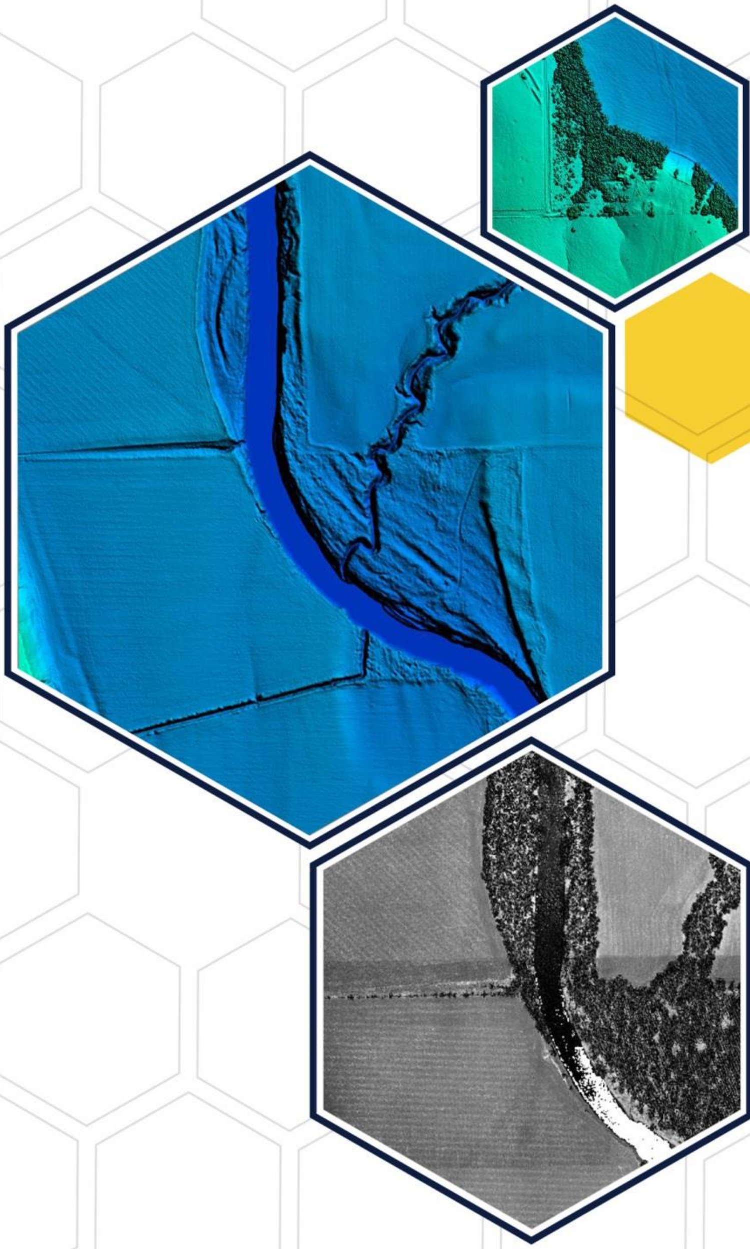

Aerial Lidar Report

17017
United States Geological Service, 2017 Georgia 22 Counties Lidar (Block 2)
May 2018

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Section 1: Lidar Acquisition

1.1 Acquisition

The Atlantic Group, LLC (Atlantic) has successfully completed lidar acquisition for the 2017 Georgia 22 Counties Lidar (Block 2) area of interest (AOI). Lidar for this AOI was acquired in nine (9) flight mission completed between March 16th and March 22nd, 2017. The project area encompasses 1,298,311.80 acres, 5254.08 square kilometers or 2028.61 square miles.

1.2 Acquisition Status Report

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

1.3 Acquisition Details

Atlantic acquired ninety-one (91) passes of the AOI as a series of perpendicular and/or adjacent flight lines. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. Differential GPS unit in aircraft recorded sample positions at 2 Hz or more frequency. Lidar data was only acquired when GPS PDOP was ≤ 4 and at least 6 satellites were in view.

Atlantic lidar sensors are calibrated at a designated site located at the Fayetteville Municipal Airport (FYM) in Fayetteville, TN and are periodically checked and adjusted to minimize corrections at project sites.

1.4 Project Purpose

The primary purpose of the lidar survey was to establish measurements of the bare earth surface, as well as top surface feature data for providing geometric inputs for modeling, other numerical modeling and economic related assessments.

1.5 Lidar Flight-line Orientation

The following graphic represents the alignment of the project area of interest (AOI) and the flight-lines executed to provide AOI coverage.

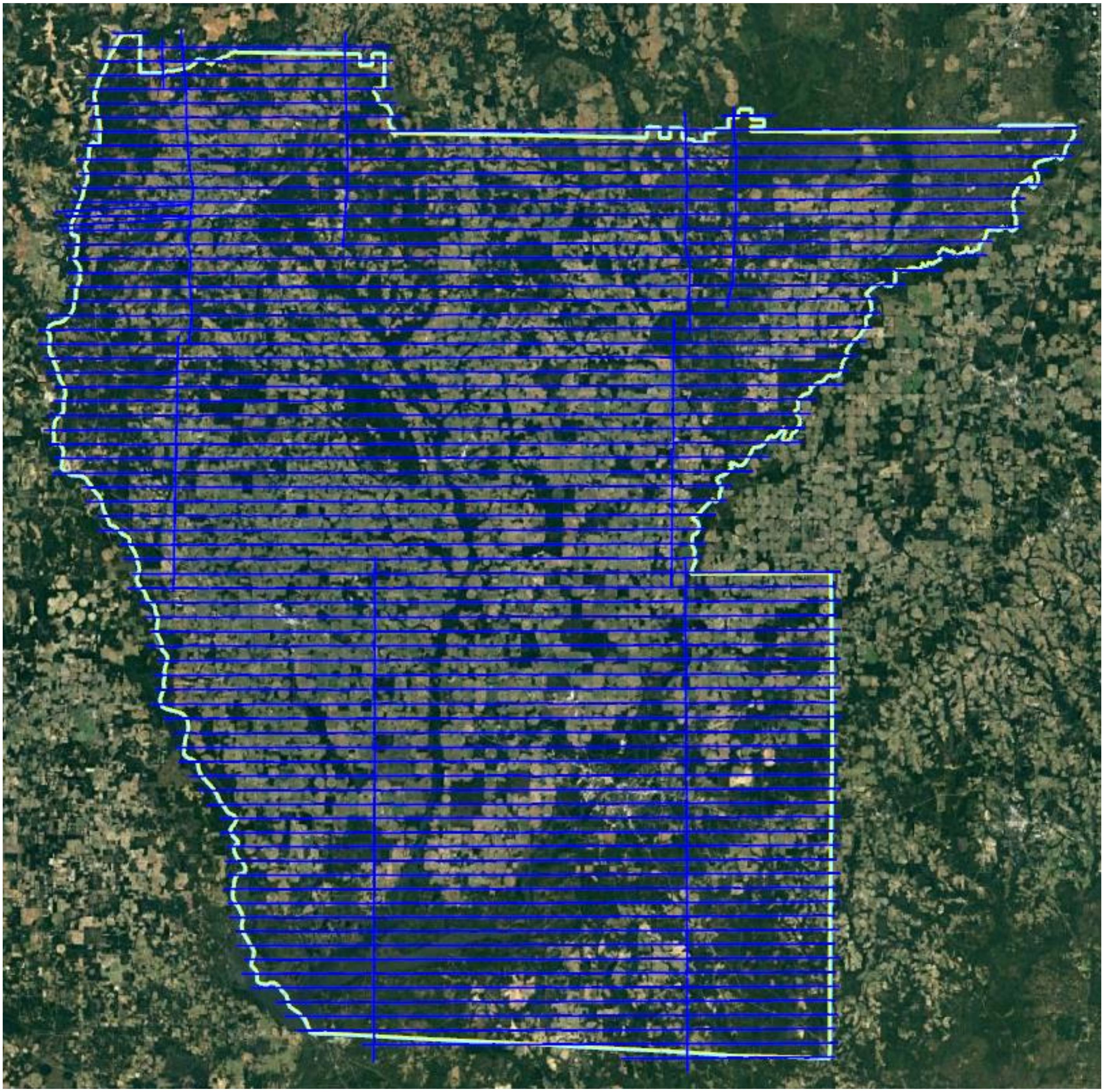


Figure 1: Trajectories as flown by Atlantic

1.6 Acquisition Equipment

Atlantic operated a Piper PA-31-350 Chieftain (N1872H) outfitted with a Leica ALS70-HP lidar system during the collection of the project area. Table 1 represents a list of the features and characteristics for the Leica ALS70-HP lidar system:

Atlantic's Sensor Characteristics		
Leica ALS70-HP		
Manufacturer	Leica	
Model	ALS70 - HP	
Platform	Fixed-Wing	
Scan Pattern	Sine, Triangle, Raster	
Maximum Scan Rate (Hz)	Sine	200
	Triangle	158
	Raster	120
Field of View (°)	0 - 75 (Full Angle, User Adjustable)	
Maximum Pulse rate (kHz)	500	
Maximum Flying height (m AGL)	3500	
Number of returns	Unlimited	
Number of Intensity Measurements	3 (First, Second, Third)	
Roll Stabilization (Automatic Adaptive, °)	75 - Active FOV	
Storage Media	Removable 500 GB SSD	
Storage Capacity (Hours @ Max Pulse Rate)	6	
Size (cm)	Scanner	37 W x 68 L x 26 H
	Control Electronics	45 W x 47 D x 36 H
Weight (kg)	Scanner	43
	Control Electronics	45
Operating Temperature	0 - 40 °C	
Flight Management	FCMS	
Power Consumption	927 @ 22.0 - 30.3 VDC	

Table 1: Atlantic Sensor Characteristics

1.7 Lidar System Acquisition Parameters

Table 2 illustrates Atlantic's system parameters for lidar acquisition on this project.

Lidar System Acquisition Parameters	
Item	**Parameter**
System	Leica ALS-70 HP
Nominal Pulse Spacing (m)	0.7
Nominal Pulse Density (pls/m²)	2.4
Nominal Flight Height (AGL meters)	2075
Nominal Flight Speed (kts)	130
Pass Heading (degree)	Varies
Sensor Scan Angle (degree)	45
Scan Frequency (Hz)	35.2
Pulse Rate of Scanner (kHz)	265.6
Line Spacing (m)	1057
Pulse Duration of Scanner (ns)	4
Pulse Width of Scanner (m)	0.46
Central Wavelength of Sensor Laser (nm)	1064
Sensor Operated with Multiple Pulses	Yes
Beam Divergence (mrad)	0.22
Nominal Swath Width (m)	1657
Nominal Swath Overlap (%)	20
Scan Pattern	Triangle

Table 2: Atlantic Lidar System Acquisition Parameters

1.8 GPS Reference Station(s)

Three (3) Trimble CORS were used to control the lidar acquisition for the project area. The coordinates provided in Table 3 below are in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

GPS Reference Station Coordinates					
Designation	**Type**	**PID**	**Latitude (N)**	**Longitude (W)**	**Elevation**
GAFI	Trimble	N/A	31 16 24.99806	084 32 47.69400	35.539
GATH	Trimble	N/A	30 57 42.66813	084 54 54.60932	25.066
GACL	Trimble	N/A	30 52 20.84130	084 23 55.85968	57.823

Table 3: GPS Reference Station Coordinates

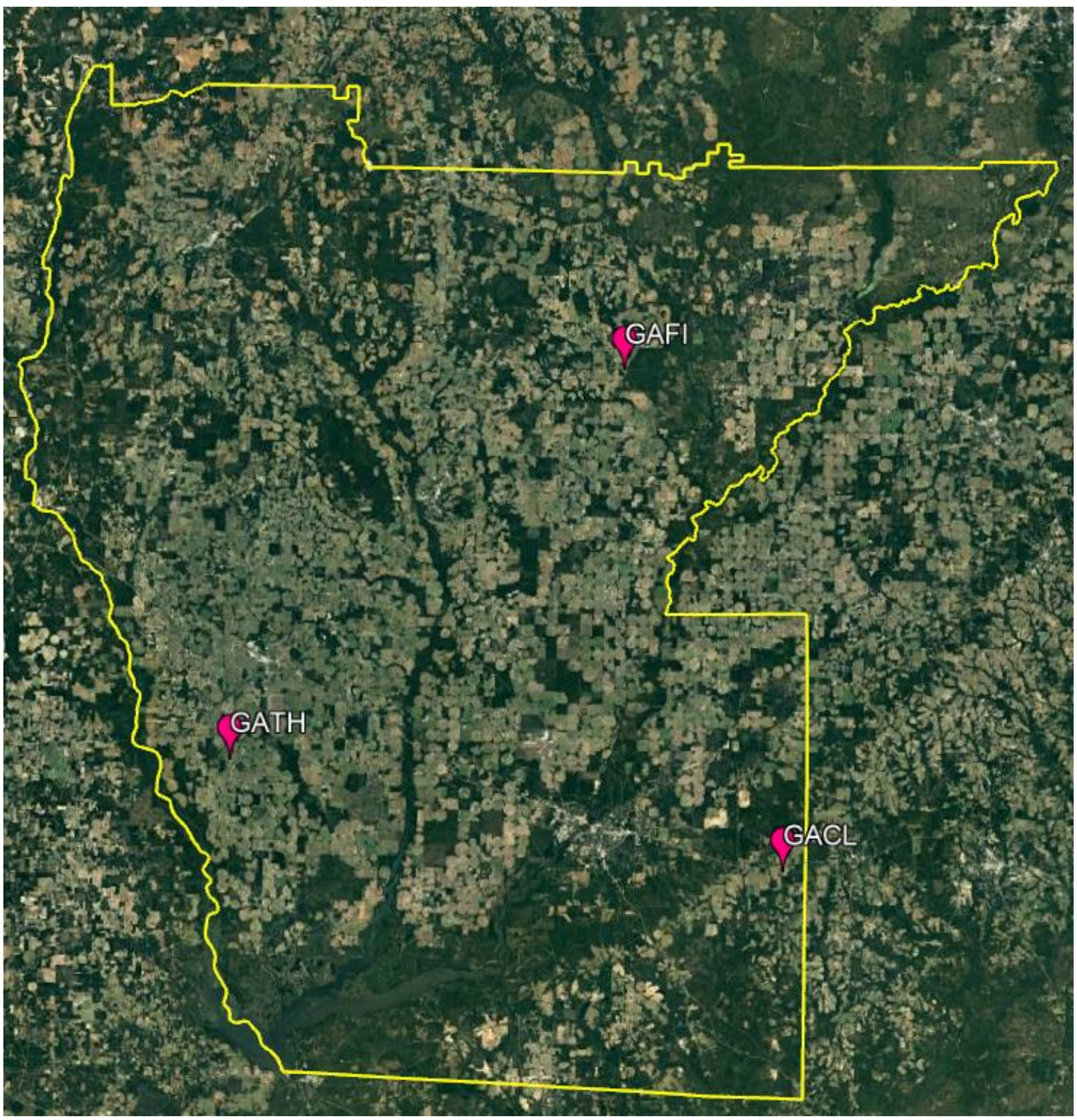


Figure 2: GPS Reference Station(s)

1.9 Airborne GPS Kinematic

Differential GPS unit in aircraft collected positions at 2 Hz. Airborne GPS data was processed using the Inertial Explorer (version 8.60.5025) software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of ≤4 when the laser was online.

For all flights, the GPS data can be classified as good, with GPS residuals of 3cm average or better but none larger than 10cm being recorded.

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.

GPS processing results for each lift are included in **Section 5: GPS Processing**.

Section 2: Lidar Processing

2.1 Generation of Laser Points

Atlantic used a combination of Waypoint and Leica software products to extract the lidar swath data from the raw flight records. Waypoint Inertial Explorer is used to extract the raw IPAS ABGPS/IMU data, which is further processed in combination with controlled base stations to provide the final Smoothed Best Estimate Trajectory (SBET) for each mission. The SBET's are combined with the raw laser scan files to export the (*.las) formatted swath point clouds.

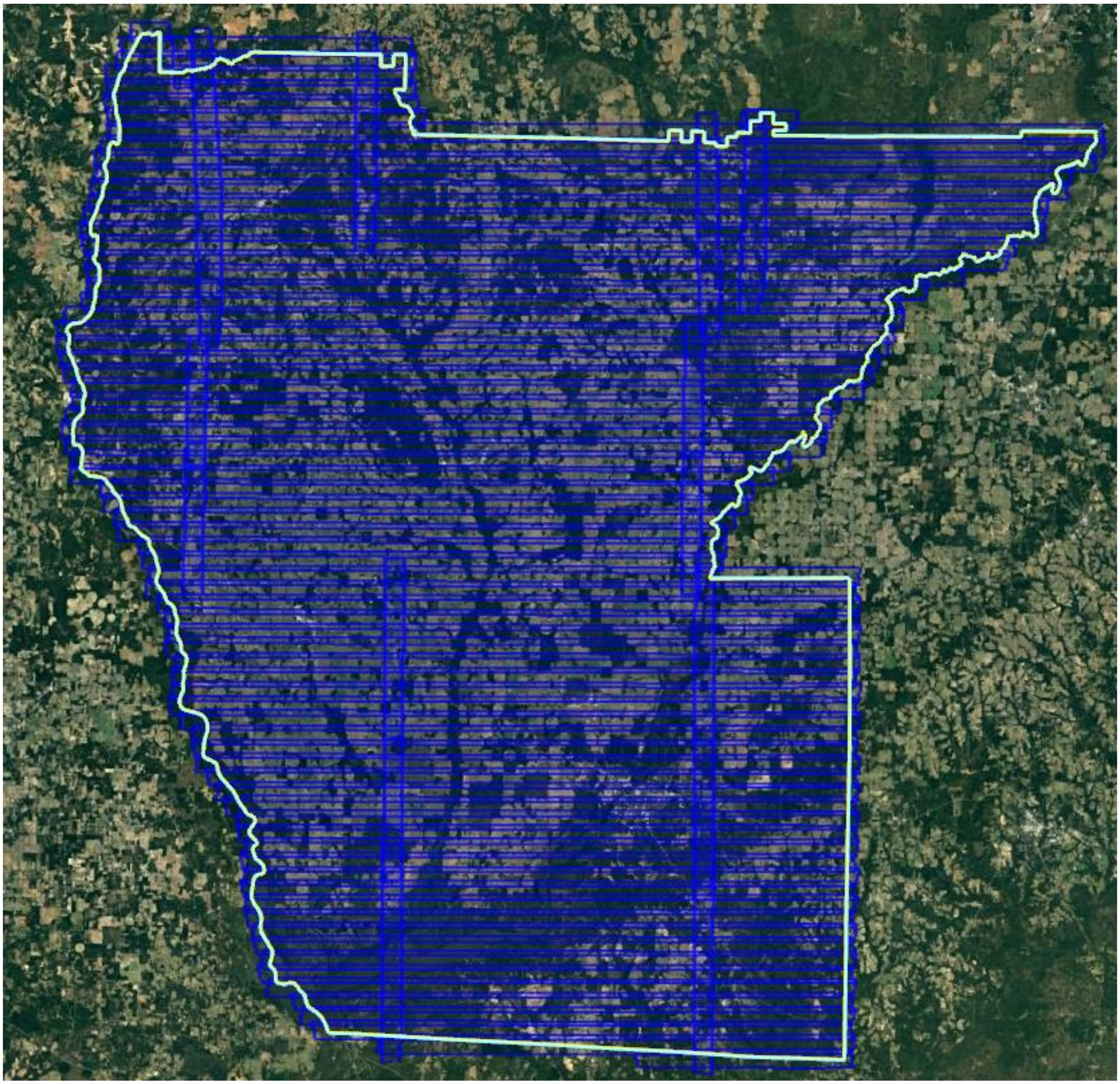


Figure 3: Lidar swath data showing complete coverage

2.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Coordinate System:	State Plane Georgia West (FIPS 1002)
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units of Reference:	U.S. Survey Feet

2.3 Lidar Point Cloud Statistics

Table 4 illustrates the overall lidar point cloud statistics for this project.

