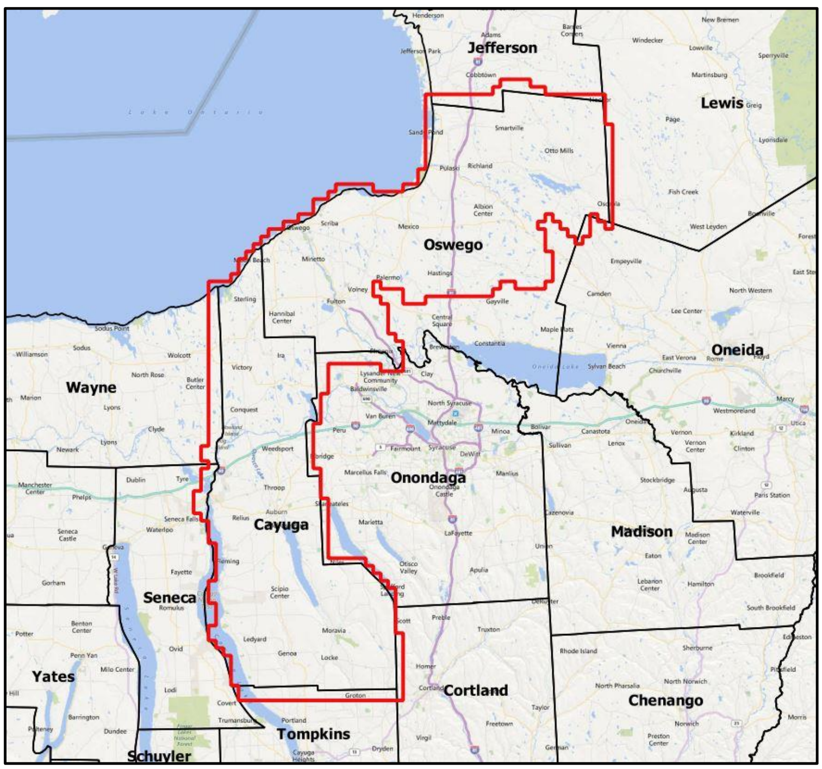
New York State
Airborne LiDAR Acquisition Report

for

New York State Office of Information Technology Services
10B Airline Drive
Albany, New York 12235



Cayuga-Oswego Counties

by

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Axis Project 13367-1811
Oct 2018

Section 1: Table of Contents

Section 2: Introduction

The New York State Office of Information Technology Services requested delivery of three-dimensional classified point cloud and terrain data derived from LiDAR (Light Detection and Ranging) technology for the New York State LiDAR project area covering Cayuga and Oswego Counties. The data must meet Quality B standards as defined by the State. See Table 1: "NYS ITS LiDAR Quality Specification".

NYS ITS LiDAR Quality Specification		
Parameter	**Quality A**	**Quality B**
Nominal Point Spacing (m)	1.5	0.7
Vertical Accuracy (cm)	18.5	9.25
Final DEM Spacing (m)	2.0	1.0

Table 1 NYS ITS LiDAR Quality Specification

The point cloud is to include all returns from the sensor. Points are to be classified to differentiate between bare earth and other return sources using the following classes:

- 1 Processed, but unclassified
- 2 Bare-earth ground
- 7 Noise (low noise)
- 9 Water
- 11 Withheld (if the Withheld bit is not implemented in processing software)
- 12 Overlap
- 17 Bridges
- 18 High Noise
- 20 Ignored Ground
- 21 Snow
- 22 Temporal Exclusion

The project area is located in central New York State, southeast of Lake Ontario, and covers approximately 1,720 square miles. The project area includes the cities of Auburn and Oswego. See Figure 1: "Location of Project Area". The project area measures approximately 51 miles from the eastern boundary to the western boundary and approximately 76 miles from the northern boundary to the southern boundary. See Figure 2: "Project Area".

The acquisition planning task took into account the various terrain changes and land surface configurations within the project area and created an overall plan that was efficient and complete.

Data is stored in a non-proprietary format such as LAS and meets the requirements of "U.S. Geological Survey, National Geospatial Program, LiDAR Base Specification, Techniques and Methods 11-B4 Version 1.3-February 2018" except as specified by the governing contract.

LiDAR data was processed and projected to UTM Zone 18 North, referenced to the North American Datum 1983 (NAD83) (2011), in units of meters. The vertical datum used for the project is the North American Vertical Datum 1988 (NAVD88) in meters. Orthometric heights are to be determined using Geoid 12B.

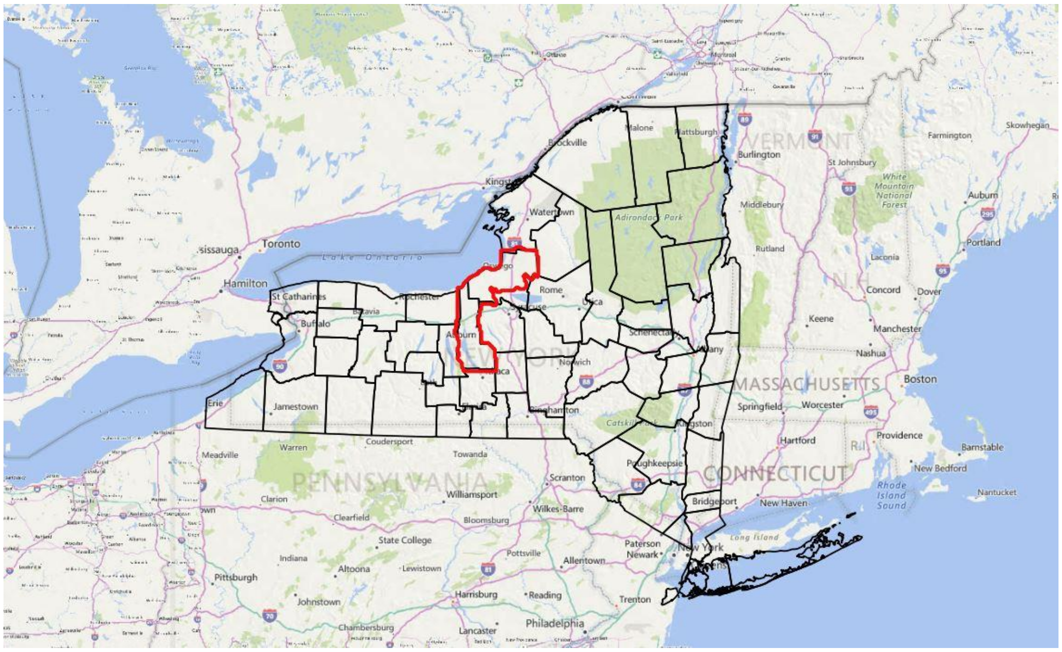


Figure 1: Location of Project Area

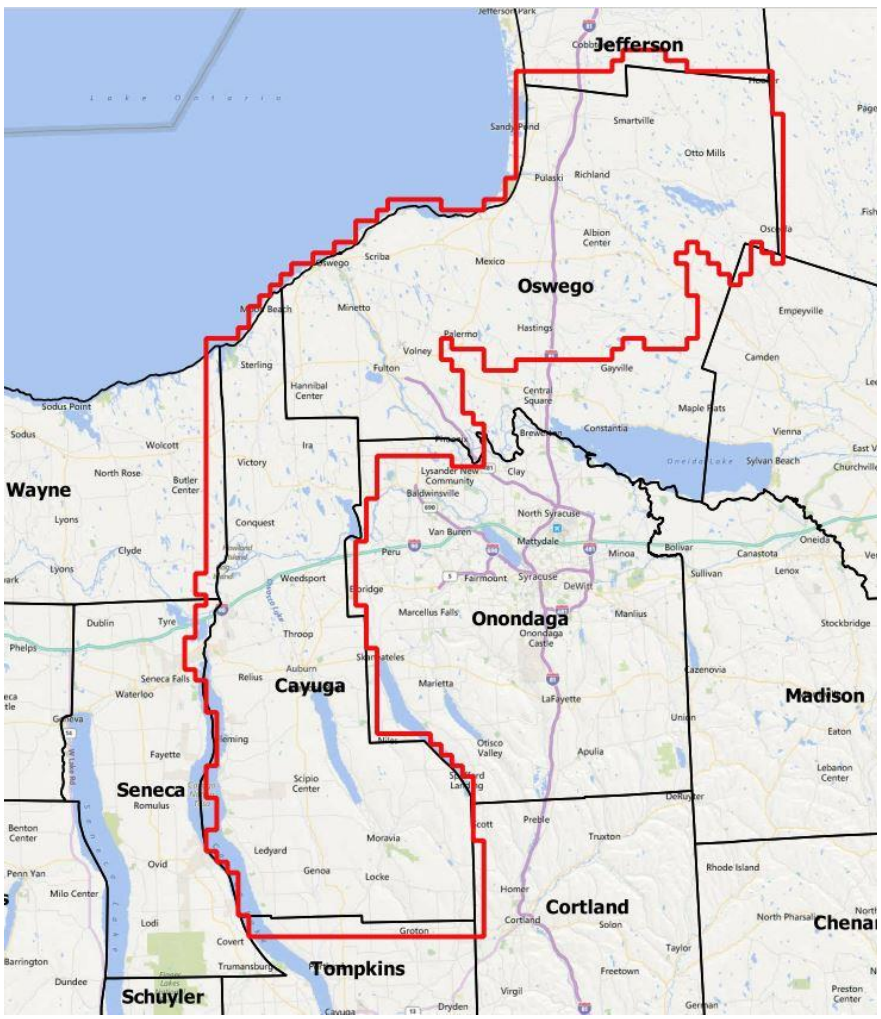


Figure 2: Project Area

Section 3: LiDAR Acquisition

3.1 Acquisition

Airborne LiDAR was acquired by Airborne Imaging based in Calgary, Canada with a Riegl VQ1560i LiDAR sensor. The VQ1560i sensor was installed in a Piper PA31 with the tail number of C-GKSX.

Table 2: "Riegl VQ1560i Sensor Specifications" provides a list of the features and specifications for the LiDAR sensor system.

Minimum Range [8]	100 m
Accuracy [9,10]	20 mm
Precision [10,11]	20 mm
Laser Pulse Repetition Rate	up to 2 MHz
Effective Measurement Rate	up to 1.33 MHz @ 60° scan angle
Echo Signal Intensity	provided for each echo signal
Laser Wavelength	near infrared
Laser Beam Divergence	≤ 0.18 mrad @ 1/e [12], ≤ 0.25 mrad @ 1/e² [13]
Number of Targets per Pulse	with online waveform processing: practically unlimited [14,15] monitoring data output: first pulse
Scanner Performance	
Scanning Mechanism	rotating polygon mirror
Scan Pattern	parallel scan lines per channel, crossed scan lines between channels
Tilt Angle of Scan Lines	± 14° = 28°
Forward/ Backward Scan Angle in Non-Nadir Direction	± 8° at the edges
Scan Angle Range	60° total per channel, resulting in an effective FOV of 58°
Total Scan Rate	40 [16] - 600 lines/sec
Angular Step Width Δϑ	0.006° ≤ Δϑ ≤ 0.180° [17,18]
Angle Measurement Resolution	0.001°

Table 2: Riegl VQ1560i Sensor Specifications

3.2 Acquisition Details

Seventy-five (75) lines (not including cross strips) were planned to complete coverage of the project area. See Figure 3: "Flight Line Plan (75 flightlines)". Cross strips and calibration flight lines acquired to compensate and correct for the inherent IMU drift associated with all IMU systems were determined "on the fly" by the flight crew. The location and extent of these lines are based on the number of lines acquired during each mission. Weather and atmospheric conditions were to be monitored and LiDAR missions conducted only when conditions existed that would not degrade sensor ability in the collection of data. Overall, eighty-eight (88) flight lines were obtained.

Of the eighty-eight (88) acquired lines:

1) Seventy-five (75) of the acquired lines were planned acquisition lines;
2) Eight (8) "tie" lines were acquired;
3) A total of eighty-three (83) lines were used for the project
4) Five (5) lines had sensor warnings at the time of acquisition. These 5 lines were not used but were re-acquired at the time of acquisition.

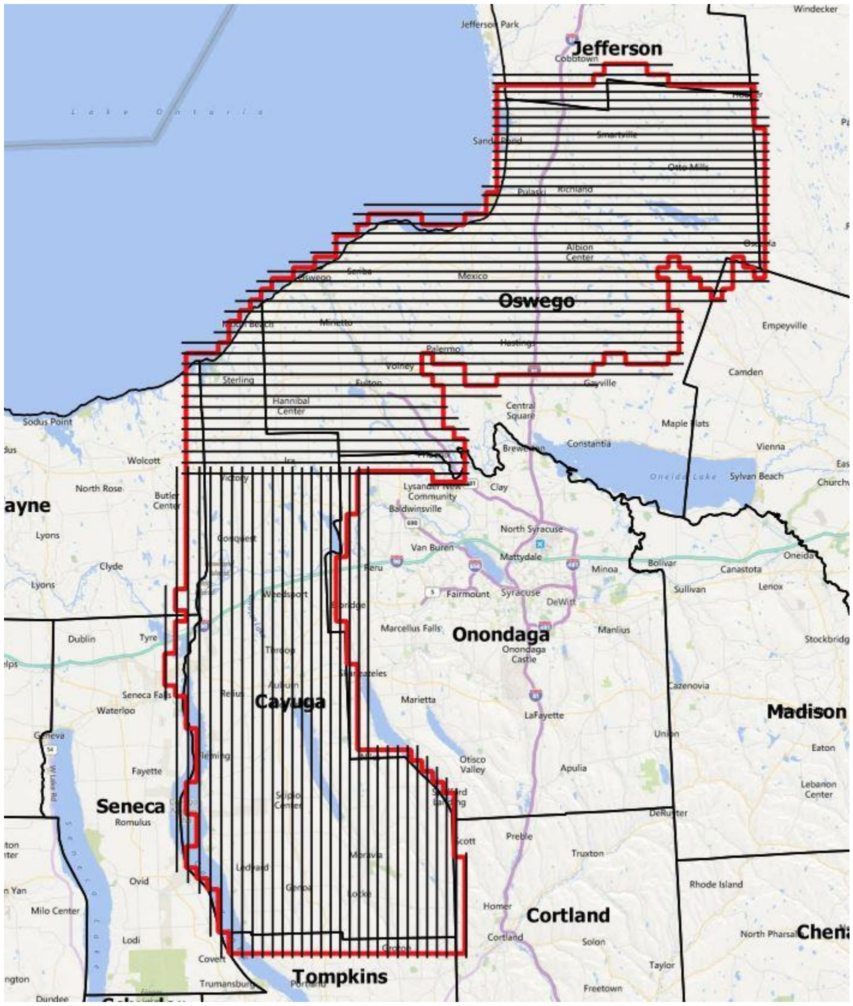


Figure 3: Flight Line Plan (75 flightlines)

From Wednesday, April 4, 2018 through Wednesday, May 2, 2018, Airborne Imaging was stationed to acquire LiDAR. Snow cover on the ground and unfavorable weather conditions prevented acquisition until Monday, April 23. On this date, Airborne Imaging flew two sorties and acquired twenty-eight (28) flight lines. All twenty-eight (28) lines were acquired in a north-south direction in the south area of the project.

The preferred acquisition plan was to begin acquisition in the south of the project area, acquiring data in a north-south flight direction and proceeding west to east. Once the south area was acquired, the north area would be acquired using an east-west flight direction, starting at the southern end and proceeding northward. This approach coincided with the snow melting, generally occurring from south to north. Acquisition continued on Tuesday, April 24 with Airborne Imaging flying one sortie and acquiring twenty-nine (29) flight lines. Ten (10) of these lines were flown in a north-south direction and completed the south area. The remaining lines were acquired in an east-west direction, in the north area.

Unfavorable weather prevented acquisition until Tuesday, May 1. Airborne Imaging acquired eleven (11) flight lines during a single sortie. Airborne Imaging acquired the remaining twenty (20) flight lines on Wednesday, May 2. This completed the acquisition of the airborne LiDAR.

3.3 LiDAR Flightline Orientation

Figure 4: "Cayuga-Oswego Actual Flight Lines Acquired" illustrates the location and number of flightlines that were acquired during the Spring of 2018.

