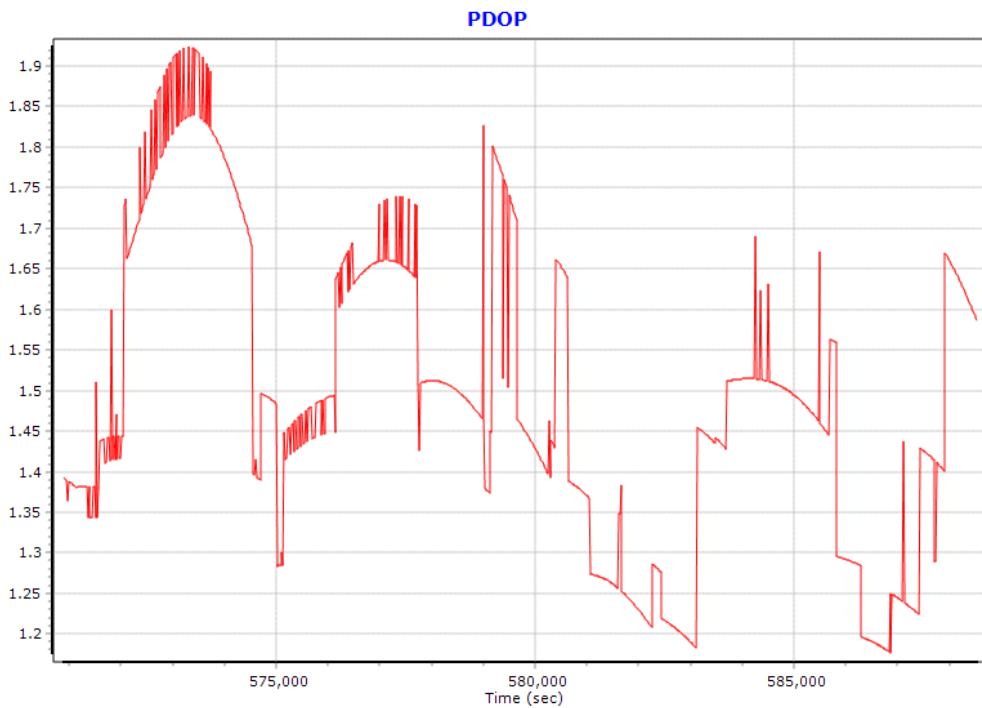
### Number of Satellites



### Forward/Reverse Separation



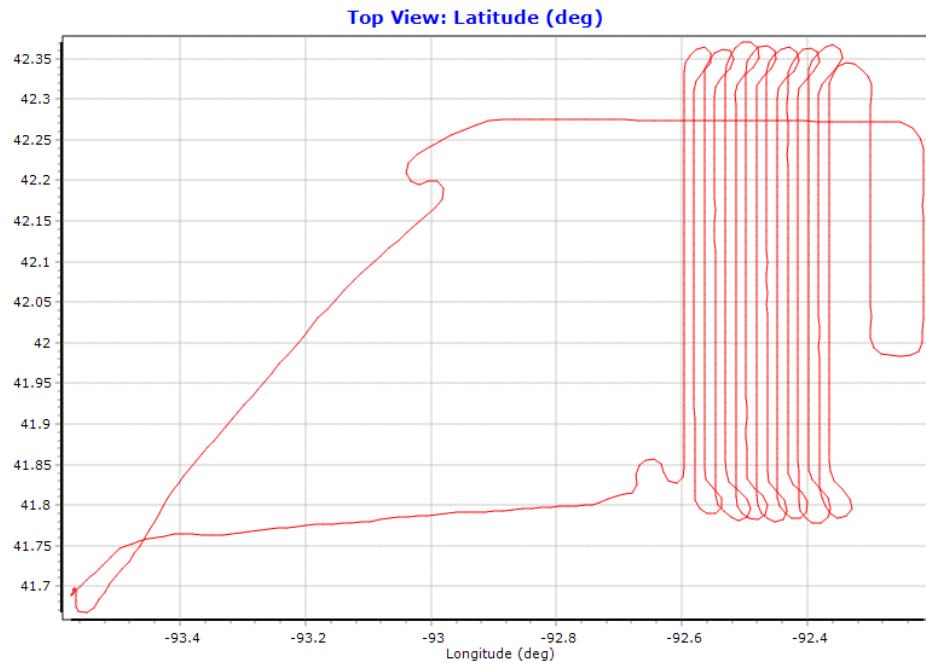
## PDOP



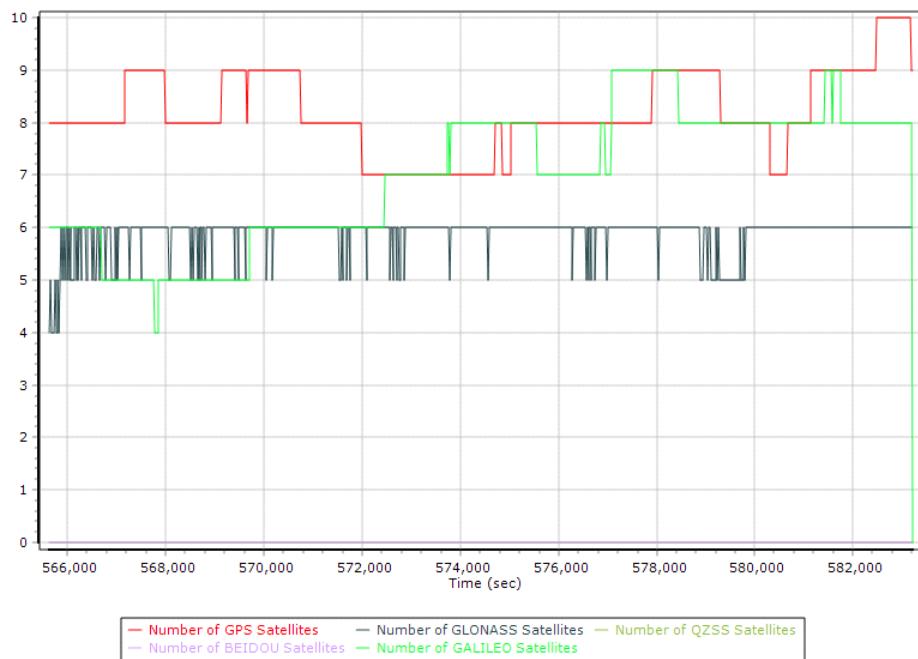
Block 1 IA North Central 2020  
5/12/2021

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Smoothed Trajectory Information

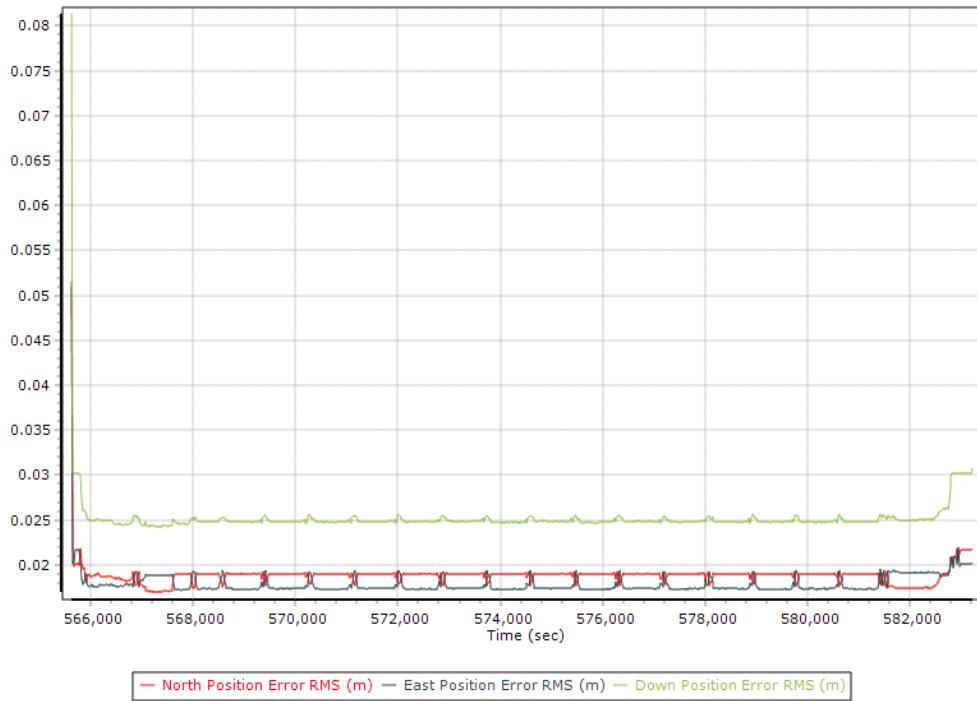
### Top View



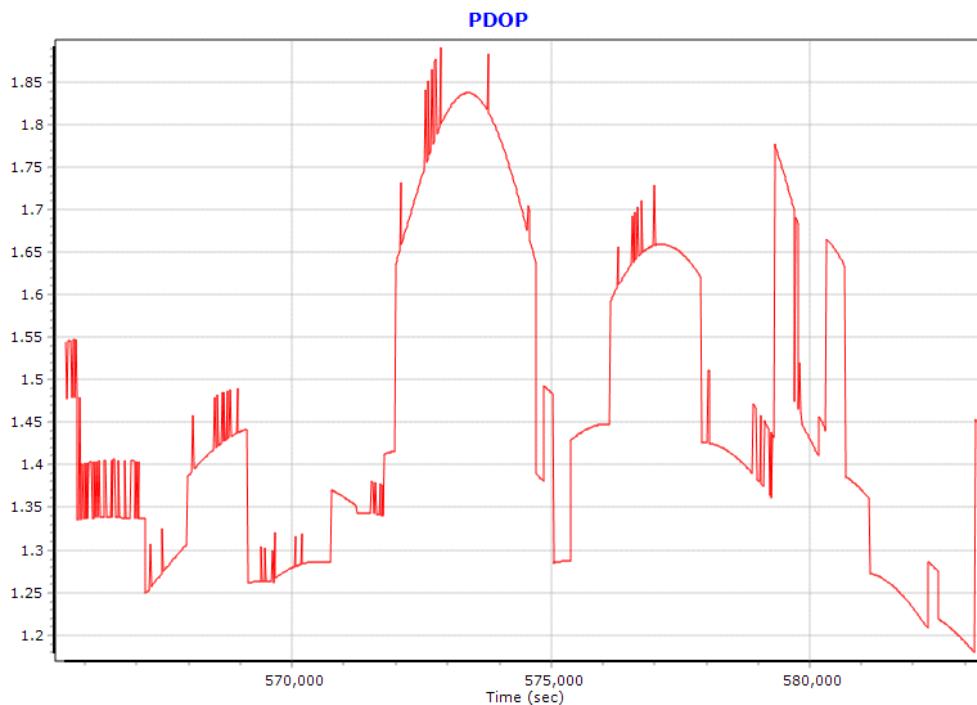
### Number of Satellites



### Forward/Reverse Separation

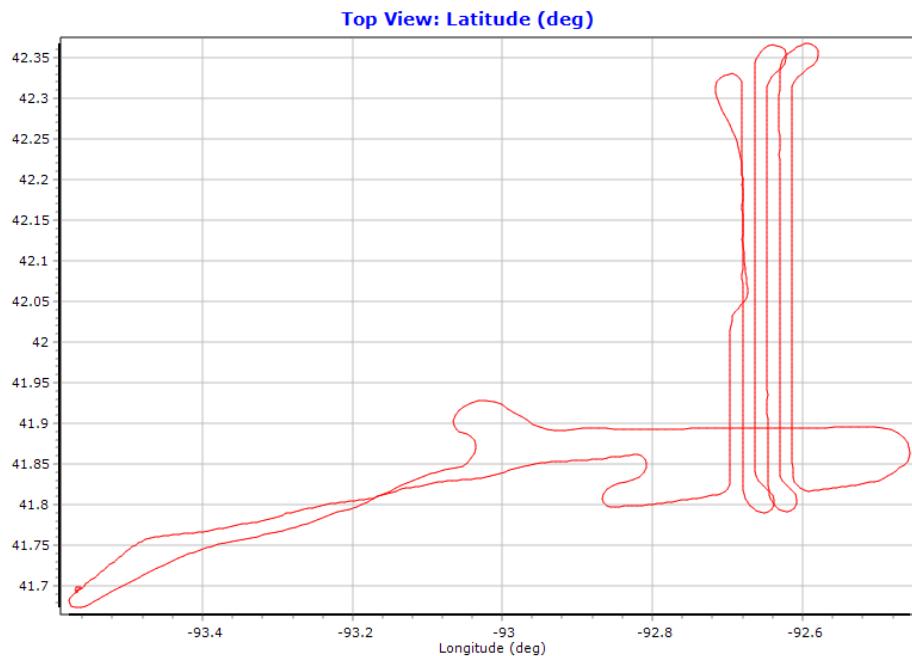


## PDOP

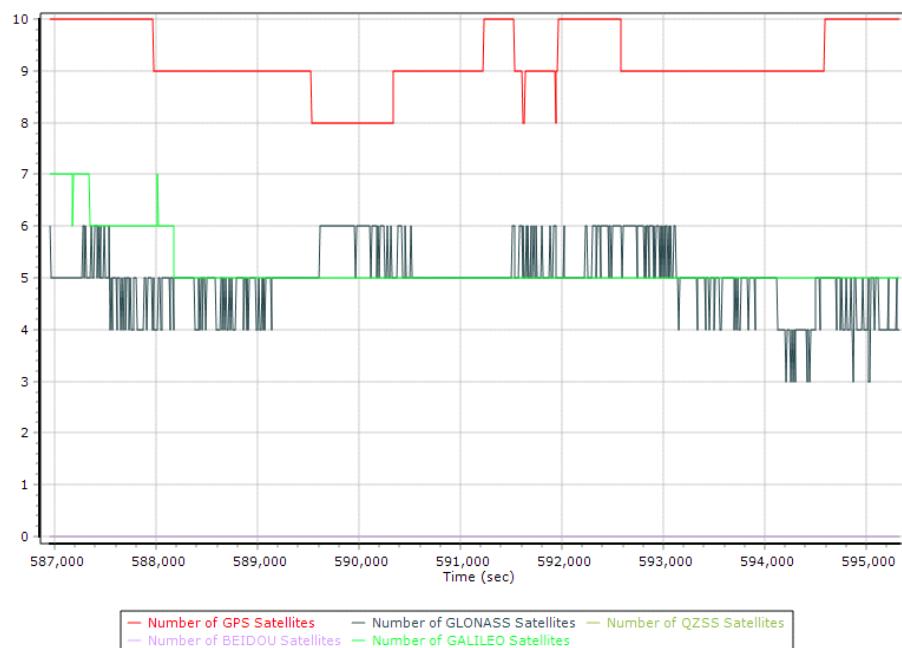


South\_041820B\_12-442.docx QC Report - 4/07/2021 14:05:25  
Smoothed Trajectory Information

### Top View



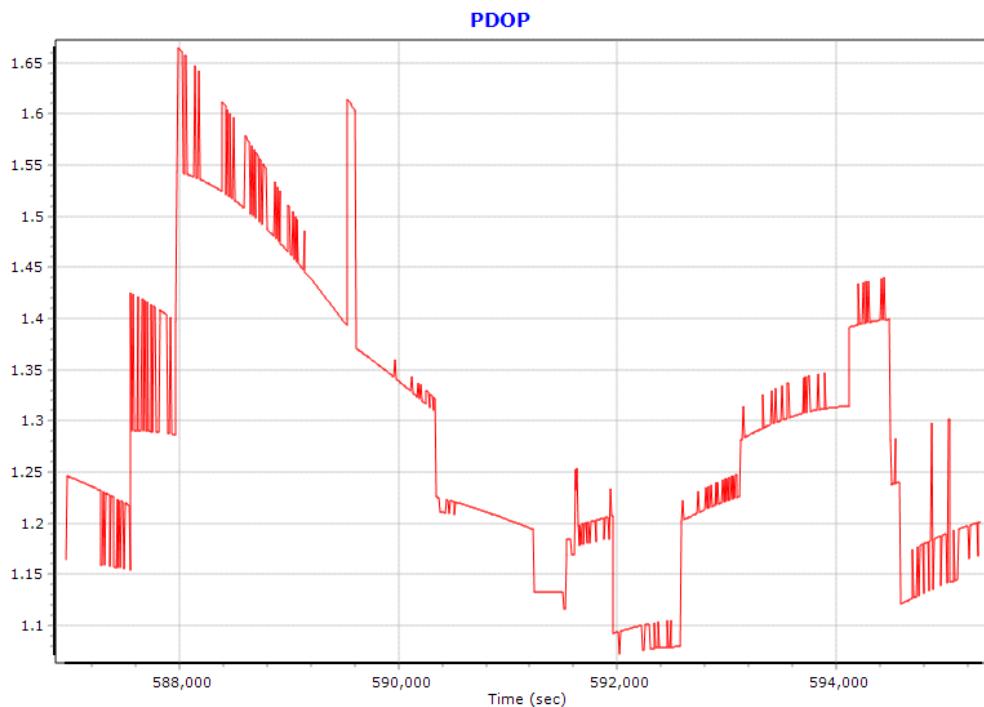
### Number of Satellites



### Forward/Reverse Separation

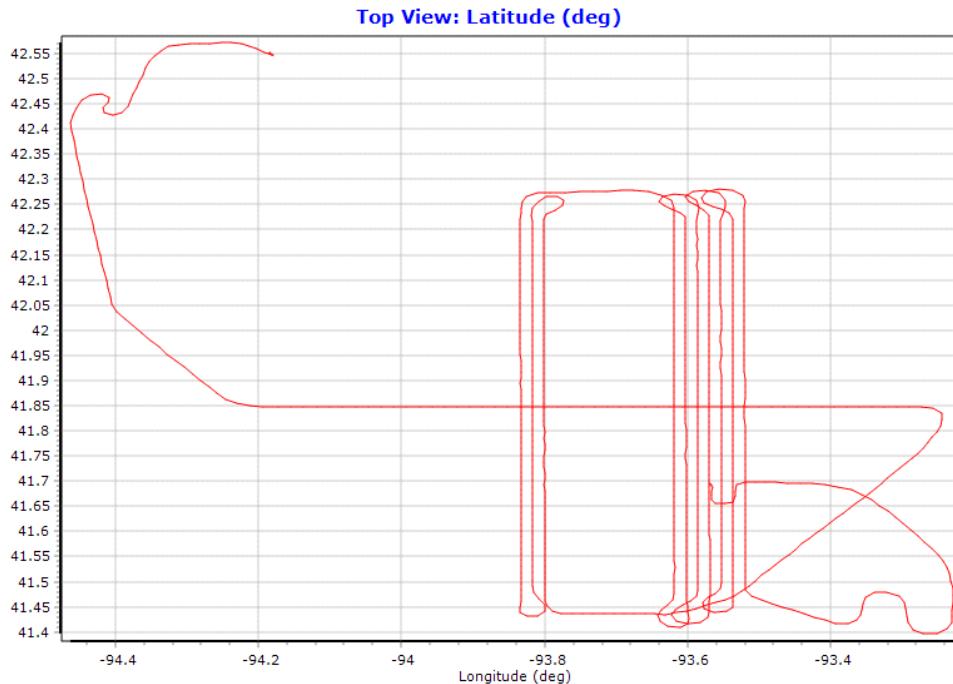


## PDOP

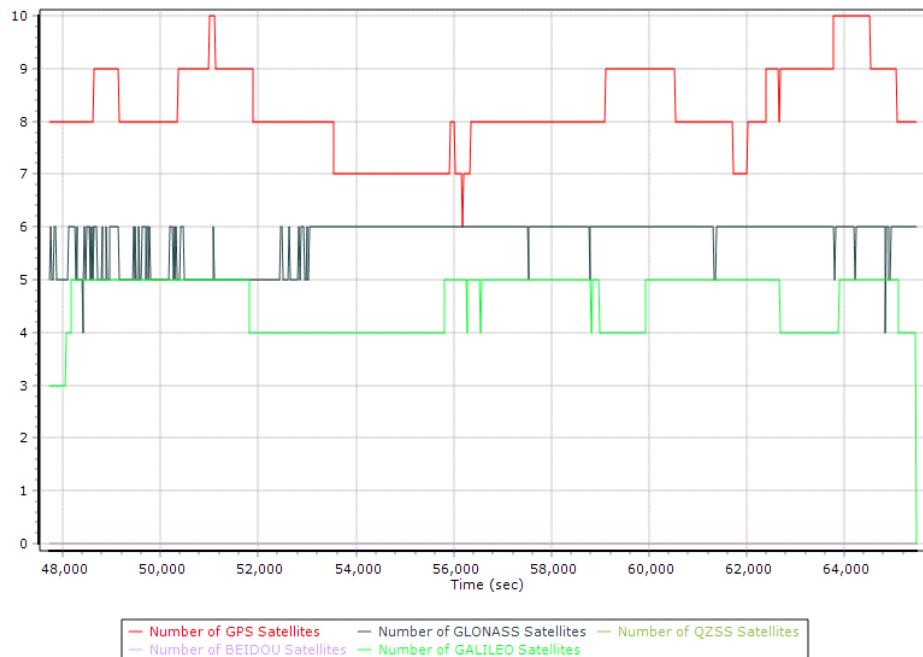


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Smoothed Trajectory Information