Point Cloud Statistics	
Category	**Value**
Total Points	23,421,222,144
Nominal Pulse Spacing (m)	0.4526
Nominal Pulse Density (pls/m²)	4.88
Nominal Pulse Spacing (ft)	1.4848
Nominal Pulse Density (pls/ft²)	0.45
Aggregate Total Points	21,923,485,511
Aggregate Nominal Pulse Spacing (m)	0.4303
Aggregate Nominal Pulse Density (pls/m²)	5.40
Aggregate Nominal Pulse Spacing (ft)	1.4117
Aggregate Nominal Pulse Density (pls/ft²)	0.50

Table 4: Lidar Point Cloud Statistics

2.4 Lidar Classification

The calibrated point cloud data from the laser sensor was merged to produce processed (*.las) file(s) including but not limited to 3D position, intensity, and time-stamp. A filtering methodology was utilized to produce a multi-return surface elevation model dataset with bare-earth conditions. GeoCue, TerraScan, and TerraModel software was used for the initial batch processing and manual editing of the (*.las) point clouds. Atlantic utilized collected breakline data to preform classification for classes' 9-Water and 10-Ignored Ground in LP360. Outlined in Table 5 are the classification codes utilized for this project.

ASPRS Standard Lidar Point Classes	
Code	**Description**
1	Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
7	Low Noise
9	Water
10	Ignored Ground
17	Bridges
18	High Noise
Flags	Overlap & Withheld

Table 5: Point Cloud Classification Scheme

2.5 Smooth Surface Repeatability (Intraswath)

Departures from planarity of first returns within single swaths in non-vegetated areas were assessed at multiple locations with hard surface areas (parking lots or large rooftops) inside the project area. Each area was evaluated using signed difference raster's (maximum elevation – minimum elevation) at a cell size equal to 2 x ANPS, rounded to the next integer. The following graphic depicts a sample of the assessment.

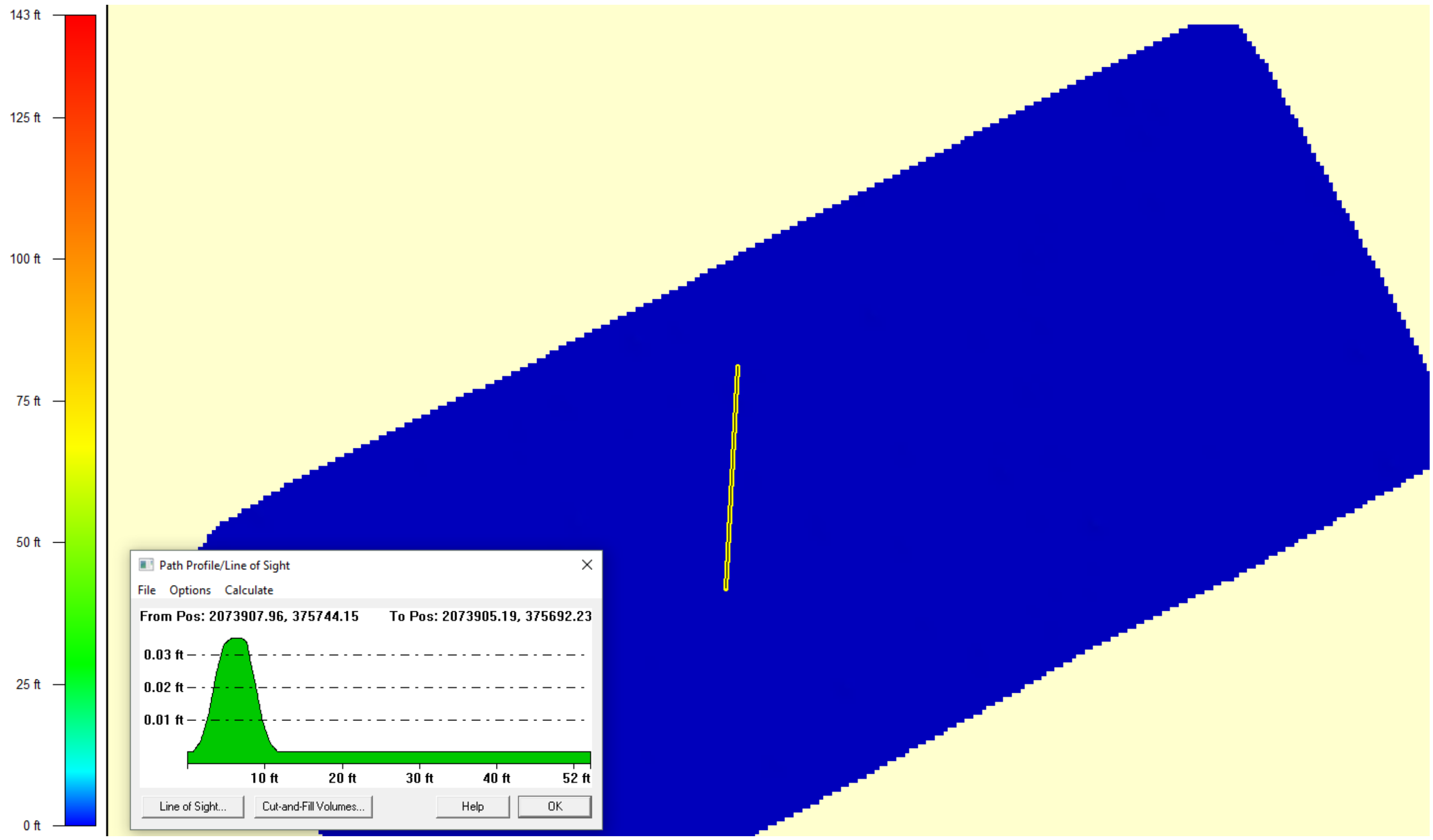


Figure 4: Smooth Surface Repeatability of ≤3ft

Section 3: Relative Accuracy Assessment

3.1 Expected Horizontal Positional Error

As described in Section 7.5 of the ASPRS Positional Accuracy Standards for Digital Geospatial Data the horizontal errors in lidar data are largely a function of GNSS positional error, INS angular error, and flying altitude. Therefore, lidar data collected with GNSS error of 8cm and the IMU error of 0.00427 degrees at an altitude of 2,075m; the expected radial horizontal positional error will be $RMSE_r$ = 29.9cm.

3.2 Calibration of Lidar Point Cloud

LiDAR ranging data were initially calibrated using previous best parameters for this instrument and aircraft. Using a combination of GeoCue, and TerraSolid's TerraScan and TerraMatch the overlapping swath point clouds are corrected for any orientation or linear deviations to obtain the best fit swath-to-swath calibration. Relative calibration was evaluated using advanced plane-matching analysis and parameter corrections derived. This process was repeated interactively until residual errors between overlapping swaths, across all project missions, was reduced to 2 cm or less. A final analysis of the calibrated LiDAR is preformed using a TerraMatch Tie Line report for an overall statistical model of the project area.

3.3 Relative Vertical Accuracy

Upon completion of the data calibration, Atlantic runs a complete set of Delta-Z (dZ) ortho images. A user-defined color ramp is applied depicting the offsets between overlapping swaths based on project specifications. The dZ orthos provide an opportunity to review the data calibration in a qualitative manner. Atlantic assigns green to all offset values that fall below the required interswath accuracy RMSDz requirement of the project. A yellow color is assigned for offsets that fall between the RMSDz value and 1.5x of that value. Finally, red values are assigned to all values that fall beyond 1.5x of the RMSDz requirements of the project.

No Data	0ft to 0.131ft	0.131ft to 0.262ft	0.262ft to 0.393ft	> 0.393ft

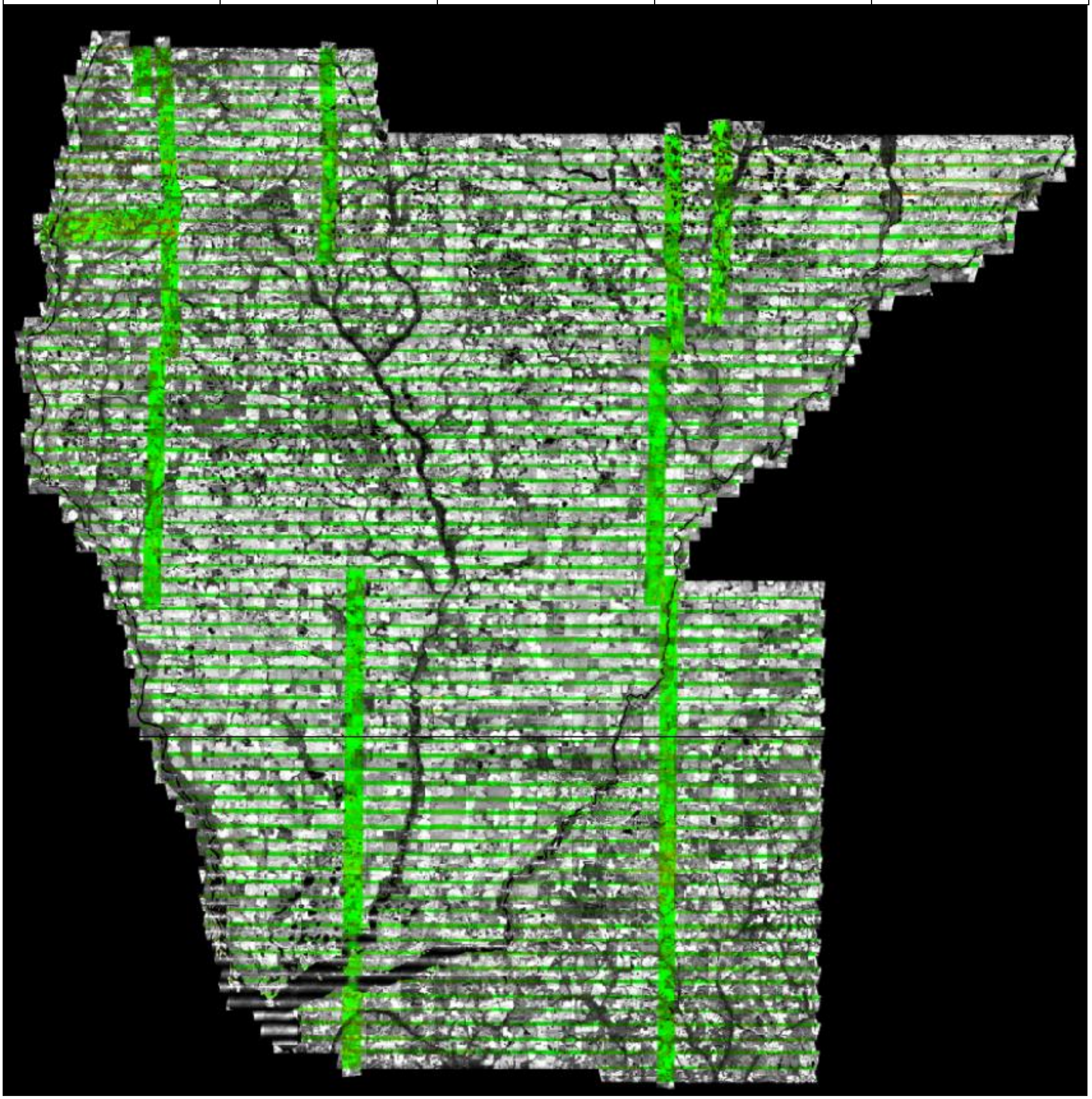


Figure 4: dZ ortho sample

3.4 Interswath Accuracy Results

An overall statistical assessment of the relative accuracy using TerraMatch Tie Line Report between lidar swaths can be found in Tables 6, 7, 8, and 9 below. The values provided are in feet.

Average Magnitudes Per Line											
Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
29	0.079	0.097	0.06	60	0.081	0.149	0.051	91	0.221	0.255	0.096
30	0.099	0.143	0.05	61	0.098	0.161	0.052	92	0.111	0.168	0.053
31	0.103	0.127	0.049	62	0.097	0.17	0.052	93	0.093	0.162	0.051
32	0.088	0.096	0.064	63	0.087	0.134	0.053	94	0.108	0.161	0.054
33	0.135	0.16	0.054	64	0.121	0.174	0.053	95	0.091	0.14	0.054
34	0.08	0.132	0.051	65	0.083	0.163	0.051	96	0.108	0.191	0.052
35	0.087	0.133	0.056	66	0.078	0.16	0.049	97	0.159	0.274	0.052
36	0.087	0.117	0.049	67	0.087	0.202	0.05	98	0.142	0.242	0.054
37	0.066	0.098	0.053	68	0.106	0.212	0.053	99	0.156	0.279	0.061
38	0.125	0.121	0.049	69	0.132	0.199	0.054	100	0.166	0.353	0.08
39	0.115	0.136	0.052	70	0.131	0.083	0.068	105	-	-	0.058
40	0.095	0.131	0.053	71	0.133	0.188	0.055	106	0.148	0.186	0.056
41	0.13	0.147	0.053	72	0.071	0.123	0.067	107	0.189	0.235	0.069
42	0.115	0.157	0.051	73	0.148	0.209	0.052	108	0.033	0.068	0.087
43	0.126	0.158	0.059	74	0.116	0.206	0.054	118	0.141	0.136	0.094
44	0.143	0.097	0.056	75	0.089	0.159	0.051	119	0.131	0.197	0.086
45	0.116	0.197	0.05	76	0.115	0.18	0.054	142	0.034	0.038	0.042
46	0.157	0.124	0.069	77	0.167	0.181	0.054	143	0.086	0.104	0.059
47	0.081	0.225	0.05	78	0.137	0.156	0.053	144	0.083	0.14	0.06
48	0.112	0.171	0.052	79	0.12	0.124	0.055	145	0.141	0.223	0.06
49	0.106	0.136	0.052	80	0.078	0.062	0.069	146	0.096	0.121	0.056
50	0.086	0.123	0.05	81	0.119	0.113	0.052	147	0.095	0.137	0.049
51	0.086	0.106	0.05	82	0.119	0.115	0.063	148	-	-	0.049
52	0.091	0.1	0.051	83	0.158	0.154	0.05	149	0.102	0.201	0.053
53	0.102	0.118	0.05	84	0.152	0.144	0.048	150	0.067	0.158	0.051
54	0.125	0.14	0.049	85	0.101	0.154	0.05	151	0.089	0.122	0.054
55	0.121	0.203	0.051	86	0.102	0.186	0.051	152	0.076	0.081	0.047
56	0.075	0.081	0.056	87	0.114	0.187	0.056	153	0.053	0.073	0.059
57	0.061	0.15	0.052	88	0.066	0.13	0.055	154	0.026	0.026	0.051
58	0.075	0.112	0.066	89	0.088	0.145	0.056				
59	0.065	0.14	0.052	90	0.185	0.189	0.083				

Table 6: Average Tie Line Magnitudes per Line

Internal Observation Statistics			
Category	X	Y	Z
Average Magnitude	0.104	0.149	0.054
RMS Values	0.170	0.236	0.073
Maximum Values	2.007	1.936	0.936
Observation Weight	15847.0	15847.0	510687.0

Table 7: Tie Line Observation Statistics

Overall Relative Accuracy	
Category	Mismatch
Average 3D Mismatch	0.05959
Average XY Mismatch	0.21973
Average Z Mismatch	0.05397

Table 8: Relative Accuracy Results

TerraMatch Tie Lines	
Category	Observations
Section Lines	216,347
Roof Lines	7,688

Table 9: Total Tie Lines

Section 4: Vertical Accuracy Assessment

4.1 Ground Surveyed Check Points

Atlantic established a total of sixty-nine (71) check points for this project (43 NVA + 28 VVA). Point cloud data accuracy was tested against a Triangulated Irregular Network (TIN) constructed from lidar points in clear and open areas. A clear and open area can be characterized with respect to topographic and ground cover variation such that a minimum of 5 times the NPS exists with less than 1/3 of the $RMSE_Z$ deviation from a low-slope plane. Slopes that exceed 10 percent were avoided. Each land cover type representing 10 percent or more of the total project area were tested and reported with a VVA. In land cover categories other than dense urban areas, the tested points did not have obstructions 45 degrees above the horizon to ensure a sufficient TIN surface. The VVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. The NVA value is a requirement that must be met, regardless of any allowed “busts” in the VVA(s) for individual land cover types within the project. Checkpoints for each assessment (NVA & VVA) are required to be well-distributed throughout the land cover type, for the entire project area.