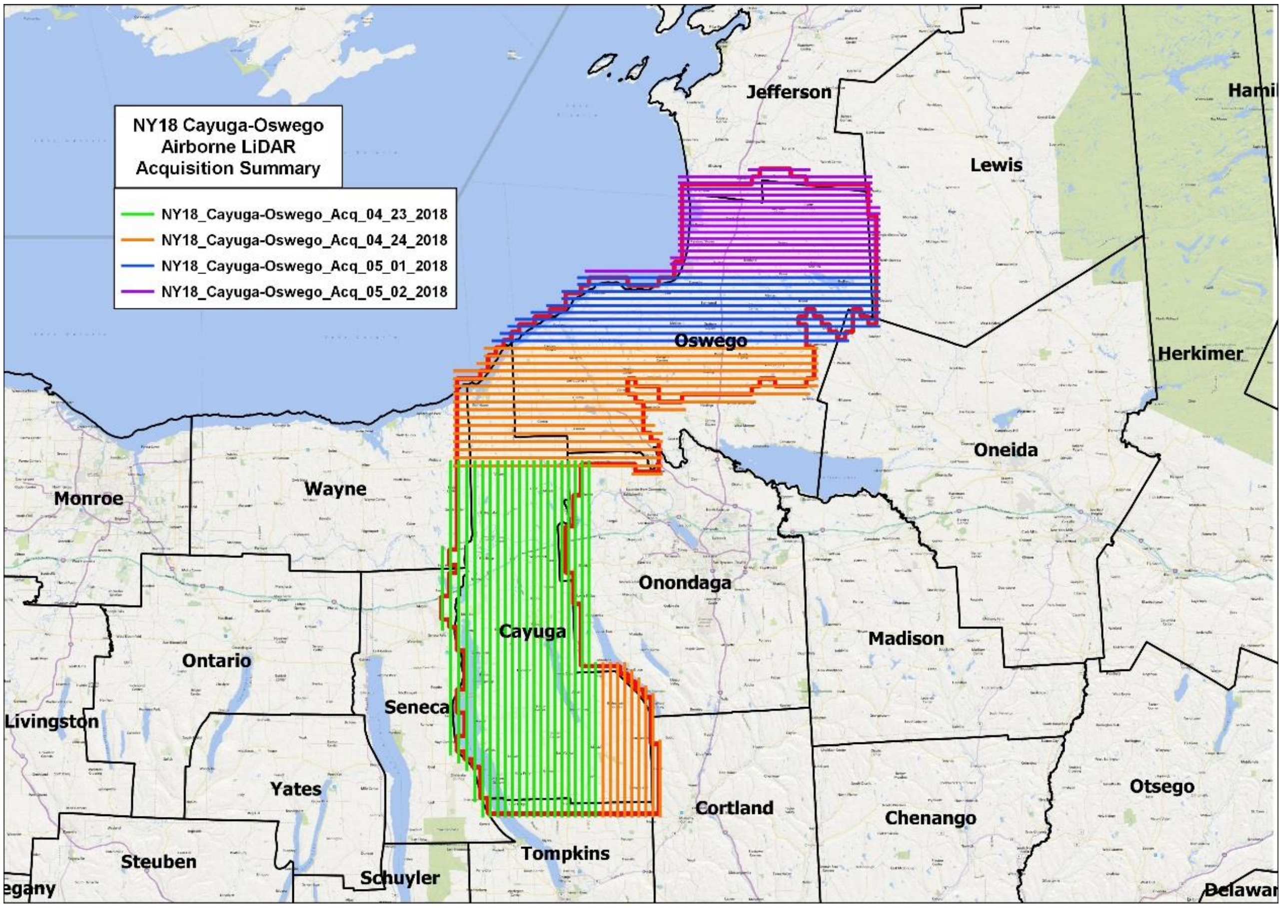


Figure 4: Cayuga-Oswego Actual Flight Lines Acquired (Spring Acquisition)

3.4 Acquisition Flight Summary

Five (5) LiDAR acquisition missions were flown between April 23, 2018 and May 2, 2018. Flights were planned at various flying heights above 5,905 ft. (1,800 m) AMSL

Flight Logs for each acquisition mission are provided in Section 4 Flight Logs. Calibration lines were run at the beginning or end of the day and a cross strip running east or west was obtained at the end of each successful lift.
Table 3: "Acquisition Dates and Parameters", provides a summary of the acquisition missions.

Date of Mission(s)	Mission Number	Number of Lifts	# of Lines Acquired*	Sensor	Mission Time (GPS)	Aircraft Tail Number
April 23, 2018	AI-1	1	11	VQ1560i	16:09-- 19:13	C-GKSX
April 23, 2018	AI-2	1	17	VQ1560i	20:53-- 01:49	C-GKSX
April 24, 2018	AI-3	1	29	VQ1560i	14:34 – 20:50	C-GKSX
May 01, 2018	AI-4	1	11	VQ1560i	14:50 – 18:40	C-GKSX
May 02, 2018	AI-5	1	20	VQ1560i	11:16 – 16:11	C-GKSX

*Includes cross tie lines

Table 3: Acquisition Dates and Parameters

The System Parameters for LiDAR Acquisition are provided in Section 3.7 in Table 5: “System Parameters for LiDAR Acquisition” on Page 10 of this report.

3.5 LiDAR System Acquisition Limitations

There are several limiting factors to LiDAR data acquisition which include weather, ground conditions, satellite configuration and equipment malfunctions.

During a LiDAR acquisition mission, there can be no clouds below the aircraft, rain, fog or excessive humidity between the sensor and the ground. Excessive, heavy winds, engaging the aircraft perpendicular to the line of flight, can result in “crab” of the aircraft which results in “gaps” or “slivers’ in the data between flight lines. Ground conditions which include pools of standing water and ditches filled with moving water affect the accuracy of LiDAR returns. The number of satellites “visible” to the aircraft during acquisition is an important factor and a poor Global Positioning System (GPS) configuration will contribute to less than desired accuracy. Therefore, satellite configuration, measured by PDOP (Positional Dilution of Precision) is checked each morning to ensure acquisition occurs during the most favorable geometric configuration of the satellites. Finally, despite the best maintenance routines and practices, systems malfunction and fail. Operator awareness is paramount to identifying the exact moment when a system malfunctions. This enables the crew to stop acquisition and correct the issue before continuing. At times, lines acquired with anomalies will need to be re-acquired.

3.6 Acquisition Issues and Resolutions

The project area is notorious for having cold and unfavorable weather for LiDAR acquisition, especially in the spring and winter months. Snow cover, clouds and rain were the factors that prevented acquisition. When snow did fall, it melted quickly. The initial data reviews did not show any significant issues in the quality and coverage of the acquired data. However, subsequent reviews identified an area of concern.

In reviewing previous LiDAR acquisition data sets using the Riegl VQ1560i, it was noted that there were small areas of missing data. The “dropout” areas were located over surfaces (rooftops) with very dark composite roofing material and over areas with very low near infrared reflectivity.

With this in mind, Airborne Imaging planned and acquired the Cayuga-Oswego airborne LiDAR at a flying height of 1,800 m above ground. The flying height was lowered 500 m from the previous project acquisition. The Scan Rate was increased from 179 Hz to 188 Hz and the Pulse Rate was set at 700 kHz (350 kHz per channel). The line spacing was reduced from .89 m to .85 m. These adjustments increased the Nominal Pulse Density to 2.81 pls/m^2.
Even with the noted changes in acquisition parameters, small areas were identified with dropout points. However, due to the small size of the dropout areas, the acquired swath data meets USGS 3DEP specifications.

3.7 LiDAR System Acquisition Parameters

LiDAR acquisition was planned to meet the following specifications in Table 4: “System Parameters for LiDAR Acquisition VQ1560i” provides the acquisition parameters for the VQ1560i sensor.

Item	Parameter
System	Riegl VQ1560i
Nominal Pulse Spacing (m)	0.60
Nominal Pulse Density (pls/m²)	2.81
Nominal Flight Height (MSL meters)	1800
Nominal Flight Speed (kts)	160
Pass Heading (degree)	180,360 / 90, 270
Sensor Scan Angle (degree)	60
Scan Rate	188 Hz
Pulse Rate of Scanner (kHz)	700 kHz (350 per channel)
Line Spacing (m)	.85
Pulse Duration of Scanner (ns)	3
Pulse Width of Scanner (m)	0.60
Central Wavelength of Sensor Laser	1064nm
Sensor Operated with Multiple Pulses	Yes
Beam Divergence (mrad)	0.25
Nominal Swath Width (m)	2017
Nominal Swath Overlap (%)	20%
Scan Pattern	Parallel scan lines per channel, crossed scan lines between channels

Table 4: System Parameters for LiDAR Acquisition VQ1560i

3.8 CORS Reference Stations

The presence of a strong CORS (Continuously Operating Reference Station) and base station configuration allowed for the LiDAR to be acquired with Global Navigation Satellite System (GNSS) techniques and procedures. Table 5; "GPS Reference Station Coordinates" and Figure 5; "GPS Reference Stations" below contain a listing and graphic of the CORS and base stations that were used during the processing, their calculated latitude, longitude and ellipsoid height. Minor variations in position, due to changes in satellite availability, geometry and varying availability of the CORS stations, were observed, and are of millimeter level magnitude. These variations had no impact on system positioning and are unavoidable. Note that four of the stations (CAGS, CBRG, KNGS, and NRC1) are from the Canadian Spatial Reference System (CSRS) and were used by POSPac's Smartbase processing software. The coordinates were transformed from ITRF2000 to NAD83 (2011). The remaining stations are from the NOAA NGS CORS Global Navigation Satellite System (GNSS)

NAME	LATITUDE (N)	LONGITUDE (W)	ELEVATION (M)
CAGS	45°35'06.03971" N	075°48'26.36392" W	236.043 m
CBRG	43°57'23.25784" N	078°09'51.76814" W	43.575 m
KNGS	44°13'07.25275 "N	076°31'02.14201" W	49.931 m

NRC1	45°27’14.95030" N	075°37’25.76467" W	83.620 m
NYCL	42°35’03.70673" N	076°12’40.79203" W	330.860 m
NYLV	43°47’47.24300" N	075°29’07.55405" W	241.544 m
NYMX	43°28'12.37868" N	076°13'54.88561" W	91.134 m
NYPF	43°05’35.48422" N	077°31’31.11164" W	113.479 m
NYRM	43°10'40.02812" N	075°29'13.88195" W	128.527 m
NYSB	42°40'45.03216" N	075°30'47.47680" W	297.150m
NYWG	42°21'03.79548" N	076°52'33.29987" W	283.533 m
NYWL	40°53'55.22669" N	076°51'07.30156" W	109.952 m
NYWT	44°01'41.65759" N	075°55'15.94805" W	118.249 m
NYWV	42°00'44.59964" N	076°31'17.66827" W	222.145 m

Table 5: GPS Reference Station Coordinates

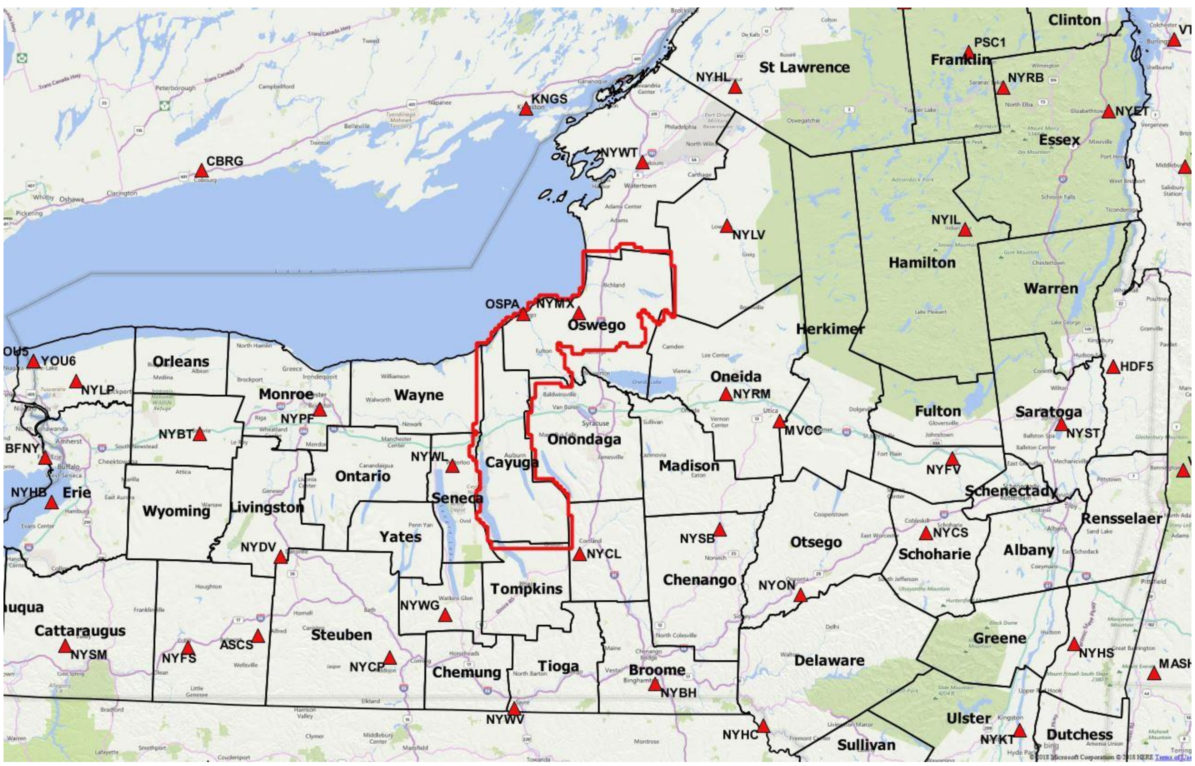


Figure 5: GPS Reference Stations

3.9 Airborne GPS Kinematic and Processing

The Differential GPS unit in the aircraft collected positions at 2Hz. Airborne GPS data was processed using the POS Pac

MMS v.8.1 software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of ≤3 when laser online. Distances from base station to aircraft were kept to a maximum of 50km.

For all flights, the GPS data can be classified as good, with GPS residuals of 3cm average or better but none larger than 15cm being recorded when the laser is online.

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

Airborne Imaging utilized the latest in Airborne-GPS (AGPS) and Inertial Measurement Unit (IMU) systems to determine the precise three-dimensional trajectory of their aircraft in flight. These state-of-the-art sensor systems use the global navigation satellite system (GNSS), pitch-roll-yaw sensors, accelerometers and gyrocompasses to measure and record every change in the attitude, speed and direction of the aircraft during its data collection mission.

These measurements are linked together according to a precise time baseline that is collected as part of the GNSS message stream, allowing corrections for attitude variations to be known at the exact time the digital sensor records an image.

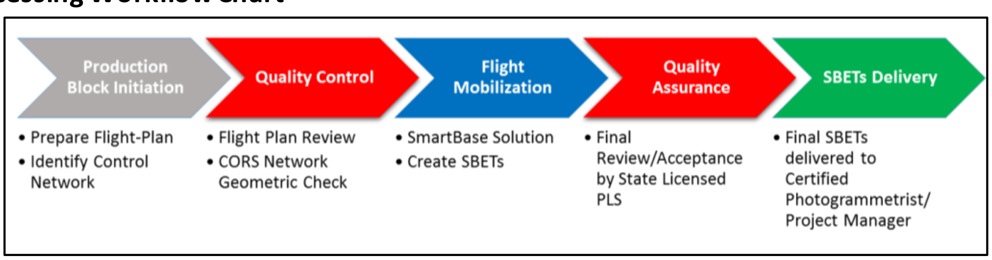
AGPS/IMU Processing

Airborne Imaging used Applanix POS Pac MMS v.8.1 to process Airborne GNSS/IMU datasets and compute Smoothed Best Estimated Trajectory (SBET) files for our LiDAR missions. This state-of-the-art GNSS/IMU processing technology uses a combination of GNSS data collected onboard the aerial platform during the mission, twenty-four (24) hours of satellite geometry and ephemeris data from the National CORS network that surrounds the flight mission footprint, and data from the onboard IMU that tracks the heading, acceleration/deceleration, pitch, roll and yaw of the aircraft during the flight.

The processing software uses all of the data inputs to determine the precise three-dimensional trajectory of the aircraft during the mission. The process includes operator managed and software driven QA/QC checks, focusing on the geometry and spacing of the CORS network control points around the project area, data integrity and ensuring that software inputs and settings are properly configured to account for the system hardware locations in relation to the IMU reference location.

The workflow for each production block will follow a structured path, modified as needed to make adjustments for buy ups or other optional tasks:

SBET Processing Workflow Chart



First, a flight plan and project are reviewed prior to mobilization to confirm CORS network geometry, station availability and data observation rates. Once approved for flight, the mission is executed by the flight operations team within the parameters of the flight plan, STATE requirements, applicable mapping guidelines, industry standards and in-house protocols. These requirements include collection of data on the ground before and after the flight, proper manipulation of the IMU during flight to avoid heading drift and careful navigation of the aircraft to avoid loss of satellite lock during the entire mission such as unduly steep banking turns, flight line deviations, or operation during turbulent conditions. Upon return to the airfield, the IMU and other data are downloaded, copied and made available for post processing. Post processing involves assembling flight data from the onboard GNSS and IMU, downloaded CORS vector data for a time balanced observation period centered on the takeoff to touchdown flight window of the data collection mission, published and vetted positional data for the CORS control stations, broadcast and precise ephemeris data documenting the projected and actual positions of the satellites during the mission.

GNSS Base Stations for the SmartBase processing are selected based on conformance with requirements of the software, including distance from the center of the flight mission, network station spacing, observation rates of the network base stations, and availability of both broadcast and precise ephemeris data for the satellites included in the GNSS dataset.

All of these datasets are linked to the project database, checked for accuracy and readied for processing. The software uses a proprietary process to compute GNSS based forward and backward trajectories, IMU based forward and backward trajectories based on accelerometer and gyrocompass data, pitch, roll and yaw sensors, and then combine all of the independent solutions into a precisely computed string of plane and sensor positions during the mission. Due to the speed of travel of the aircraft, positioning is determined at the rate of fifty (50) times per second, based on actual observed data from equipment operating at that recording interval, not from interpolated data from equipment operating at slower data rates. This method yields truer positioning from direct observation rather than estimated positions between true fixes. The IMU system operates at very high speed, typically at two hundred measurements (200) per second, which allows the system to maintain a precise track on changes in aircraft attitude during acquisition. The GNSS data is combined with the IMU data to bridge the separations in position fixes and refine the precision of the planes trajectory down to nearly centimeter level three-dimensional precision.

The software downloads GNSS data from the CORS stations around the project area, and performs a dataset integrity check of the GNSS RINEX files to find errors in the data such as gaps, incompatible collection rates or missing antenna information. The Applanix SmartBase software includes a SmartBase Quality Check module that performs an extremely accurate network analysis and adjustment on all the base-lines and reference stations in the network. The Quality Check module uses 18 to 24 hours of reference station data to accurately compute the base-lines between one station set as the control and the rest of the stations. The long duration of data is used to ensure that all multipath variations due to changes in satellite positions are averaged out as much as possible.

The output of the Quality Check module is a table indicating the estimated error for each set of reference station coordinates. If the estimated error is larger than 5 cm, the coordinates are flagged as unacceptable, indicating the input coordinate cannot be trusted. The user has the option of using the adjusted coordinates instead of the input coordinates, or not using the reference station at all in the Applanix SmartBase computations.

Additional quality checks are made on the individual reference station observation files before the Applanix SmartBase is computed. The final result of this process ensures the integrity of the computed reference station data and coordinates are known and trusted before the airborne data set is even processed.