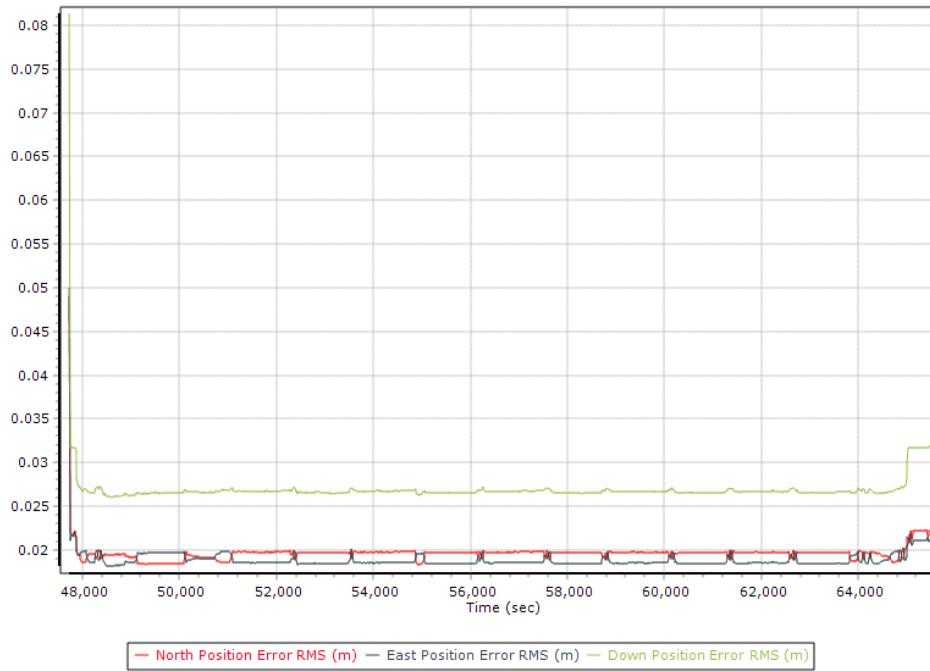
### Top View



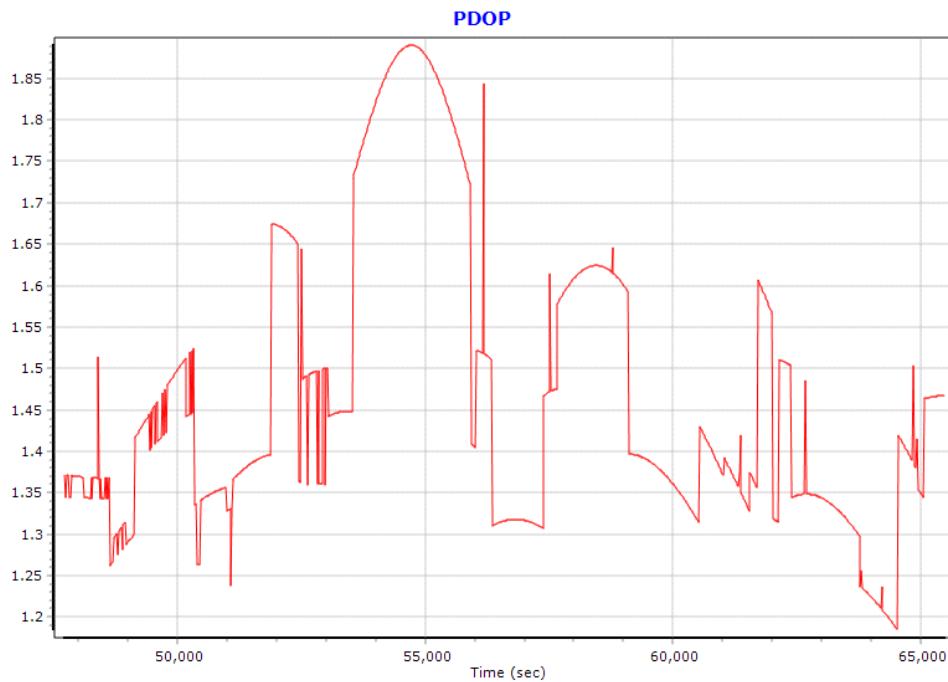
### Number of Satellites



### Forward/Reverse Separation



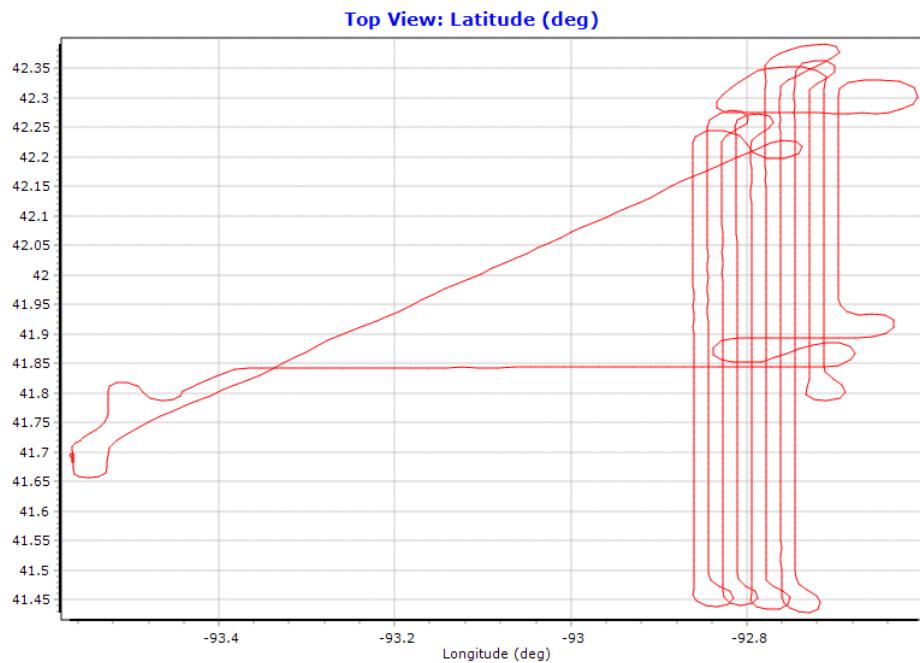
## PDOP



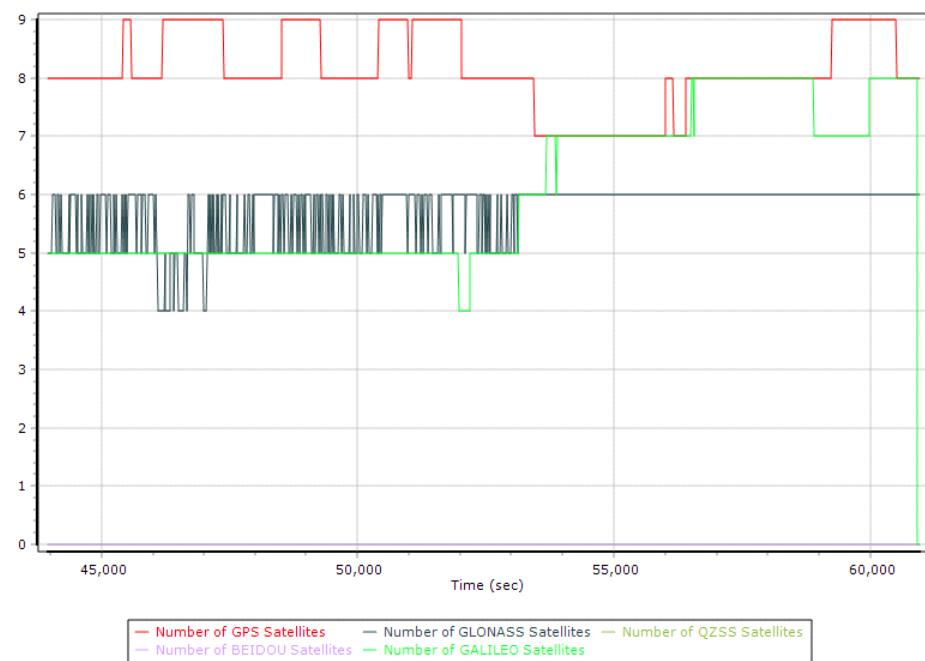
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5/12/2021

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Smoothed Trajectory Information

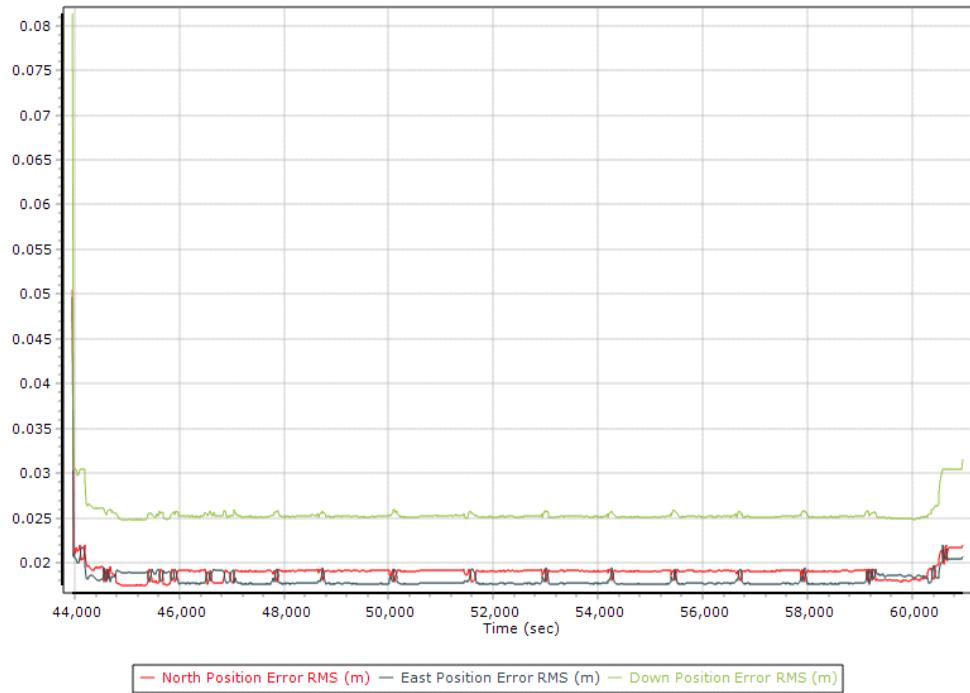
### Top View



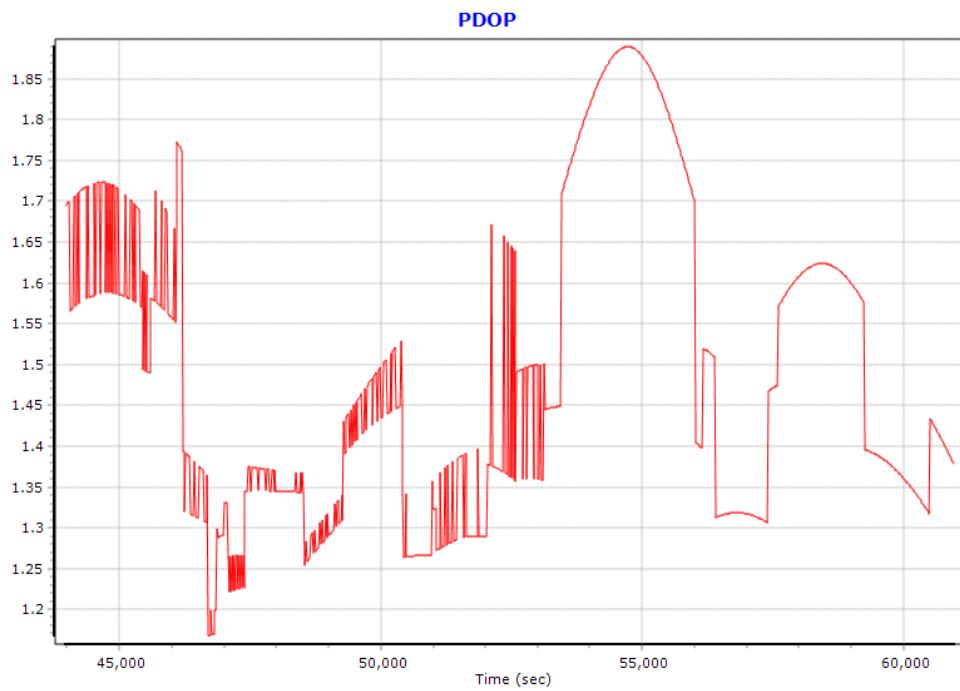
### Number of Satellites



### Forward/Reverse Separation

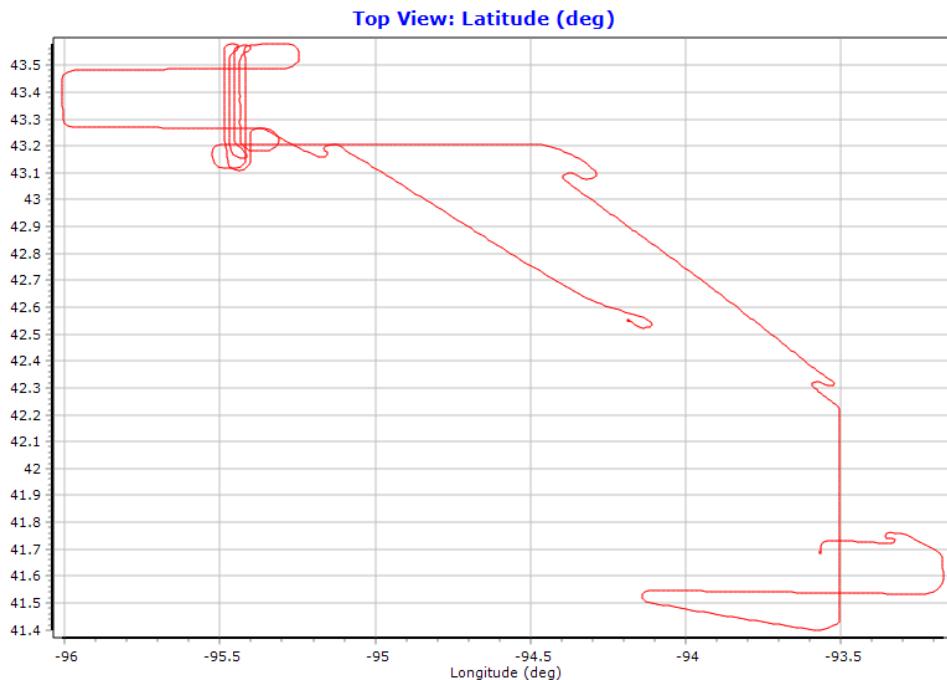


## PDOP

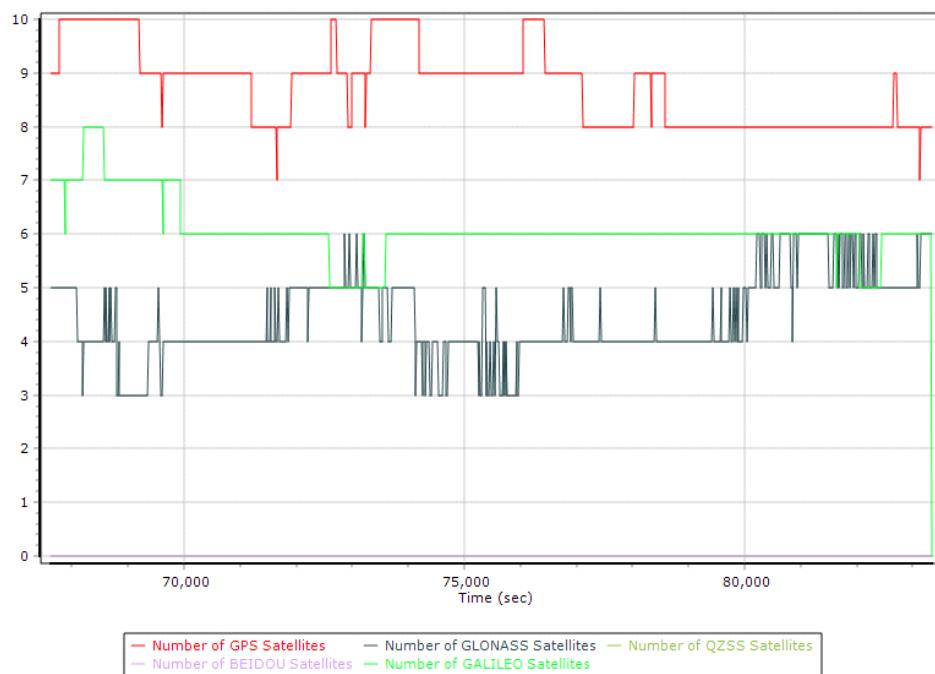


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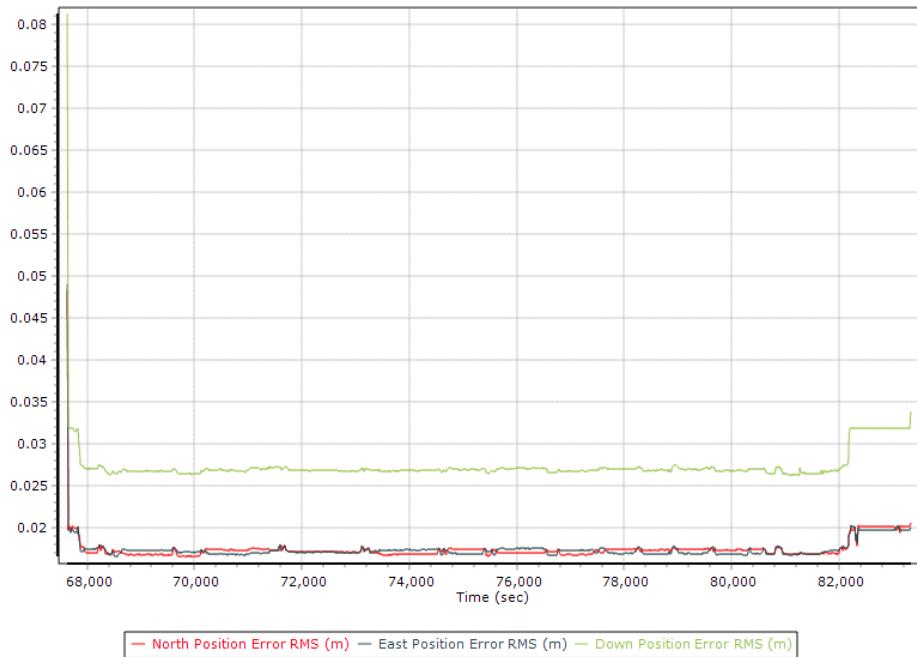
### Top View



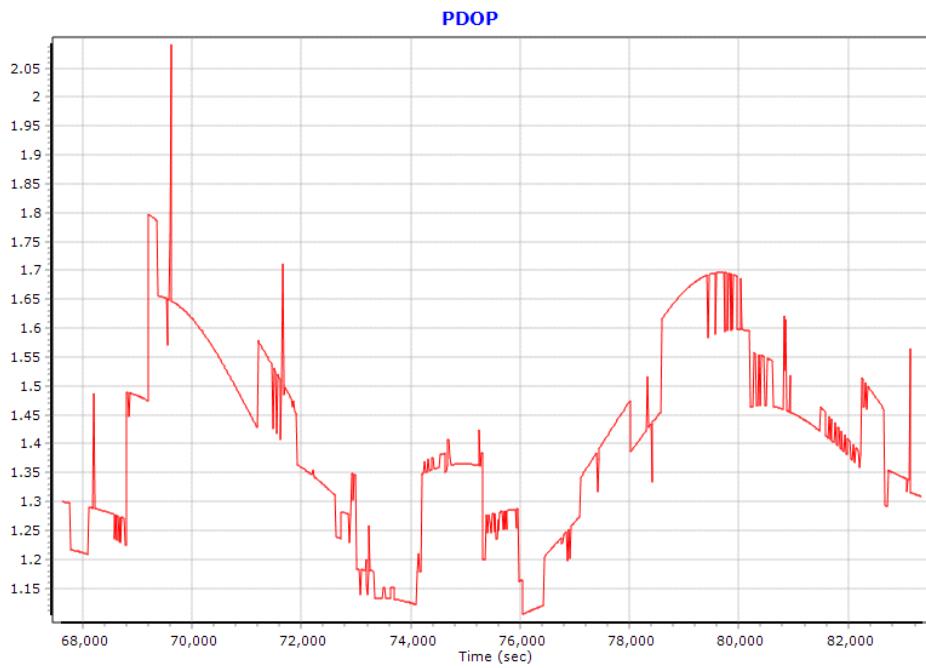
### Number of Satellites



### Forward/Reverse Separation



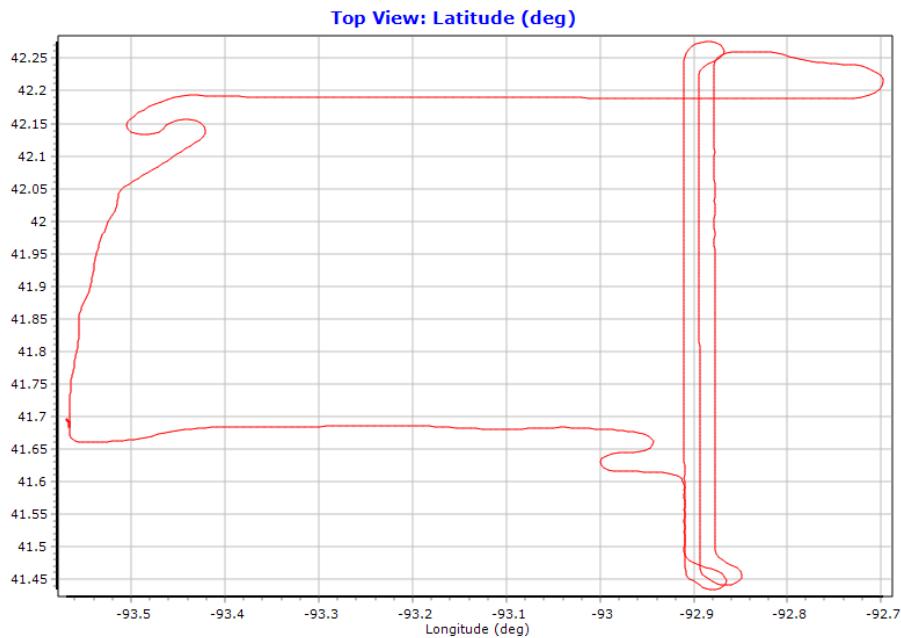
## PDOP



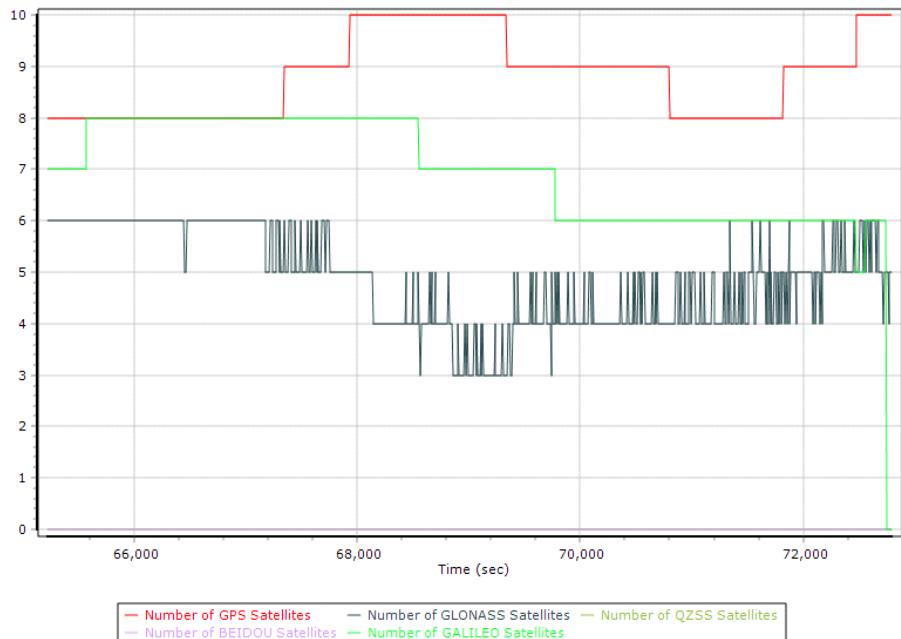
Block 1 IA North Central 2020  
5/12/2021

South\_041920B\_14-442.docx QC Report - 4/07/2021 13:59:58  
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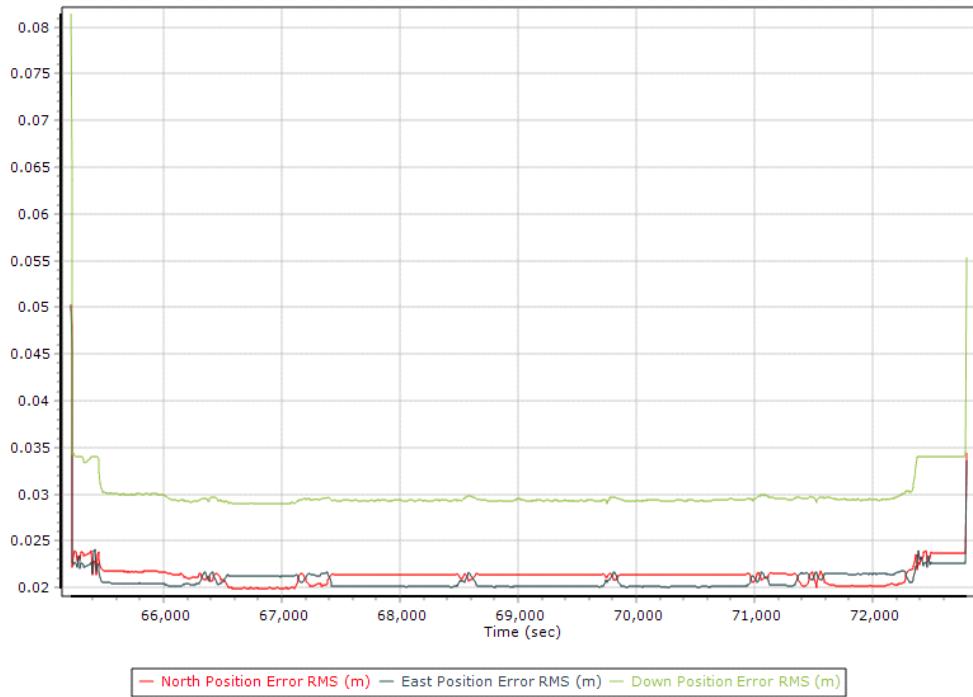
### Top View