4.2 Vertical Accuracy

Below are the vertical accuracy reporting requirements for this project:

Vertical Accuracy Reporting Requirements in Meters:

$RMSE_Z$ ≤ 10.0cm (Non-Vegetated Swath, DEM)
NVA ≤ 19.6cm 95% Confidence Level (Swath, DEM)
VVA ≤ 29.4cm 95^{th} Percentile (DEM)

Vertical Accuracy Reporting Requirements in Feet:

$RMSE_Z$ ≤ 0.328ft (Non-Vegetated Swath, DEM)
NVA ≤ 0.643ft 95% Confidence Level (Swath, DEM)
VVA ≤ 0.965ft 95^{th} Percentile (DEM)

*The terms FVA (Fundamental Vertical Accuracy), SVA (Supplemental Vertical Accuracy) and CVA (Consolidated Vertical Accuracy) are from the National Digital Elevation Program (NDEP) Guidelines for Digital Elevation Data (2004). The term FVA refers to open terrain, urban and levee classes; the term SVA refers to classes tested that are in addition or supplemental to the open terrain; the term CVA refers to the consolidated accuracy of the data from all classes (FVA + SVA).

*The terms NVA (Non-vegetated Vertical Accuracy) and VVA (Vegetated Vertical Accuracy) are from the ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014). The term NVA refers to assessments in clear, open areas (which typically produce only single lidar returns); the term VVA refers to assessments in vegetated areas (typically characterized by multiple return lidar).

4.3 Check Point Distribution

The following graphics depict the location and distribution of NVA and VVA Check Points established for this project.

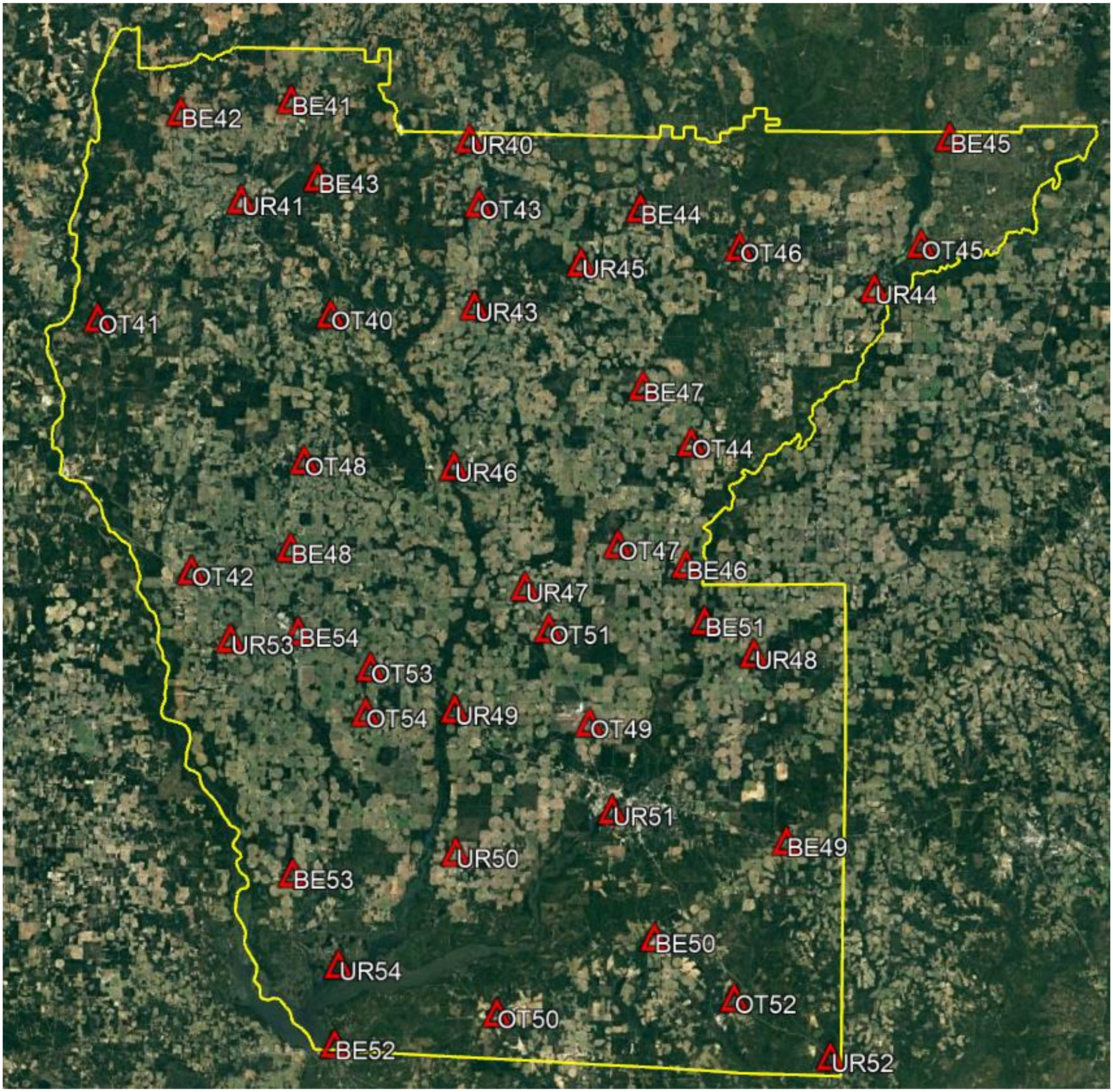


Figure 5: Non-vegetated Vertical Accuracy (NVA) Check Point Distribution

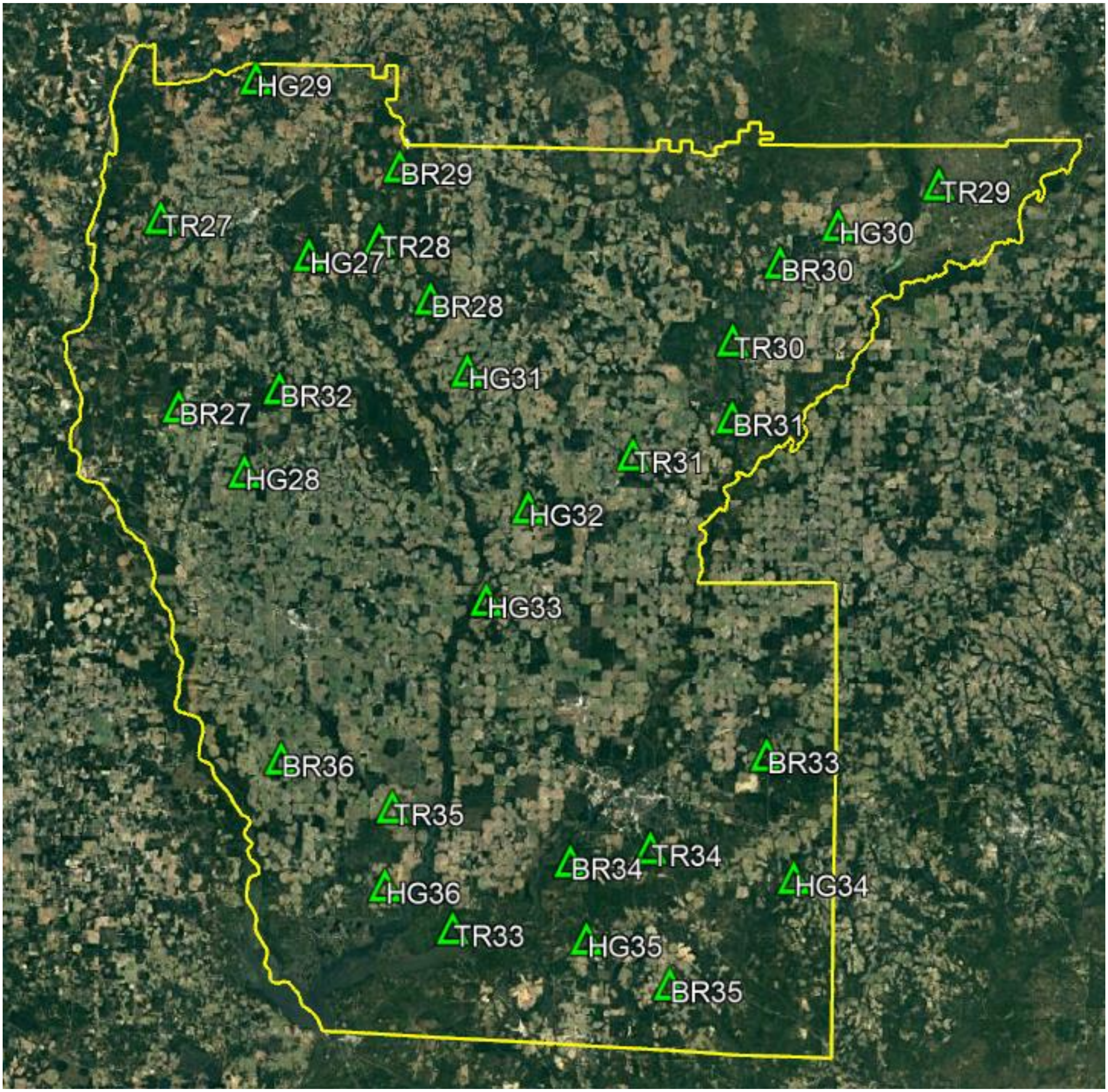


Figure 6: Vegetated Vertical Accuracy (VVA) Check Point Distribution

4.4 Check Point Assessment

A vertical accuracy assessment of the NVA & VVA check points against the lidar point cloud and bare-earth lidar can be found in Tables 10, 11, 12, and 13 below. The coordinates provided are in NAD83 (2011), State Plane Georgia West (FIPS 1002, NAVD88 (Geoid12B), U.S. Survey Feet.

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Point Cloud)						
PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
BE41	2071807.255	532377.199	287.230	287.250	Bare Earth/Open Terrain	0.020
BE42	2039869.644	528966.450	318.288	318.502	Bare Earth/Open Terrain	0.214
BE43	2079432.638	509916.624	209.410	209.771	Bare Earth/Open Terrain	0.361
BE44	2172425.039	500690.206	186.587	186.743	Bare Earth/Open Terrain	0.156
BE45	2261983.967	520891.966	172.477	173.041	Bare Earth/Open Terrain	0.564
BE46	2185139.084	398502.387	136.217	136.024	Bare Earth/Open Terrain	-0.193
BE47	2172979.848	449608.896	176.592	176.371	Bare Earth/Open Terrain	-0.221
BE48	2071128.135	403632.864	158.834	158.940	Bare Earth/Open Terrain	0.106
BE49	2213814.214	318891.720	285.939	285.918	Bare Earth/Open Terrain	-0.021
BE50	2175614.908	291419.494	309.925	309.705	Bare Earth/Open Terrain	-0.220
BE51	2190440.492	382187.645	130.064	129.781	Bare Earth/Open Terrain	-0.283
BE52	2083185.515	261104.478	238.444	238.269	Bare Earth/Open Terrain	-0.175
BE53	2071299.218	310222.790	97.685	97.363	Bare Earth/Open Terrain	-0.322
BE54	2073244.339	379659.011	142.481	142.961	Bare Earth/Open Terrain	0.480
OT40	2082921.865	470626.994	190.018	190.366	Bare Earth/Open Terrain	0.348
OT41	2015725.827	469856.158	217.255	217.211	Bare Earth/Open Terrain	-0.044
OT42	2042491.109	397242.842	151.414	151.954	Bare Earth/Open Terrain	0.540
OT43	2125887.100	502289.663	235.972	236.309	Bare Earth/Open Terrain	0.337
OT44	2186825.721	433383.650	147.039	146.763	Bare Earth/Open Terrain	-0.276
OT45	2253529.389	490182.770	146.231	146.719	Bare Earth/Open Terrain	0.488
OT46	2201054.389	489530.712	157.921	158.243	Bare Earth/Open Terrain	0.322
OT47	2165530.964	404214.078	146.445	146.479	Bare Earth/Open Terrain	0.034
OT48	2075152.051	428725.988	189.565	189.433	Bare Earth/Open Terrain	-0.132
OT49	2157154.280	353075.378	128.904	128.920	Bare Earth/Open Terrain	0.016
OT50	2130097.204	269875.715	289.190	289.124	Bare Earth/Open Terrain	-0.066
OT51	2145531.198	380134.114	129.961	130.060	Bare Earth/Open Terrain	0.099
OT52	2198630.050	273849.756	297.287	297.569	Bare Earth/Open Terrain	0.282
OT53	2094024.835	369241.388	143.621	143.457	Bare Earth/Open Terrain	-0.164
OT54	2092609.011	356348.523	121.807	121.909	Bare Earth/Open Terrain	0.102
UR40	2123229.691	520876.051	270.415	270.274	Urban	-0.141
UR41	2057274.990	503629.439	259.195	259.228	Urban	0.033
UR43	2124417.512	472844.155	223.915	223.842	Urban	-0.073
UR44	2239919.162	477440.660	164.140	164.243	Urban	0.103
UR45	2155266.287	485126.831	243.301	243.369	Urban	0.068
UR46	2118349.238	426845.916	179.297	179.107	Urban	-0.190

UR47	2138667.804	392218.298	131.488	131.166	Urban	-0.322
UR48	2204642.613	372686.703	134.143	134.060	Urban	-0.083
UR49	2118245.653	357122.148	112.390	112.305	Urban	-0.085
UR50	2118361.444	316110.390	123.193	122.970	Urban	-0.223
UR51	2163544.181	327961.162	87.717	87.530	Urban	-0.187
UR52	2226395.892	256807.919	258.673	258.699	Urban	0.026
UR53	2053655.462	377621.257	184.960	185.033	Urban	0.073
UR54	2084450.423	283883.342	94.259	94.016	Urban	-0.243

Table 10: Lidar Point Cloud NVA Assessment

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Bare-Earth)						
PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
BE41	2071807.255	532377.199	287.230	287.250	Bare Earth/Open Terrain	0.020
BE42	2039869.644	528966.450	318.288	318.387	Bare Earth/Open Terrain	0.099
BE43	2079432.638	509916.624	209.410	209.771	Bare Earth/Open Terrain	0.361
BE44	2172425.039	500690.206	186.587	186.686	Bare Earth/Open Terrain	0.099
BE45	2261983.967	520891.966	172.477	172.716	Bare Earth/Open Terrain	0.239
BE46	2185139.084	398502.387	136.217	136.024	Bare Earth/Open Terrain	-0.193
BE47	2172979.848	449608.896	176.592	176.281	Bare Earth/Open Terrain	-0.311
BE48	2071128.135	403632.864	158.834	158.940	Bare Earth/Open Terrain	0.106
BE49	2213814.214	318891.720	285.939	285.918	Bare Earth/Open Terrain	-0.021
BE50	2175614.908	291419.494	309.925	309.705	Bare Earth/Open Terrain	-0.220
BE51	2190440.492	382187.645	130.064	129.781	Bare Earth/Open Terrain	-0.283
BE52	2083185.515	261104.478	238.444	238.269	Bare Earth/Open Terrain	-0.175
BE53	2071299.218	310222.790	97.685	97.363	Bare Earth/Open Terrain	-0.322
BE54	2073244.339	379659.011	142.481	142.680	Bare Earth/Open Terrain	0.199
OT40	2082921.865	470626.994	190.018	190.280	Bare Earth/Open Terrain	0.262
OT41	2015725.827	469856.158	217.255	217.211	Bare Earth/Open Terrain	-0.044
OT42	2042491.109	397242.842	151.414	151.954	Bare Earth/Open Terrain	0.540
OT43	2125887.100	502289.663	235.972	236.309	Bare Earth/Open Terrain	0.337
OT44	2186825.721	433383.650	147.039	146.763	Bare Earth/Open Terrain	-0.276
OT45	2253529.389	490182.770	146.231	146.719	Bare Earth/Open Terrain	0.488
OT46	2201054.389	489530.712	157.921	158.310	Bare Earth/Open Terrain	0.389
OT47	2165530.964	404214.078	146.445	146.479	Bare Earth/Open Terrain	0.034
OT48	2075152.051	428725.988	189.565	189.354	Bare Earth/Open Terrain	-0.211
OT49	2157154.280	353075.378	128.904	128.920	Bare Earth/Open Terrain	0.016
OT50	2130097.204	269875.715	289.190	289.130	Bare Earth/Open Terrain	-0.060
OT51	2145531.198	380134.114	129.961	130.060	Bare Earth/Open Terrain	0.099
OT52	2198630.050	273849.756	297.287	297.569	Bare Earth/Open Terrain	0.282
OT53	2094024.835	369241.388	143.621	143.457	Bare Earth/Open Terrain	-0.164
OT54	2092609.011	356348.523	121.807	121.909	Bare Earth/Open Terrain	0.102
UR40	2123229.691	520876.051	270.415	270.274	Urban	-0.141
UR41	2057274.990	503629.439	259.195	259.228	Urban	0.033

UR43	2124417.512	472844.155	223.915	223.842	Urban	-0.073
UR44	2239919.162	477440.660	164.140	164.211	Urban	0.071
UR45	2155266.287	485126.831	243.301	243.369	Urban	0.068
UR46	2118349.238	426845.916	179.297	179.107	Urban	-0.190
UR47	2138667.804	392218.298	131.488	131.157	Urban	-0.331
UR48	2204642.613	372686.703	134.143	133.942	Urban	-0.201
UR49	2118245.653	357122.148	112.390	112.305	Urban	-0.085
UR50	2118361.444	316110.390	123.193	122.970	Urban	-0.223
UR51	2163544.181	327961.162	87.717	87.530	Urban	-0.187
UR52	2226395.892	256807.919	258.673	258.699	Urban	0.026
UR53	2053655.462	377621.257	184.960	185.033	Urban	0.073
UR54	2084450.423	283883.342	94.259	94.016	Urban	-0.243