Once the network framework is approved, the software establishes a Virtual Reference Station in close proximity to the project area. This technology is known as the Applanix SmartBase Solution, and allows the software to minimize vector length from the primary base station to the aircraft, minimizing the effect of atmospheric and other systematic errors. Once the Virtual Reference Station is established, forward and backward processing of the GNSS and IMU datasets is executed to determine the exact path, known as the Smoothed Best Estimated Trajectory (SBET), of the airborne platform and its associated equipment.

ABGPS/IMU QA Review & Analysis

Once the SBET file is created, reports and output files of the data are automatically generated for review by the system operator. The primary analysis tool are the charts showing differences in values for aircraft roll-pitch and yaw values, positional quality information, satellite health and geometry, signal to noise ratios, and variances in direction or velocity vectors between forward and backward processed data that indicate some environmental variable has affected the data.

The primary means of mitigating these errors is proper positioning support by the surrounding base station network, management of flight path length to eliminate IMU drift, and flight procedures that avoid interruption of satellite data reception.

ABGPS/IMU Data Finalization and Preparation for LiDAR Production

The SBET QA/QC review is finalized by independent assessment of the output charts and reports showing deviations between processing directions, spikes in aircraft attitude variations and quality of GNSS data and positional fixes. GPS processing results for each lift are included in Section5: GPS Processing.

Section 4: Flight Logs

April 23, 2018; Lift 1

Julian Day 113	Flight A

LIDAR Flight Log

AIRBORNE IMAGING — A Clean Harbors Company

Date	APR. 23/18	Aircraft	C-GKSX
Project	3145 OSWEGO	Pilot	A. MURRAY
Location	FULTON, NY-KFZY	Operator	D. TARR
Mission Objective			

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes
TEMP 17°C
HUM 22
BER 102.9

Aircraft Block Time		
Engine On 1517	Ramp Out 1546	Takeoff 1552
Engine Off 1935	Ramp In 1923	Landing 1922
Total 4.3 hrs	Total hrs	Total 3.5 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	1526	1531
Post Mission	1925	1930

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
TEST		101	160939	161044			180423-160939	
1001		101	1612	1614			-161203	Snow on east end } Do not process!
1002		282	1620	1628			180423-162028	Snow on east end
1045		191	1646	1650			-164636	WENT TO NORTH/SOUTH LINES.
1046		11	1659	1710			-165913	
1047		181	1714	1727			-171447	
1048		11	1730	1742			-173033	
1049		181	1746	1800			-174600	
1050		11	1803	1817			-180330	
1051		181	1821	1826			-182110	STOPPED, RIACQUIRE SHOT DOWN
1051		11	1853	1908			?	NO TIME STAMP
X-TIE		90	1911	1913			?	" "

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April 23, 2018; Lift 2

Julian Day 113	Flight B

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date APR 23/18	Aircraft C-GKSX
Project 3145 OSWEGO	Pilot A. MURRAY
Location FULTON KFZY	Operator TARR
Mission Objective	

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	3
Scanner 2 Drive	4

Additional Notes
T 20°C
H 16%
BAR 1026

Aircraft Block Time		
Engine On 2006	Ramp Out 2040	Takeoff 2045
Engine Off 0218	Ramp In 0205	Landing 0203
Total 6.2 hrs	Total hrs	Total 5.3 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	2033	2038
Post Mission	0209	0214

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
TEST		254	2053	2055			180423-205354	
1051		191	2057	2113			-205740	
1052		11	2115	2129			-211557	
1053		191	2133	2148			-213322	
1054		11	2151	2206			-215158	
1055		191	2210	2225			-221009	
1056		11	2228	2242			-222822	
1057		191	2246	2301			-224601	
1058		11	2304	2319			-230424	
1059		191	2322	2337			-232210	
1060		11	2340	2354			-234027	
1061		191	0000	0015			180424-000004	
1062		11	0018	0033			-001854	
1063		191	0037	0052			-003705	
1064		11	0055	0109			-005544	
1065		191	0113	0128			180424-011349	
1066		11	0132	0138			-013206	
X-TIE		280	0142	0149			-014254	

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April 24, 2018; Lift 1, Page 1

Julian Day	114	Flight	A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	APR. 24 2018	Aircraft	C-GKSX
Project	3145 OSWEGO	Pilot	A. MURRAY
Location	OSWEGO KFZY	Operator	D. TARR
Mission Objective			

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes
T - 17°C
H - 29%
P - 1026

Aircraft Block Time		
Engine On 1404	Ramp Out 1418	Takeoff 1423
Engine Off 2112	Ramp In 2102	Landing 2101
Total 7.1 hrs	Total hrs	Total 6.6 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	1411	1416
Post Mission	2104	2109

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
TEST		185	1434	1436			180424 - 143450	
1067		191	1438	1445			-143856	STARTED ON LAKE!! ECHO WARNING! FLY AGAIN
1067		11	1449	1455			-144904	REFLY
1068		191	1459	1505			-145918	
1069		11	1510	1516			-151013	
1070		191	1519	1526			-151957	
1071		11	1529	1535			-152930	
1072		191	1540	1546			-154004	
1073		11	1549	1554			-154934	
1074		191	1558	1604			-155848	
1075		11	1607	1610			-160711	
X-TIEWS75-66		280	1615	1618			-161515	
1044		101	1634	1635			-163424	
1043		281	1639	1647			-163905	
1042		101	1651	1659			-165135	

Pg 1 of 2

April 24, 2018; Lift 1 Page 2

Julian Day 114	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date APR. 24/18	Aircraft C-GKSX
Project 3145 OSWEGO	Pilot A. MURRAY
Location OSWEGO [redacted] KFZY	Operator D. TARR
Mission Objective	

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes
T-17°C
H-29%
P-1026

Aircraft Block Time		
Engine On 1404	Ramp Out 1418	Takeoff 1423
Engine Off 2112	Ramp In 2102	Landing 2101
Total 7.1 hrs	Total hrs	Total 6.6 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	1411	1416
Post Mission	2104	2109

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
1041		281	1703	1711			180424-170316	
1040		101	1715	1723			-171502	
1039		281	1726	1735			-172650	
1038		101	1738	1746			-173822	
1037		281	1749	1757			-174947	
1036		101	1800	1810			-180046	
1035		281	1816	1828			-181636	
1034		101	1831	1846			-183151	
1033		281	1849	1903			-184912	
1032		101	1907	1921			-190700	
1031		281	1924	1938			-192409	
1030		101	1943	1957			-194336	
1029		281	1959	2013			-195938	
1028		101	2017	2030			-201702	
X-TIE WS44-27		67	2044	2050			-204407	

Pg 2 of 2

May 01, 2018; Lift 1

Julian Day	121	Flight	A

LIDAR Flight Log

Date	MAY 1 2018	Aircraft	C-GKSX
Project	3145 OSWEGO	Pilot	A MURRAY
Location	KINGSTON	Operator	D. TARR
Mission Objective			

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	3
Scanner 2 Drive	4

Additional Notes
T - 16°C
H - 33
P - 1019
ELEV. 140 -

AIRBORNE IMAGING
A Clean Harbors Company

Aircraft Block Time					
Engine On	14:00	Ramp Out	1419	Takeoff	1423
Engine Off	19:11	Ramp In	1857	Landing	1856
Total	5.2 hrs	Total	hrs	Total	4.5 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission *	1407	1417 *
Post Mission *	1858	1908 *

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
TEST		272	1450	1452			180501-145016	
RUN IN		269	1453	1458			—	RUN IN
KAR-OSPA		↻	150130	150630			—	
1027		102	1513	1527			180501-151317	
1026		282	1531	1547			-153150	
1025		101	1550	1605			-155050	
1024		282	1609	1625			-160931	
1023		101	1629	1643			-162926	
1022		282	1646	1701			-164659	
1021		101	1705	1718			-170533	
1020		282	1722	1736			-172213	
1019		101	1739	1751			-173948	
1018		282	1756	1809			-175650	
X-TIE LNS 16-29		192	1815	1819			-181546	
KAR-OSPA		↻	1827	1833			—	
RUN IN		16	1835	1840			—	

* DID 10 MINUTE STATIC TO CAN NET CKN3 * AT START UP *
* AND STATIC OUT *

Pg 1 of 1

May 02, 2018; Lift 1, Page 1

Julian Day 122	Flight A

LIDAR Flight Log

* 10 MINUTE STATIC IN *
* AND AT SHUTDOWN *

AIRBORNE IMAGING
A Clean Harbors Company

Date MAY 2/2018	Aircraft C-GKSX	System	Riegl VQ1560i	Additional Notes	
Project 3145 OSWEGO	Pilot A. MURRAY	Unit	S2222738	T - 11°C	
Location KINGSTON	Operator D. TARR	IMU		H - 65%	
Mission Objective		GPS Rx	Trimble	P - 1016 HPA	
		Scanner 1 Drive	1		
		Scanner 2 Drive	2		

Aircraft Block Time		
Engine On 10:39	Ramp Out 1055	Takeoff 1058
Engine Off 16:41	Ramp In 1628	Landing 1625
Total 6.0 hrs	Total hrs	Total 5.5 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End	
Pre Mission *	1044	1054	*
Post Mission *	1628	1638	*

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
TEST		174	1116	1117			180502-111621	
RUN IN		261	111830	112330			—	RUN IN
KAR-OSPA		↻	1125	1130			—	
1017		101	1134	1146			180502-113457	AROUND LAKE, SNOW PATCHY - 6NAU TO EAST
1016		282	1150	1200			-115028	PATCHY SNOW FIRST - 9NAU ON RIDGE.
1015		101	1202	1211			-120240	PATCHY SNOW ON HILLS - 9NAU TO EAST
1014		282	1214	1233			-121434	PATCHY SNOW STARTS - 11 NAU TO EAST
1013		101	1227	1235			-122744	PATCHY SNOW STARTS - 11 NAU TO EAST
1012		282	1238	1248			-123850	PATCHY SNOW STARTS - 11NAU TO EAST
1011		101	1250	1258			-125055	SNOW STARTS - 10.5 NAU TO EAST
1010		282	1302	1311			-130240	GENERAL SNOW THROUGHOUT EAST SNOW STARTS - 11NAU TO EAST
1009		101	1314	1322			-131442	SNOW STARTS - 11 NAU TO EAST
1008		282	1325	1334			-132549	SNOW STARTS - 11 NAU TO EAST
1007		101	1337		RIACQUIRE	SHUT DOWN	-133738	SNOW STARTS - 11NAU TO EAST
[illegible]		[illegible]			CAN'T	FIRE		

Pg 1 of 2

May 02, 2018; Lift 1, Page 2

Julian Day 122	Flight A

LIDAR Flight Log

* 10 MIN. STATIC IN AND OUT *

AIRBORNE IMAGING
A Clean Harbors Company

Date MAY 2 2018	Aircraft C-GKSX
Project 3145 OSWEGO	Pilot A. MURRAY
Location KINGSTON	Operator D. TARR
Mission Objective	

System	Riegl VQ1560i
Unit	S2222738
IMU	
GPS Rx	Trimble
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes
T-11°C
H-65%
P-1016 HPA

Aircraft Block Time		
Engine On 1039	Ramp Out 1055	Takeoff 1058
Engine Off 16:41	Ramp In 1628	Landing 1625
Total 6.0 hrs	Total hrs	Total 5.5 hrs

Mission Plan			
AGL Height	1800 m	Pulse Rate	700 KHz
Target Speed	160 kts	Scan Rate	188 Hz
Laser Current	100 %	FOV	60 Deg's

Static Alignment	GPS Time Start	GPS Time End
Pre Mission *	1044	1054 *
Post Mission *	1628	1638 *

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Time Stamp	Comments
1007		282	1410	1419			180502-141026	SNOW - EAST 10 NAU.
1006		101	1422	1430			-142237	SNOW - EAST 10 NAU.
1005		282	1433	1442			-143342	SNOW - EAST 10 NAU.
1004		101	1445	1452			-144519	SNOW - EAST 10 NAU.
1003		282	1456	1504			-145608	SNOW - EAST 10 NAU.
1002		101	1507	1514			-150713	SNOW - EAST 10 NAU.
1001		282	1520	1523			180502-152034	GENERAL SNOW EAST BLOCK
X-TIE WS 1-19		187	1525	1531			-152554	X-TIE
EXT X-TIE #1		11	1533	1537			-153332	EXTRA X-TIE #1
EXT X-TIE #2		191	1539	1545			-153935	EXTRA X-TIE #2
KAR-OSPA		↻	155820	160420			——	
RUN IN		08	1605	1611			——	

Pg 2 of 2

NY18 Cayuga-Oswego LiDAR Acquisition Report 2018		
Prepared by Axis Geospatial	**Status as of:**	**5/2/2018**

Project Acquisition Status

NY18 Cayuga-Oswego LiDAR Acquistion 75 of 75 flight lines acquired	**100%** Complete	Notes: Acquisition is complete;

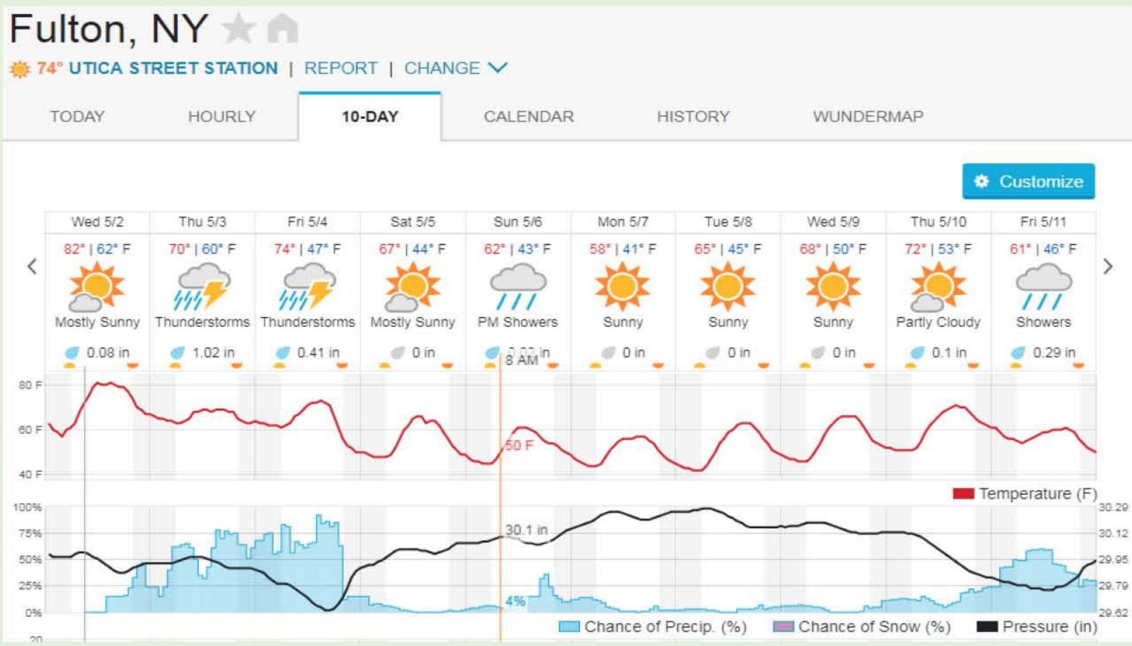
Ground Condition Report (based on NOAA Snow Cover Observations, NY Discussions, DOT web cameras, flight and survey crews)

Generally, ground conditions are favorable; Snow appears to have melted;

Current Acquisition Outlook/Weather Status Report

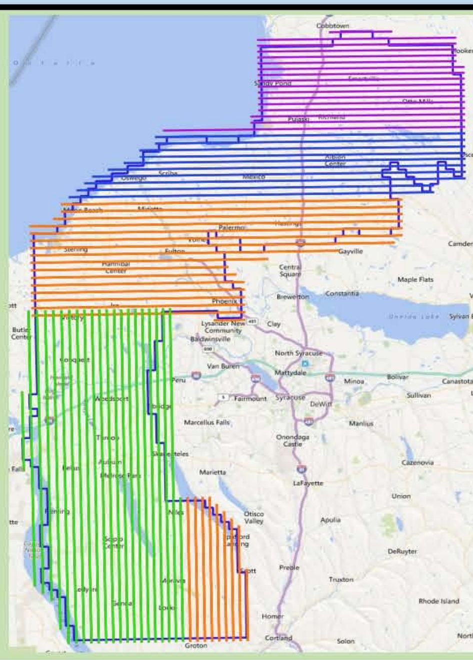
The upcoming weather forecast is favorable;

Fulton. NY



Current Project Status Graphic

GREEN Lines (22) acquired
Monday Apr 23
ORANGE Lines (26) acquired
Tuesday Apr 24
BLUE Lines (10) acquired
Tuesday May 1
PURPLE Lines (17) acquired
Wednesday May 2