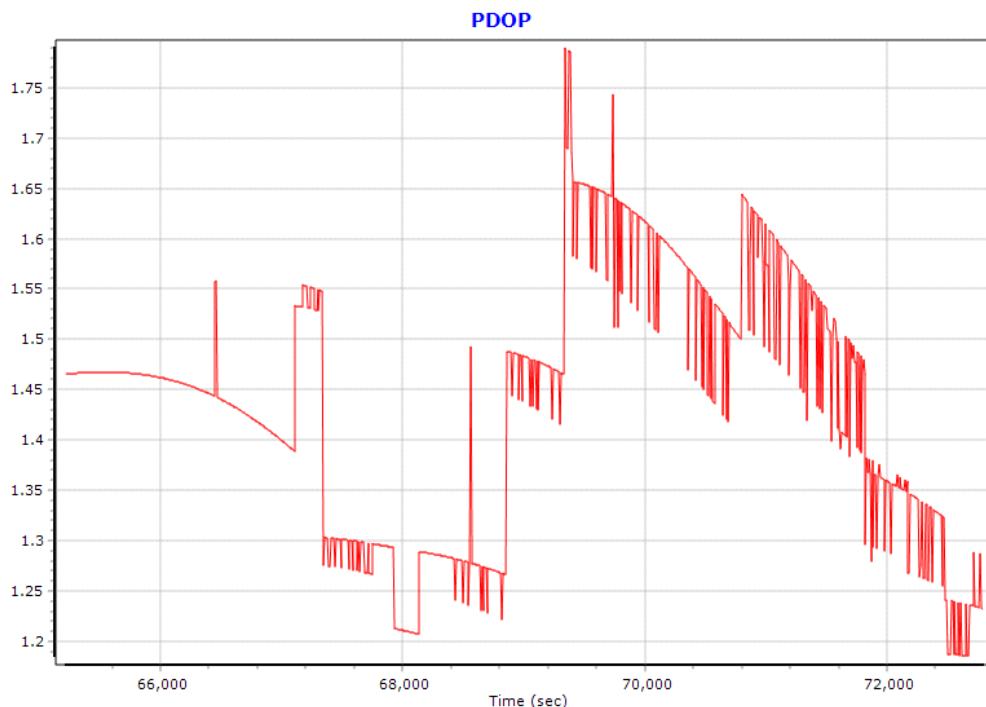
### Number of Satellites



### Forward/Reverse Separation

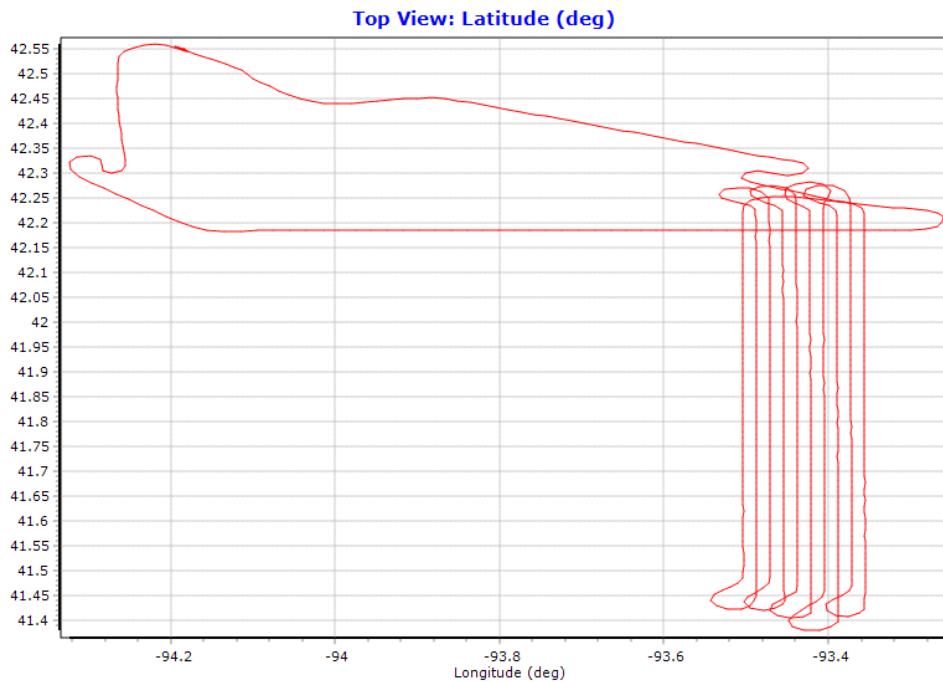


## PDOP

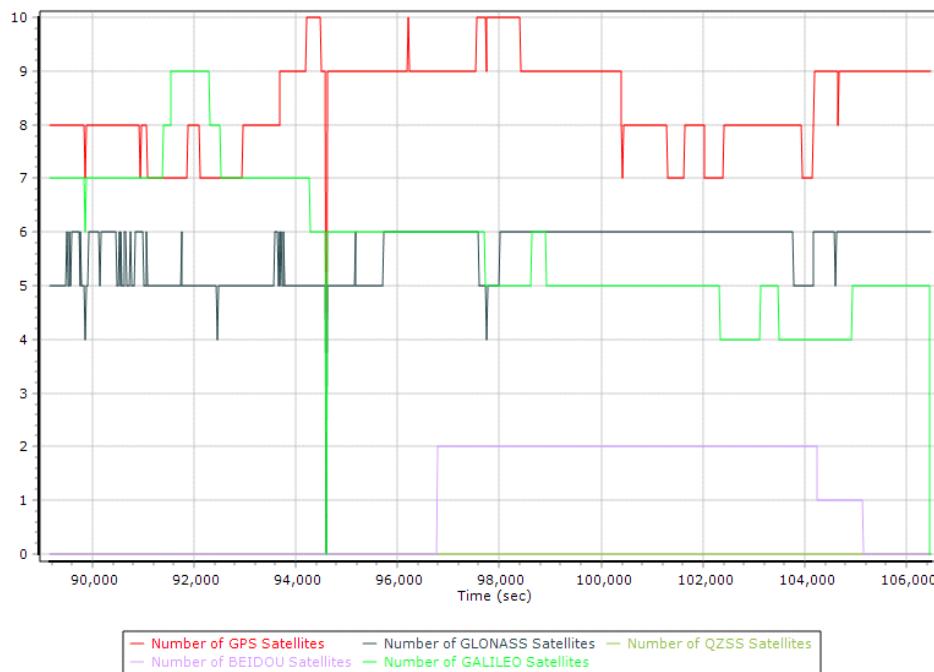


South\_041920C\_13-386.docx QC Report - 4/07/2021 13:41:23  
Smoothed Trajectory Information

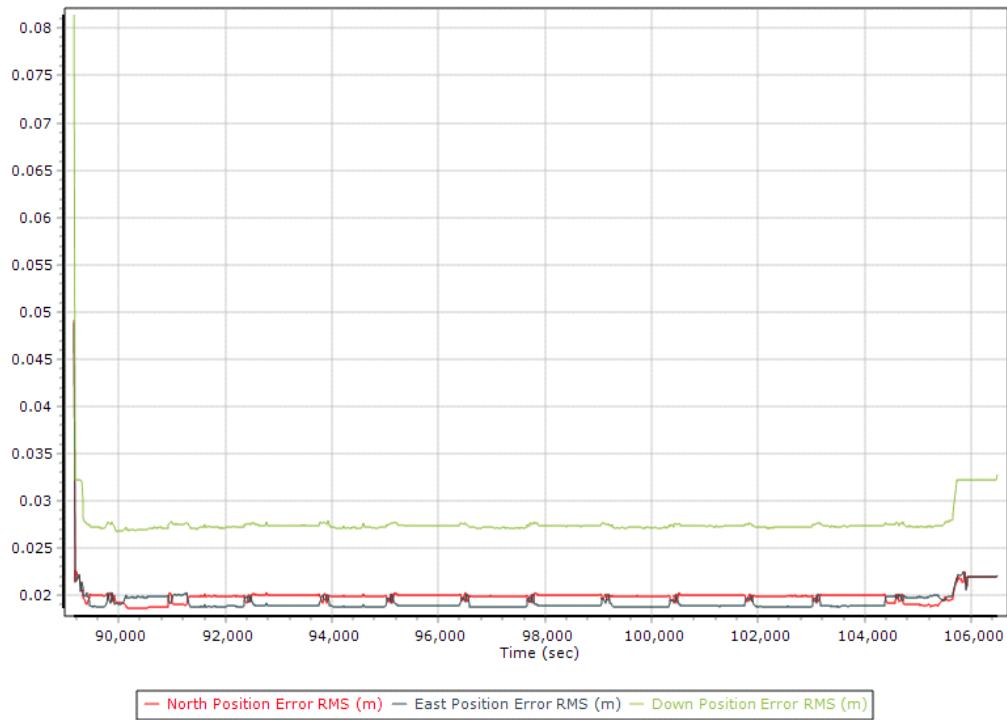
### Top View



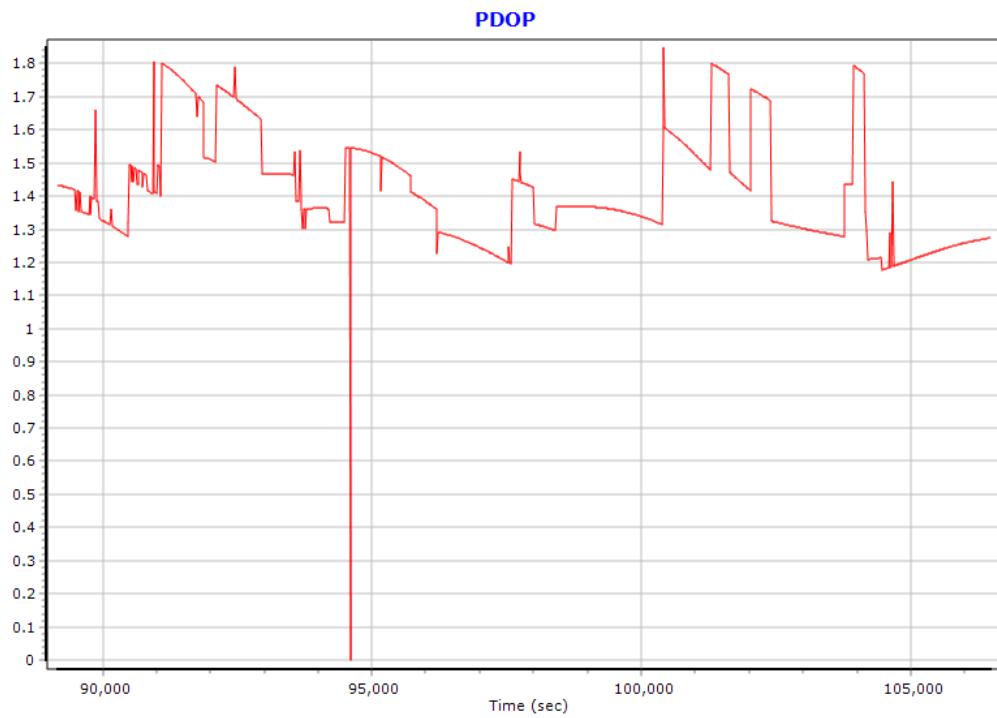
### Number of Satellites



### Forward/Reverse Separation

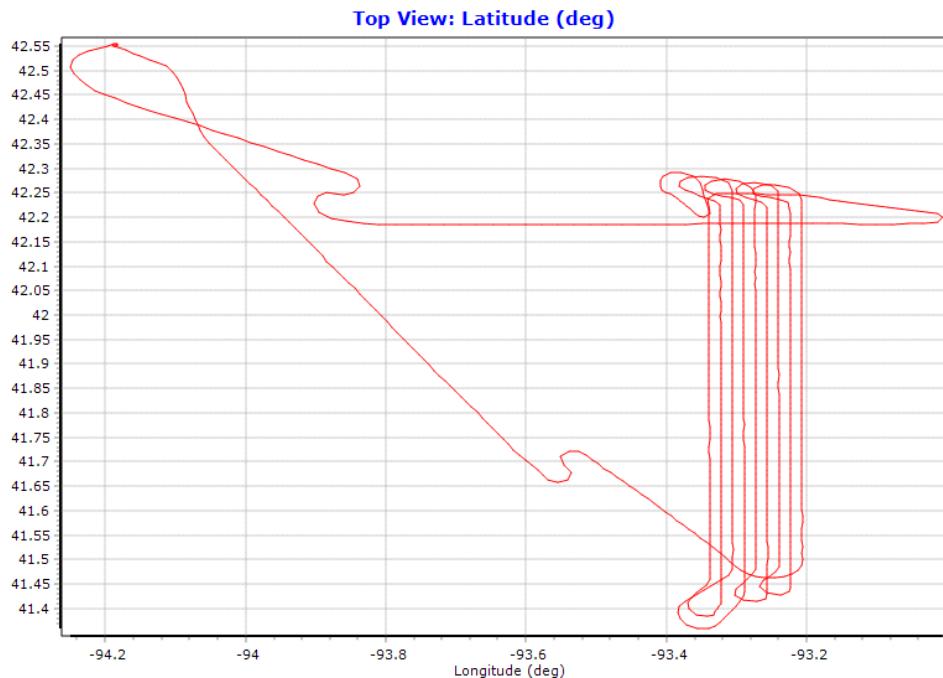


## PDOP

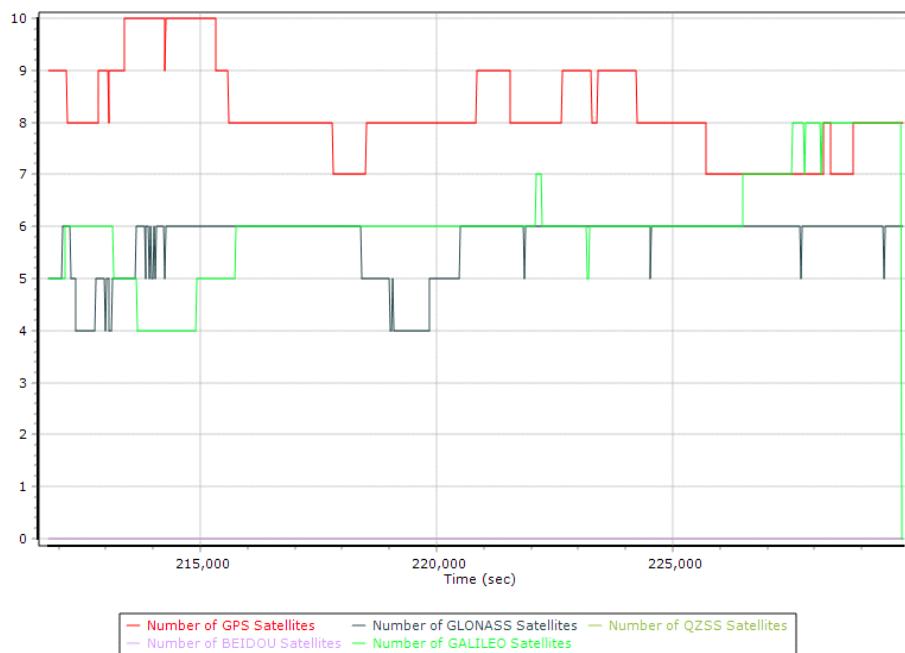


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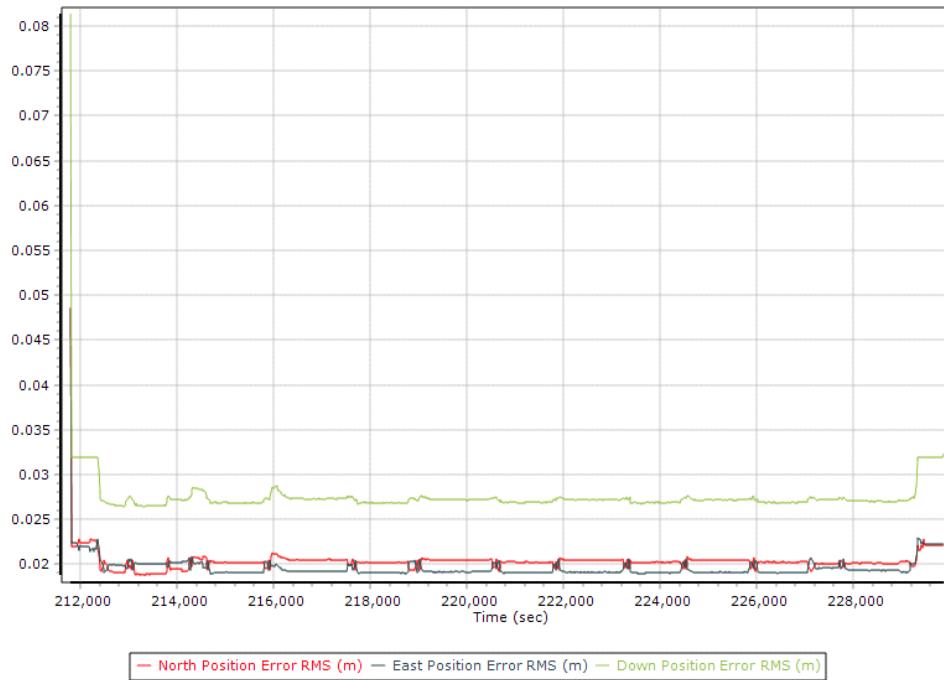
### Top View



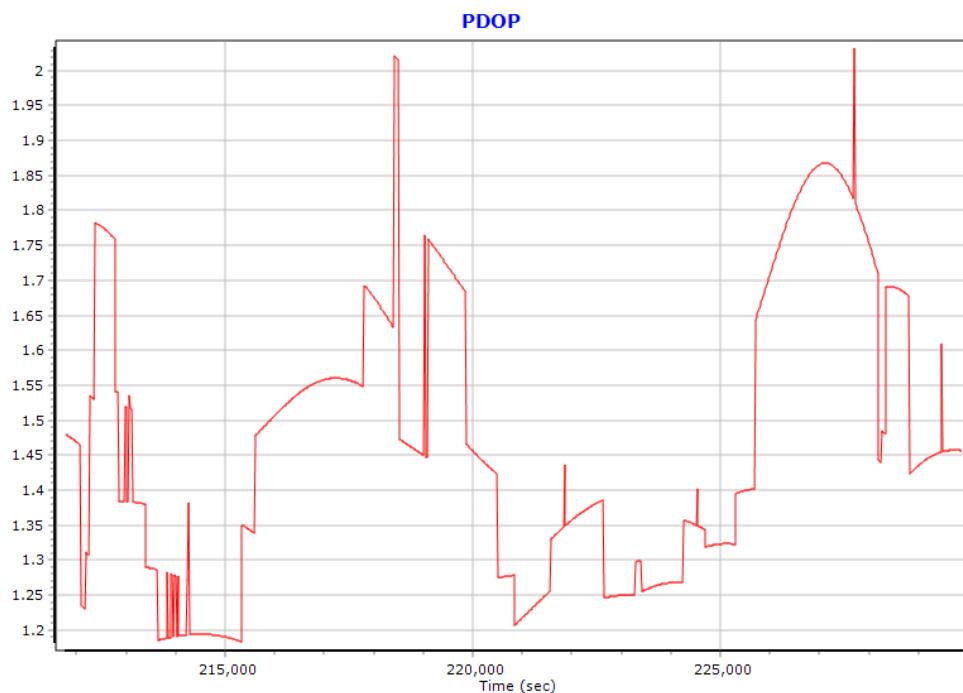
### Number of Satellites



### Forward/Reverse Separation

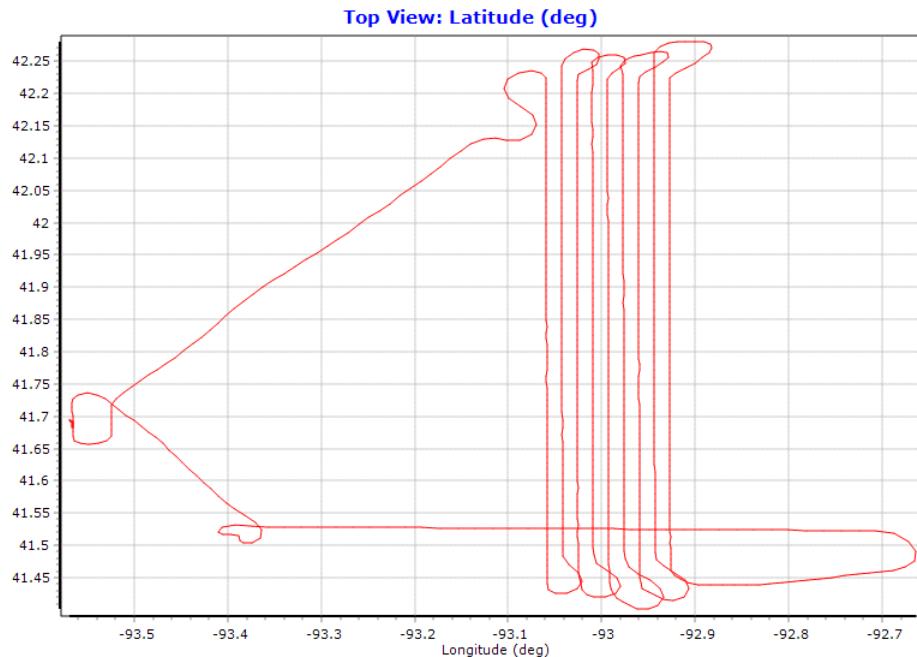


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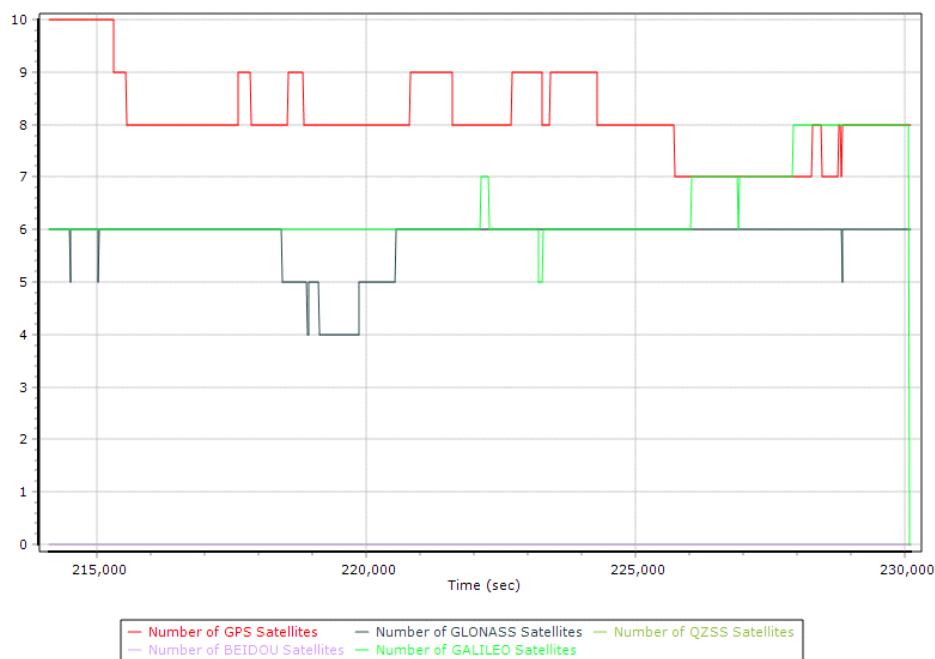