Table 11: Bare-Earth Lidar NVA Assessment

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (DEM)						
PointID	**Easting**	**Northing**	**KnownZ**	**DEMZ**	**Description**	**DeltaZ**
BE41	2071807.255	532377.199	287.230	287.248	Bare Earth/Open Terrain	-0.018
BE42	2039869.644	528966.450	318.288	318.331	Bare Earth/Open Terrain	-0.043
BE43	2079432.638	509916.624	209.410	209.773	Bare Earth/Open Terrain	-0.363
BE44	2172425.039	500690.206	186.587	186.693	Bare Earth/Open Terrain	-0.106
BE45	2261983.967	520891.966	172.477	172.711	Bare Earth/Open Terrain	-0.234
BE46	2185139.084	398502.387	136.217	136.046	Bare Earth/Open Terrain	0.171
BE47	2172979.848	449608.896	176.592	176.316	Bare Earth/Open Terrain	0.276
BE48	2071128.135	403632.864	158.834	158.946	Bare Earth/Open Terrain	-0.112
BE49	2213814.214	318891.720	285.939	285.877	Bare Earth/Open Terrain	0.062
BE50	2175614.908	291419.494	309.925	309.622	Bare Earth/Open Terrain	0.303
BE51	2190440.492	382187.645	130.064	129.728	Bare Earth/Open Terrain	0.336
BE52	2083185.515	261104.478	238.444	238.268	Bare Earth/Open Terrain	0.176
BE53	2071299.218	310222.790	97.685	97.306	Bare Earth/Open Terrain	0.379
BE54	2073244.339	379659.011	142.481	142.687	Bare Earth/Open Terrain	-0.206
OT40	2082921.865	470626.994	190.018	190.285	Bare Earth/Open Terrain	-0.267
OT41	2015725.827	469856.158	217.255	217.216	Bare Earth/Open Terrain	0.039
OT42	2042491.109	397242.842	151.414	151.898	Bare Earth/Open Terrain	-0.484
OT43	2125887.100	502289.663	235.972	236.296	Bare Earth/Open Terrain	-0.324
OT44	2186825.721	433383.650	147.039	146.738	Bare Earth/Open Terrain	0.301
OT45	2253529.389	490182.770	146.231	146.722	Bare Earth/Open Terrain	-0.491
OT46	2201054.389	489530.712	157.921	158.252	Bare Earth/Open Terrain	-0.331
OT47	2165530.964	404214.078	146.445	146.479	Bare Earth/Open Terrain	-0.034
OT48	2075152.051	428725.988	189.565	189.433	Bare Earth/Open Terrain	0.132
OT49	2157154.280	353075.378	128.904	128.841	Bare Earth/Open Terrain	0.063
OT50	2130097.204	269875.715	289.190	288.998	Bare Earth/Open Terrain	0.192
OT51	2145531.198	380134.114	129.961	130.055	Bare Earth/Open Terrain	-0.094
OT52	2198630.050	273849.756	297.287	297.540	Bare Earth/Open Terrain	-0.253

OT53	2094024.835	369241.388	143.621	143.320	Bare Earth/Open Terrain	0.301
OT54	2092609.011	356348.523	121.807	121.906	Bare Earth/Open Terrain	-0.099
UR40	2123229.691	520876.051	270.415	270.274	Urban	0.141
UR41	2057274.990	503629.439	259.195	259.146	Urban	0.049
UR43	2124417.512	472844.155	223.915	223.764	Urban	0.151
UR44	2239919.162	477440.660	164.140	164.200	Urban	-0.060
UR45	2155266.287	485126.831	243.301	243.341	Urban	-0.040
UR46	2118349.238	426845.916	179.297	179.099	Urban	0.198
UR47	2138667.804	392218.298	131.488	131.171	Urban	0.317
UR48	2204642.613	372686.703	134.143	133.942	Urban	0.201
UR49	2118245.653	357122.148	112.390	112.233	Urban	0.157
UR50	2118361.444	316110.390	123.193	122.971	Urban	0.222
UR51	2163544.181	327961.162	87.717	87.518	Urban	0.199
UR52	2226395.892	256807.919	258.673	258.493	Urban	0.180
UR53	2053655.462	377621.257	184.960	184.946	Urban	0.014
UR54	2084450.423	283883.342	94.259	94.016	Urban	0.243

Table 12: Bare=Earth DEM NVA Assessment

Vegetated Vertical Accuracy (VVA) Check Point Assessment (Bare Earth)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
BR27	2034856.529	445464.598	188.754	189.059	Brush	0.305
BR28	2110259.380	477204.727	175.019	175.845	Brush	0.826
BR30	2214714.899	487630.897	176.954	177.645	Brush	0.691
BR31	2200263.196	441655.757	133.793	133.797	Brush	0.004
BR32	2065017.275	450712.591	211.660	212.181	Brush	0.521
BR33	2210325.728	341321.395	142.389	142.834	Brush	0.445
BR34	2151579.360	309945.398	89.451	89.321	Brush	-0.130
BR36	2065262.650	340640.137	114.359	114.411	Brush	0.052
HG27	2073996.987	490364.502	224.631	224.996	High Grass	0.365
HG28	2054527.363	425931.499	202.553	202.831	High Grass	0.278
HG29	2058206.523	543052.654	320.453	320.953	High Grass	0.500
HG31	2121224.561	455804.902	178.592	178.798	High Grass	0.206
HG32	2139262.185	415067.444	147.194	147.403	High Grass	0.209
HG33	2126711.276	387677.207	127.712	127.864	High Grass	0.152
HG34	2218281.570	304735.695	262.789	263.328	High Grass	0.539
HG35	2156358.350	286852.525	305.192	305.453	High Grass	0.261
HG36	2096172.928	302839.669	100.207	100.446	High Grass	0.239
TR27	2029618.869	501540.688	273.781	274.258	Trees	0.477
TR28	2094997.625	495007.385	221.194	221.653	Trees	0.459
TR29	2262248.183	510828.520	170.248	170.665	Trees	0.417
TR30	2200486.211	464577.091	140.426	140.267	Trees	-0.159
TR31	2170585.520	430681.993	147.154	146.943	Trees	-0.211

TR33	2116405.323	290065.560	92.665	92.345	Trees	-0.320
TR34	2175529.805	313816.385	119.196	119.330	Trees	0.134
TR35	2098466.377	326124.376	120.557	120.582	Trees	0.025

Table 13: Bare-Earth Lidar VVA Assessment

4.5 Vertical Accuracy Results

An overall statistical assessment of the check points can be found in Tables 14, 15, 16, and 17 below. The values provided are in feet.

Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)				
Broad Land Cover Type	**# of Points**	**RMSEz**	**95% Confidence Level**	**95th Percentile**
NVA of Point Cloud	43	0.244	0.477	
NVA of Bare Earth	43	0.224	0.438	
NVA of DEM	43	0.229	0.450	
VVA of Bare Earth	25	0.376		0.661

Table 16: Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)

Vegetated Vertical Accuracy (VVA) 5% Outliers > 95th Percentile (0.987ft)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
BR29	2101115.570	516647.176	196.187	197.370	Brush	1.183
BR35	2181177.981	273264.557	262.941	263.927	Brush	0.986
HG30	2232080.861	498738.697	166.802	167.789	High Grass	0.987

Table 17: 5% Outlier Check Points

Section 5: Certification

5.1 Limitations of Use

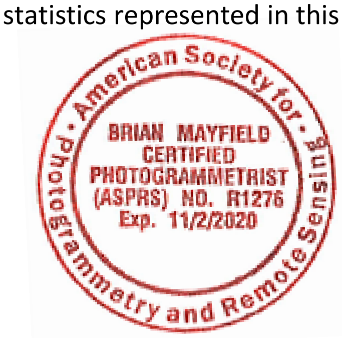
The accuracy assessment confirms that the data may be used for the intended applications stated in the **Project Purpose** section of this document. The dataset may also be used as a topographic input for other applications, but the user should be aware that this lidar dataset was designed with a specific purpose and was not intended to meet specifications and/or requirements of users outside of the United States Geological Survey.

It should also be noted that lidar points do not represent a continuous surface model. Lidar points are discrete measurements of the surface and any values derived within a triangle of three lidar points are interpolated. As such, the user should not use the resultant lidar dataset for vertical placement of a planimetric feature such as a headwall, building footprint or any other planimetric feature unless there is an associated lidar point that can be reasonably located on this structure.

Consideration should be given by the end user of this dataset to the fact that this lidar dataset was developed differently and that previous lidar datasets that may be available for this geographic location. It is likely that the data in this project was created using different geodetic control, a different Geoid, newer lidar technology and more up-to-date processing techniques. As such, any direct comparative analysis performed between this dataset and previous datasets could result in misleading or inaccurate results. Users are encouraged to proceed with caution while performing this type of comparative analysis and to completely understand the variables that make each of these datasets unique and not corollary.

It is encouraged that the user refers to the full FGDC Metadata and project reports for a complete understanding on the content of this dataset.

I, hereby, certify to the extent of my knowledge that the statements and statistics represented in this document are true and factual.



Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

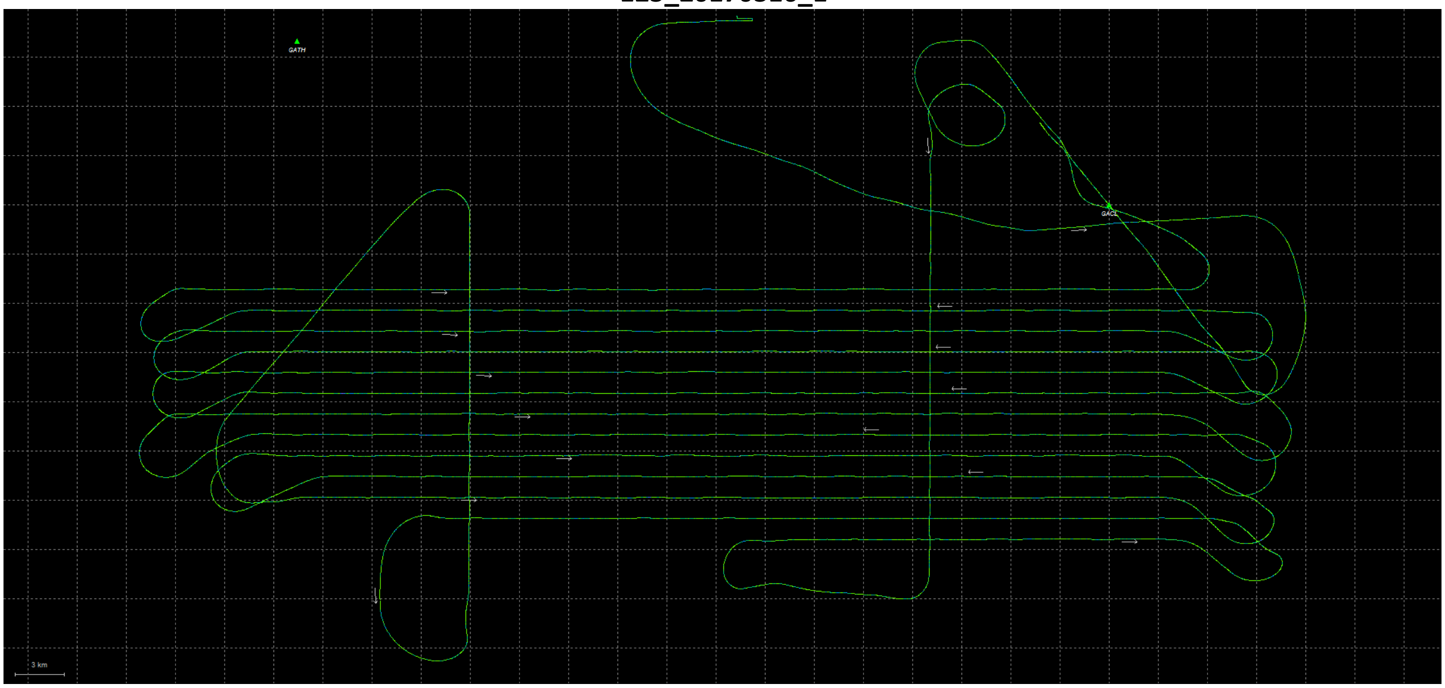
Section 6: GPS Processing

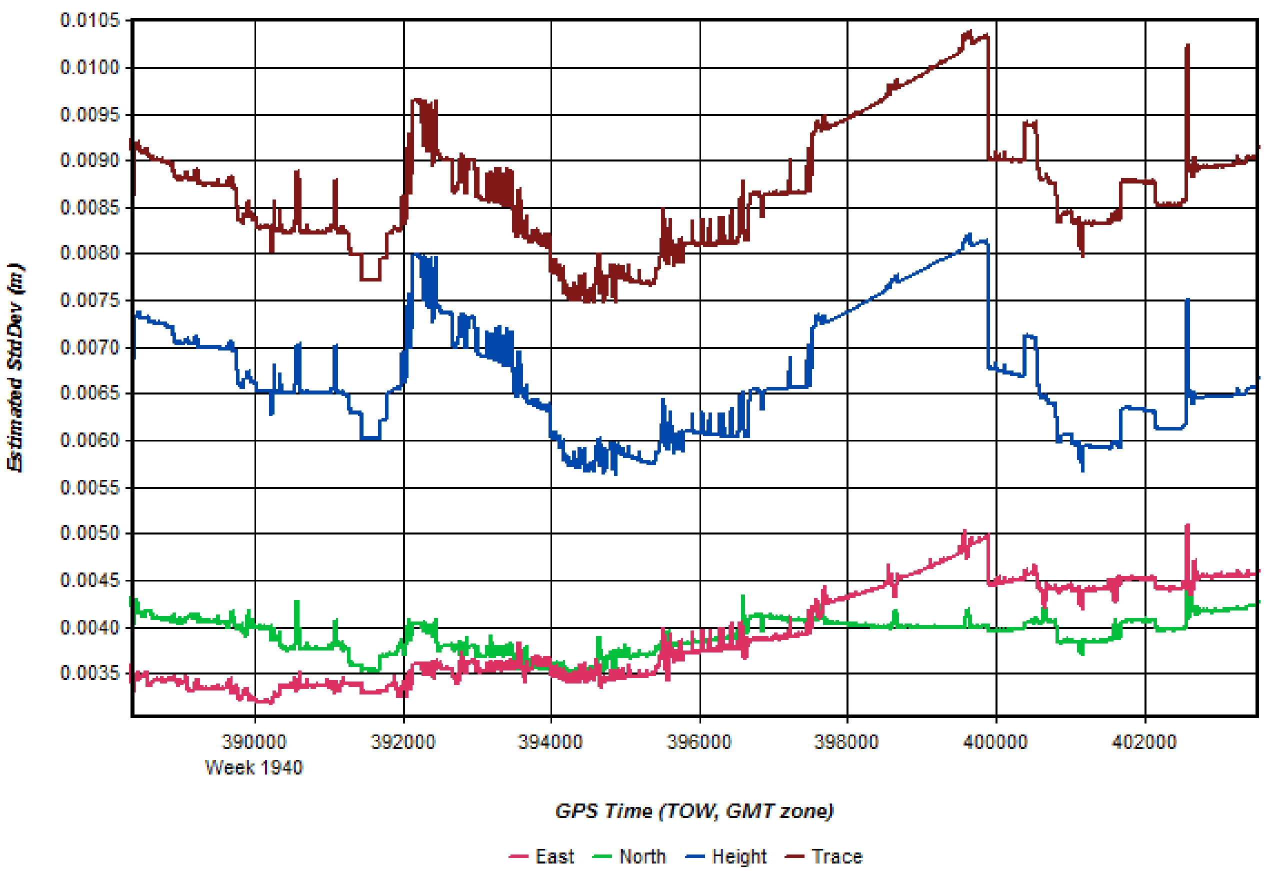
Inertial Explorer Version 8.60.5025

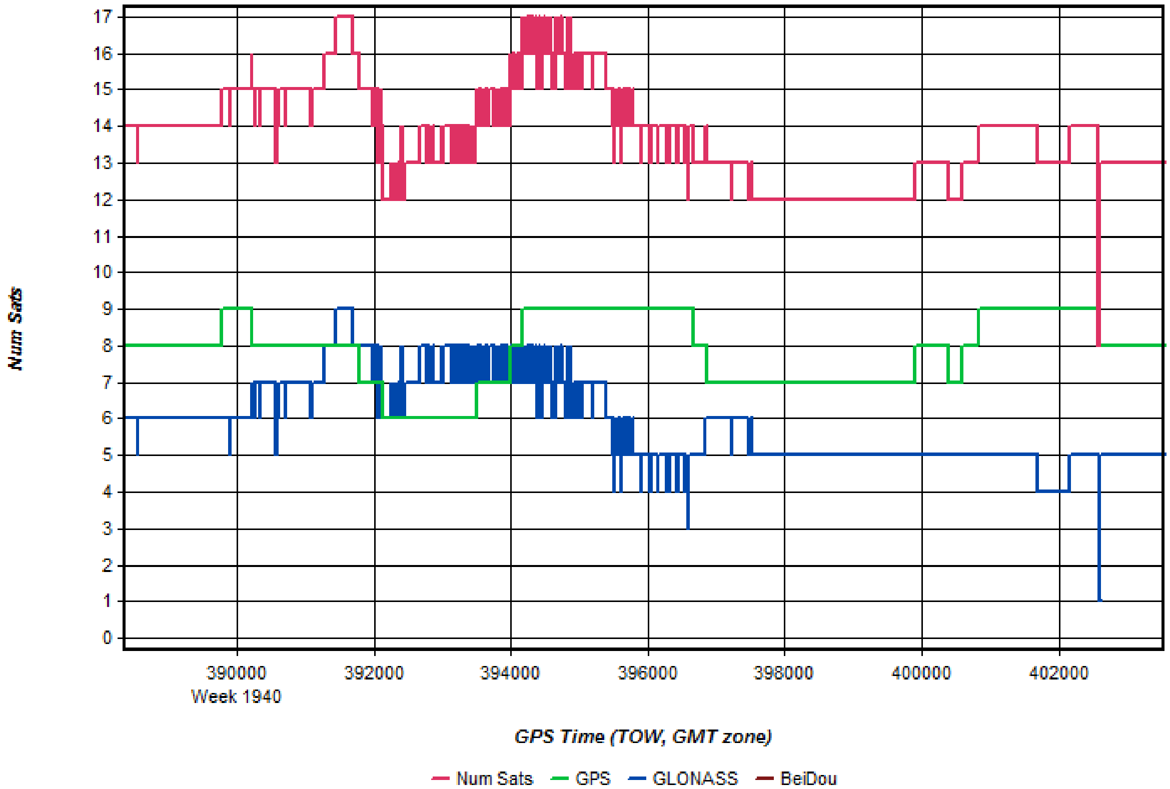
Plots by Mission: Coverage Map, Estimated Position Accuracy, Number of Satellites, Combined Separation, and PDOP.

Coverage Map	The Coverage Map plot shows the Aircraft GPS-IMU Trajectory in reference to localized GPS Reference Stations.
Estimated Position Accuracy	The Estimated Position Accuracy plot shows the standard deviations of the east, north, and up directions versus time for the solution. The total standard deviation with a distance dependent component is also plotted.
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.
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.
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. PDOP spikes can occur on aircraft turns were the antenna angle is unfavorable, these spikes while aesthetically unfavorable do not generally reduce the accuracy of the acquired data.