2018 Cayuga-Oswego LiDAR Daily Acquisition Report					
Week Day	**Date**	**Total Number of Planes**	**Total Number of Lifts**	**Number of Lines**	**Comments**
Wednesday	4/4/2018	1	0	0	Weather and ground conditions are unacceptable;
Thursday	4/5/2018	1	0	0	Weather and ground conditions are unacceptable;
Friday	4/6/2018	1	0	0	Weather and ground conditions are unacceptable;
Saturday	4/7/2018	1	0	0	Weather and ground conditions are unacceptable;
Sunday	4/8/2018	1	0	0	Weather and ground conditions are unacceptable;
Monday	4/9/2018	1	0	0	Weather and ground conditions are unacceptable;
Tuesday	4/10/2018	1	0	0	Weather conditions are unacceptable; Ground conditions improving in the western side of the southern area
Wednesday	4/11/2018	1	0	0	Weather conditions are unacceptable; Snow cover is diminshing;
Thursday	4/12/2018	1	0	0	Weather conditions are unacceptable; Snow cover is diminshing;
Friday	4/13/2018	1	0	0	Weather conditions are unacceptable; Ground clear of snow
Saturday	4/14/2018	1	0	0	Weather conditions are unacceptable; Ground clear of snow
Sunday	4/15/2018	1	0	0	Weather conditions are unacceptable; Ground clear of snow
Monday	4/16/2018	1	0	0	Weather conditions are unacceptable; Ground clear of snow
Tuesday	4/17/2018	1	0	0	Weather conditions are unacceptable; Coating of snow observed;
Wednesday	4/18/2018	1	0	0	Weather conditions are unacceptable; Coating of snow observed;
Thursday	4/19/2018	1	0	0	Weather conditions are unacceptable; Coating of snow observed;
Friday	4/20/2018	1	0	0	Weather and ground conditions are improving;
Saturday	4/21/2018	0	0	0	Airborne Imaging aircraft was not available due to oil leak
Sunday	4/22/2018	1	0	0	Airborne Imaging mobilized to Syracuse after acquiring Southwest 17-B re-flights;
Monday	4/23/2018	1	2	28	Airborne Imaging acquired 28 lines;
Tuesday	4/24/2018	1	2	29	Airborne Imaging acquired 29 lines;
Wednesday	4/25/2018	1	0	0	Poor weather conditions prevented acqusition;
Thursday	4/26/2018	1	0	0	Poor weather conditions prevented acqusition;
Friday	4/27/2018	1	0	0	Poor weather conditions prevented acqusition;
Saturday	4/28/2018	1	0	0	Poor weather conditions prevented acqusition;
Sunday	4/29/2018	1	0	0	Poor weather conditions prevented acqusition;
Monday	4/30/2018	1	0	0	Poor weather conditions prevented acqusition;
Tuesday	5/1/2018	1	1	11	Airborne Imaging acquired 11 lines;
Wednesday	5/2/2018	1	1	20	Airborne Imaging acquired 20 lines; Acqusition complete

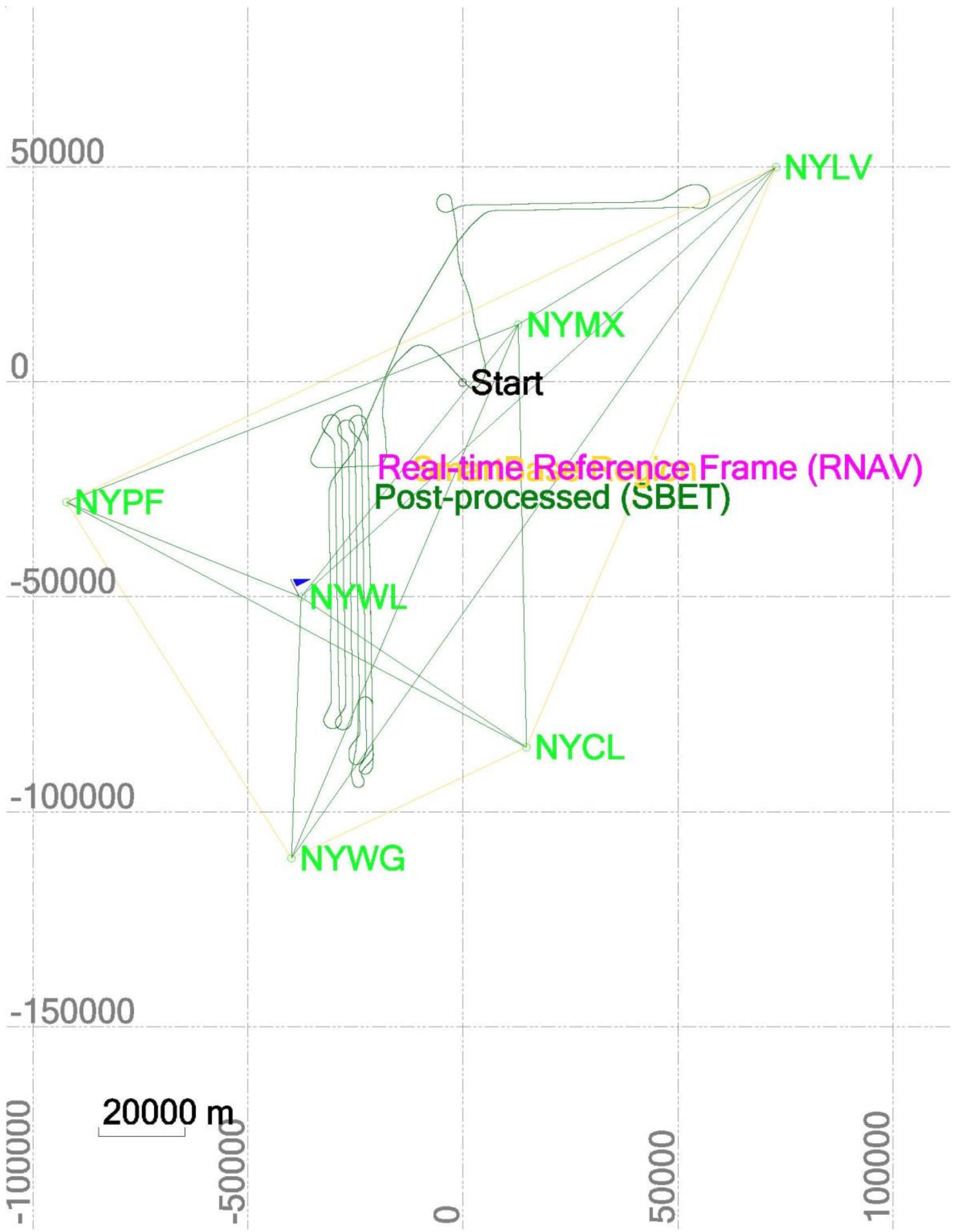
Section 5: GPS Processing Plots

POSPac MMS Version 8.1

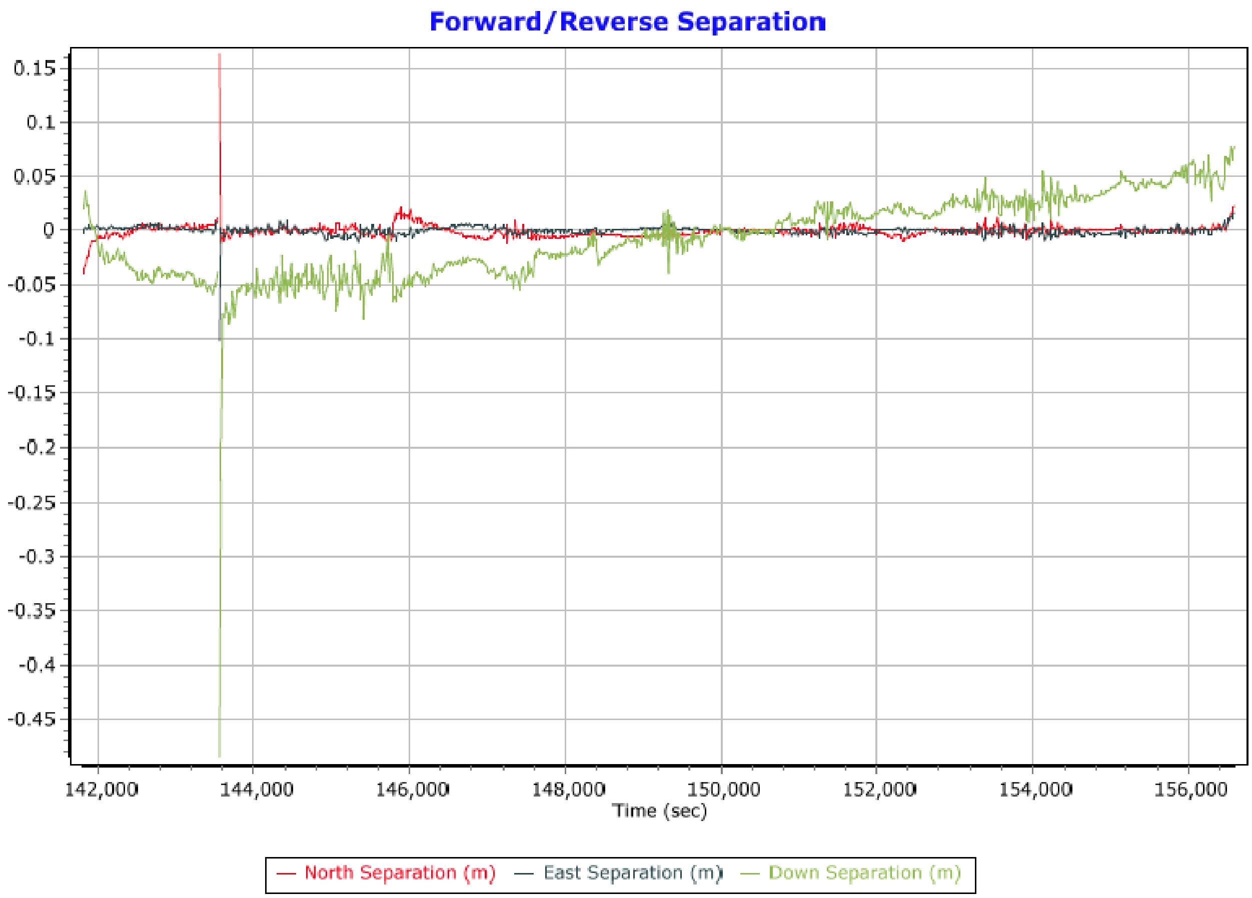
Plots by lift of the Coverage Map, Estimated Position Accuracy, Number of Satellites, Combined Separation, and PDOP.

April 23, 2018, Lift 1

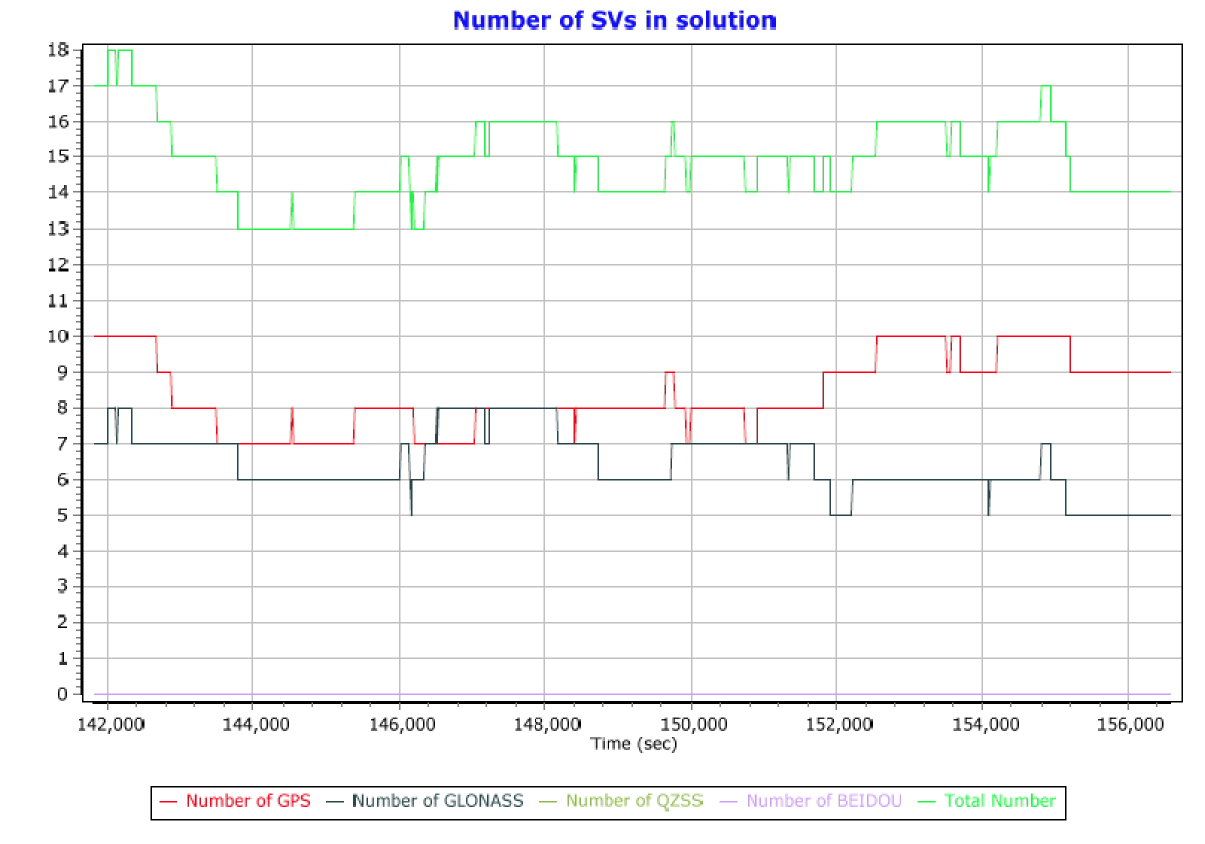
Coverage Map: The Coverage Map plot shows the Aircraft GPS-IMU Trajectory in reference to localized GPS Reference Stations.



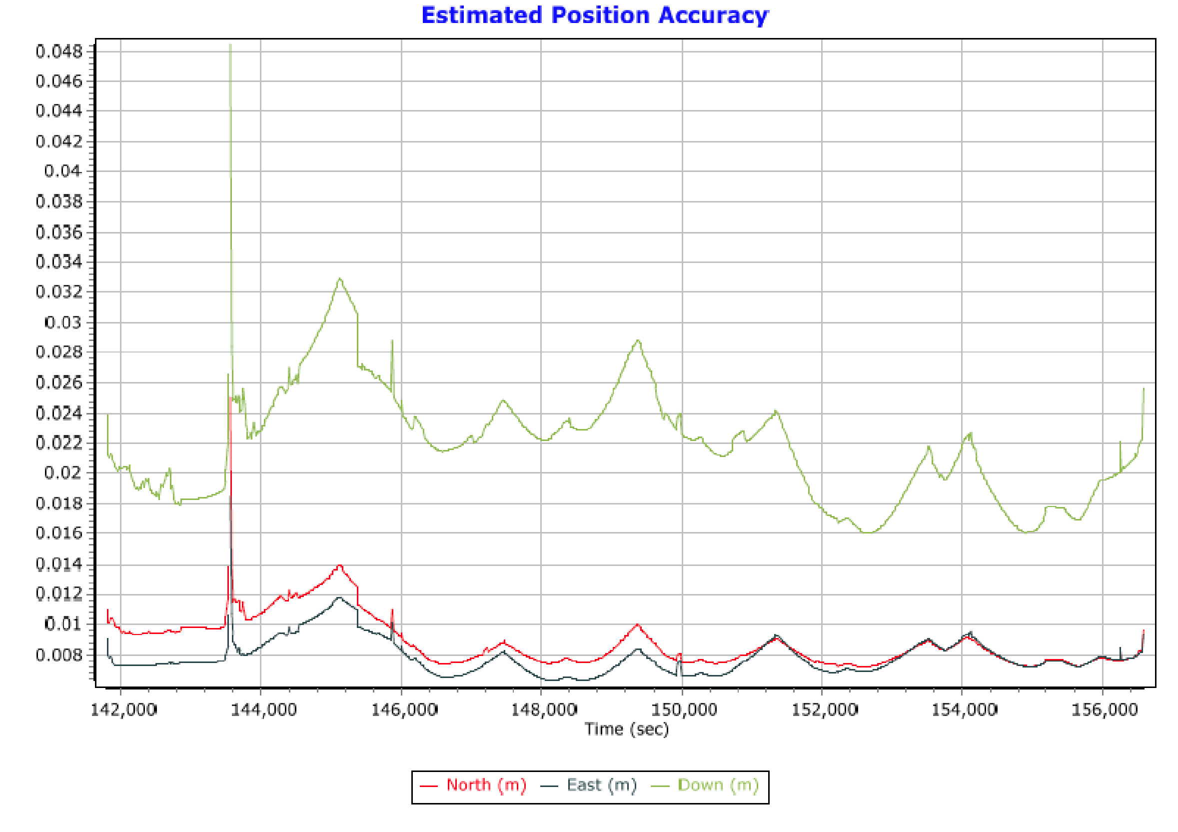
Combined Separation: Plots the north, east, and height position difference between any two solutions loaded into the project. This is most often the forward and reverse processing results, unless other solutions have been loaded from the Combine Solutions dialog. Plotting the difference between forward and reverse solutions can be very helpful in quality checking. When processing both directions, no information is shared between forward and reverse processing. Thus both directions are processed independently of each other. When forward and reverse solutions agree closely, it helps provide confidence in the solution. To a lesser extent, this plot can also help gauge solution accuracy.