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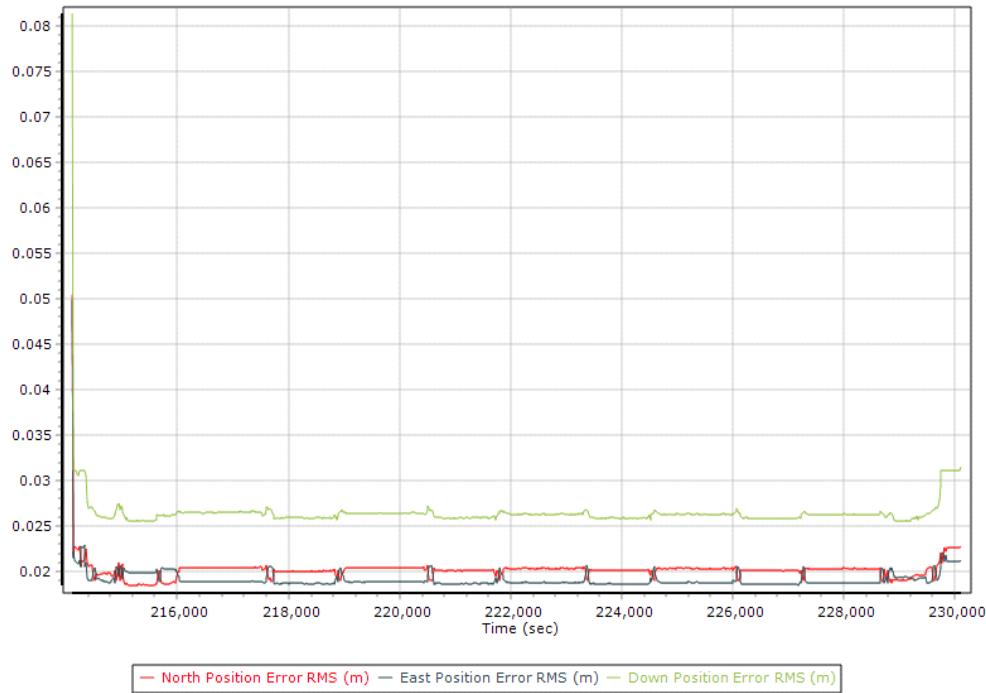
### Top View



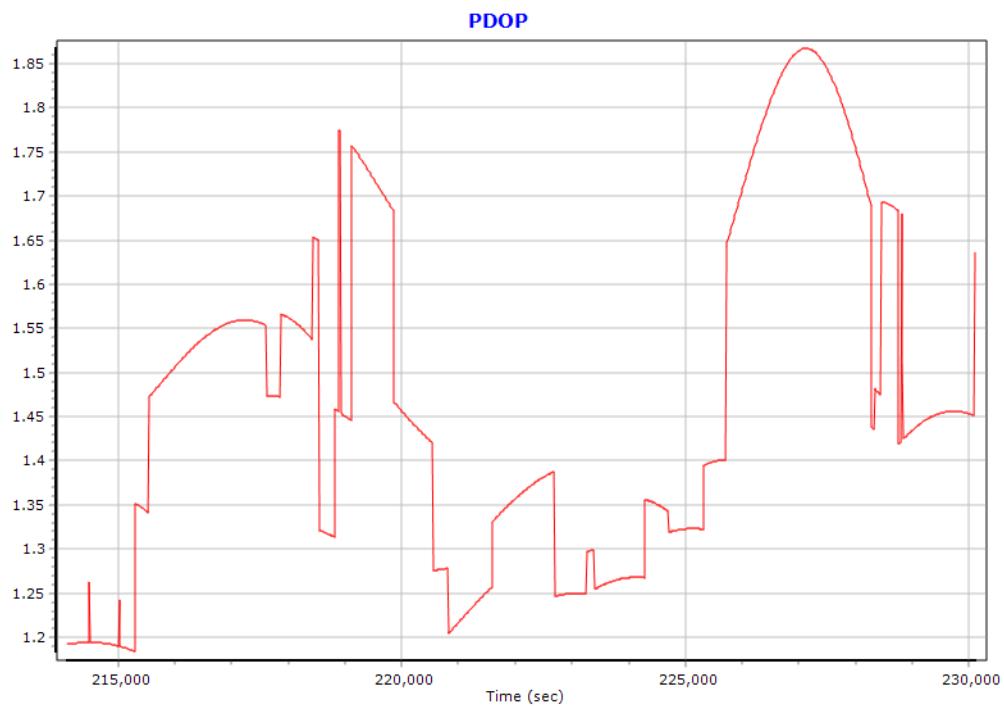
### Number of Satellites



### Forward/Reverse Separation

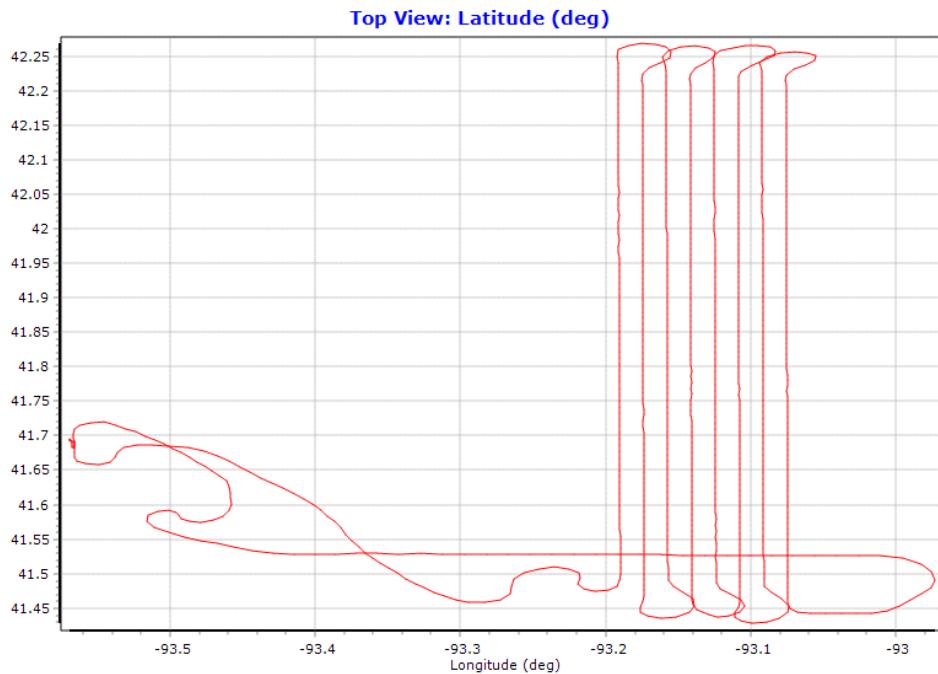


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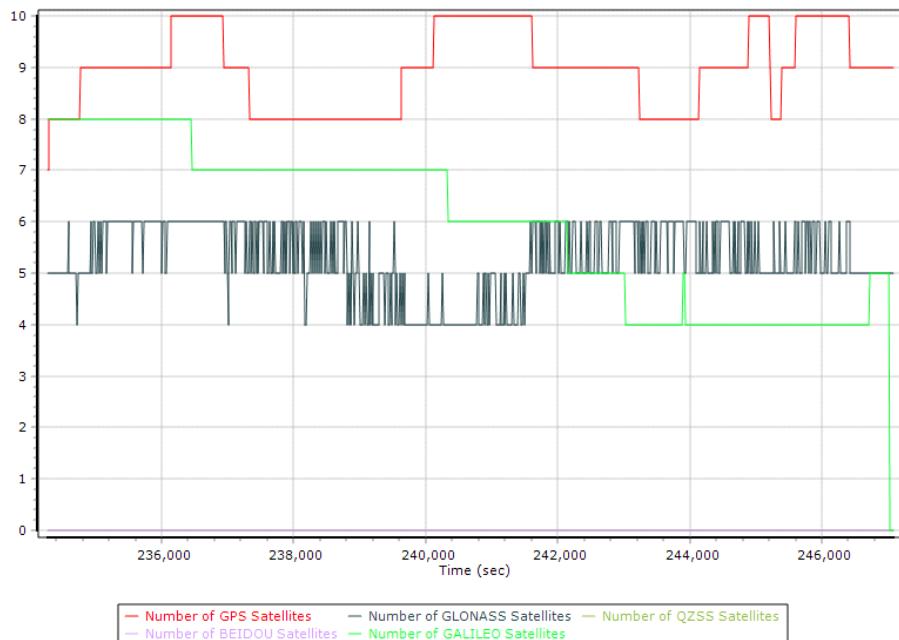


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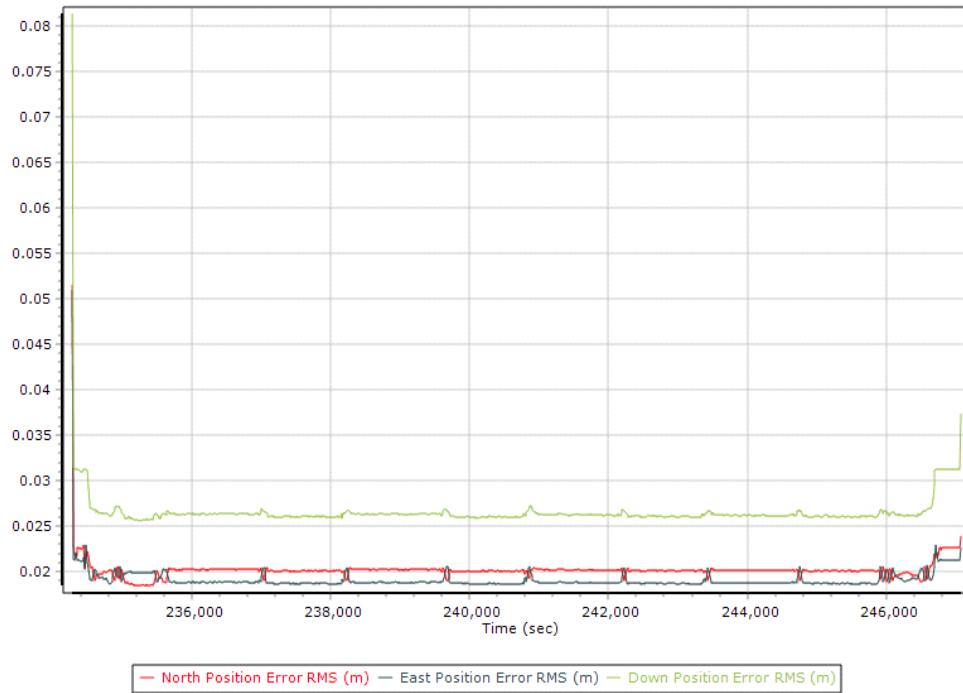
### Top View



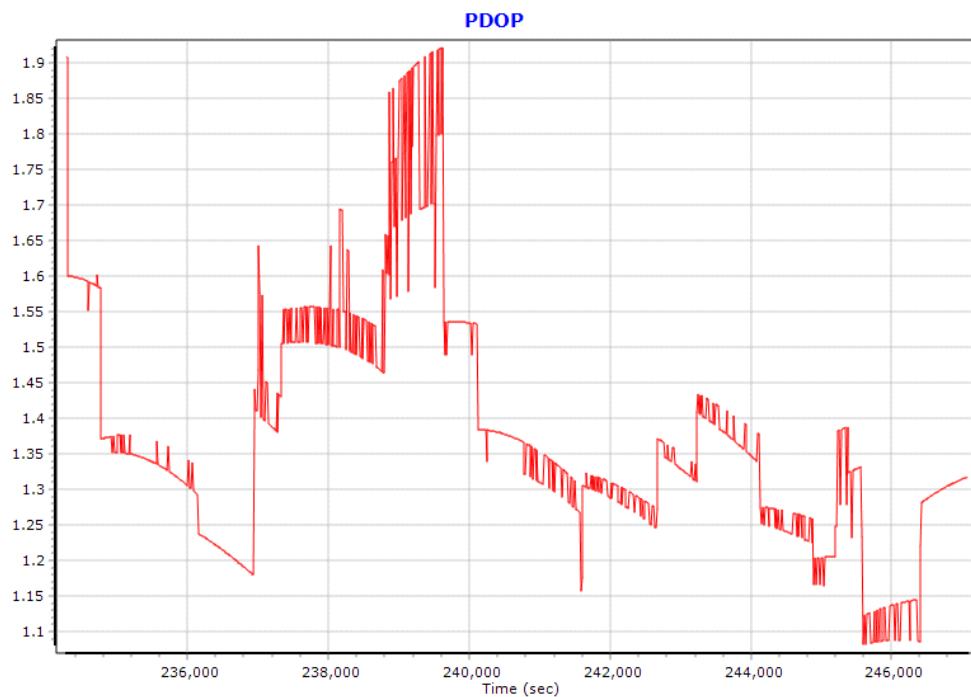
### Number of Satellites



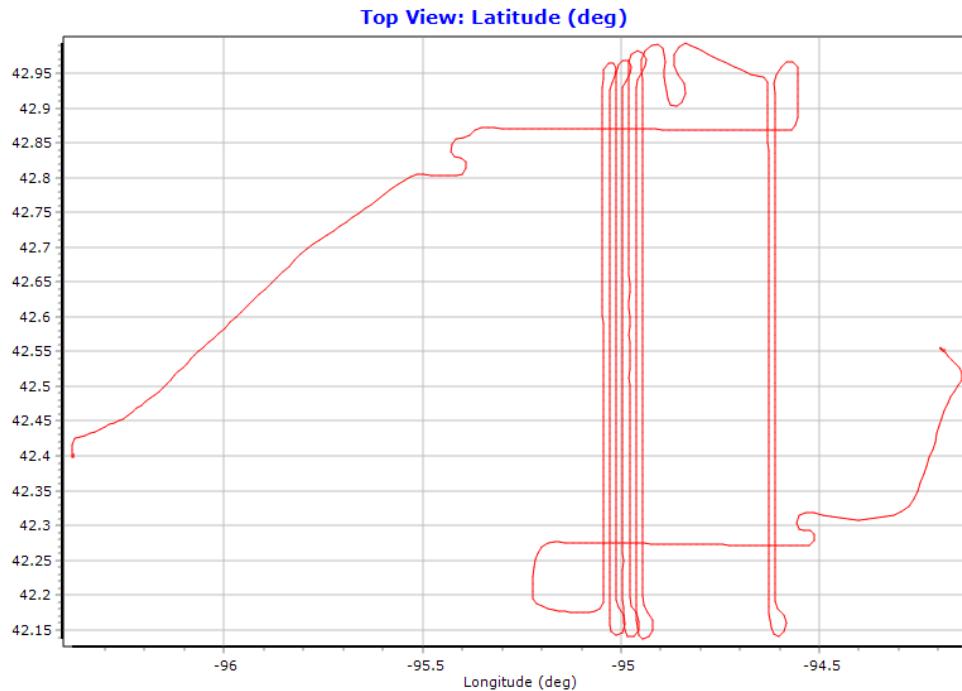
### Forward/Reverse Separation



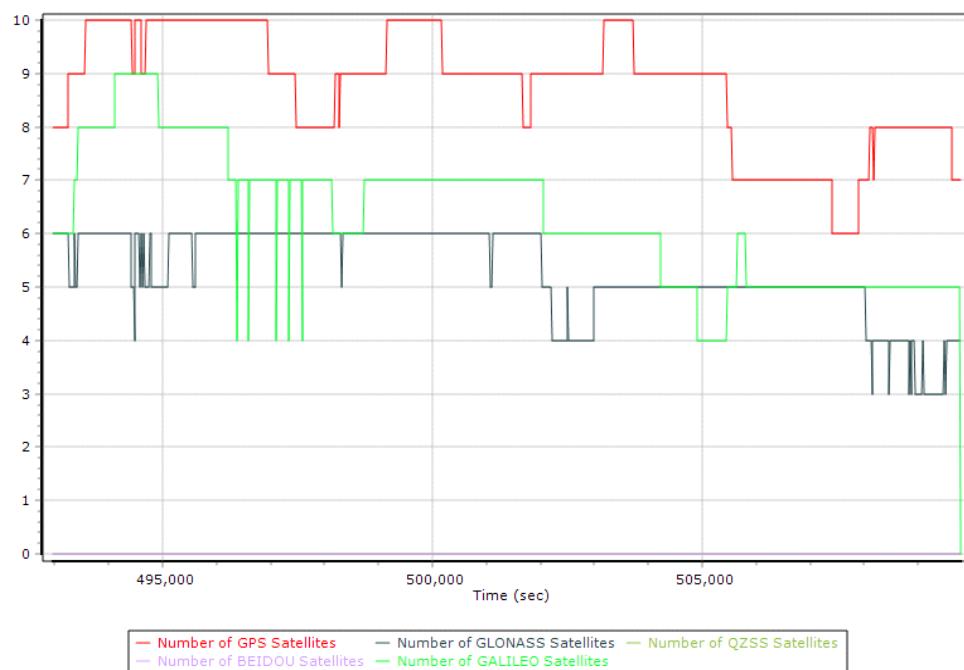
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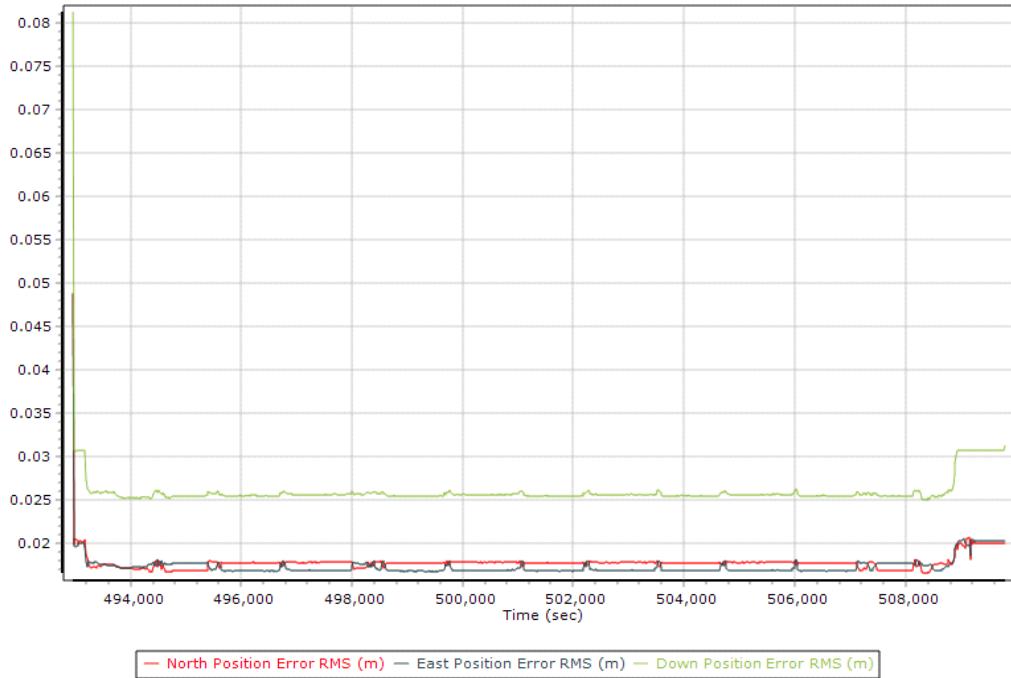
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Smoothed Trajectory Information  
Top View