123_20170316_1



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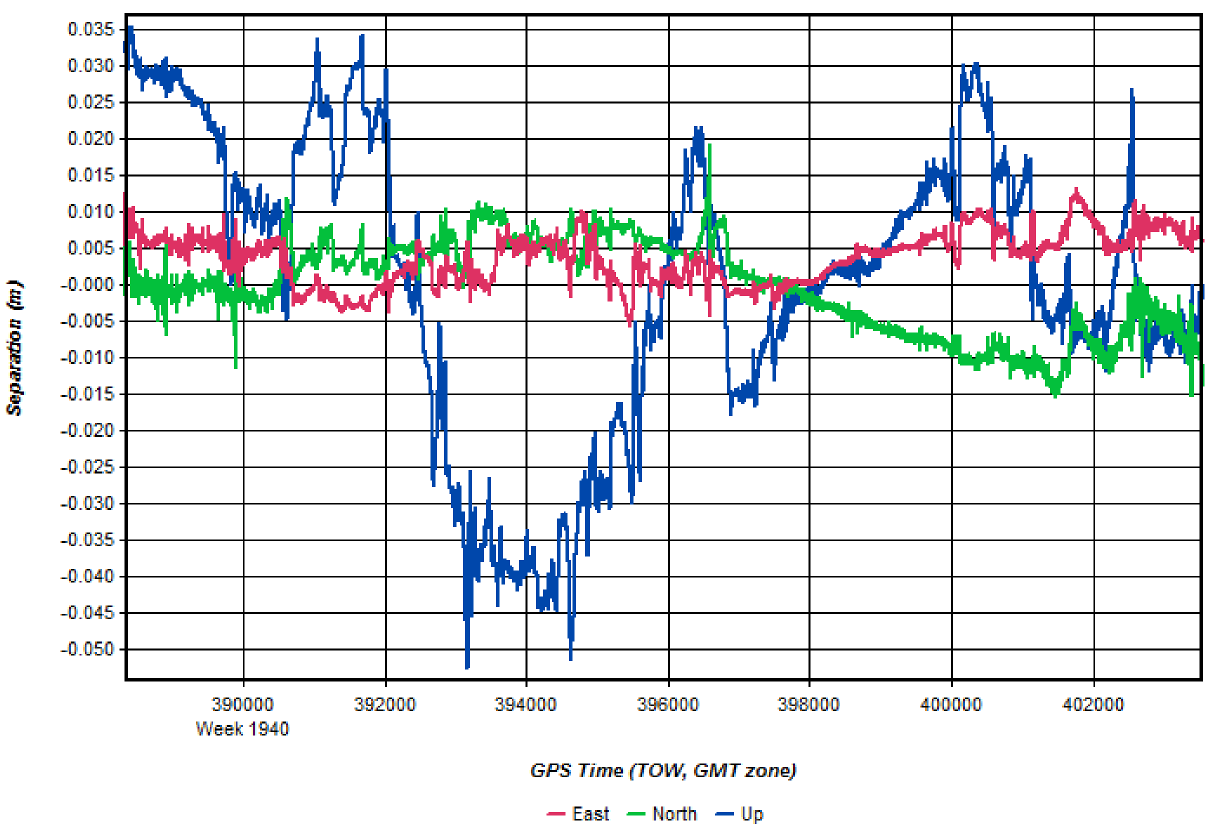
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East
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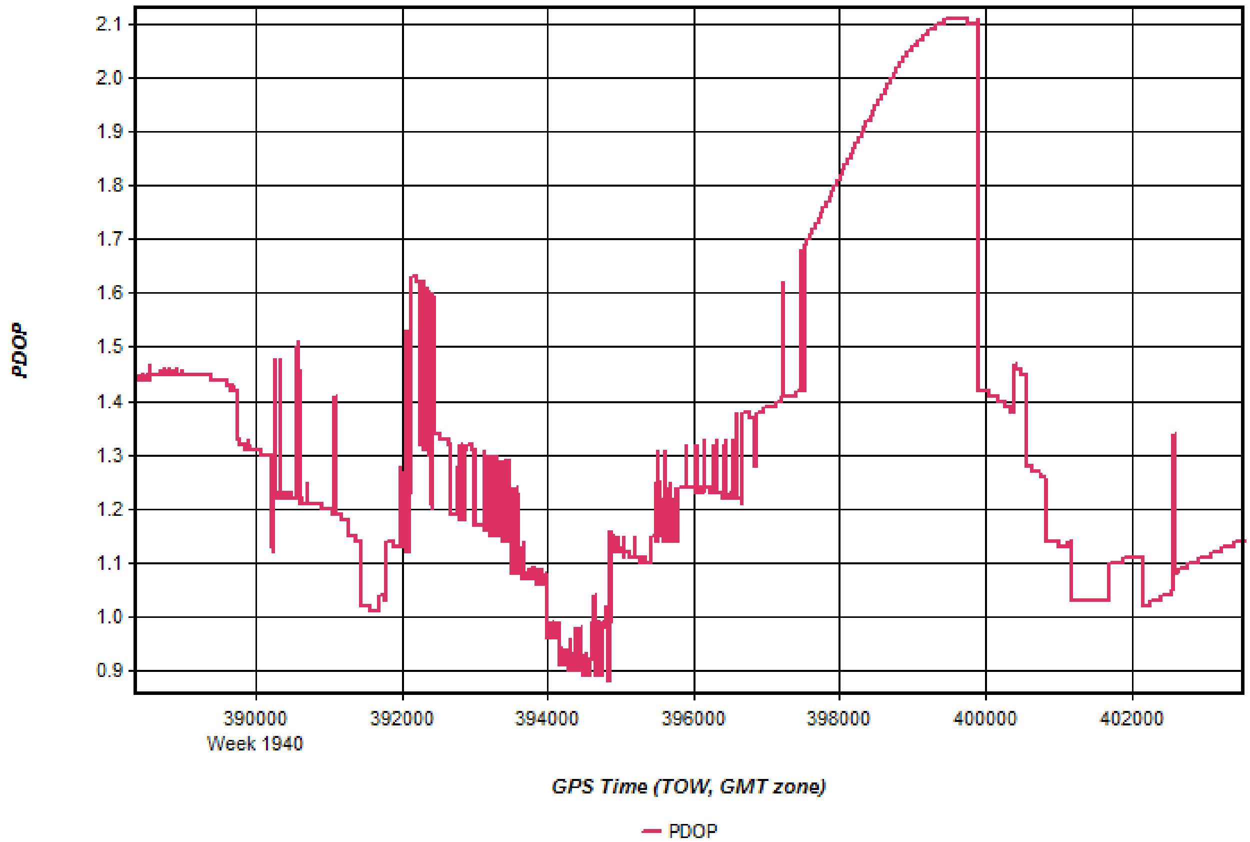
Up



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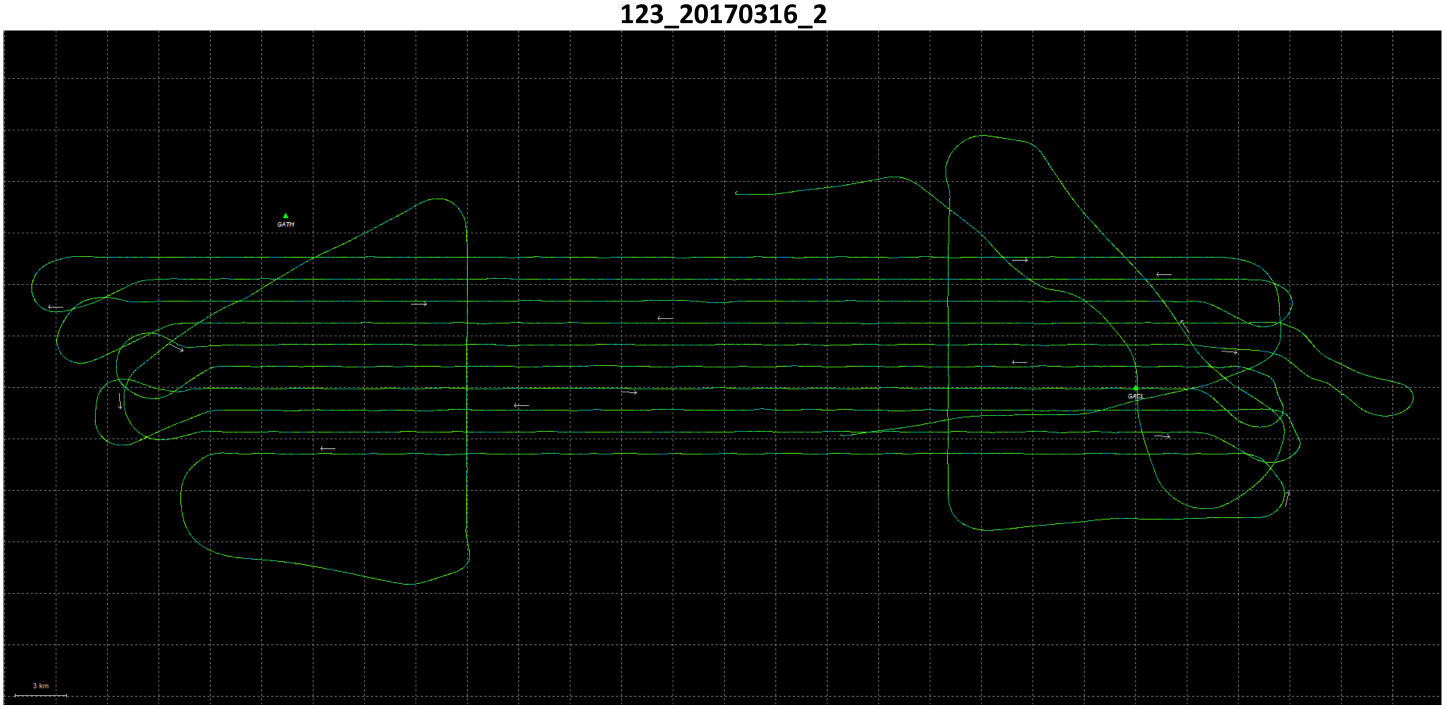

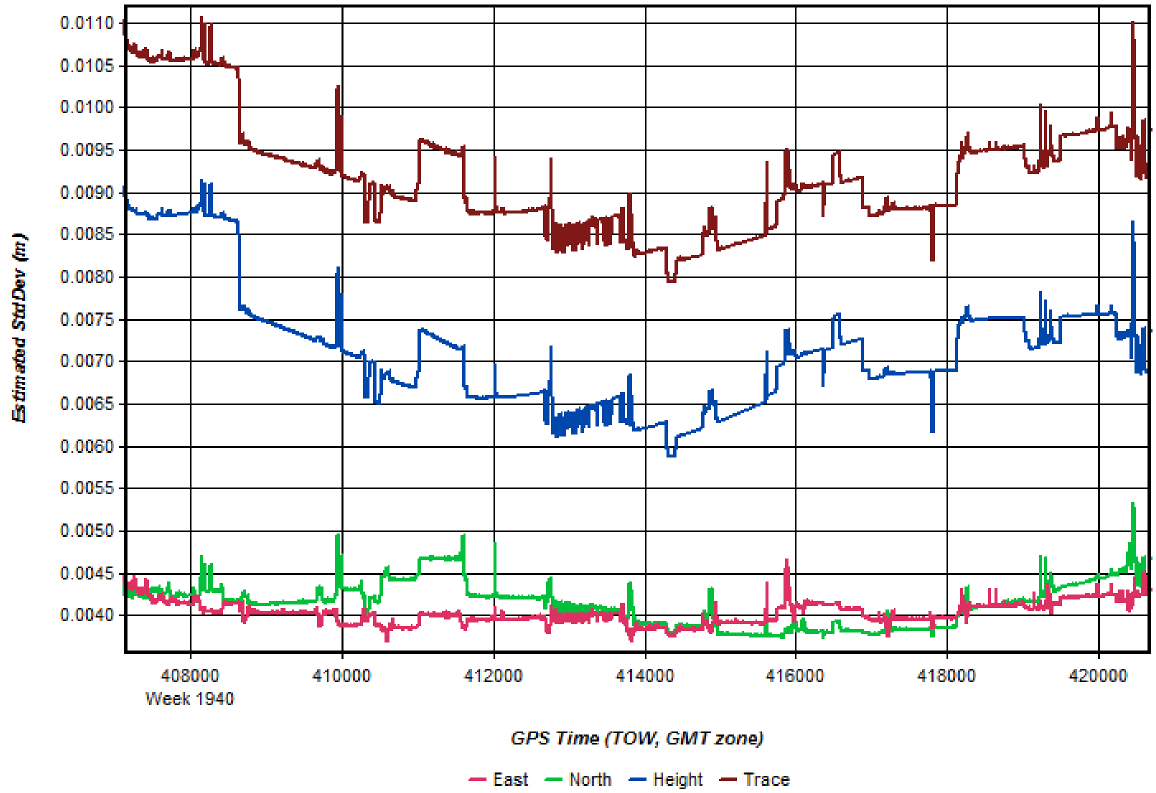
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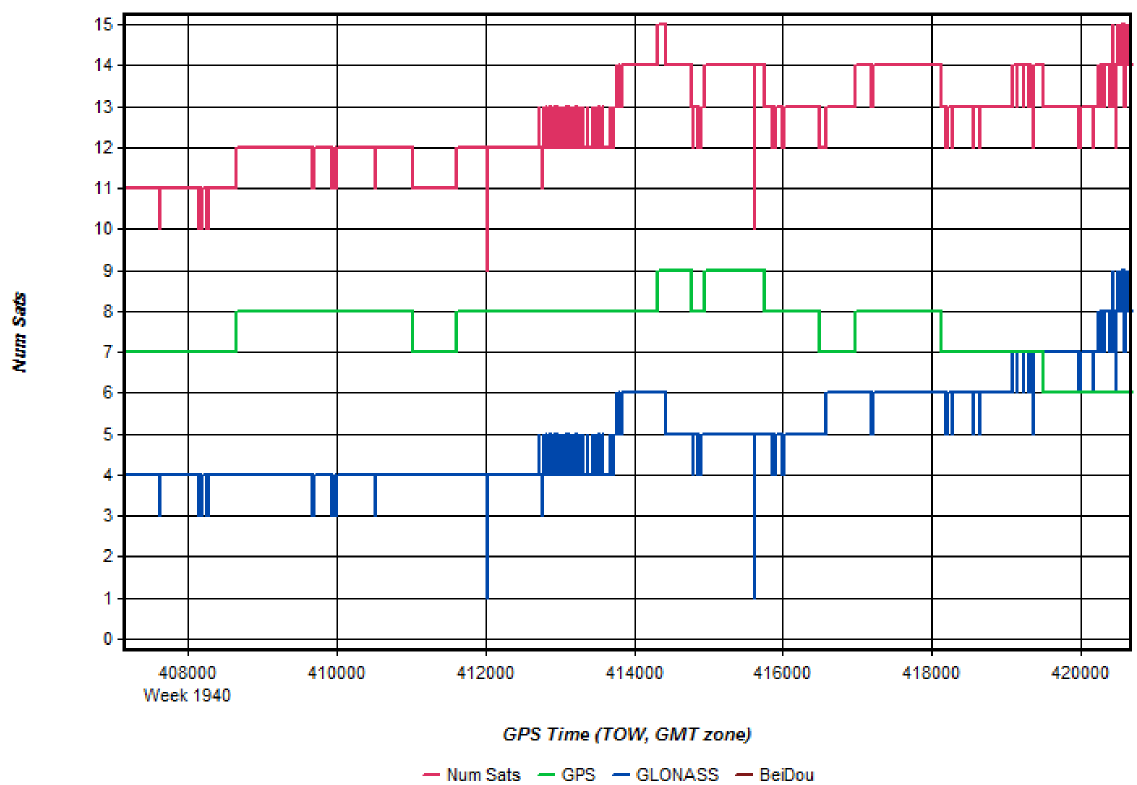
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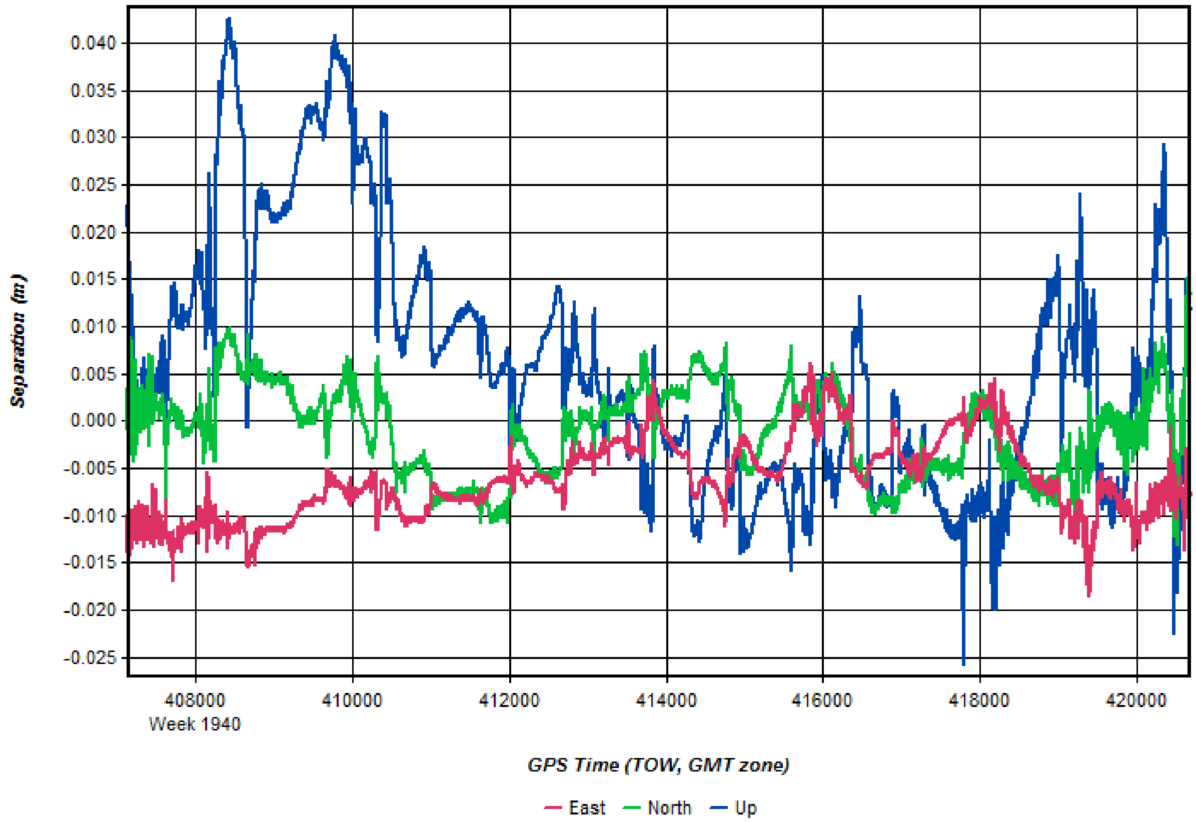
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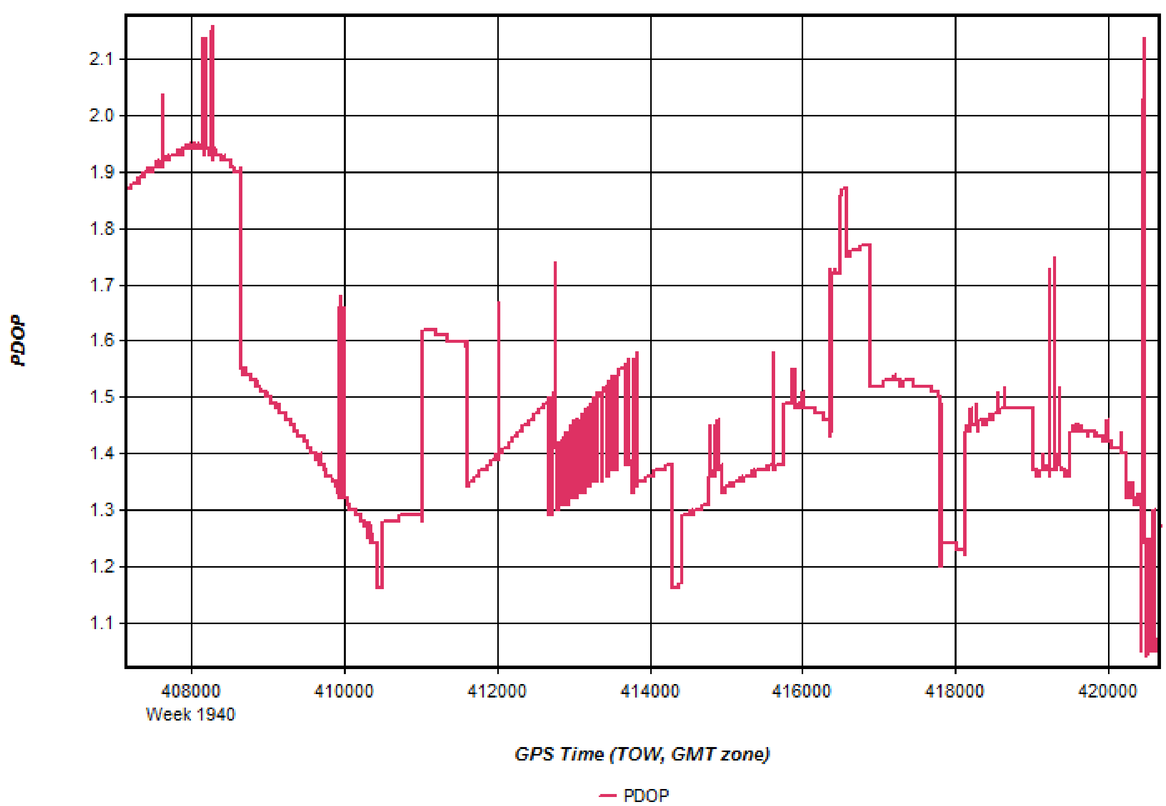
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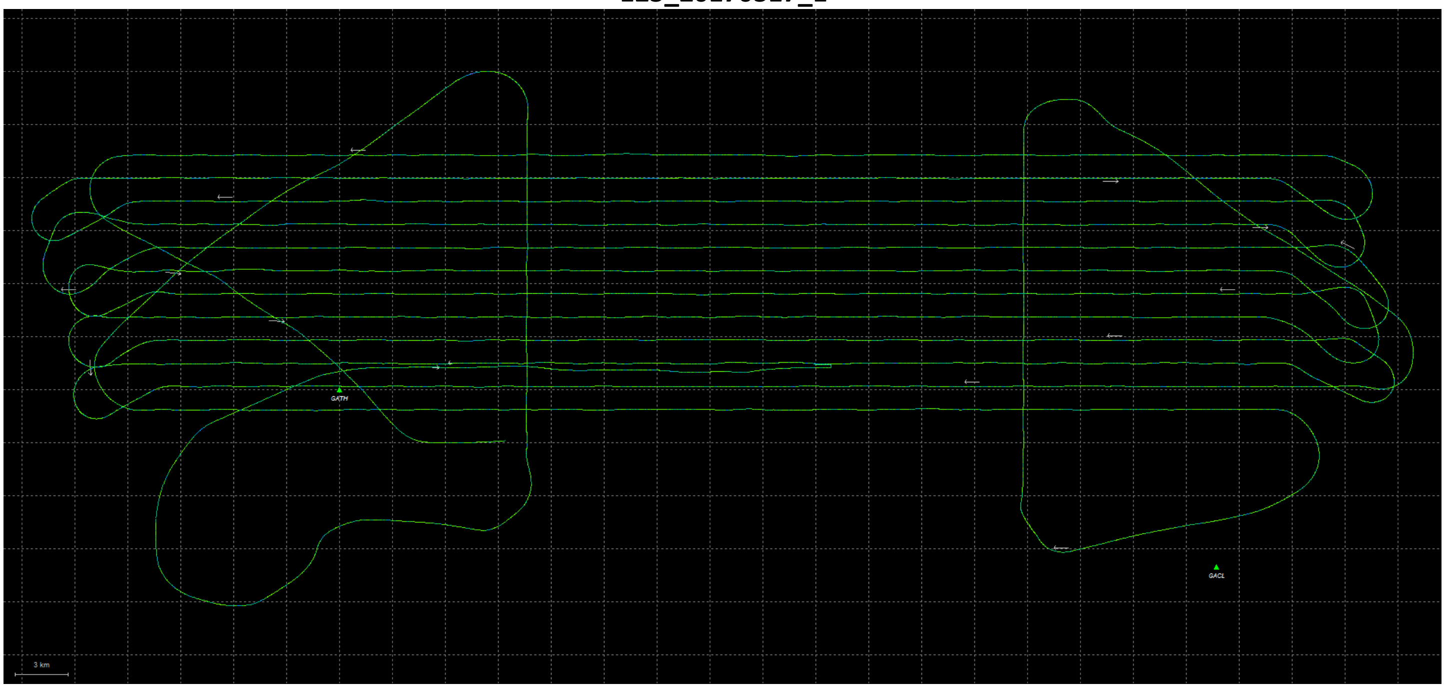