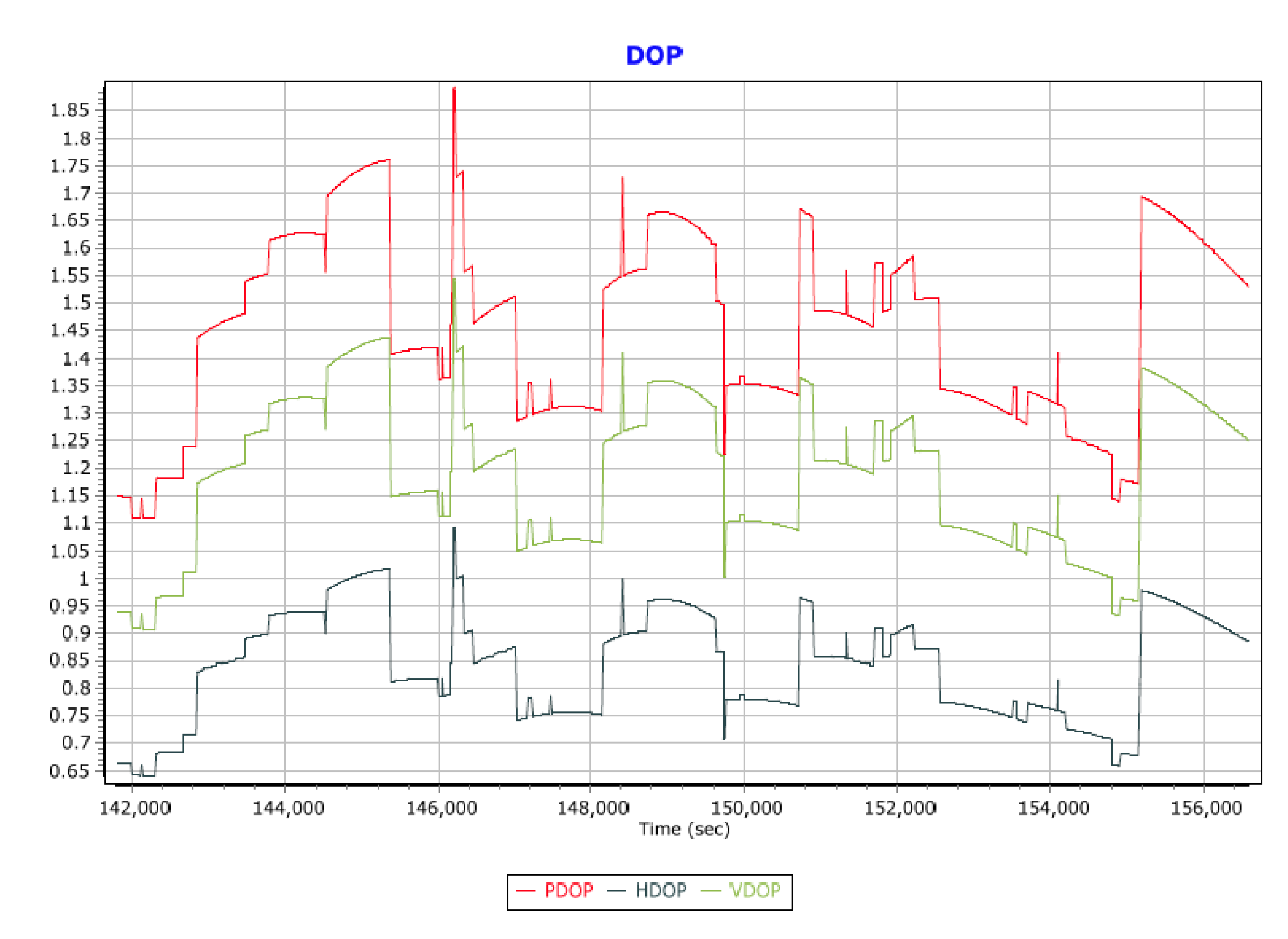
Number of Satellites: Plots the number of satellites used in the solution as a function of time. The number of GPS satellites, GLONASS satellites and the total number of satellites are distinguished with separate lines.



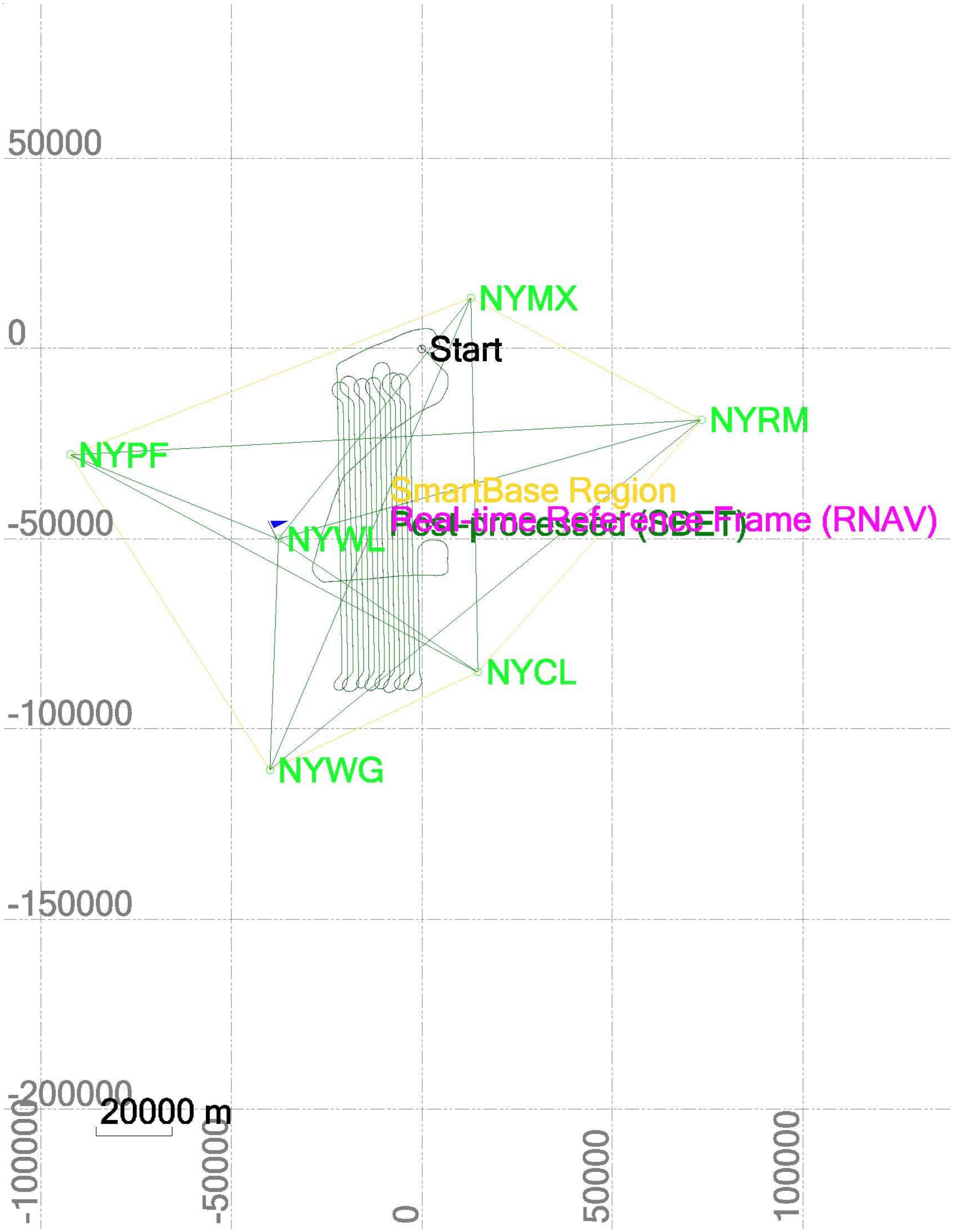
Estimated Position Accuracy: The Estimated Position Accuracy plot shows the standard deviations of the east, north, and up directions versus time for the solution.

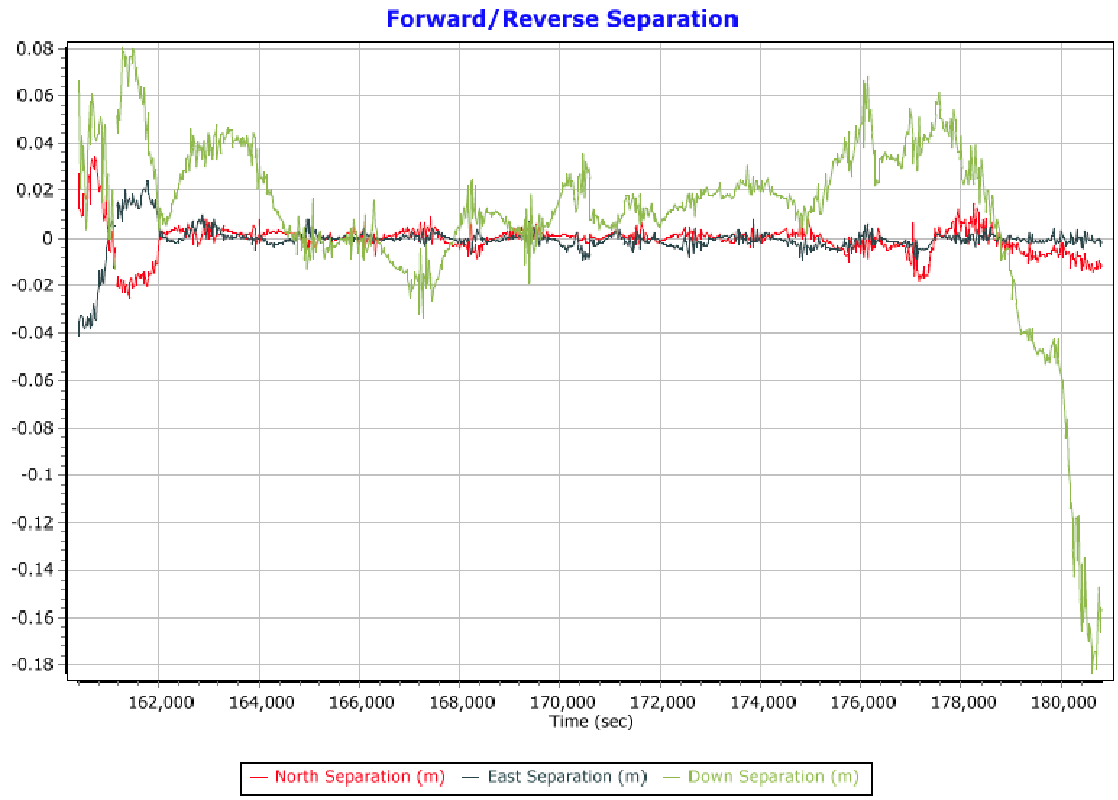

Estimated Position Accuracy
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
142,000
144,000
146,000
148,000
150,000
152,000
154,000
156,000
Time (sec)
North (m)
East (m)
Down (m)

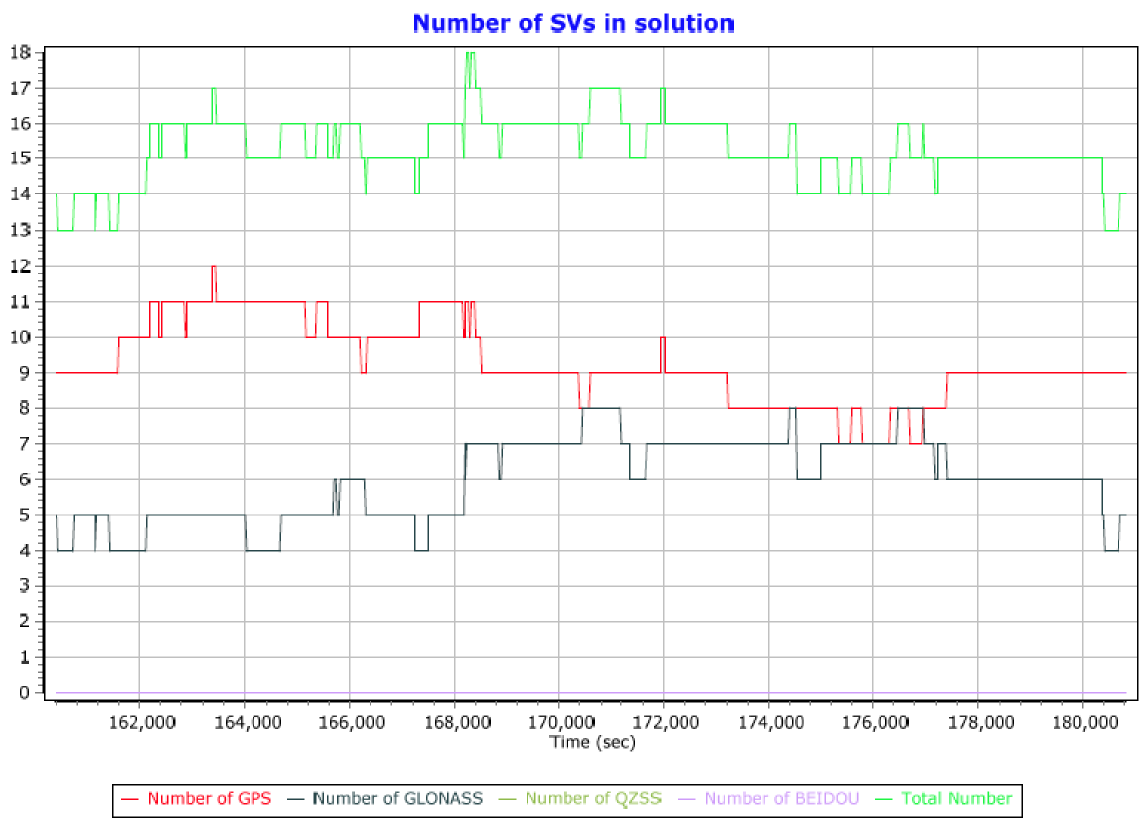
PDOP: PDOP is a unit less number which indicates how favorable the satellite geometry is to 3D positioning accuracy. A strong satellite geometry, where the PDOP is low, occurs when satellites are well distributed in each direction (north, south, east and west) as well as directly overhead. Values in the range of 1-2 indicate very good satellite geometry; 2-3 are adequate in the sense that they do not generally, by themselves, limit positioning accuracy. Values between 3 and 4 are considered marginal, and values approaching or exceeding 5 can be considered poor.

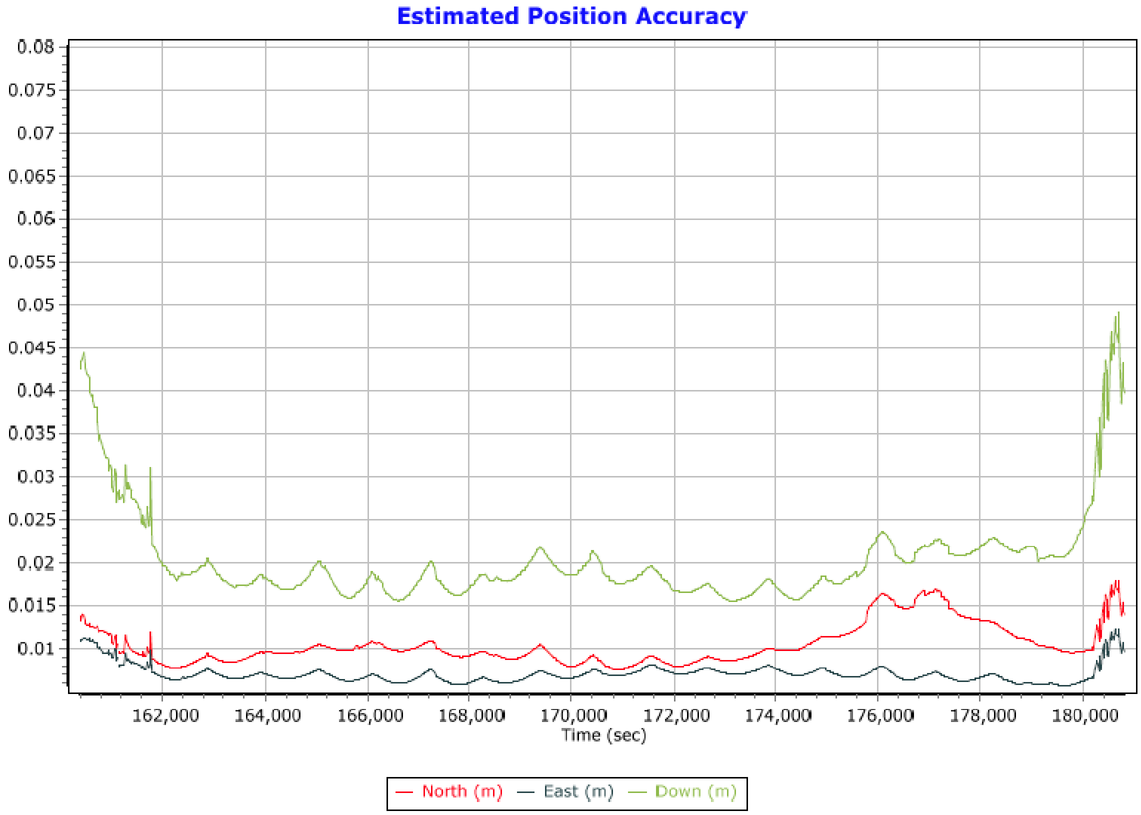


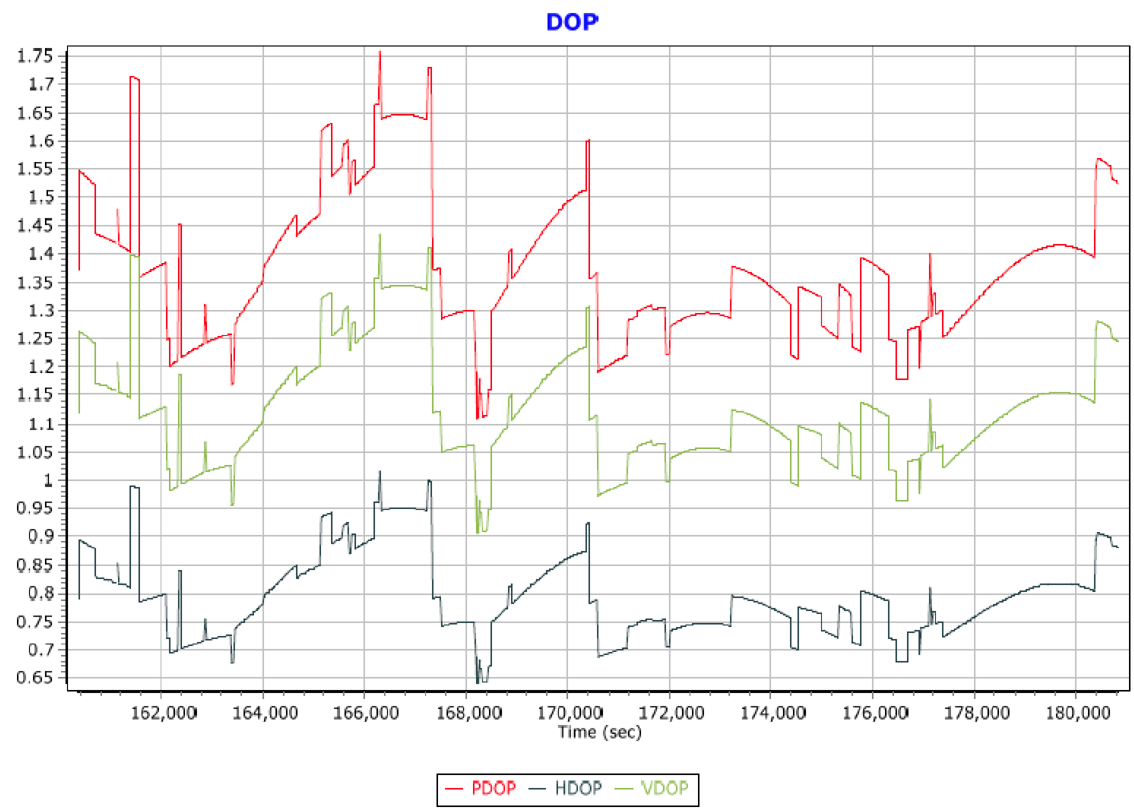
April 23, 2018, Lift 2


50000
0
-50000
-100000
-150000
-200000
-100000
-50000
0
50000
100000
20000 m
NYMX
Start
NYRM
NYPF
SmartBase Region
Real-time Reference Frame (RNAV)
Post-processed (SBET)
NYWL
NYCL
NYWG