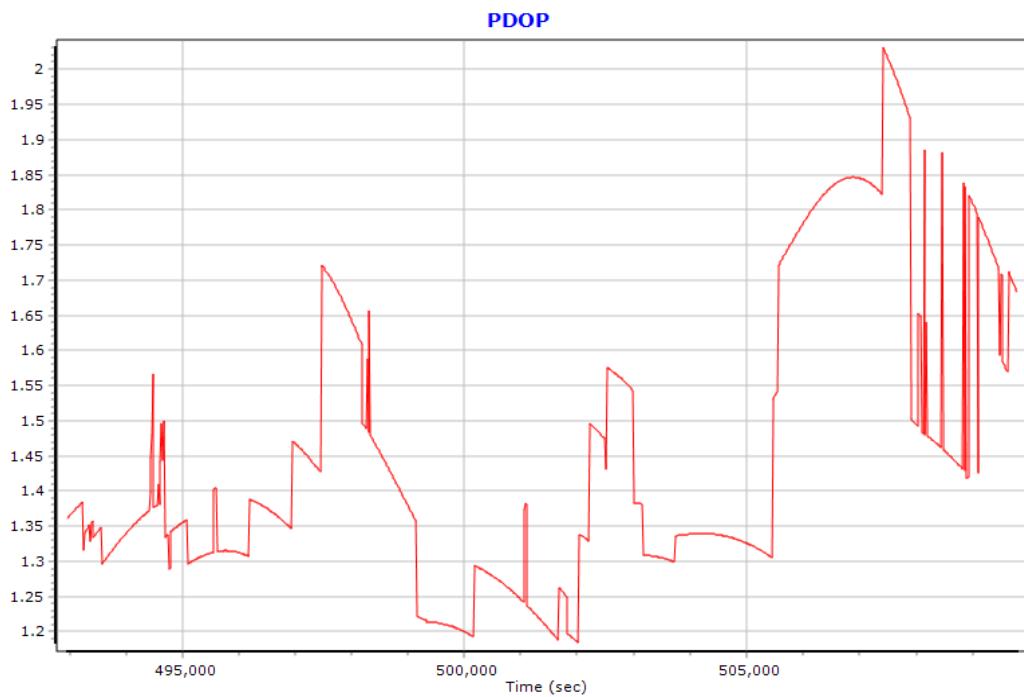
### Number of Satellites



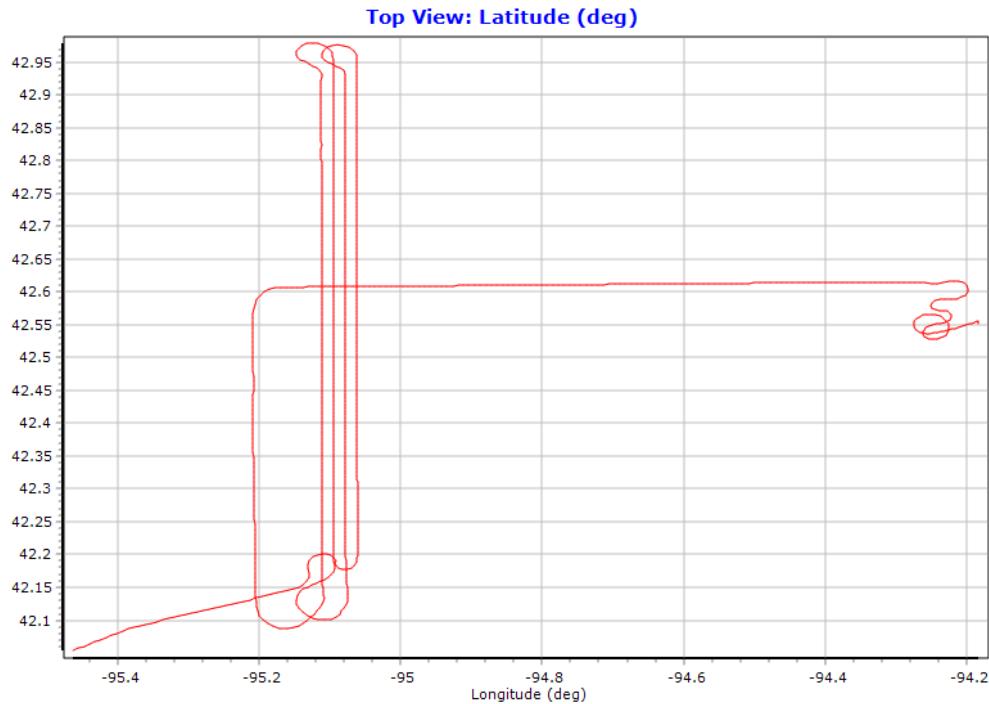
### Forward/Reverse Separation



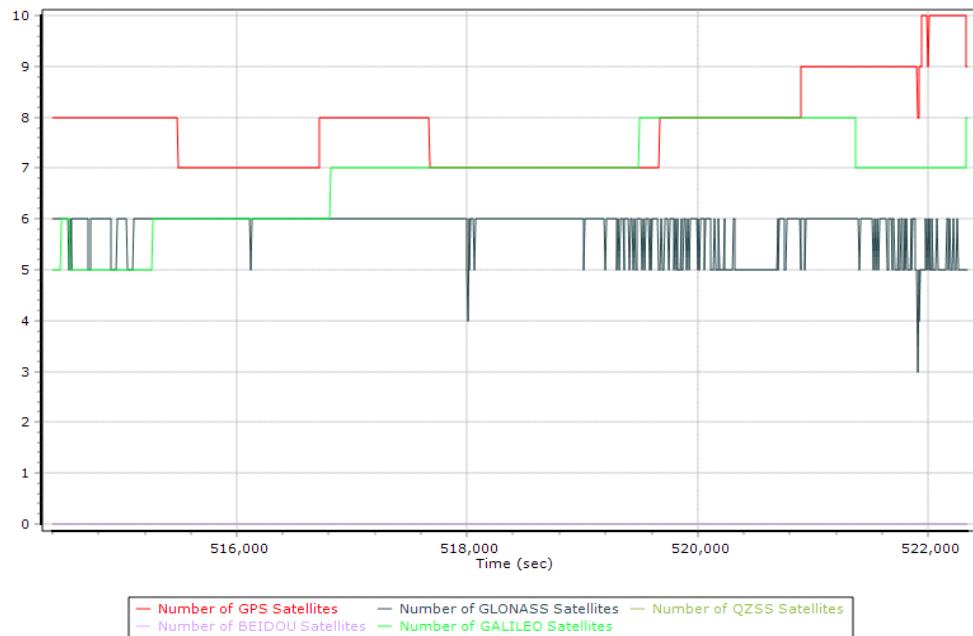
## PDOP



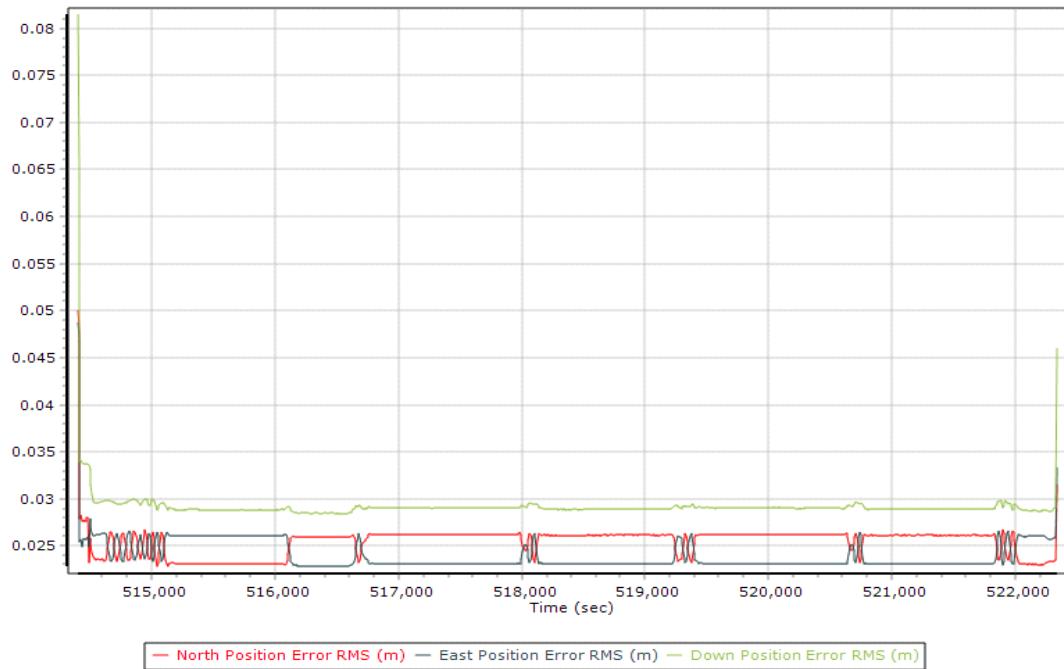
Southl\_120720B\_442.docx QC Report - 5/04/2021 07:50:21  
Smoothed Trajectory Information  
Top View



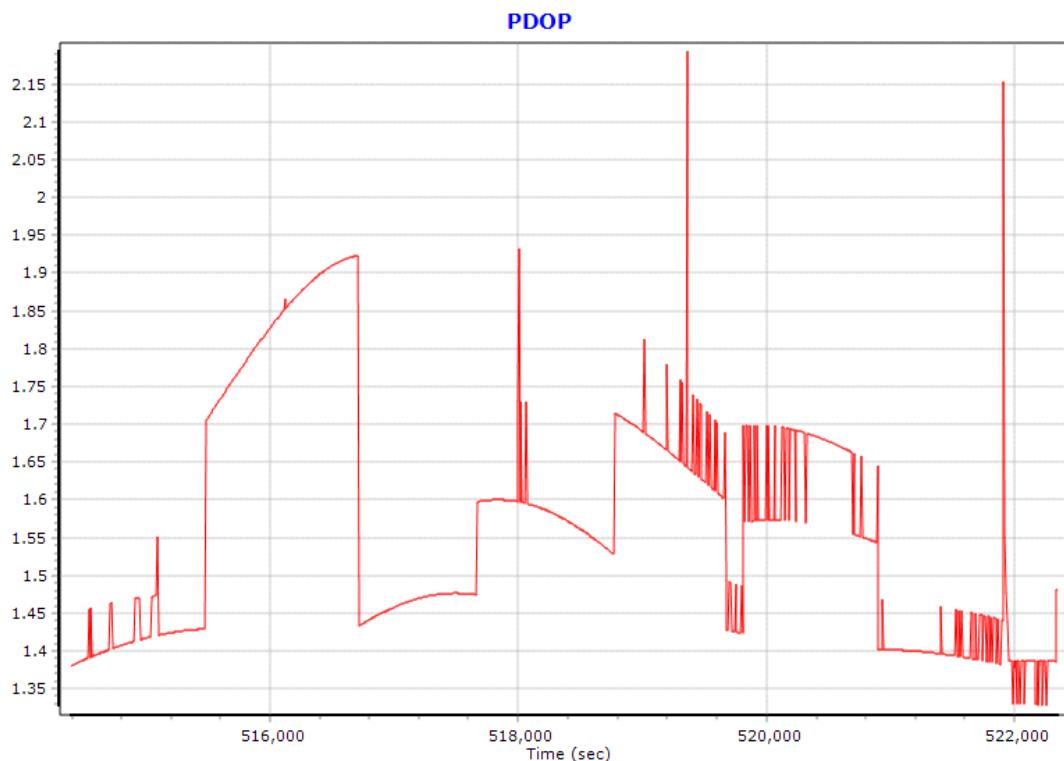
### Number of Satellites



### Forward/Reverse Separation



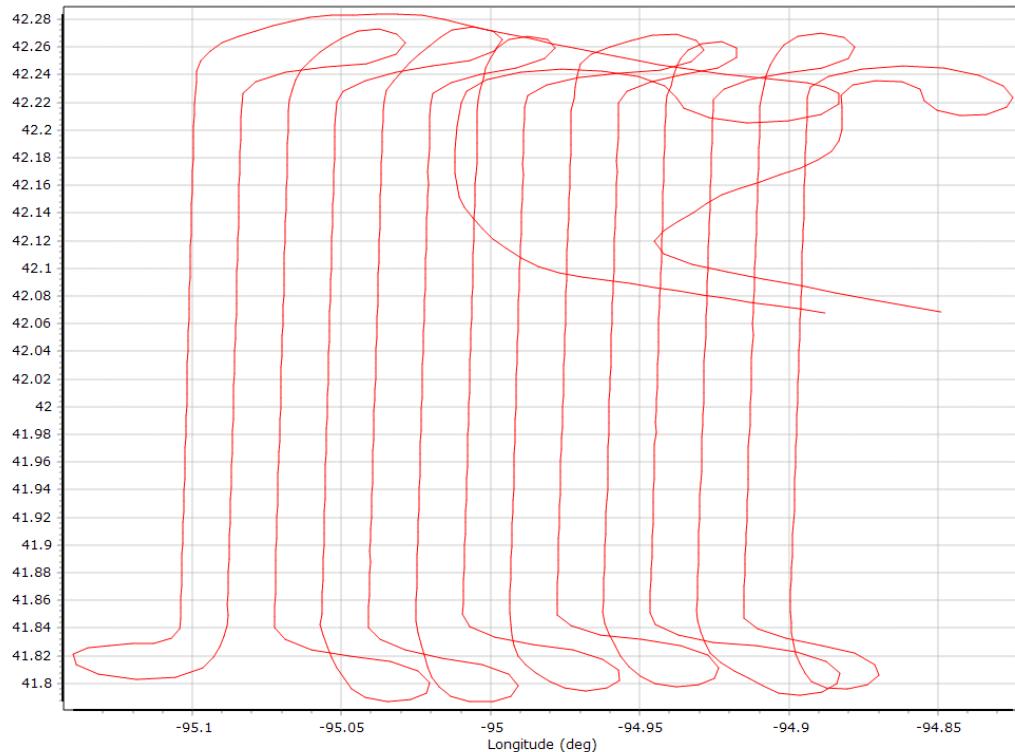
## PDOP



## Appendix C: SurvTech Solutions Mission GPS and IMU Processing Report

IA\_NC\_SURVTECH\_200418A\_QC\_Report QC Report - 5/03/2021 14:0

### Top View

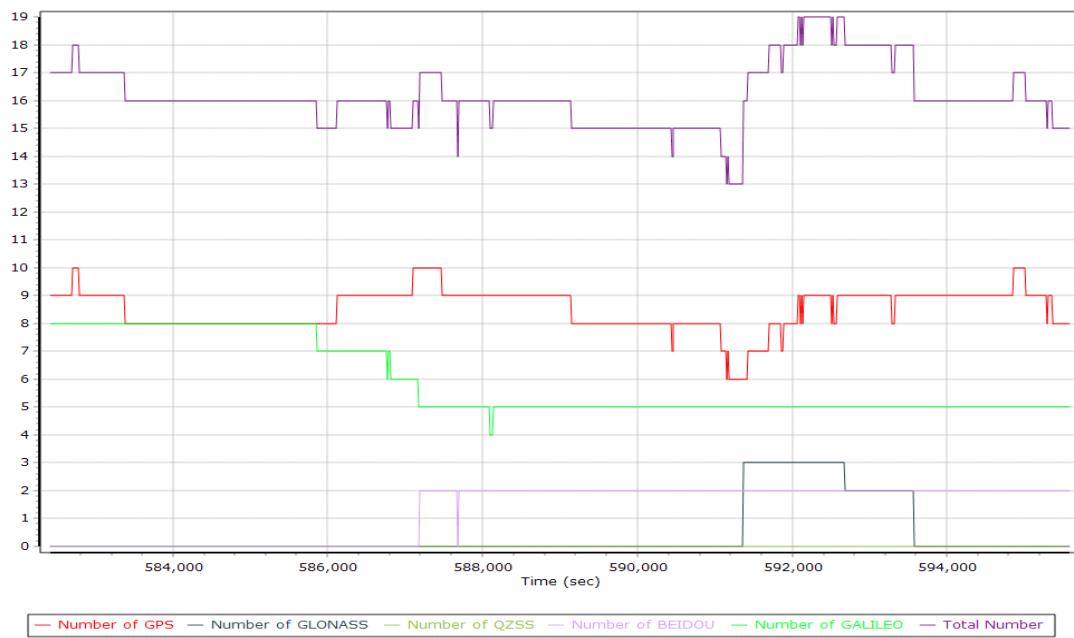


## GNSS QC

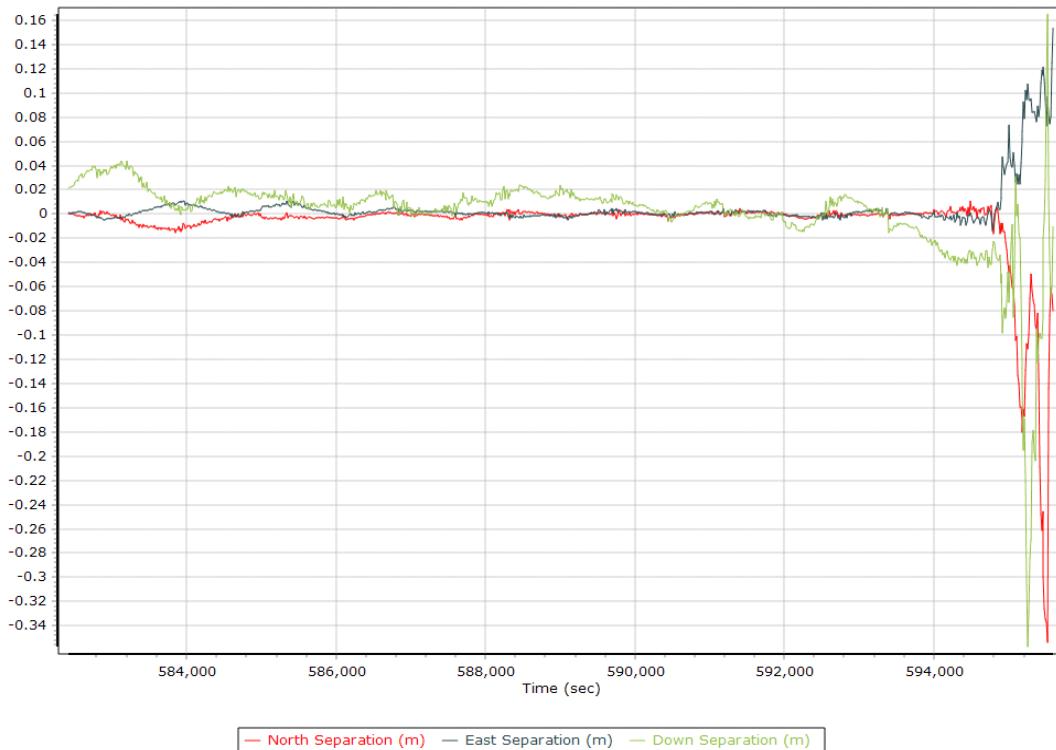
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.31	122.19	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	3	0
PDOP	1.14	1.73	1.37
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	15926.00	0.00	1.00
Percentage	99.99	0.00	0.01

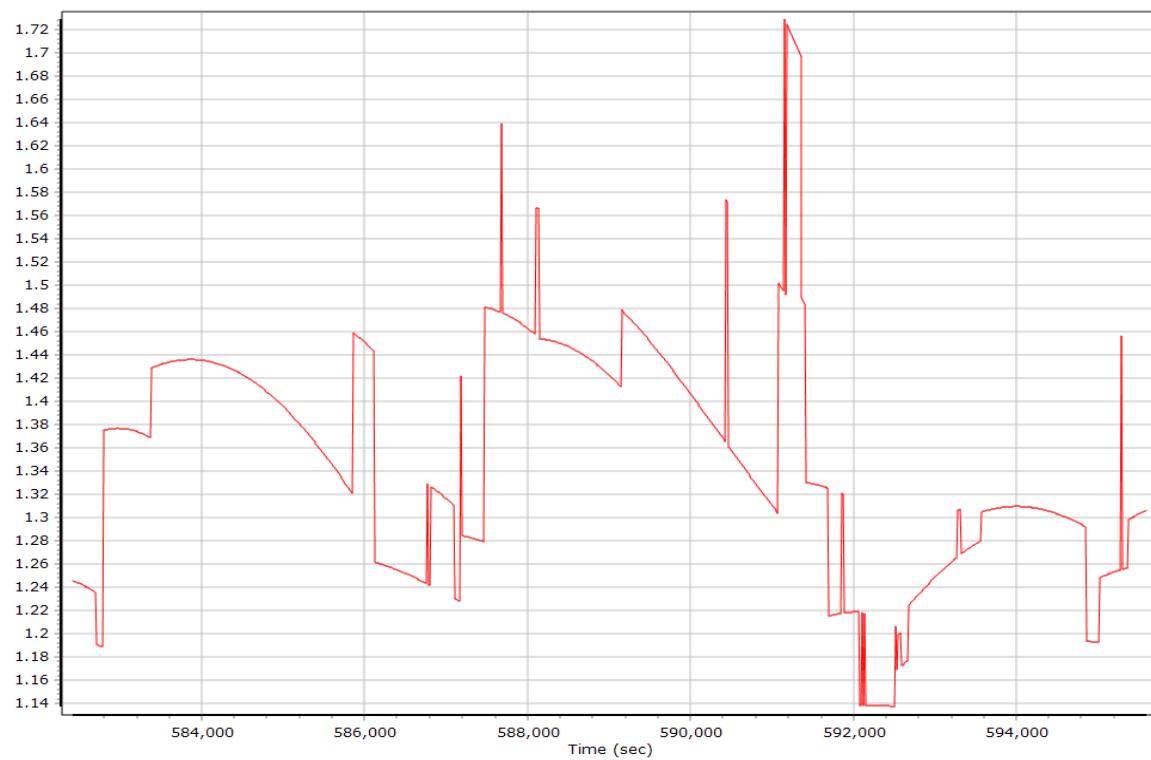
### Number of Satellites



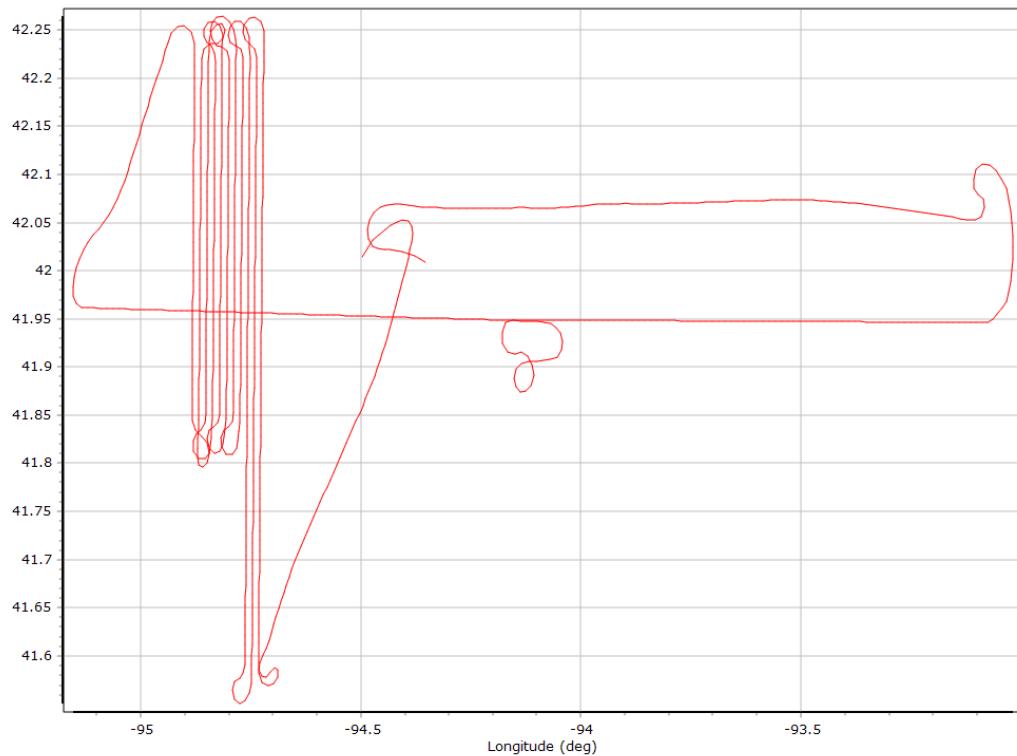
### Forward/Reverse Separation



## PDOP



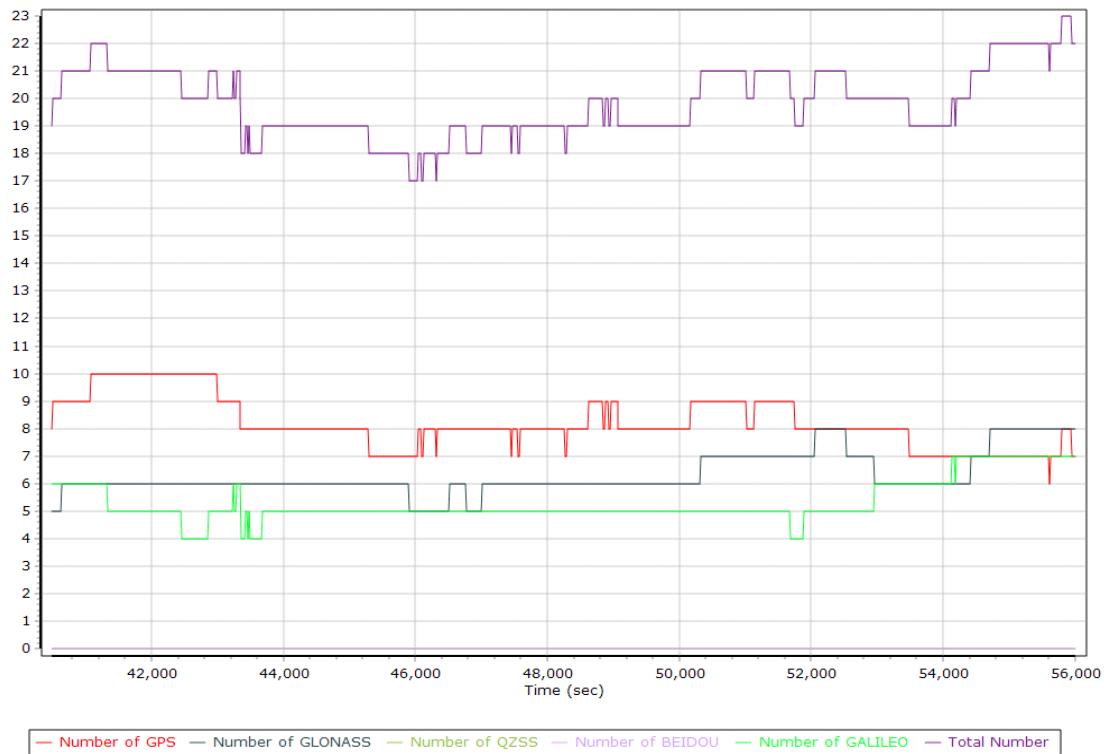
### Top View



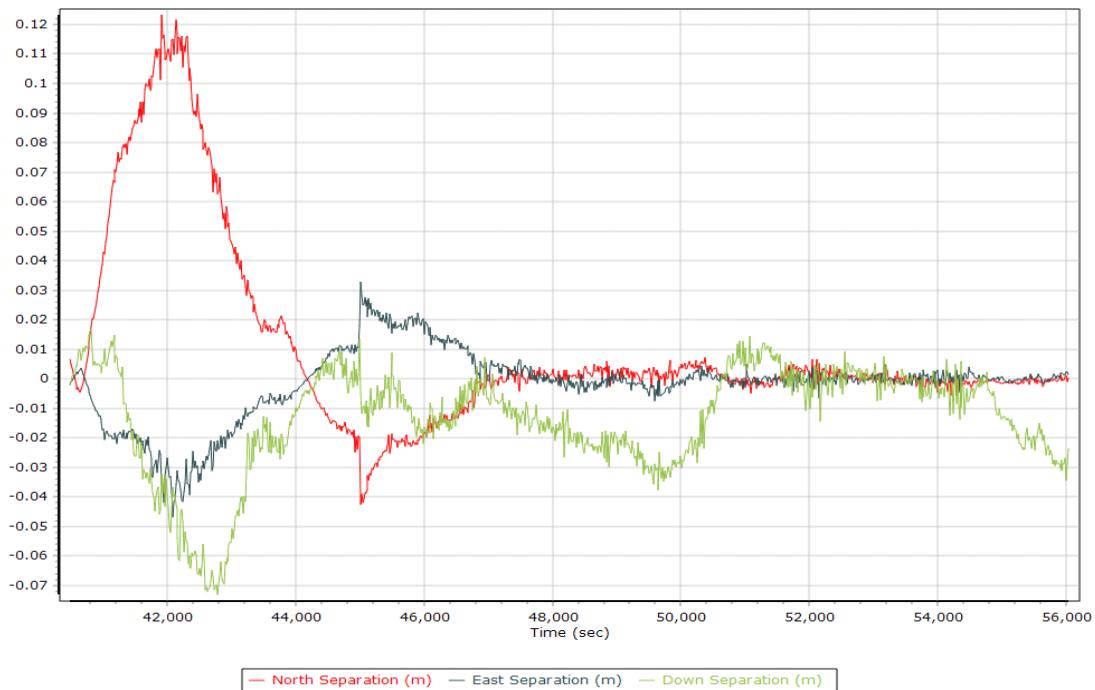
### GNSS QC

Statistics	Min	Max	Mean
Baseline length (km)	2.32	112.98	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	8	6
PDOP	0.98	1.46	1.16
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