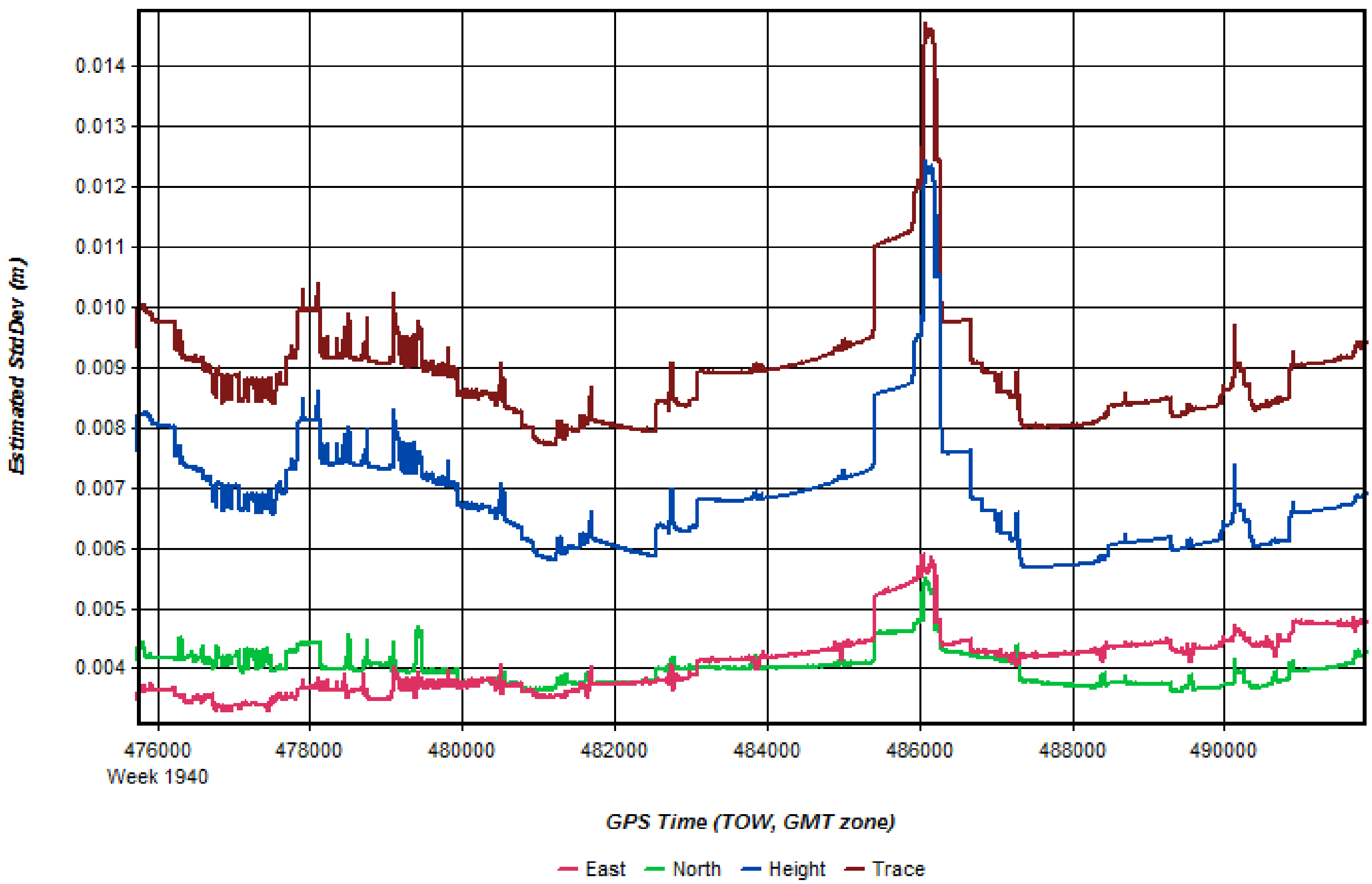

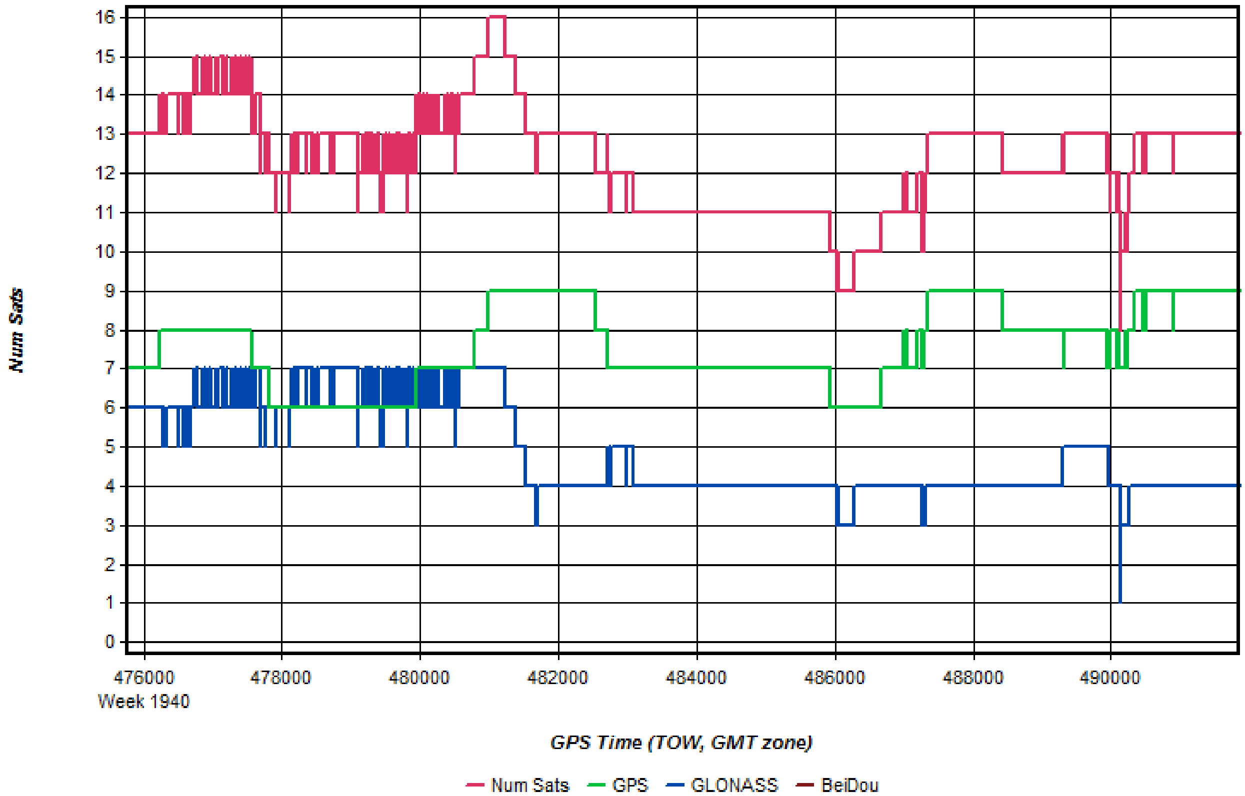
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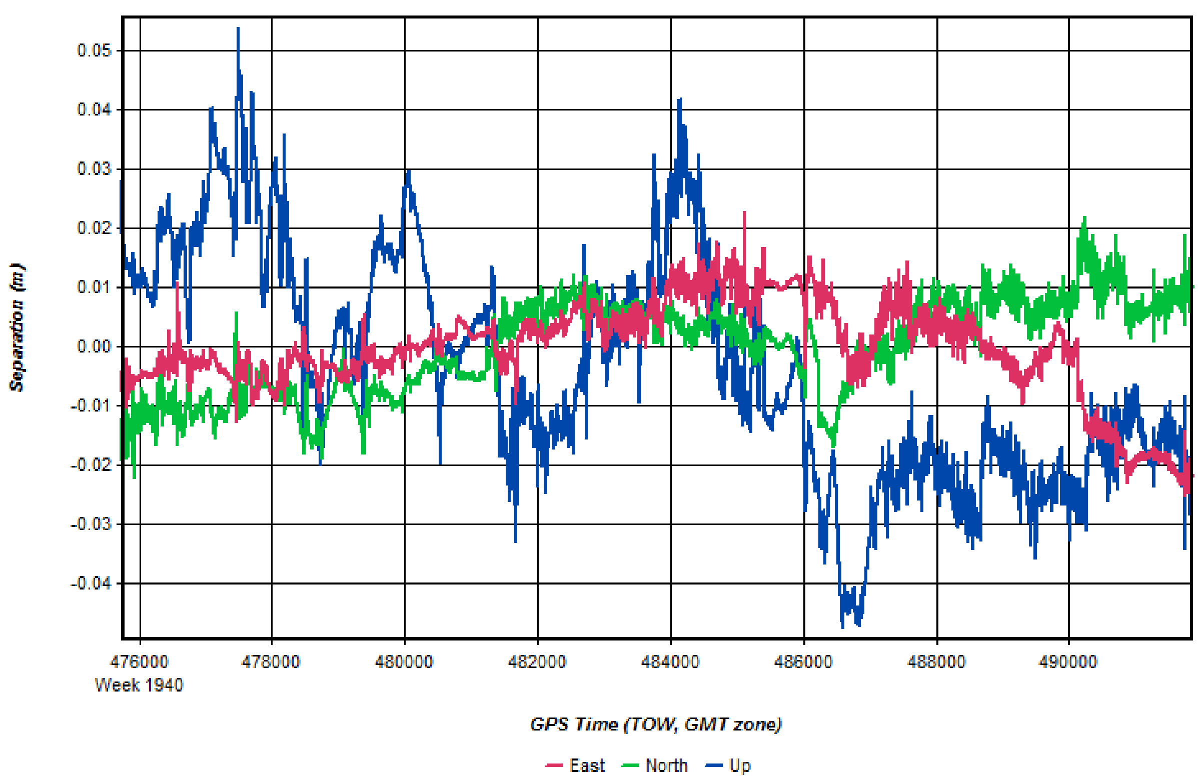
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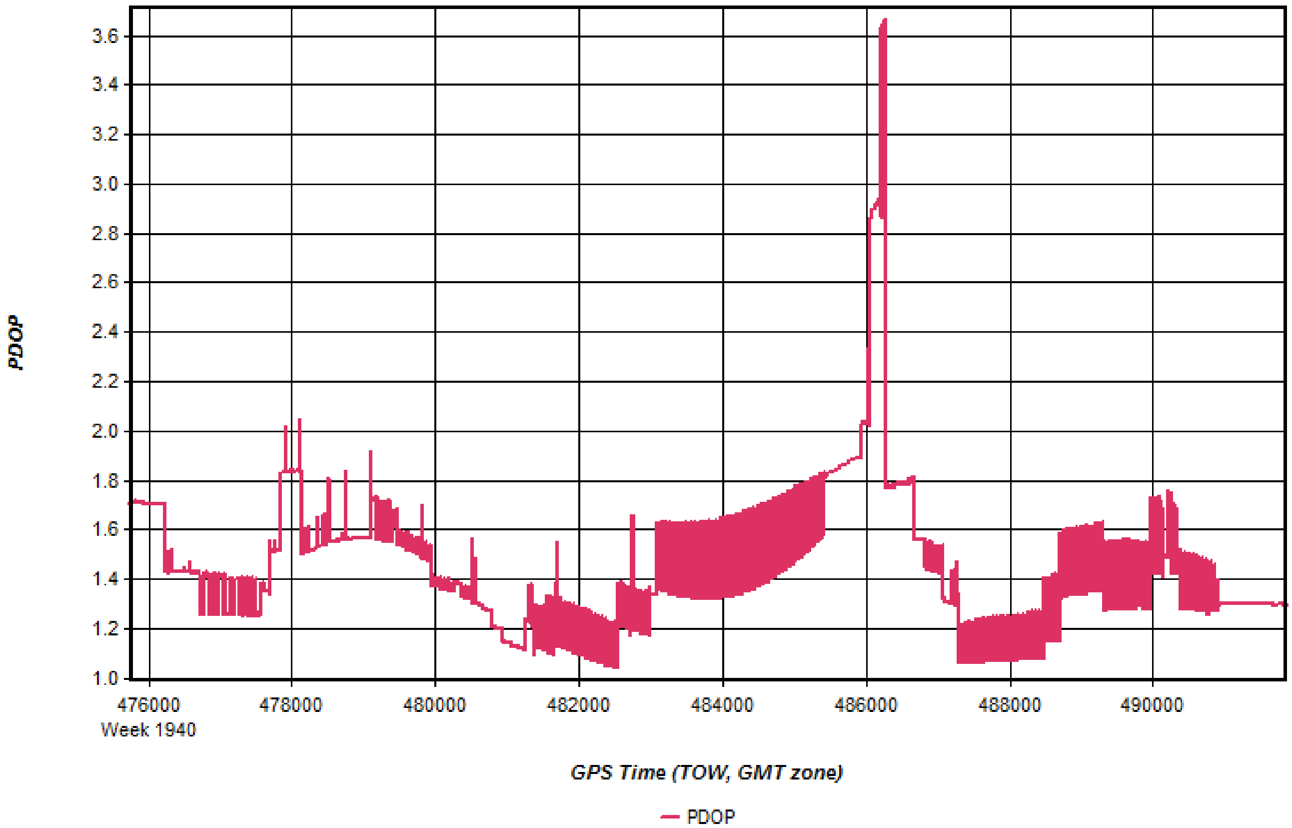