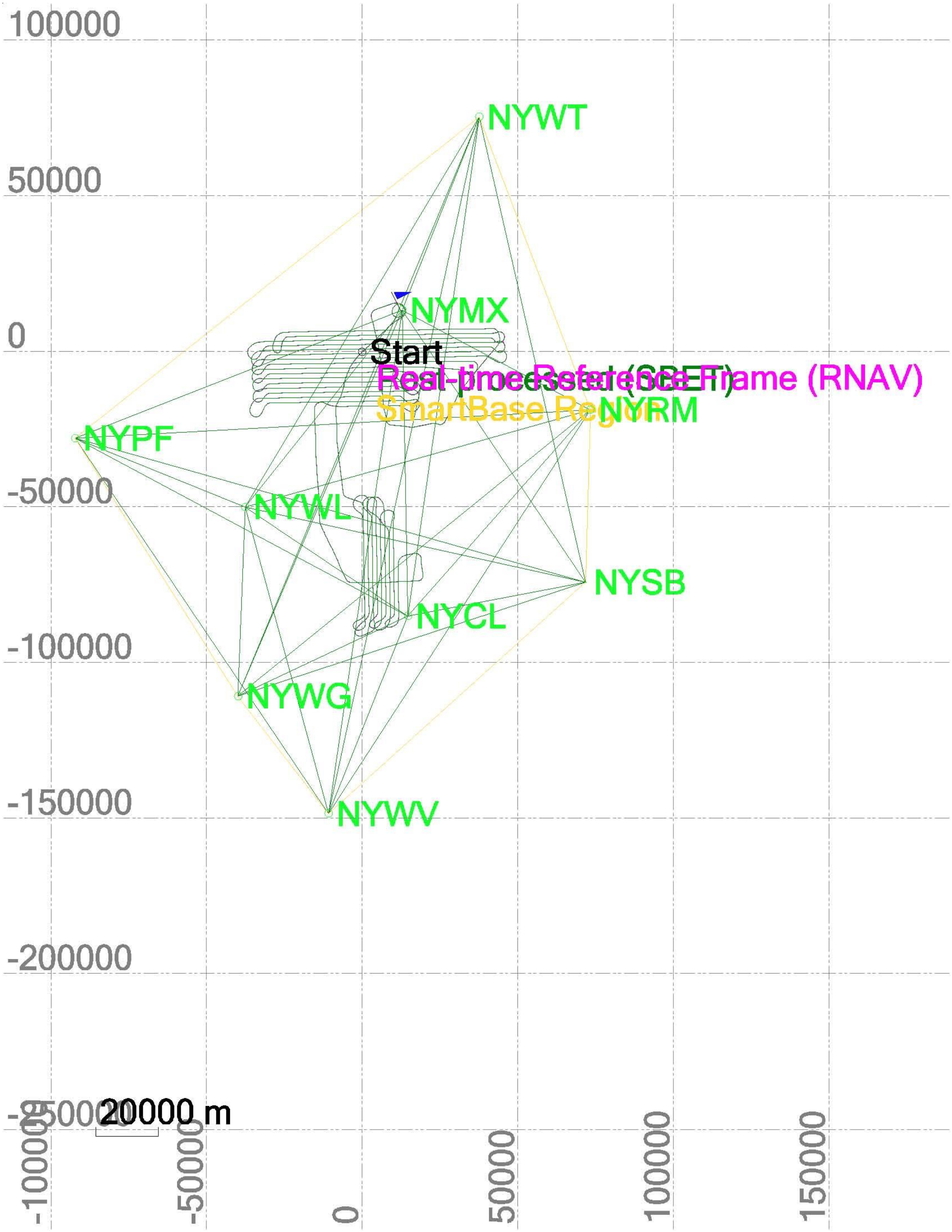

Forward/Reverse Separation
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
162,000 164,000 166,000 168,000 170,000 172,000 174,000 176,000 178,000 180,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

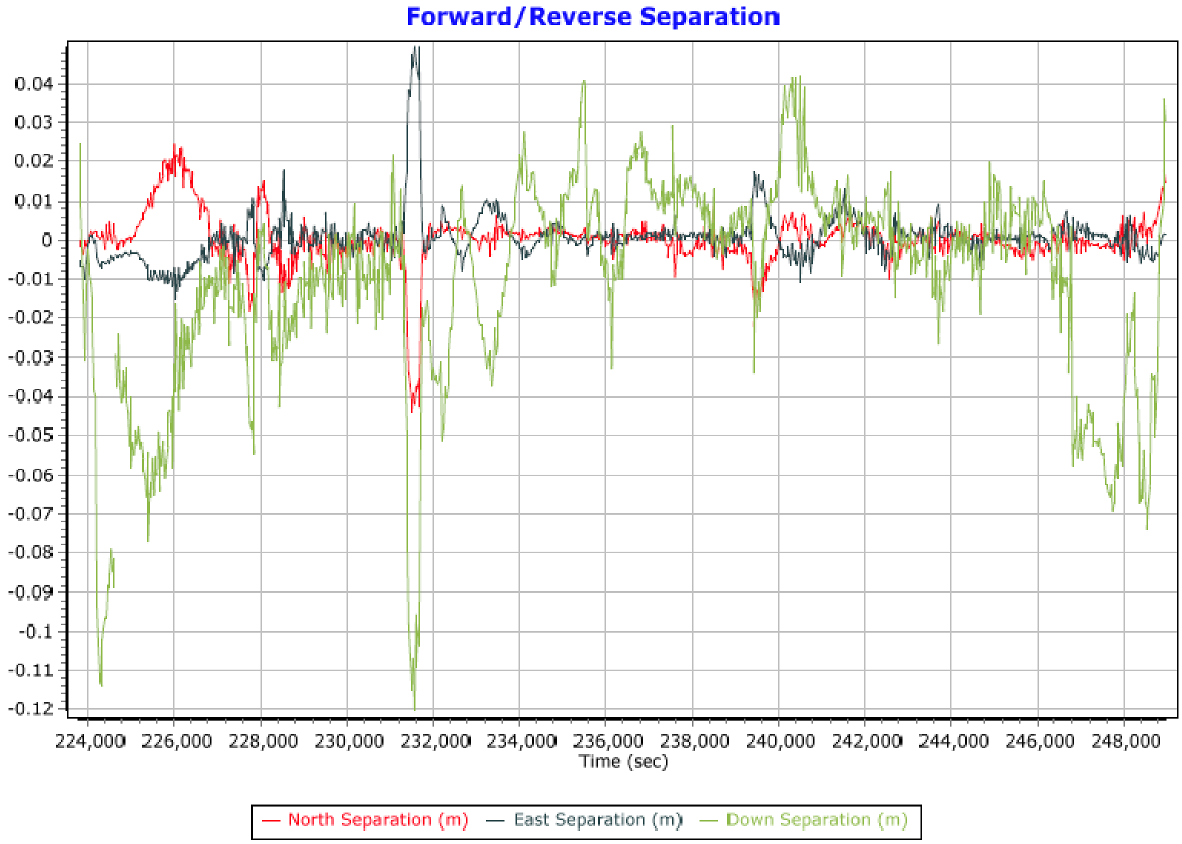

Number of SVs in solution
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
162,000 164,000 166,000 168,000 170,000 172,000 174,000 176,000 178,000 180,000
Time (sec)
Number of GPS
Number of GLONASS
Number of QZSS
Number of BEIDOU
Total Number

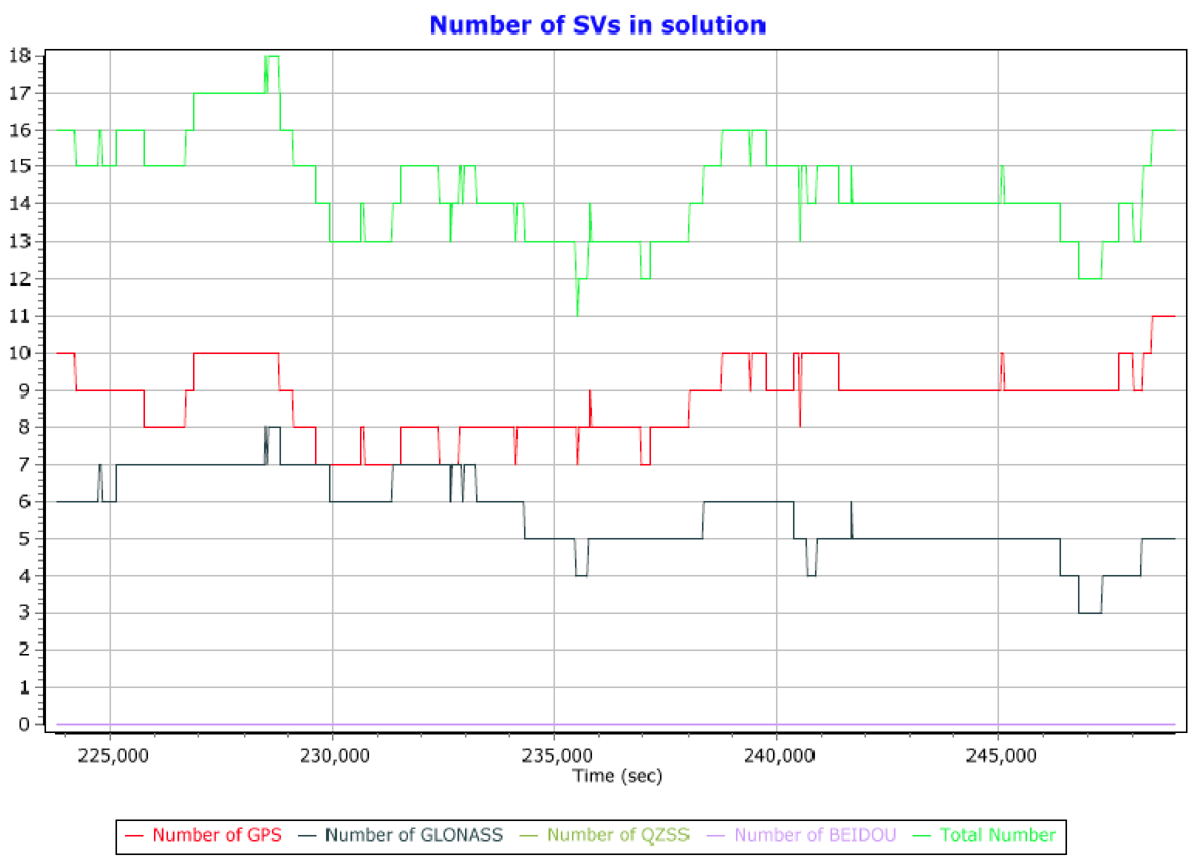

Estimated Position Accuracy
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
162,000
164,000
166,000
168,000
170,000
172,000
174,000
176,000
178,000
180,000
Time (sec)
North (m)
East (m)
Down (m)

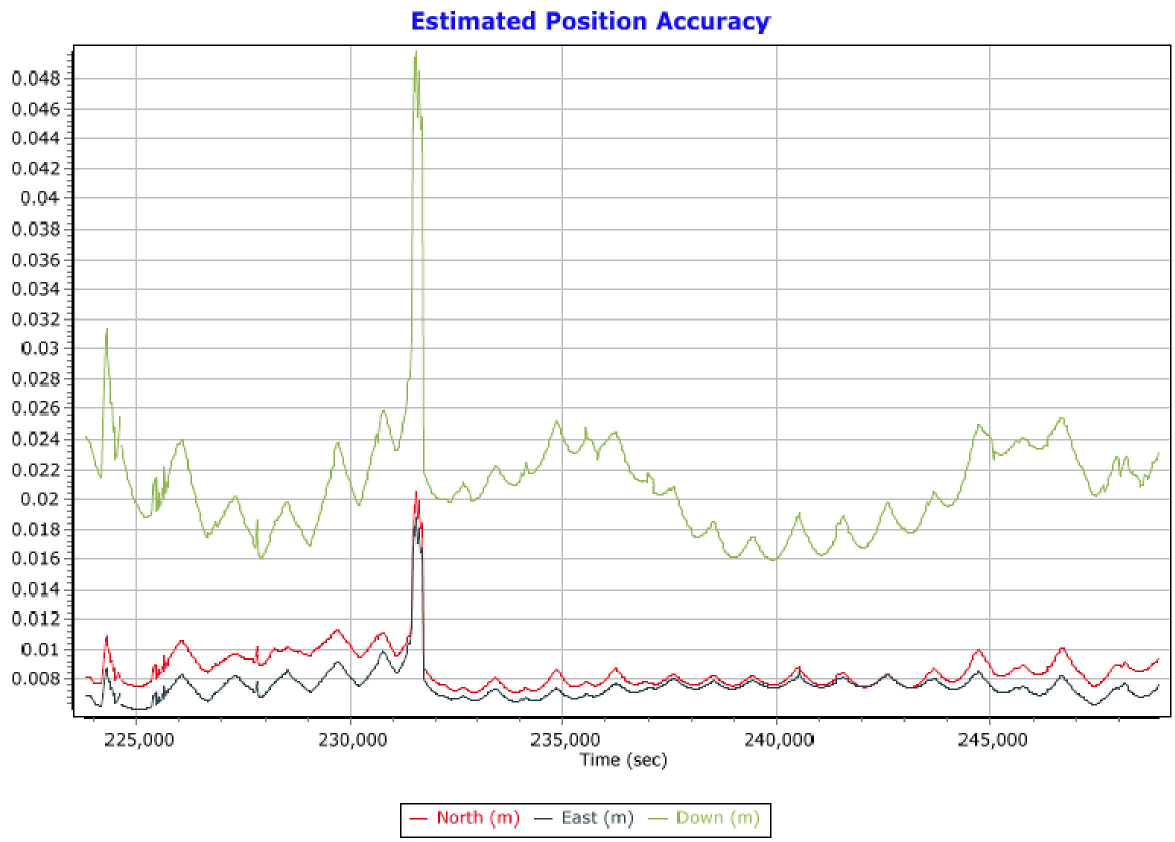

DOP
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
162,000
164,000
166,000
168,000
170,000
172,000
174,000
176,000
178,000
180,000
Time (sec)
PDOP
HDOP
VDOP