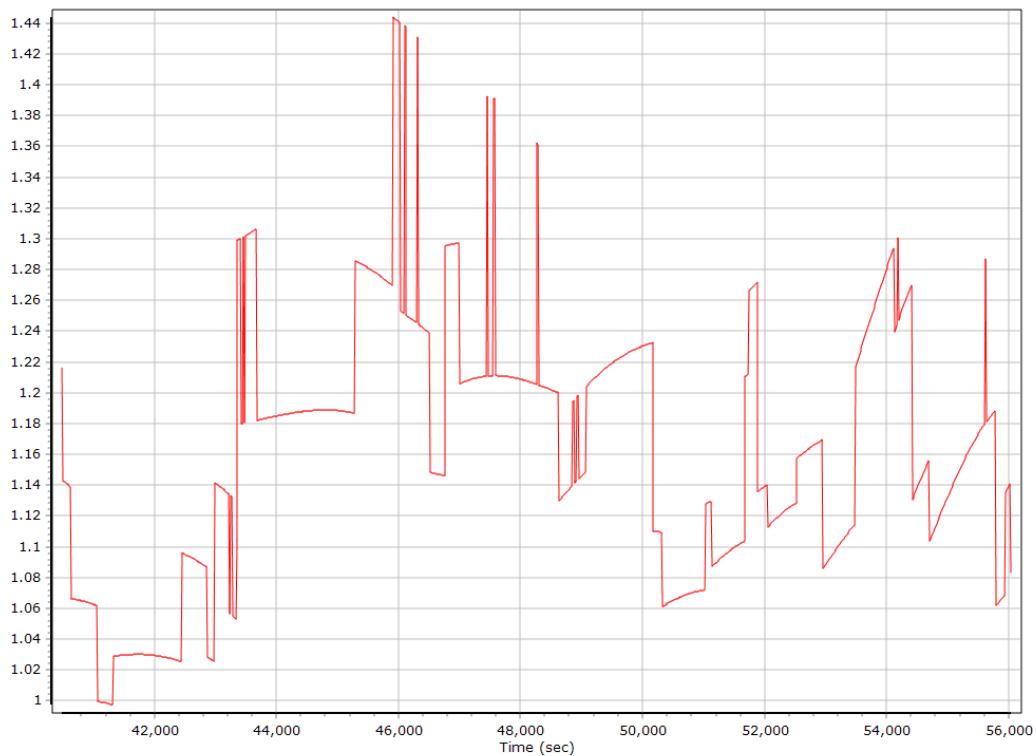
### Number of Satellites



### Forward/Reverse Separation

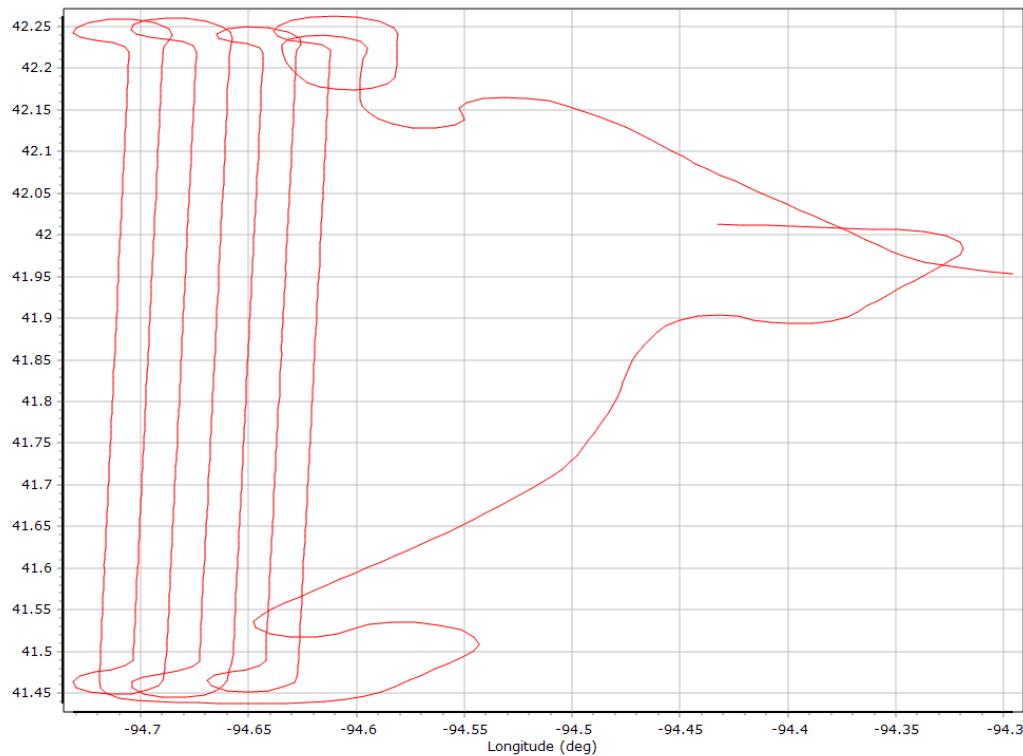


## PDOP



IA\_NC\_SURVTECH\_200419B\_QC\_Report QC Report - 5/03/2021 15:47

## Top View

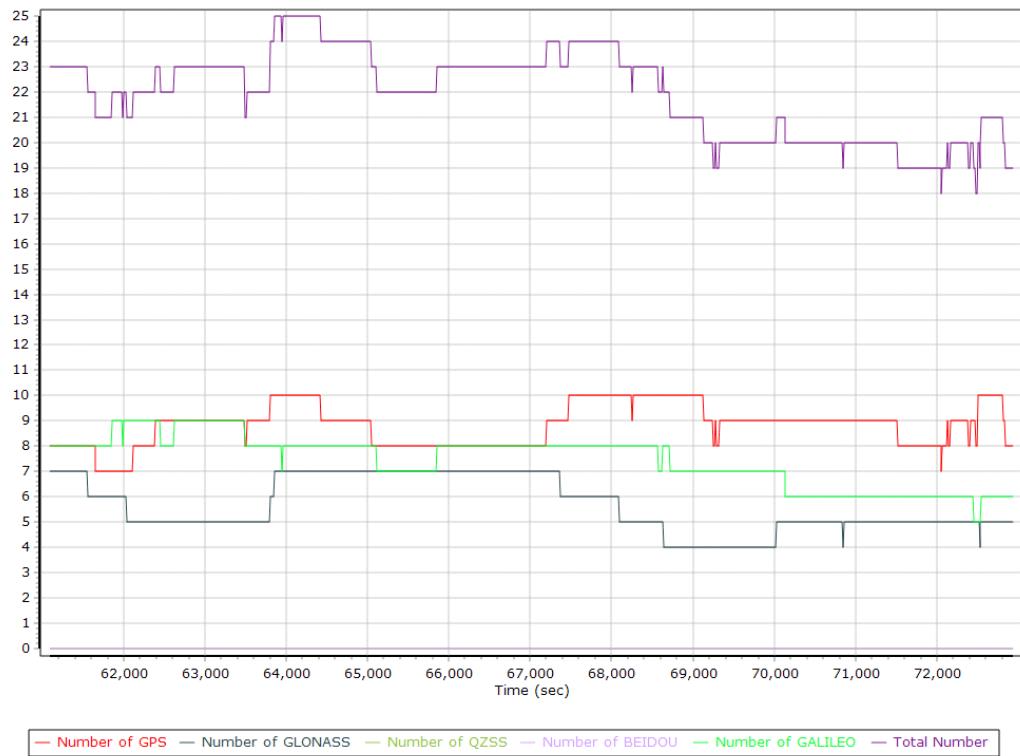


## GNSS QC

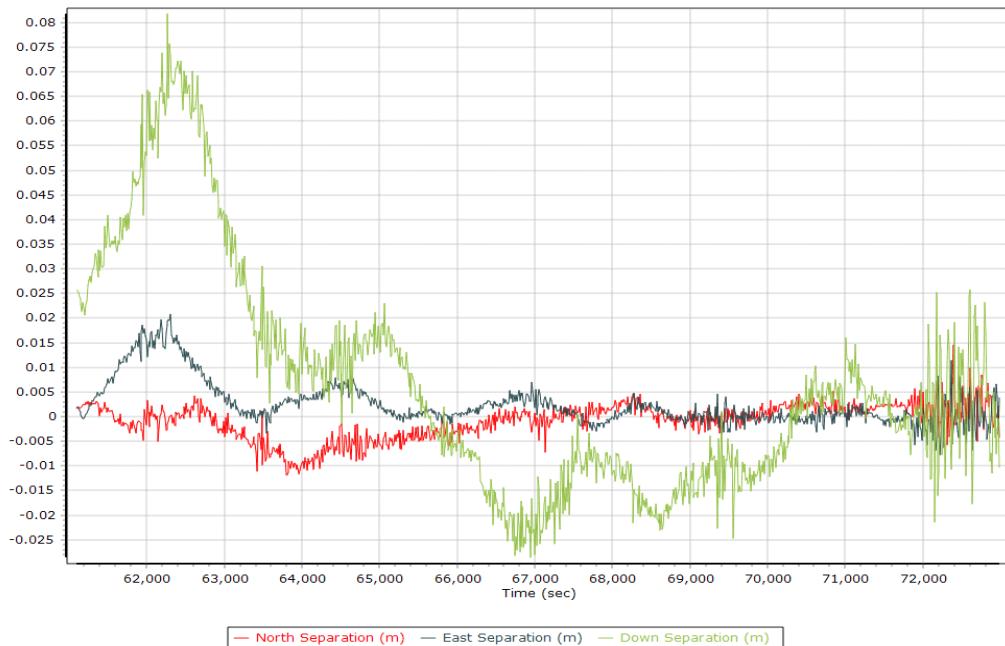
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.19	80.44	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	8	6
PDOP	0.99	1.57	1.15
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	13139.00	0.00	2.00
Percentage	99.98	0.00	0.02

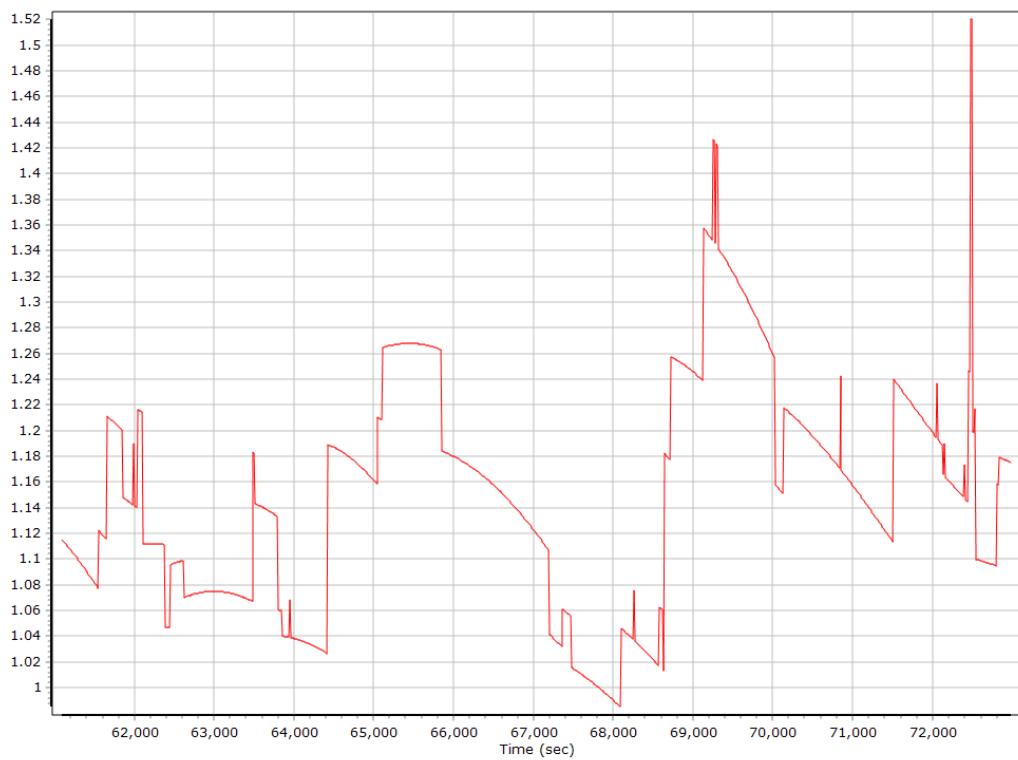
## Number of Satellites



## Forward/Reverse Separation

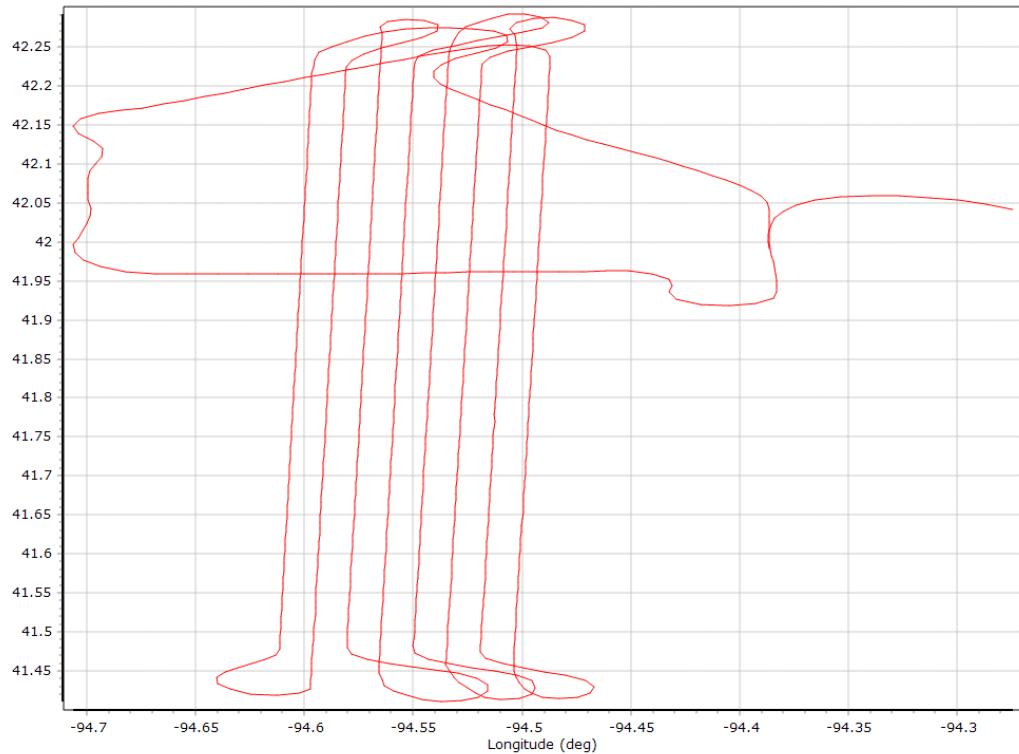


## PDOP



IA\_NC\_SURVTECH\_200419C\_QC\_Report QC Report - 5/03/2021 16:15:47

## Top View

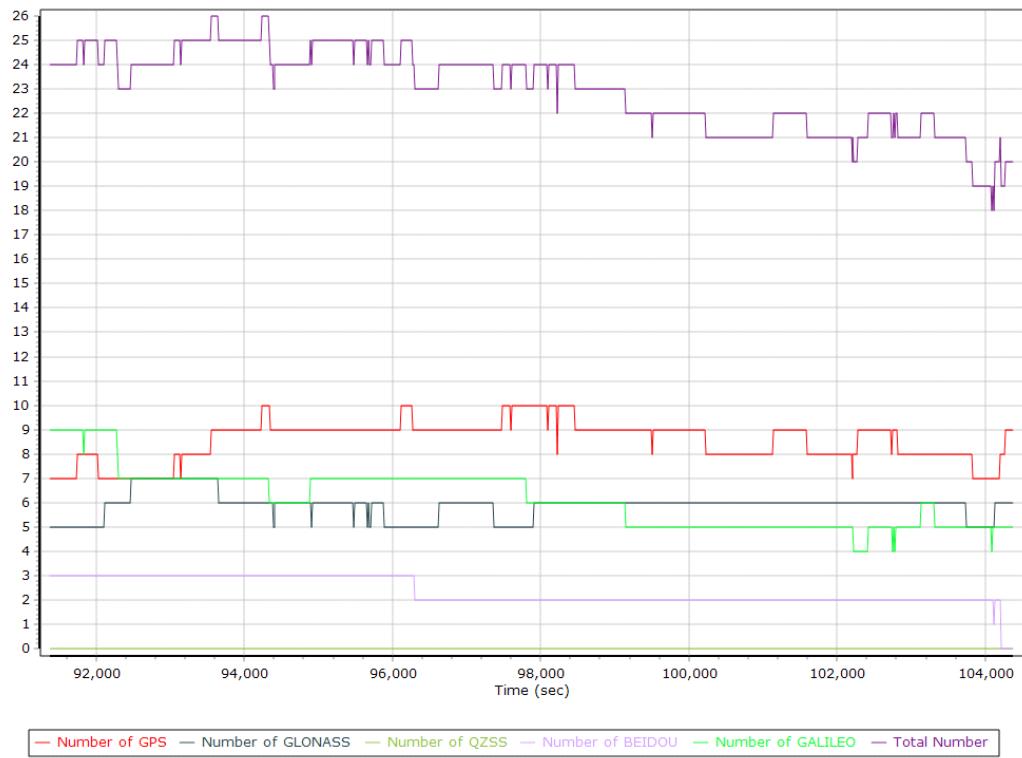


## GNSS QC

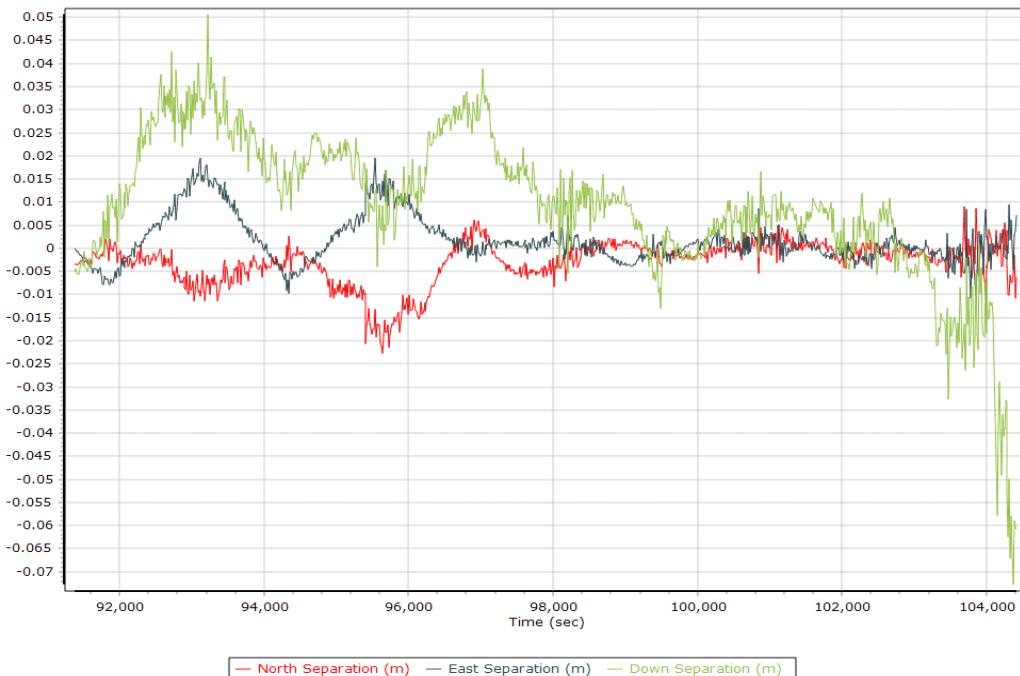
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.38	95.11	
Number of GPS SV	7	10	8
Number of GLONASS SV	0	8	6
PDOP	0.96	1.69	1.13
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17974.00	0.00	1.00
Percentage	99.99	0.00	0.01