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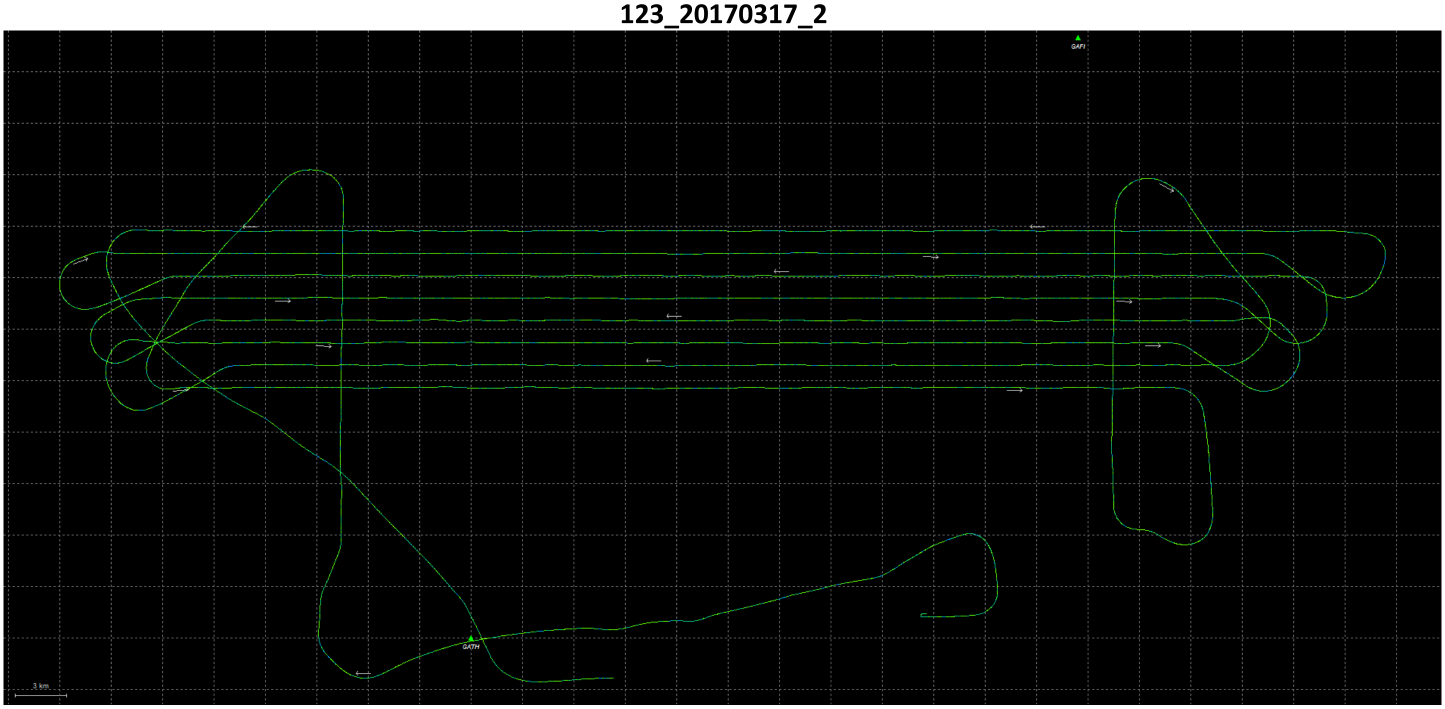

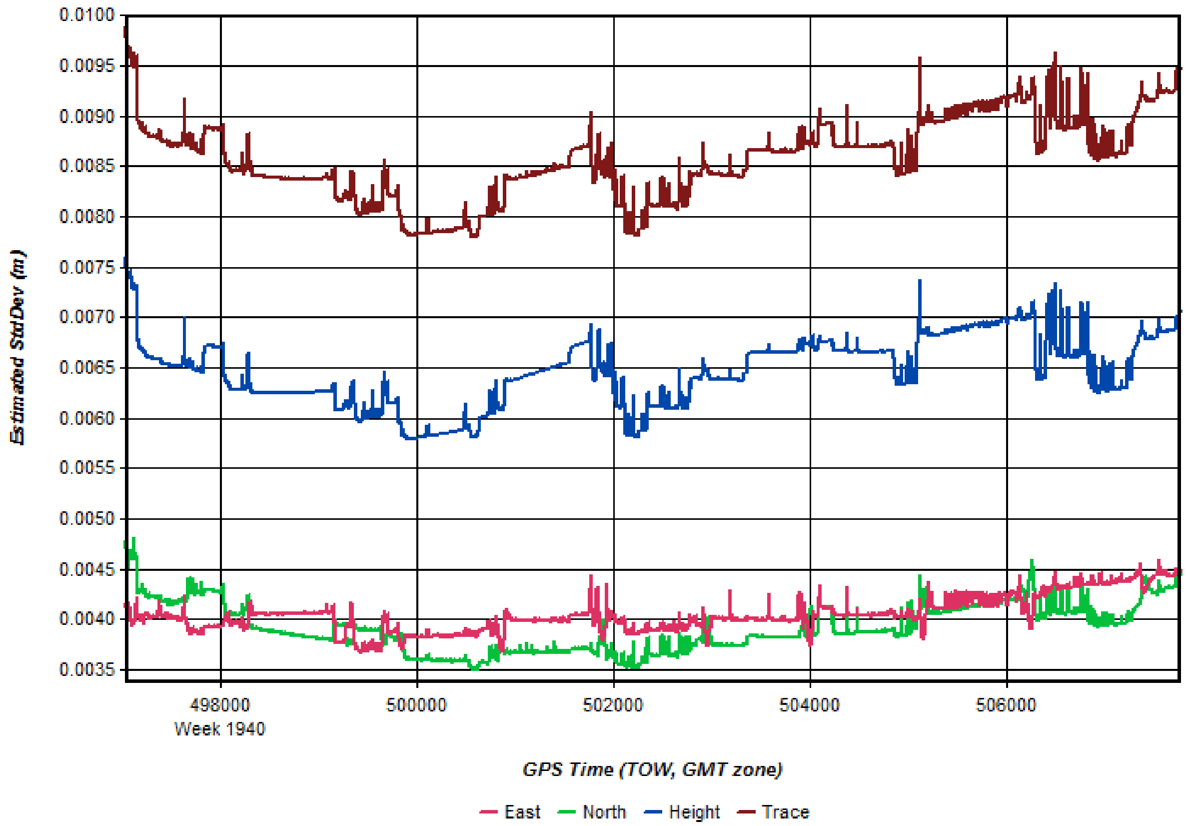
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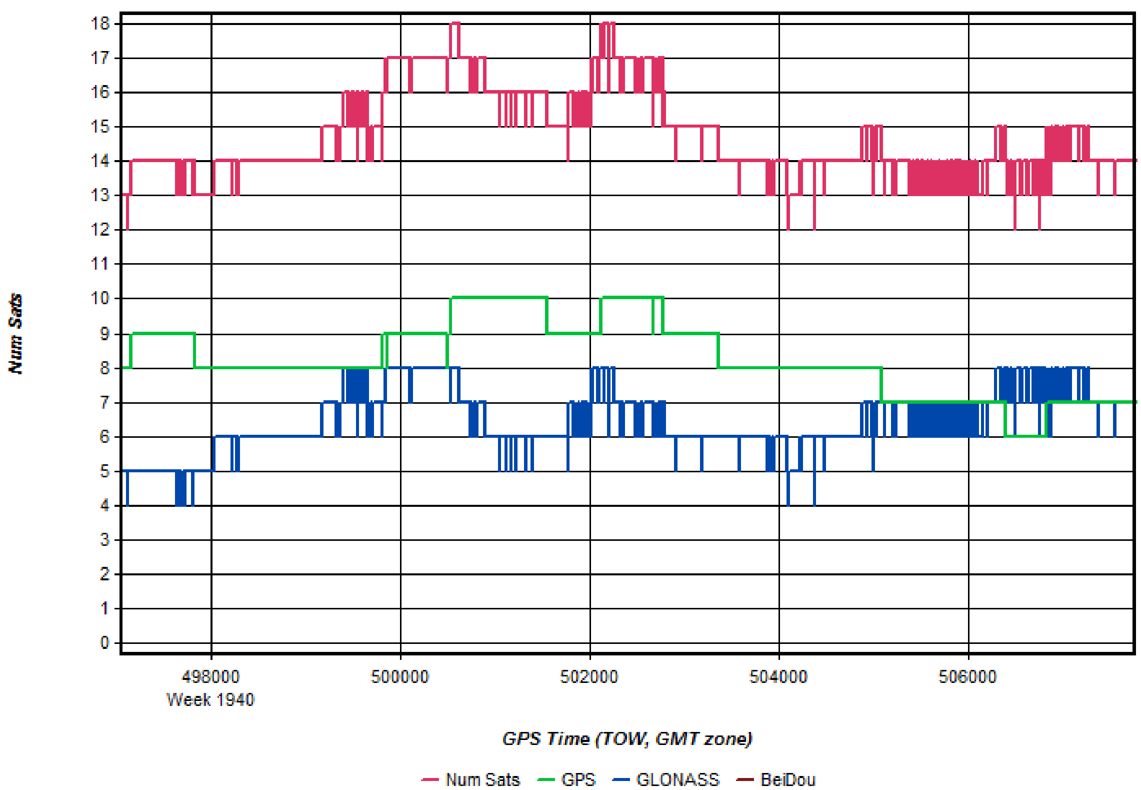
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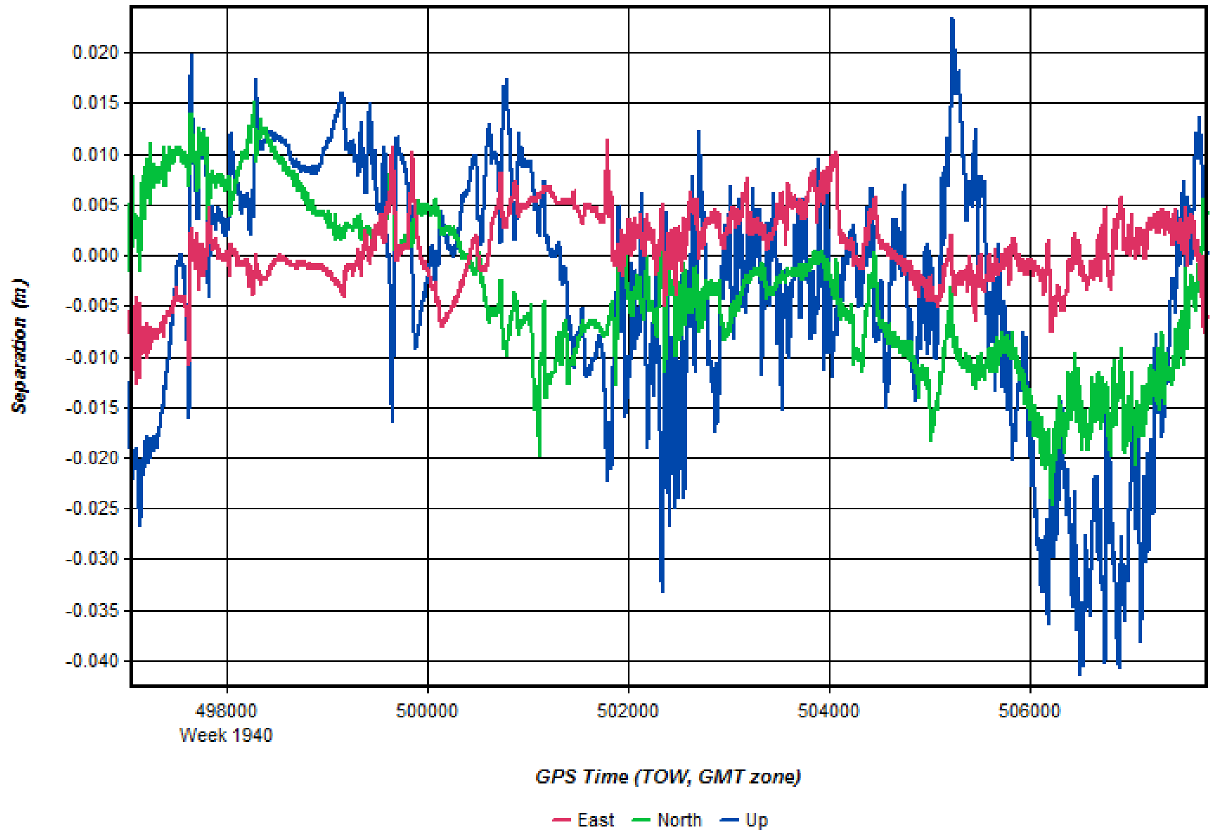
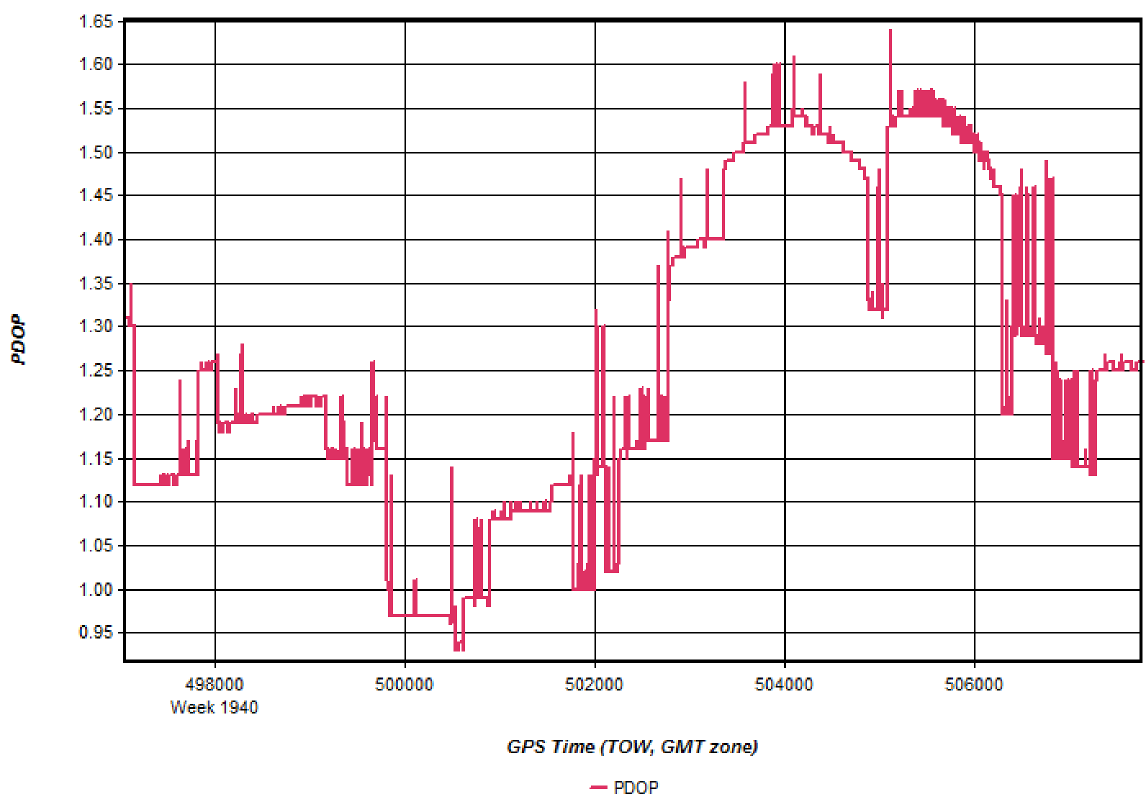
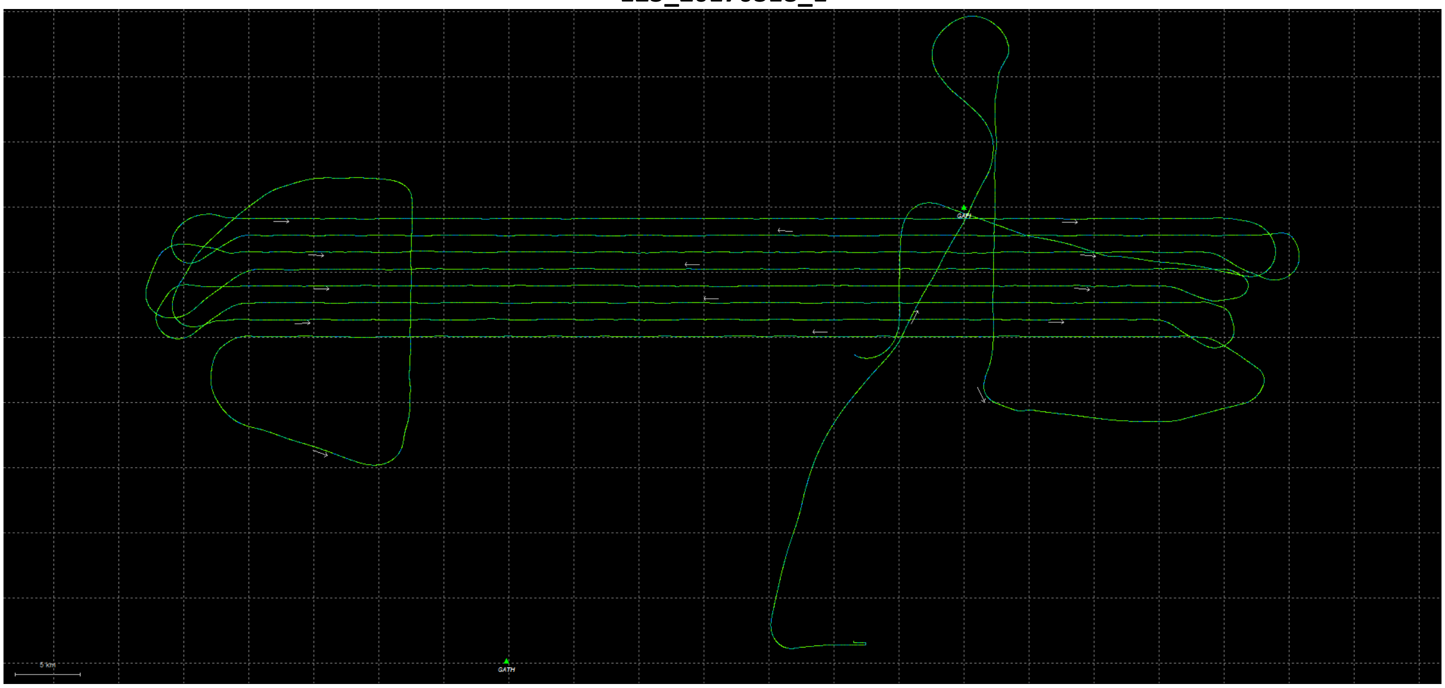
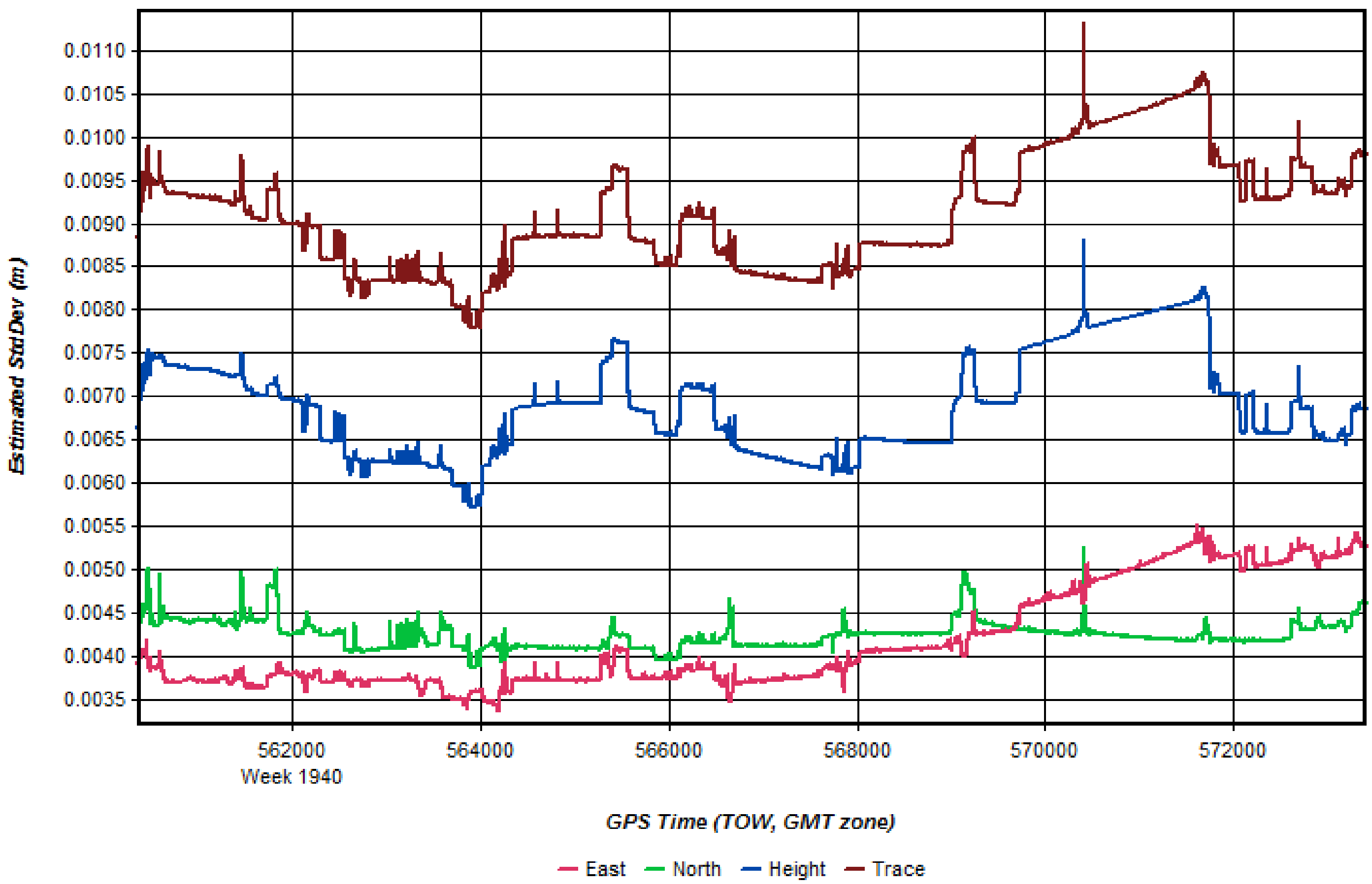
GLONASS
BeiDou