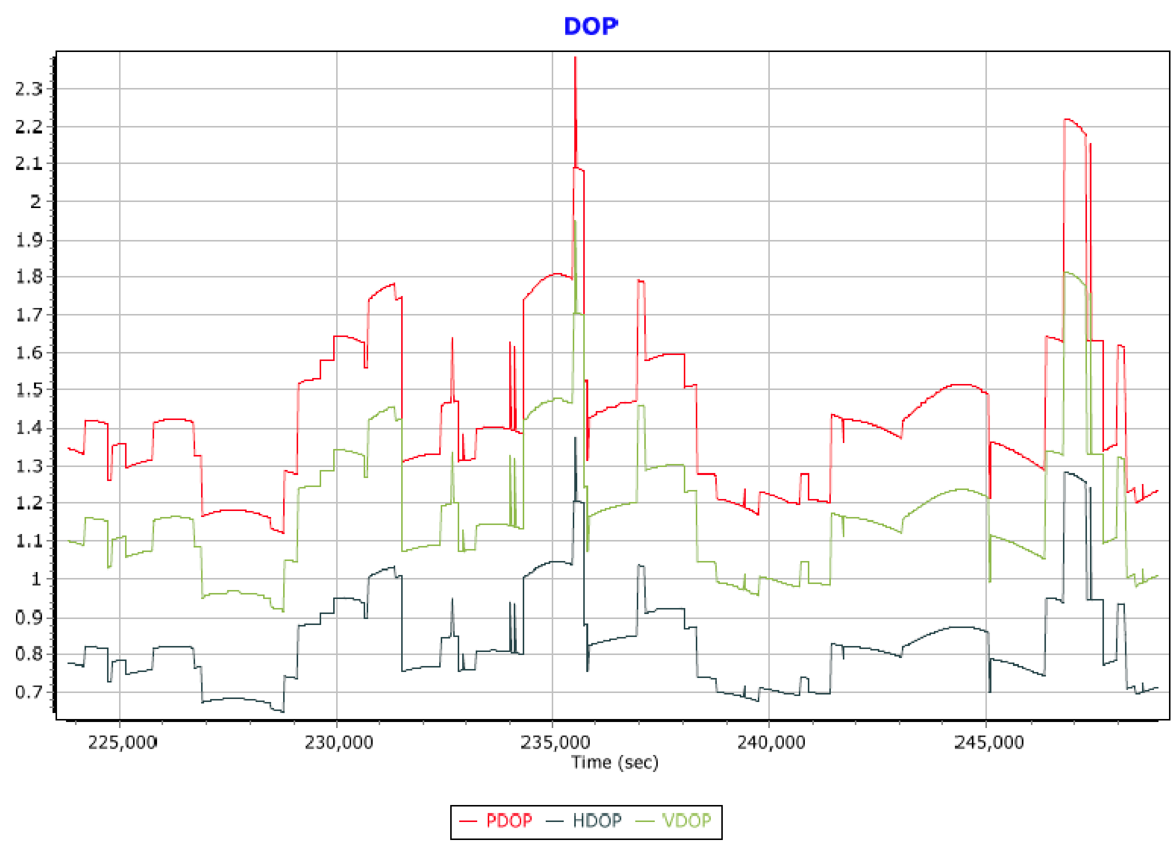
April 24, 2018

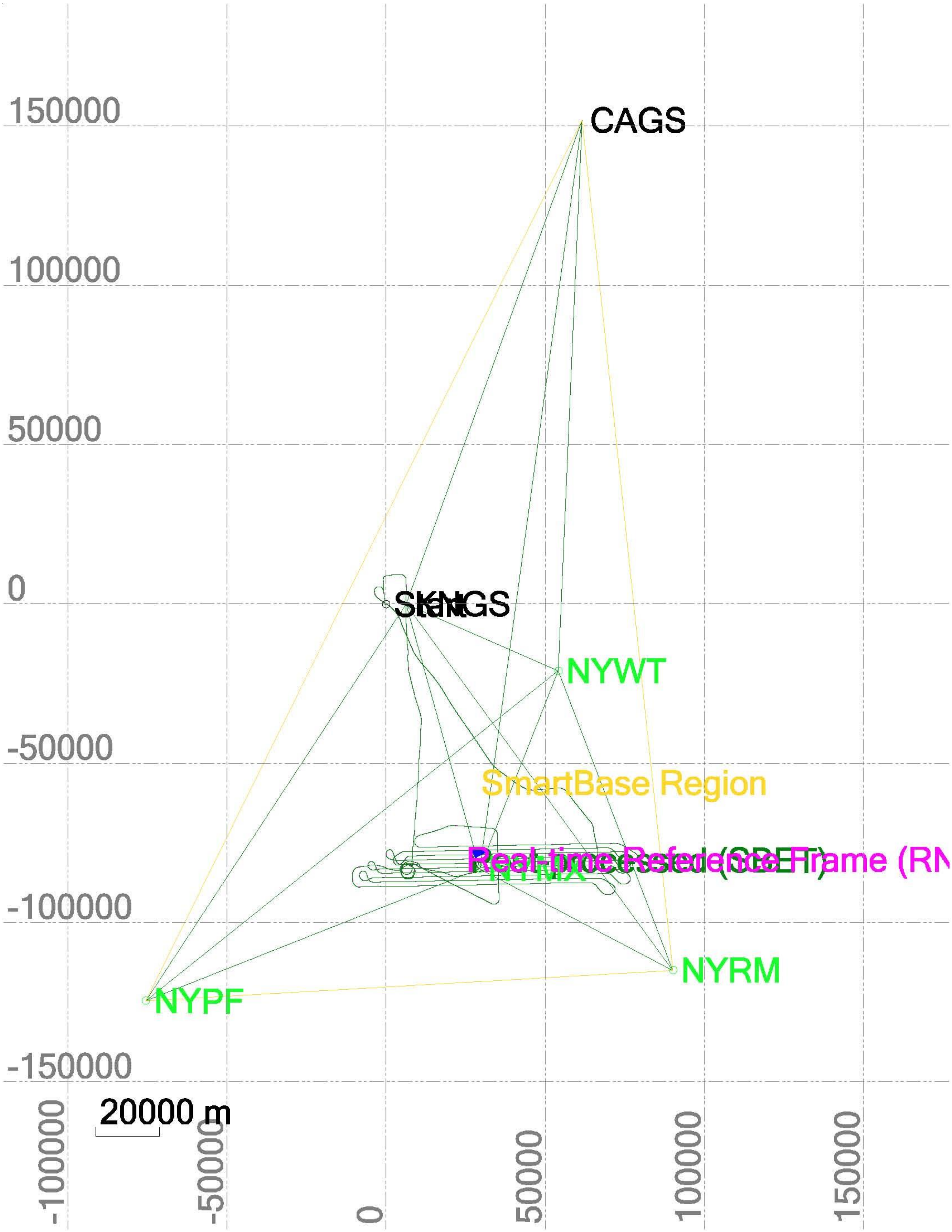


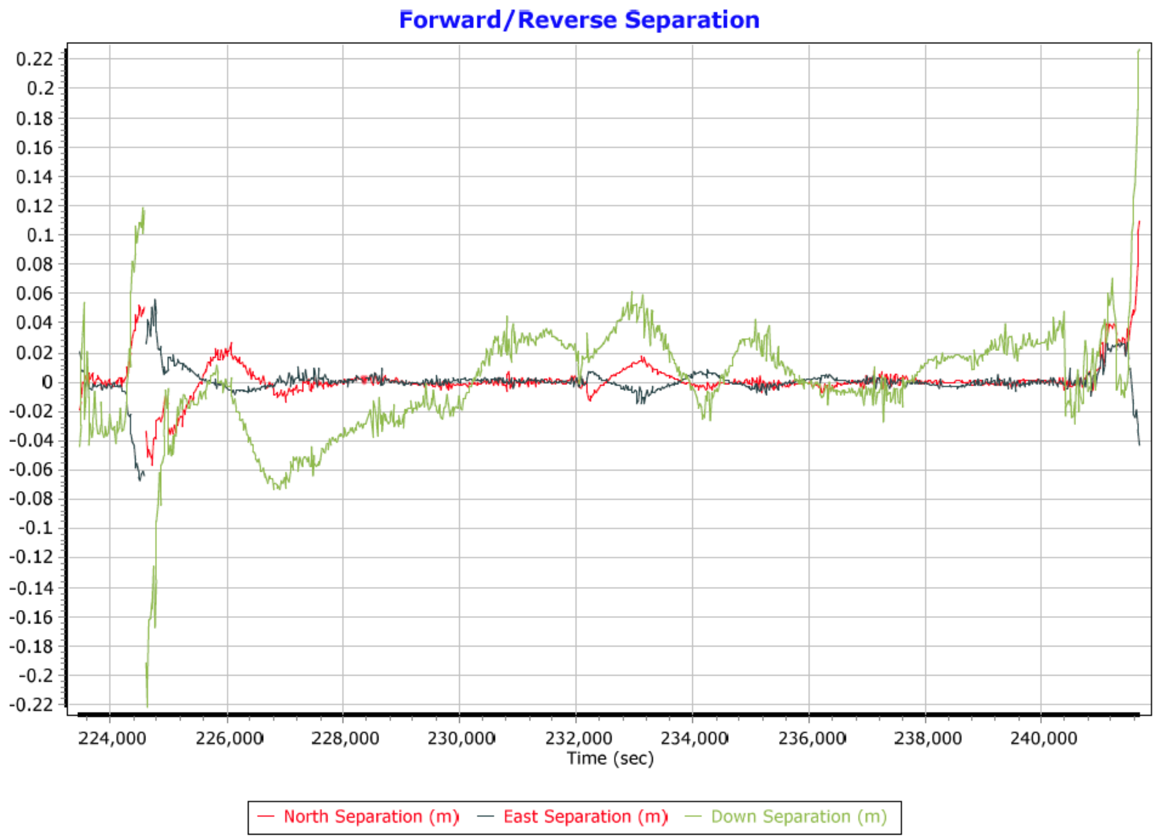

Forward/Reverse Separation
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
224,000 226,000 228,000 230,000 232,000 234,000 236,000 238,000 240,000 242,000 244,000 246,000 248,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

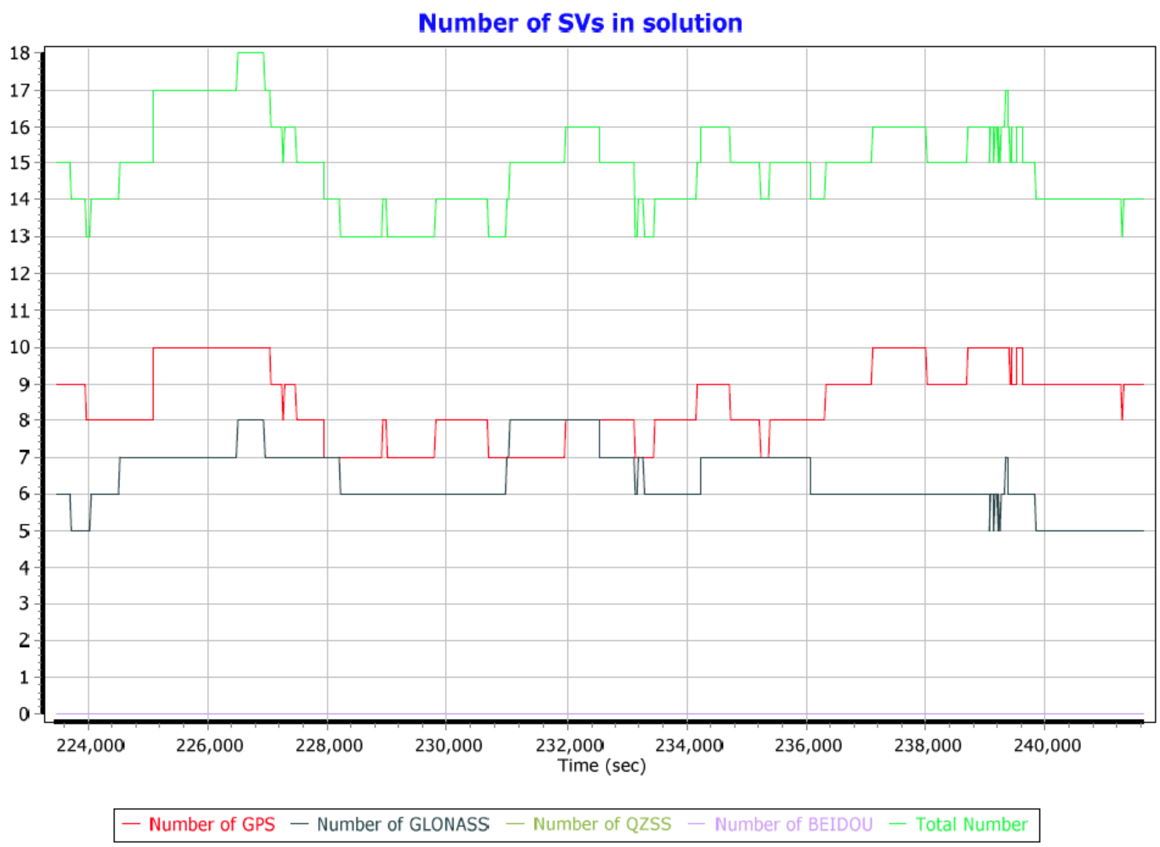

Number of SVs in solution
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
225,000 230,000 235,000 240,000 245,000
Time (sec)
Number of GPS
Number of GLONASS
Number of QZSS
Number of BEIDOU
Total Number

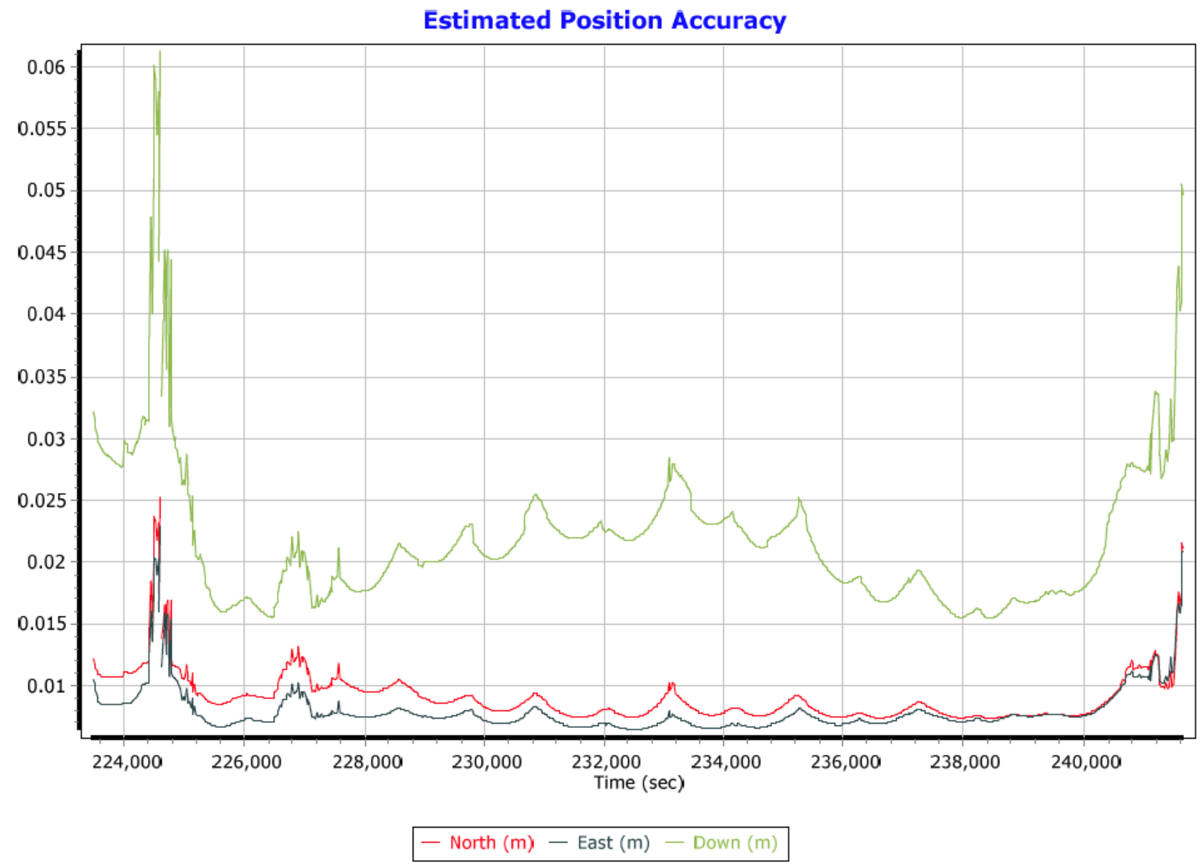

Estimated Position Accuracy
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
225,000
230,000
235,000
240,000
245,000
Time (sec)
North (m)
East (m)
Down (m)

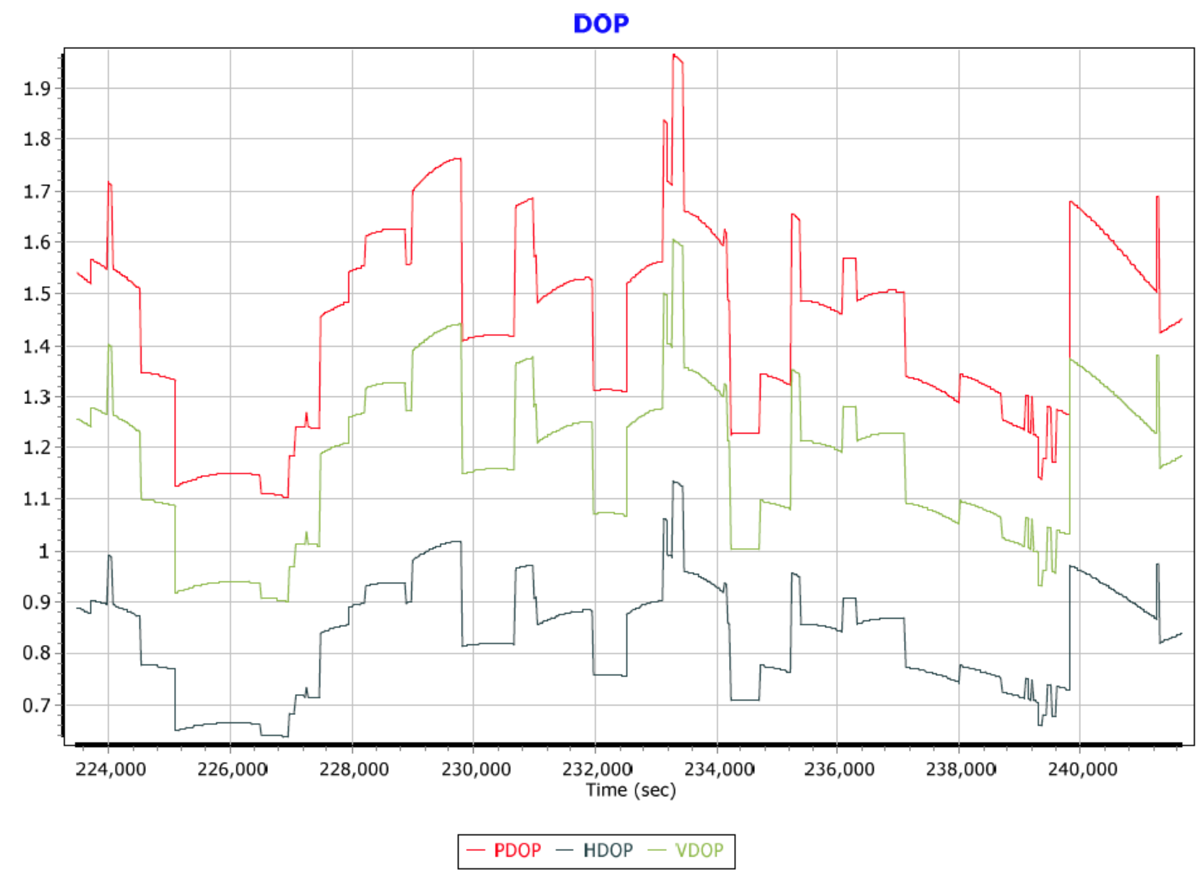

DOP
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
225,000
230,000
235,000
240,000
245,000
Time (sec)
PDOP
HDOP
VDOP