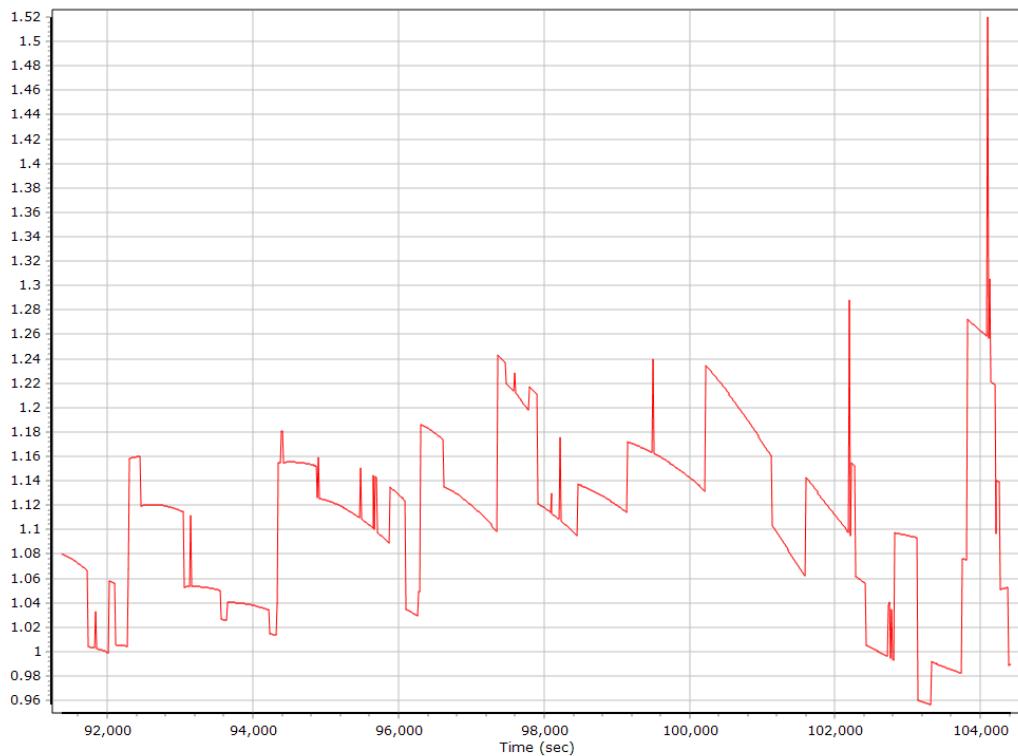
## Number of Satellites



## Forward/Reverse Separation

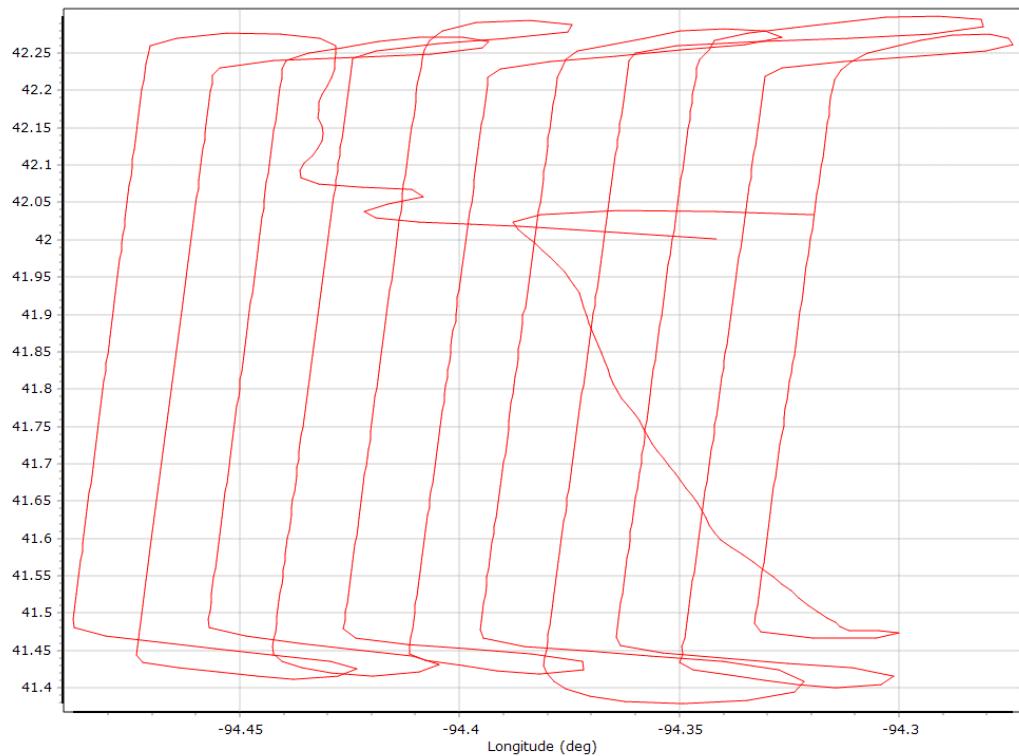


**PDOP**



IA\_NC\_SURVTECH\_200420A\_QC\_Report QC Report - 5/03/2021 16:15:47

## Top View

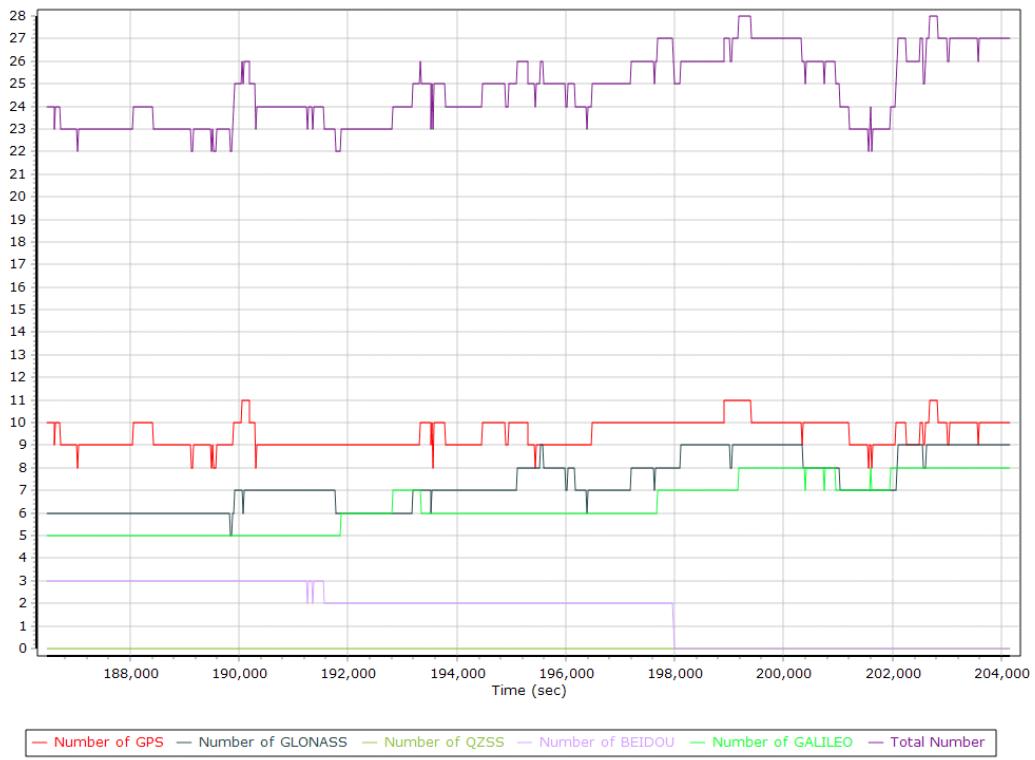


## GNSS QC

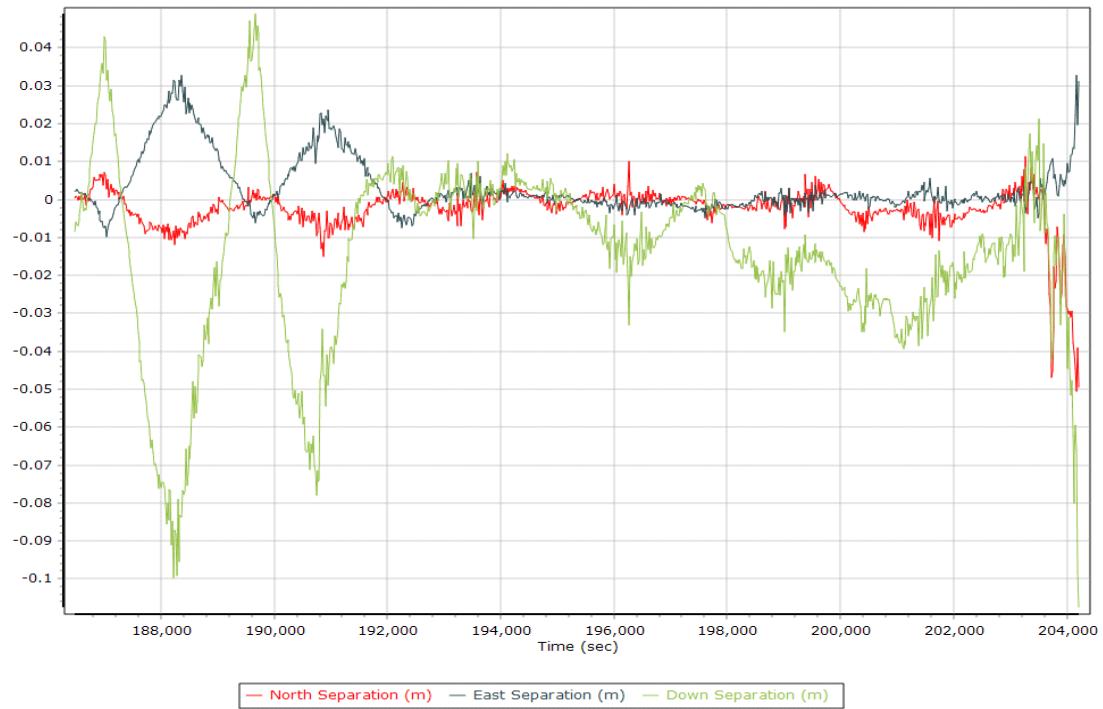
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.29	78.50	
Number of GPS SV	8	11	10
Number of GLONASS SV	0	9	7
PDOP	0.86	1.28	1.01
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	19852.00	0.00	1.00
Percentage	99.99	0.00	0.01

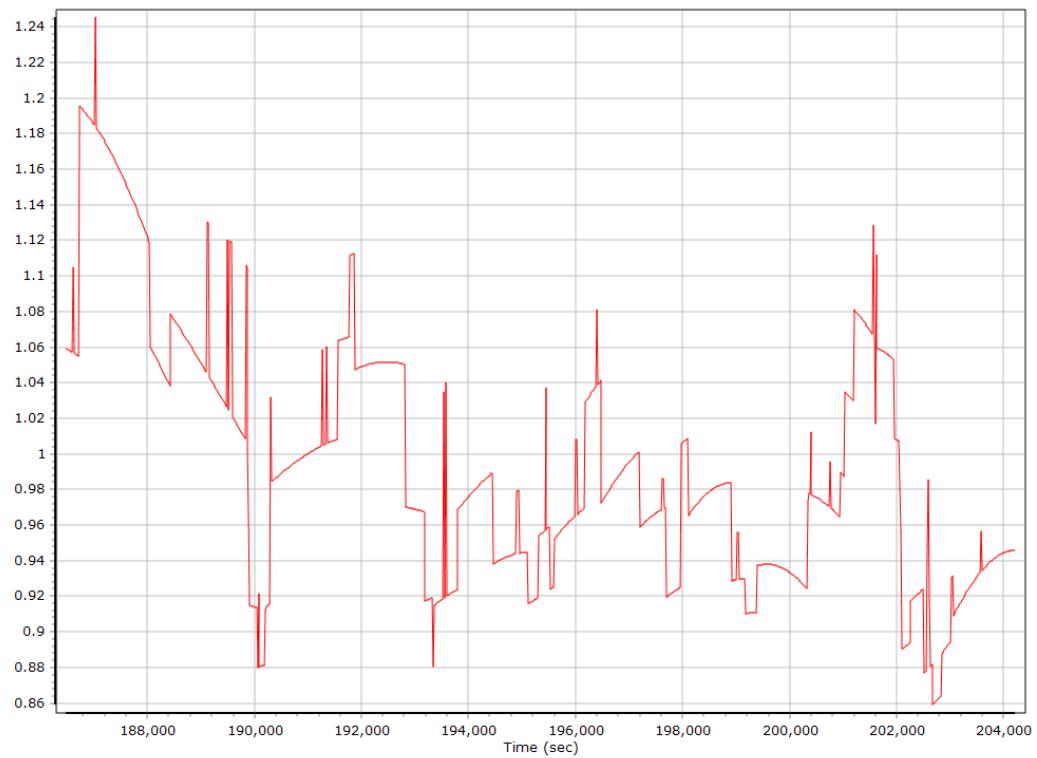
## Number of Satellites



## Forward/Reverse Separation

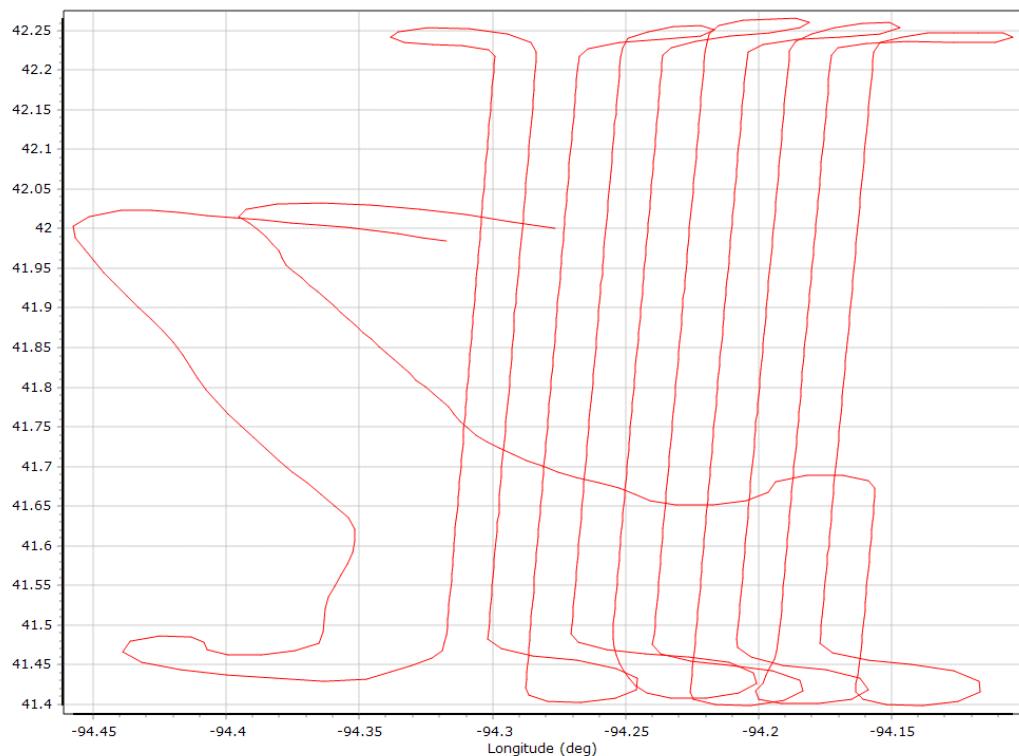


## PDOP



IA\_NC\_SURVTECH\_200421A\_QC\_Report QC Report - 5/03/2021 16:21:03

## Top View

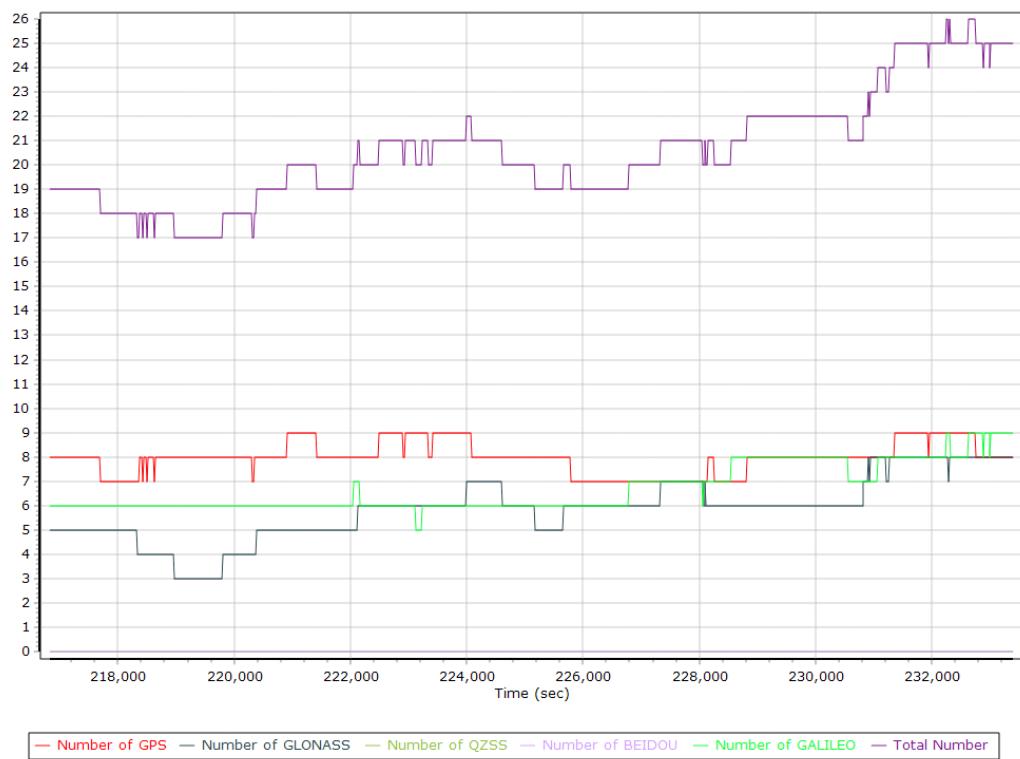


## GNSS QC

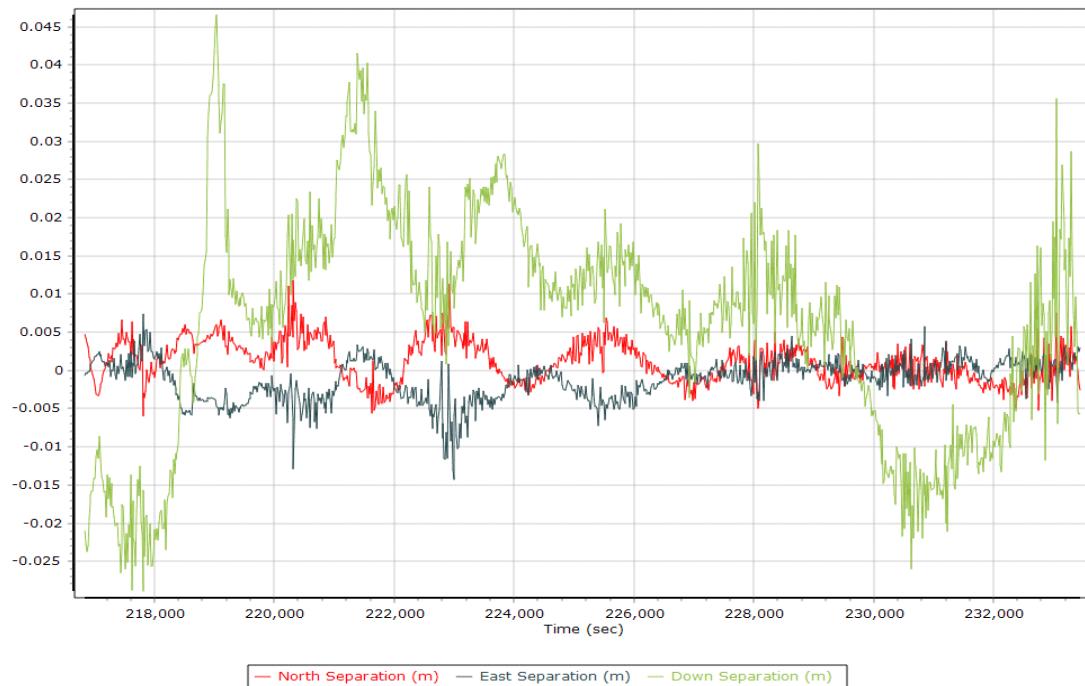
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.43	80.07	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	8	6
PDOP	0.97	1.78	1.21
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	18657.00	0.00	1.00
Percentage	99.99	0.00	0.01

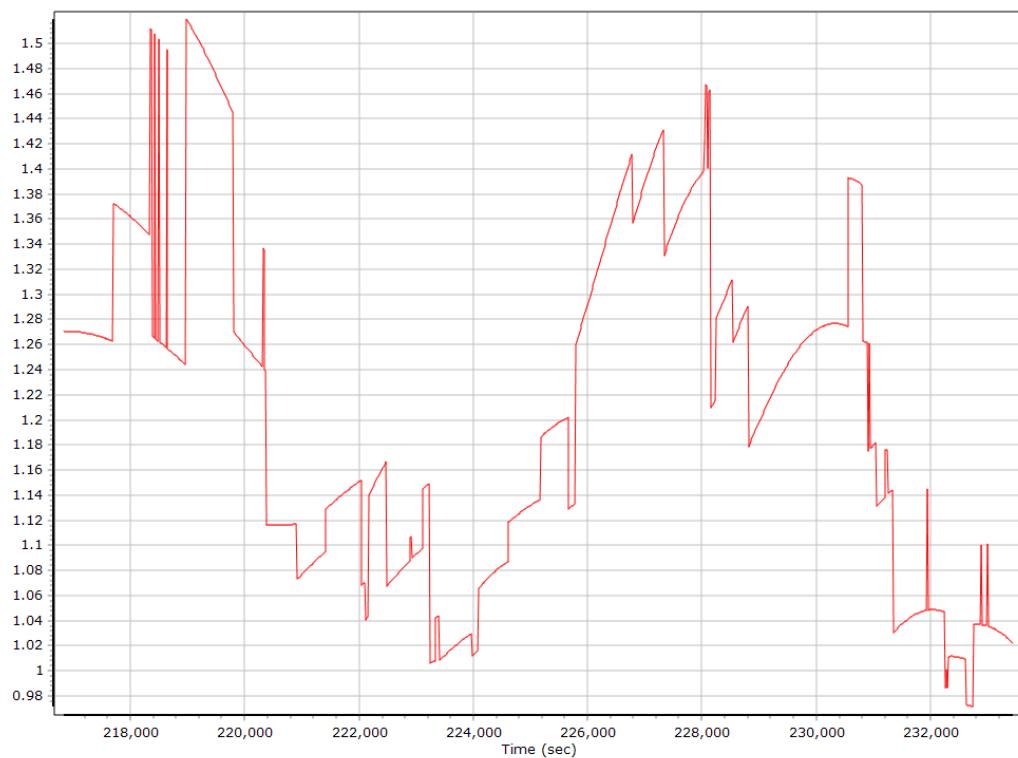
### Number of Satellites



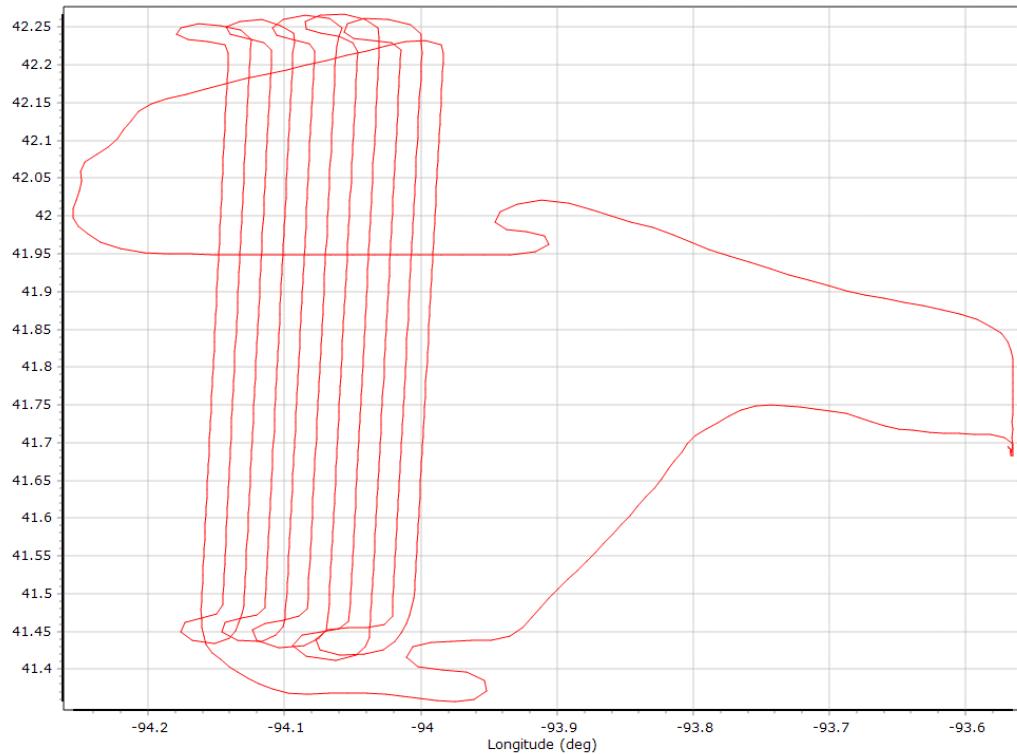
### Forward/Reverse Separation



## PDOP



## Top View

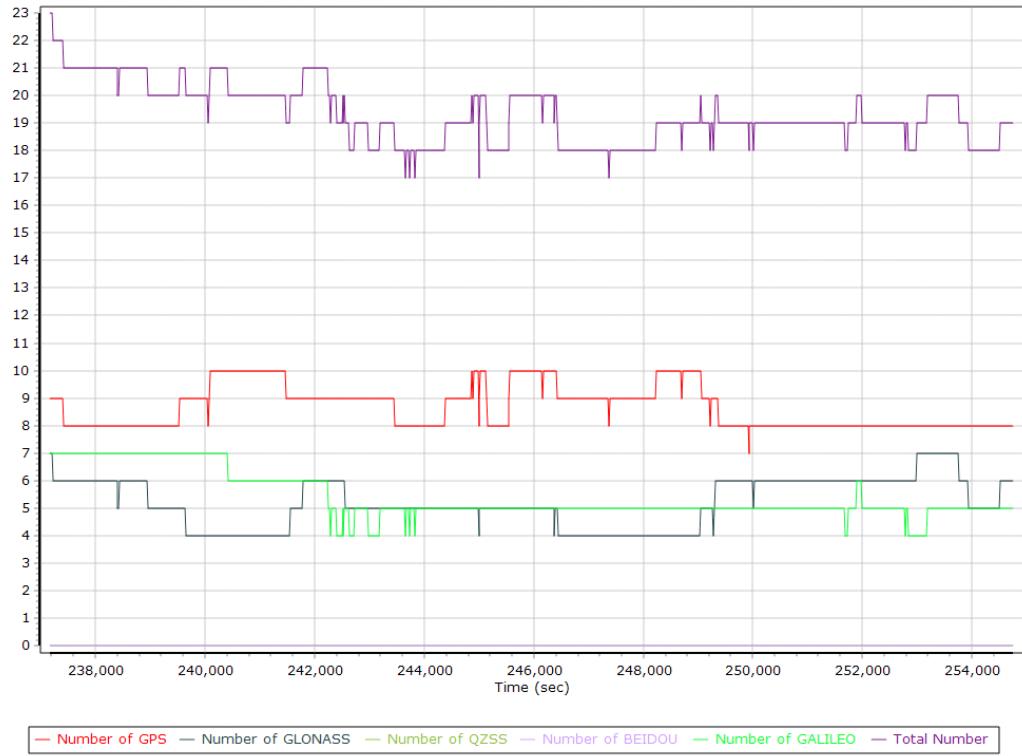


## GNSS QC

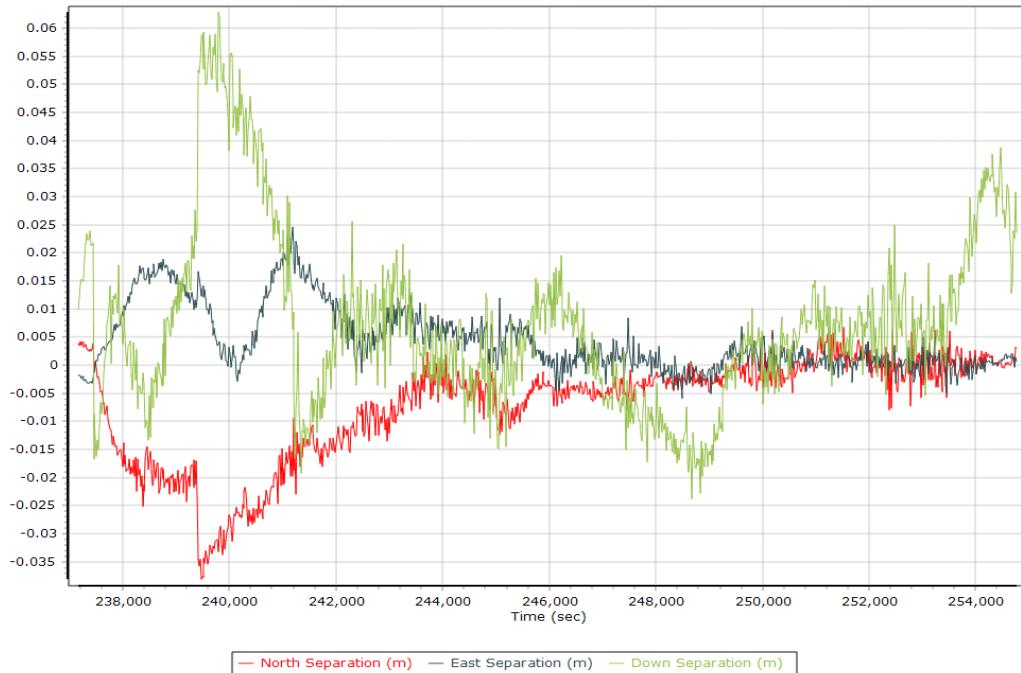
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	3.72	81.56	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	7	5
PDOP	1.00	1.55	1.17
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	17974.00	0.00	1.00
Percentage	99.99	0.00	0.01

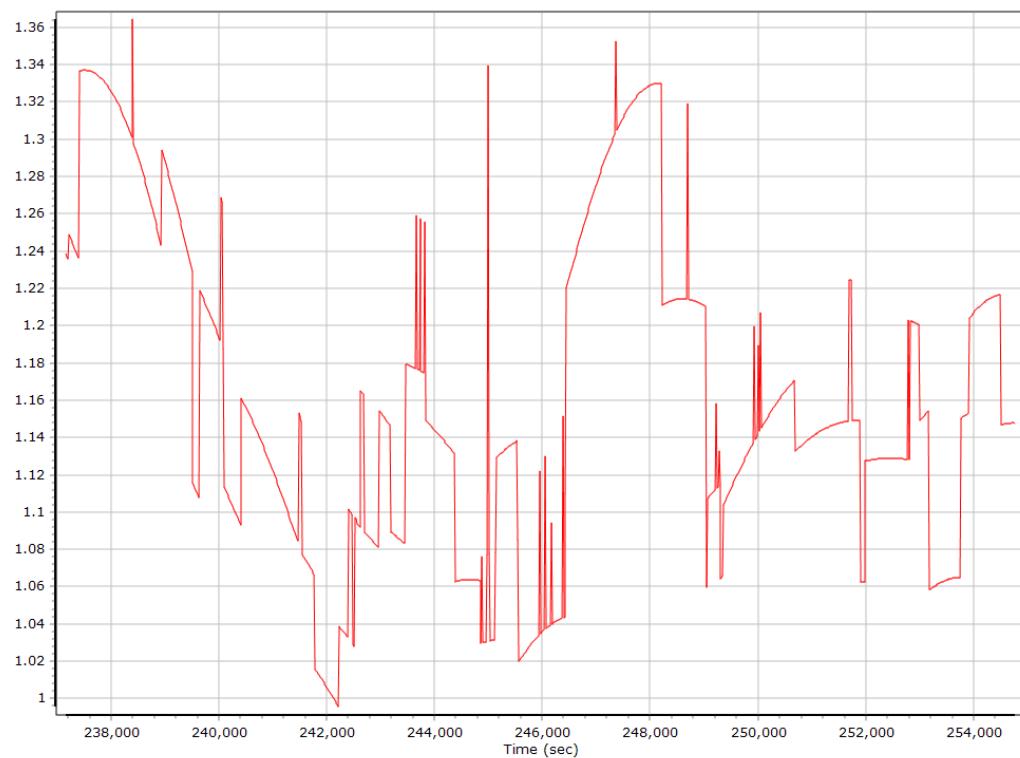
### Number of Satellites



### Forward/Reverse Separation

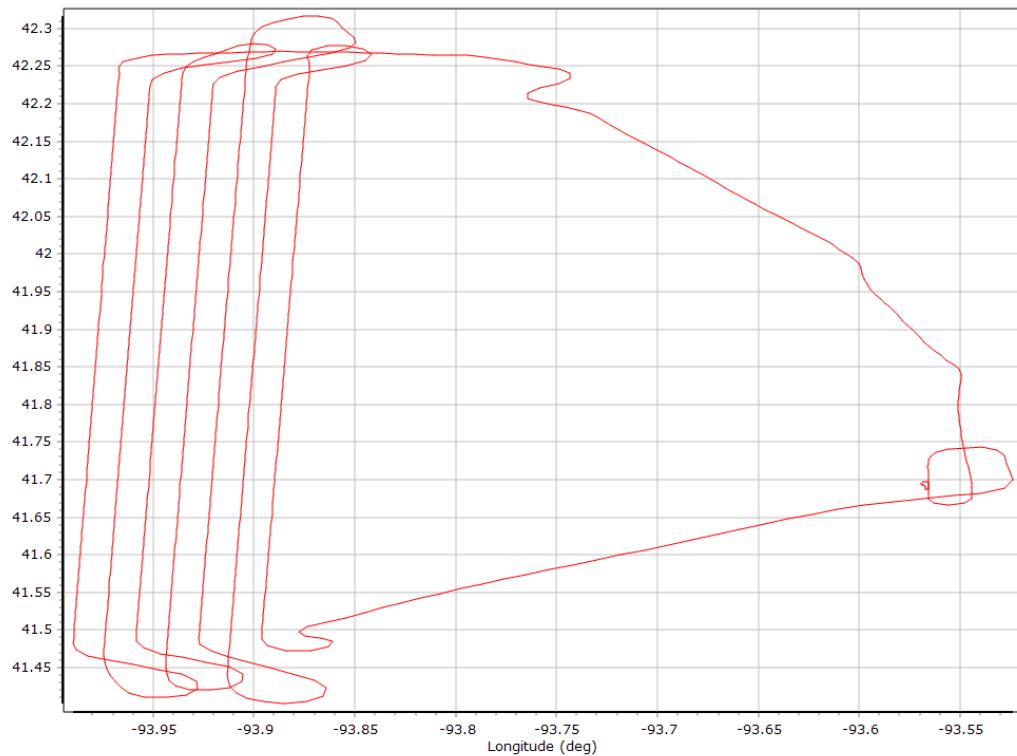


## PDOP



IA\_NC\_SURVTECH\_200421C\_QC\_Report QC Report - 5/03/2021 16:26:42

## Top View

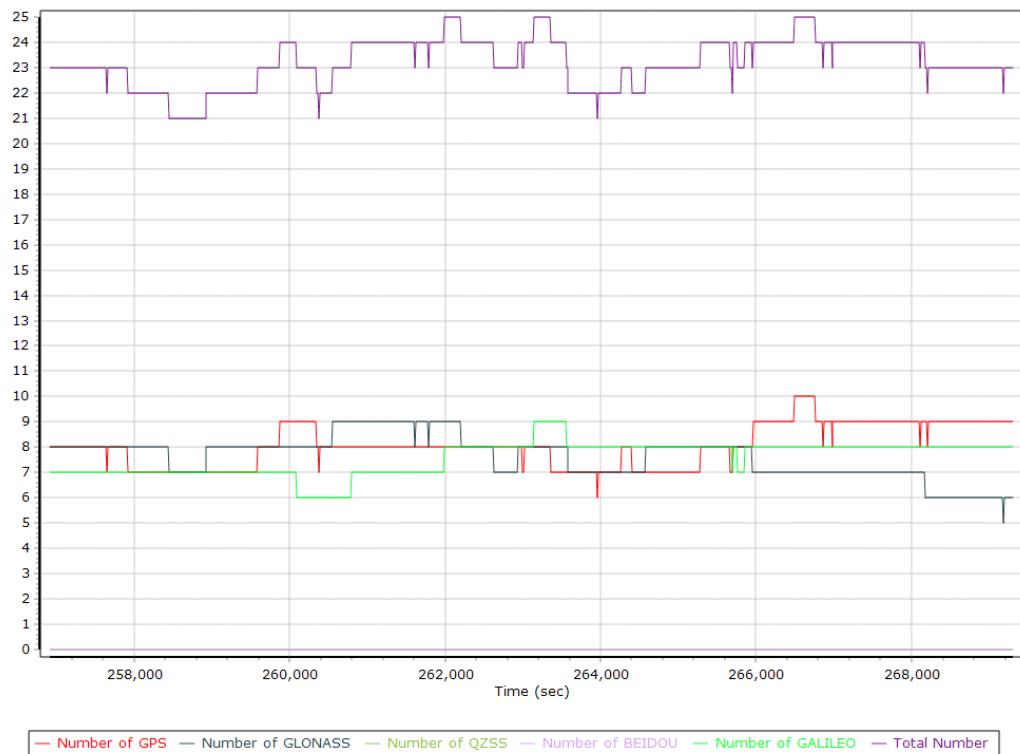


## GNSS QC

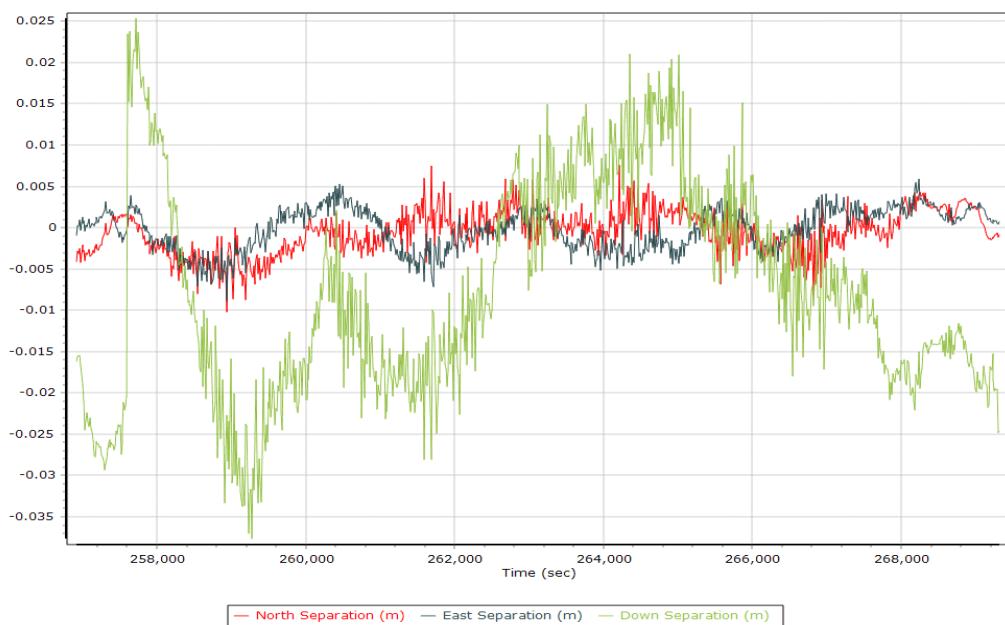
### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	1.43	76.79	
Number of GPS SV	6	10	8
Number of GLONASS SV	0	9	8
PDOP	0.99	1.45	1.18
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	12570.00	0.00	1.00
Percentage	99.99	0.00	0.01

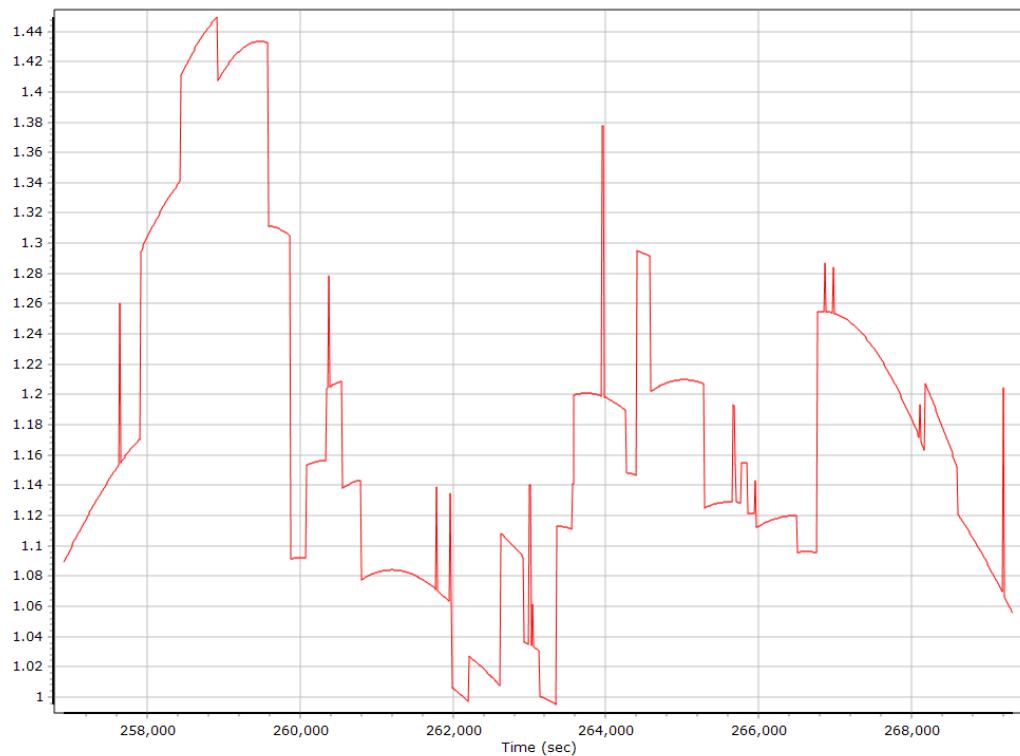
## Number of Satellites



## Forward/Reverse Separation

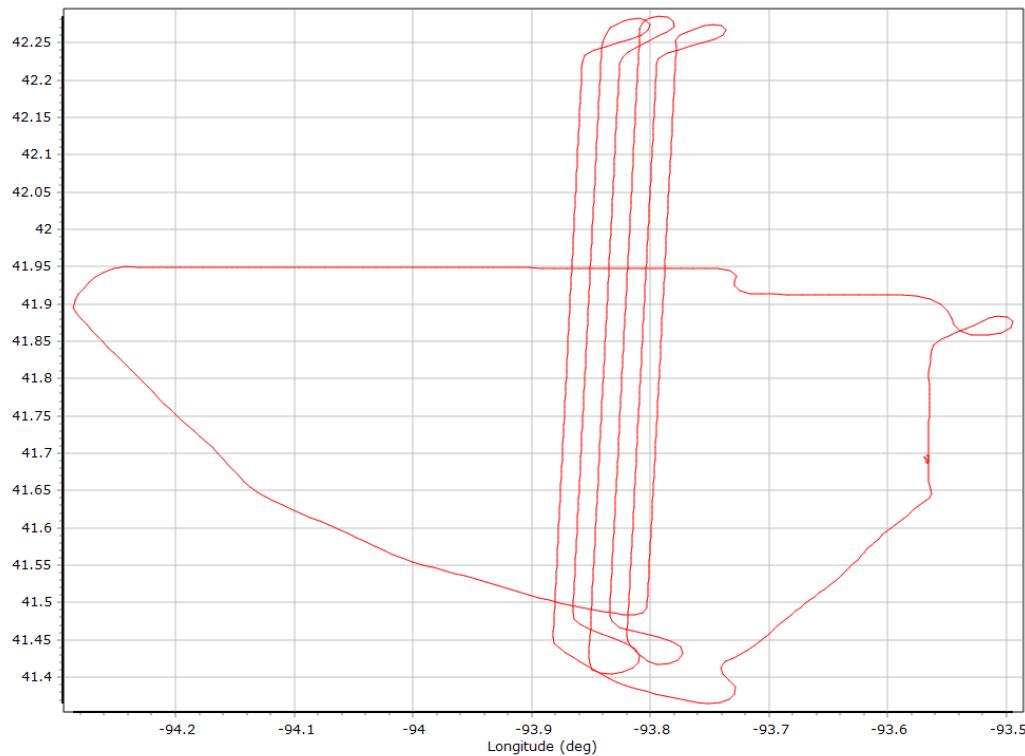


**PDOP**



IA\_NC\_SURVTECH\_200421D\_QC\_Report QC Report - 5/03/2021 16:29:29

## Top View

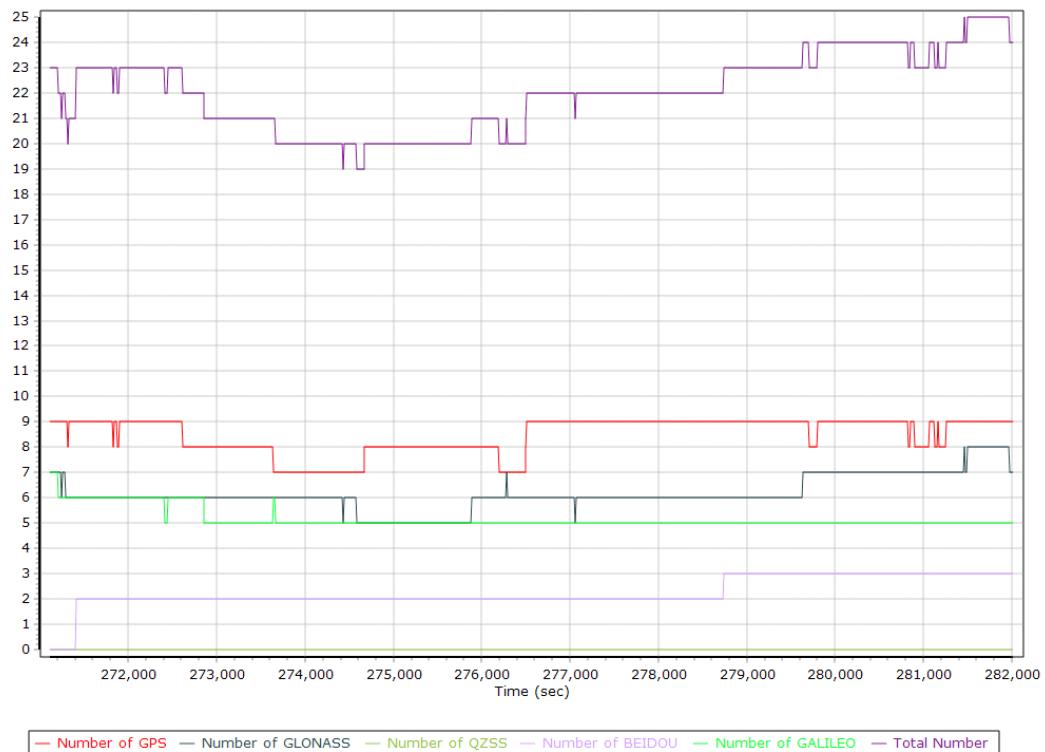


## GNSS QC

### GNSS QC Statistics

Statistics	Min	Max	Mean
Baseline length (km)	2.65	71.81	
Number of GPS SV	7	10	9
Number of GLONASS SV	0	8	6
PDOP	0.98	1.35	1.10
QC Solution Gaps	1.00	1.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	11318.00	0.00	1.00
Percentage	99.99	0.00	0.01

## Number of Satellites



## Forward/Reverse Separation



**PDOP**