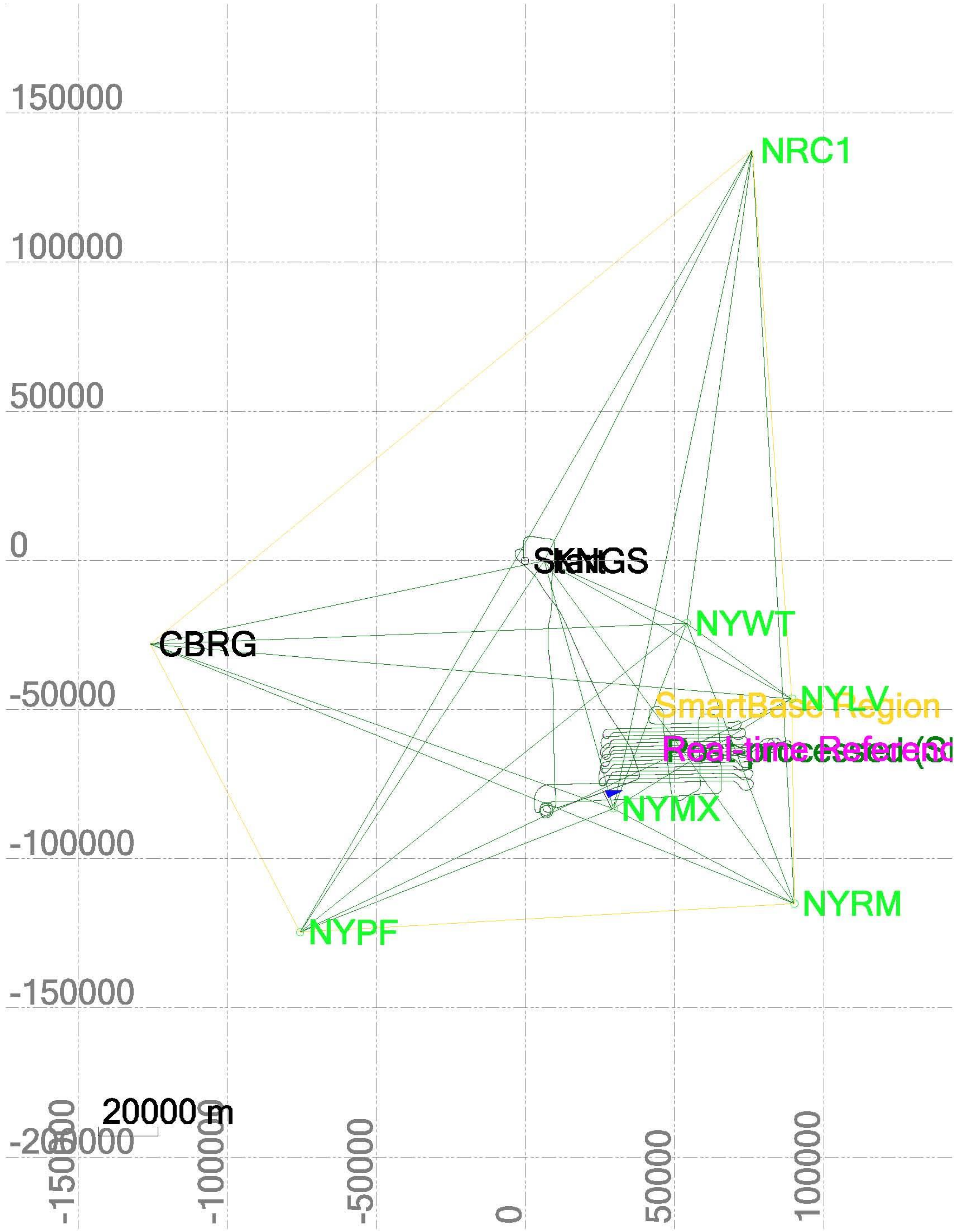

150000
100000
50000
0
-50000
-100000
-150000
CAGS
NYWT
SmartBase Region
NYRM
NYPF
20000 m
-100000
-50000
0
50000
100000
150000

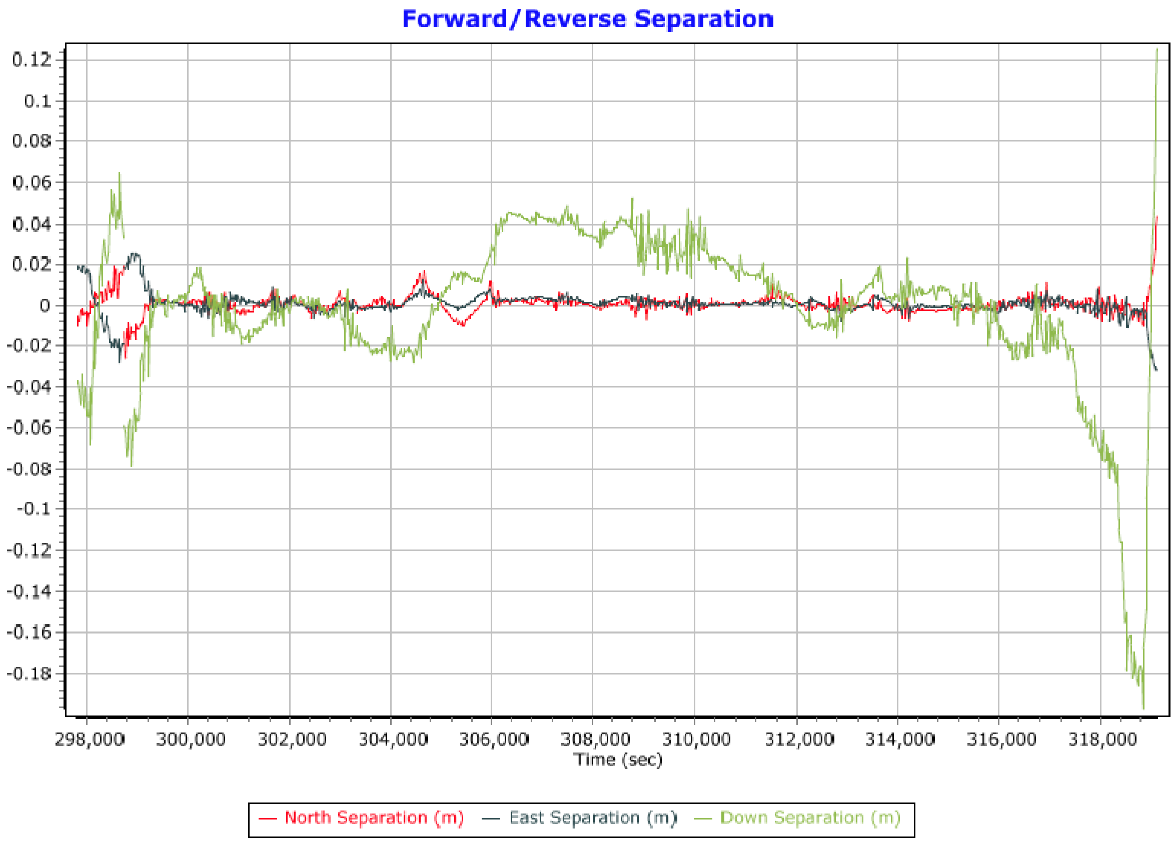

Forward/Reverse Separation
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
-0.22
224,000
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)

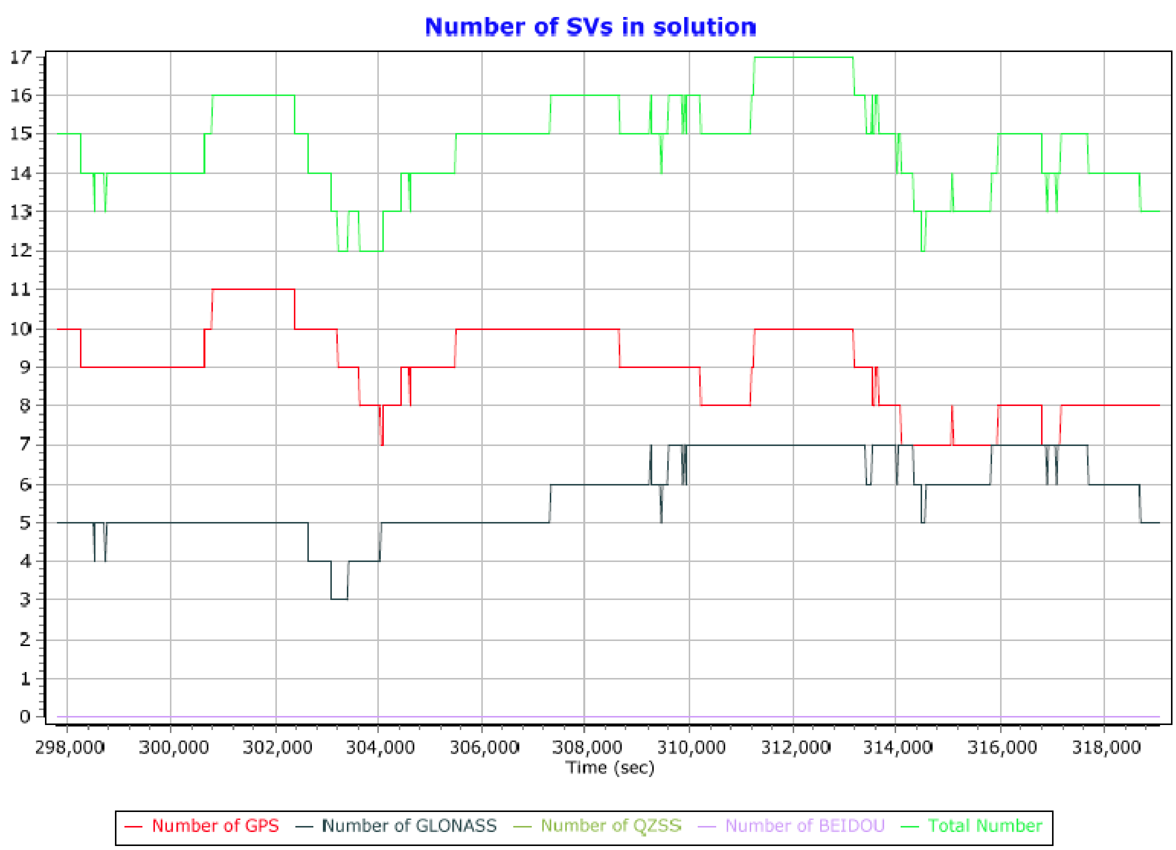

Number of SVs in solution
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
224,000
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
Number of GPS
Number of GLONASS
Number of QZSS
Number of BEIDOU
Total Number

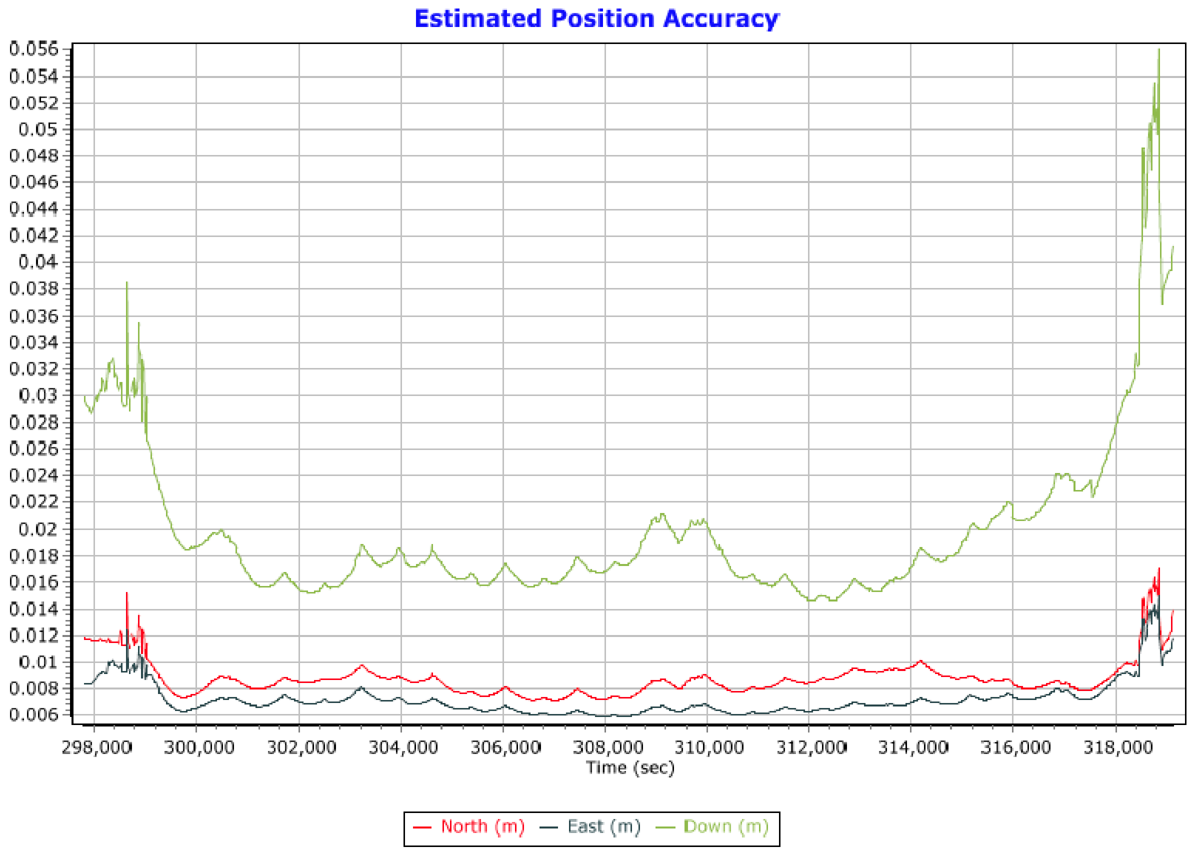

Estimated Position Accuracy
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
224,000
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
North (m)
East (m)
Down (m)

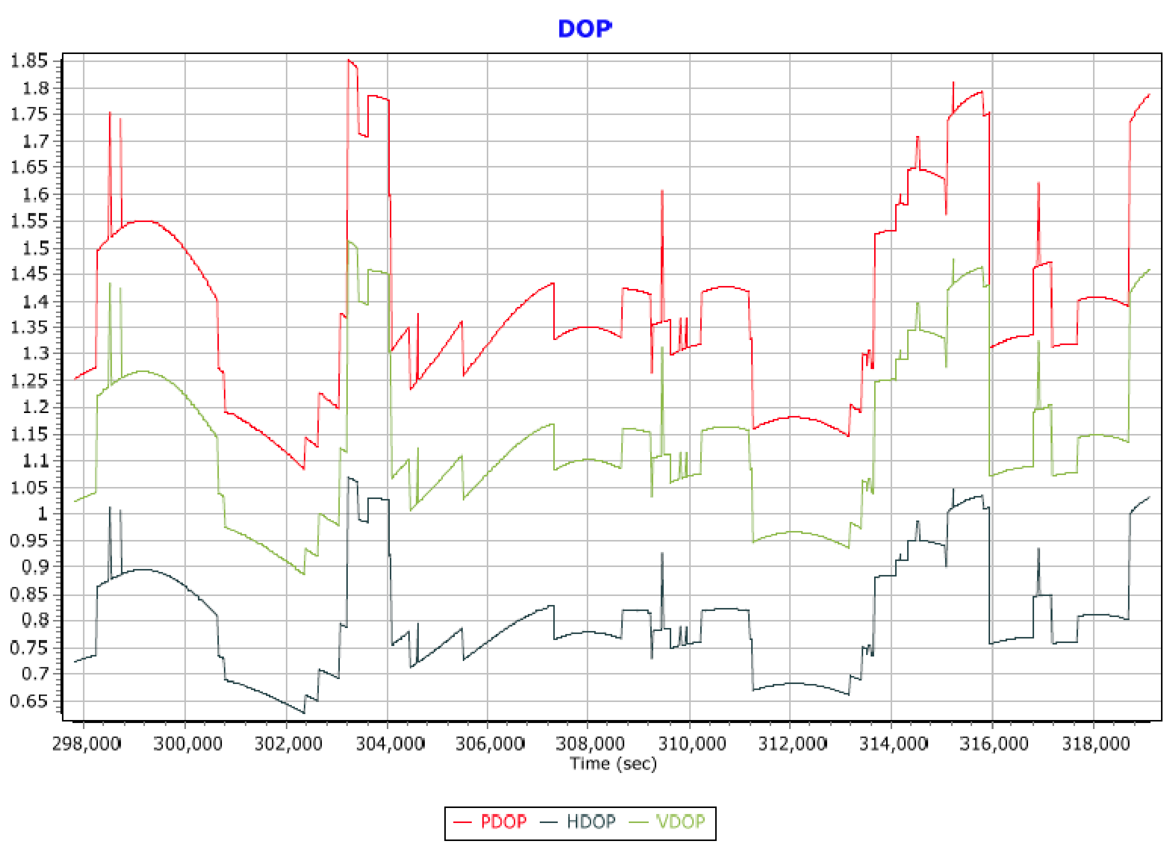

DOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
224,000
226,000
228,000
230,000
232,000
234,000
236,000
238,000
240,000
Time (sec)
PDOP
HDOP
VDOP


150000
100000
50000
0
-50000
-100000
-150000
-200000
NRC1
CBRG
NYWT
NYLV
SmartBase Region
NYMX
NYRM
NYPF
20000 m
-150000
-100000
-50000
0
50000
100000


Forward/Reverse Separation
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
298,000
300,000
302,000
304,000
306,000
308,000
310,000
312,000
314,000
316,000
318,000
Time (sec)
North Separation (m)
East Separation (m)
Down Separation (m)


Number of SVs in solution
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
298,000
300,000
302,000
304,000
306,000
308,000
310,000
312,000
314,000
316,000
318,000
Time (sec)
Number of GPS
Number of GLONASS
Number of QZSS
Number of BEIDOU
Total Number


Estimated Position Accuracy
0.056
0.054
0.052
0.05
0.048
0.046
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
298,000
300,000
302,000
304,000
306,000
308,000
310,000
312,000
314,000
316,000
318,000
Time (sec)
North (m)
East (m)
Down (m)


DOP
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
298,000
300,000
302,000
304,000
306,000
308,000
310,000
312,000
314,000
316,000
318,000
Time (sec)
PDOP
HDOP
VDOP