Separation (m)
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
498000
Week 1940
500000
502000
504000
506000
GPS Time (TOW, GMT zone)
East
North
Up

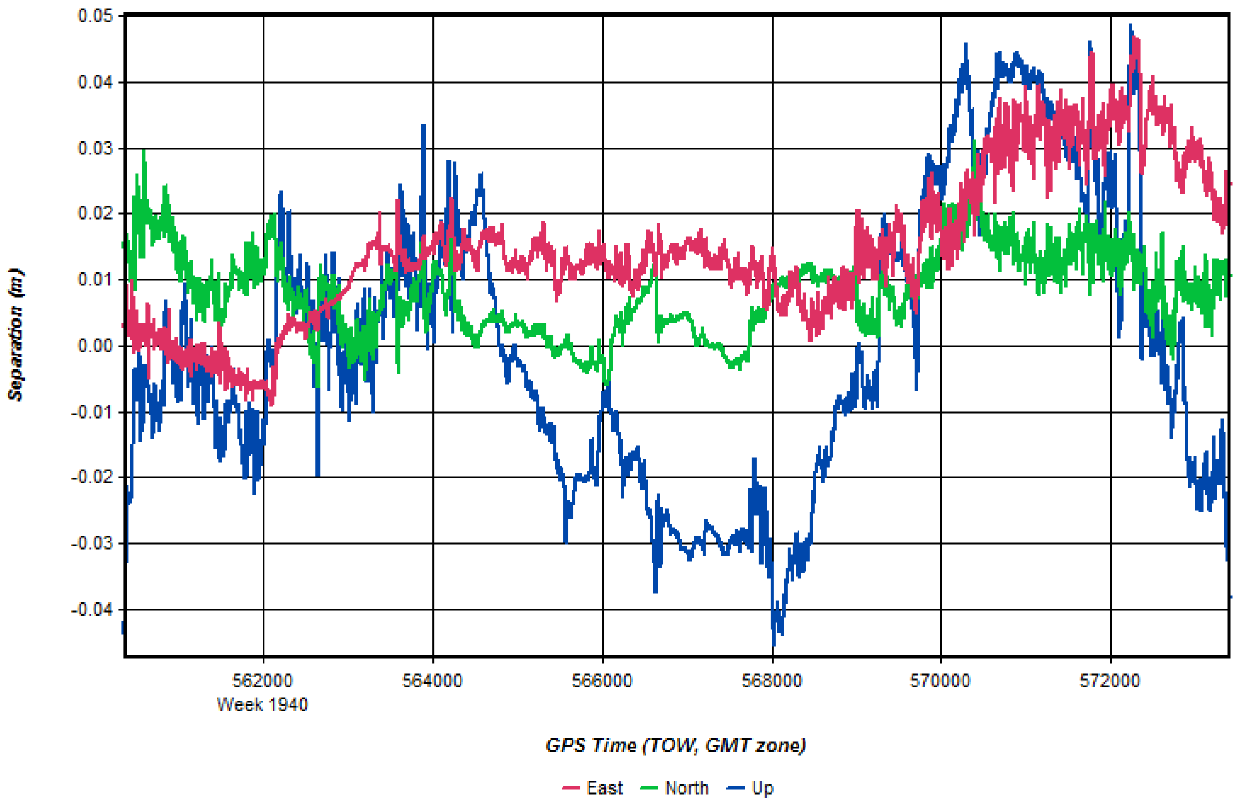

PDOP
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
498000
Week 1940
500000
502000
504000
506000
GPS Time (TOW, GMT zone)
PDOP

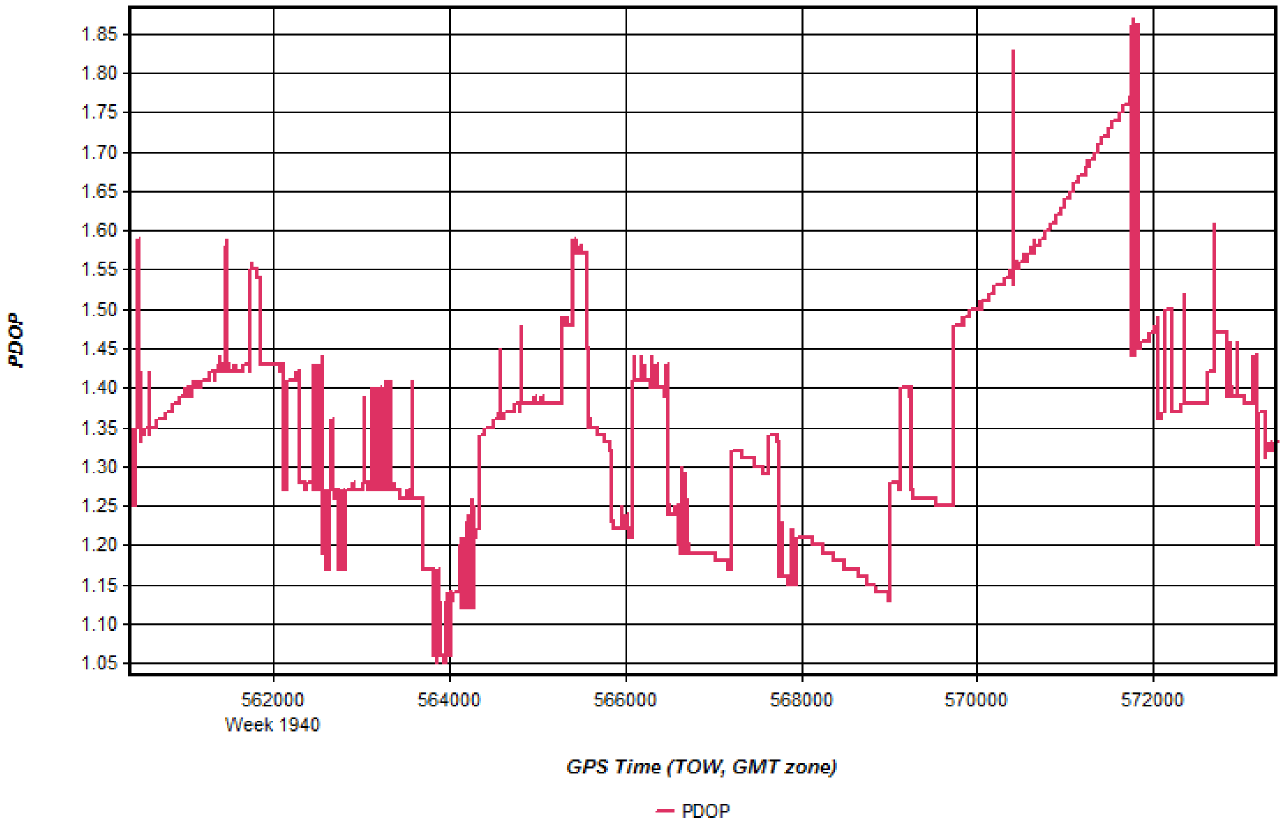
123_20170318_1



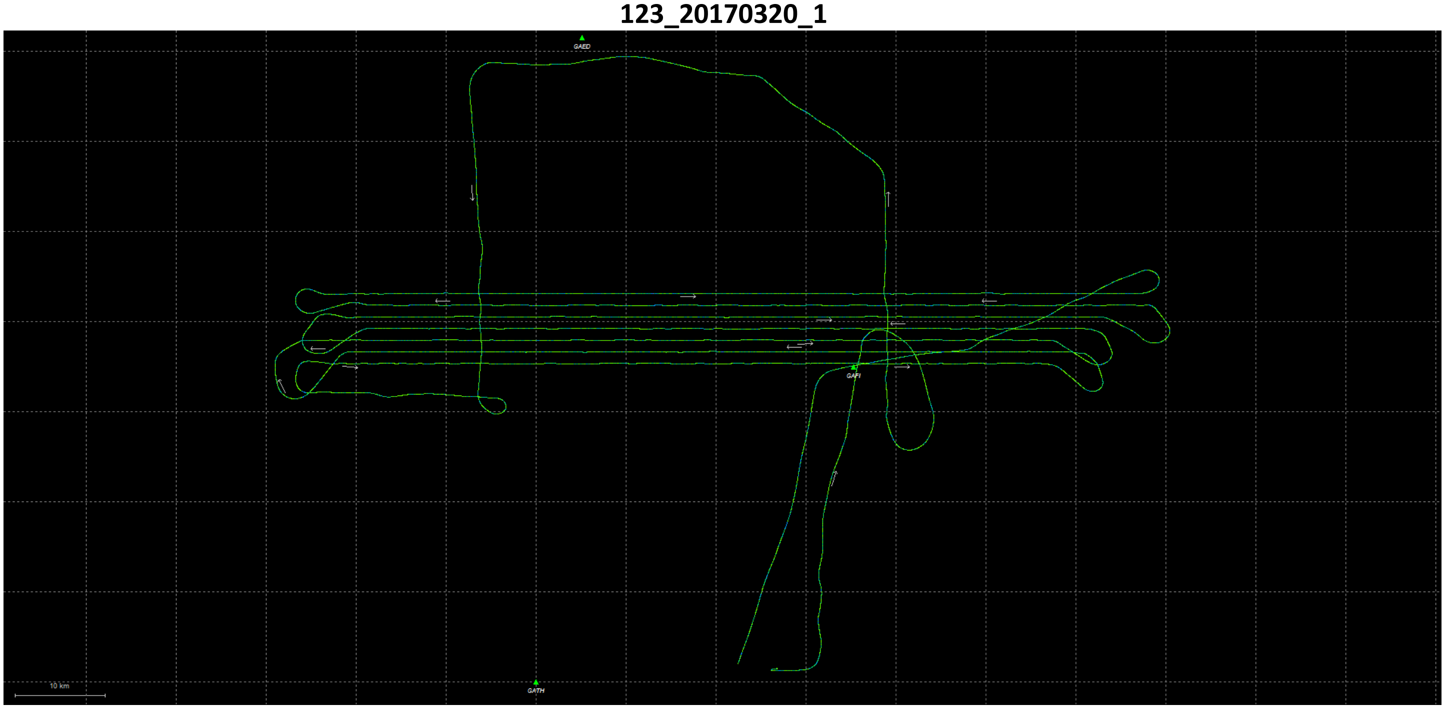


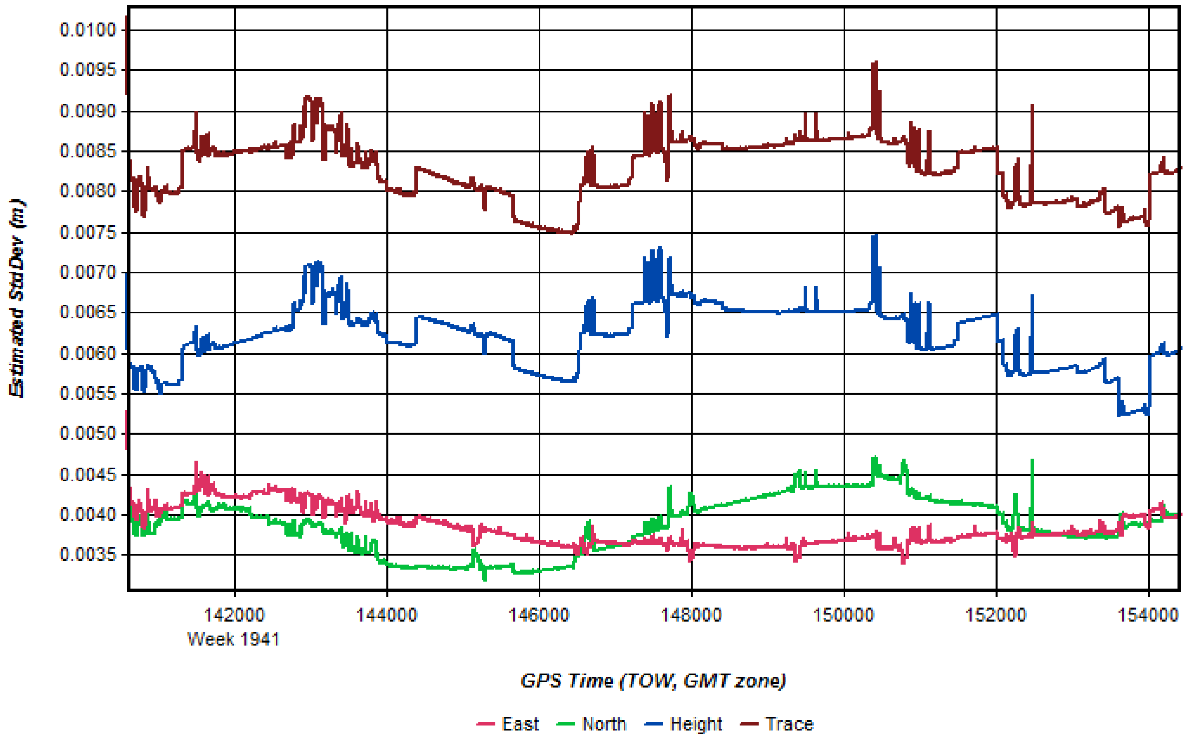

12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
562000
Week 1940
564000
566000
568000
570000
572000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

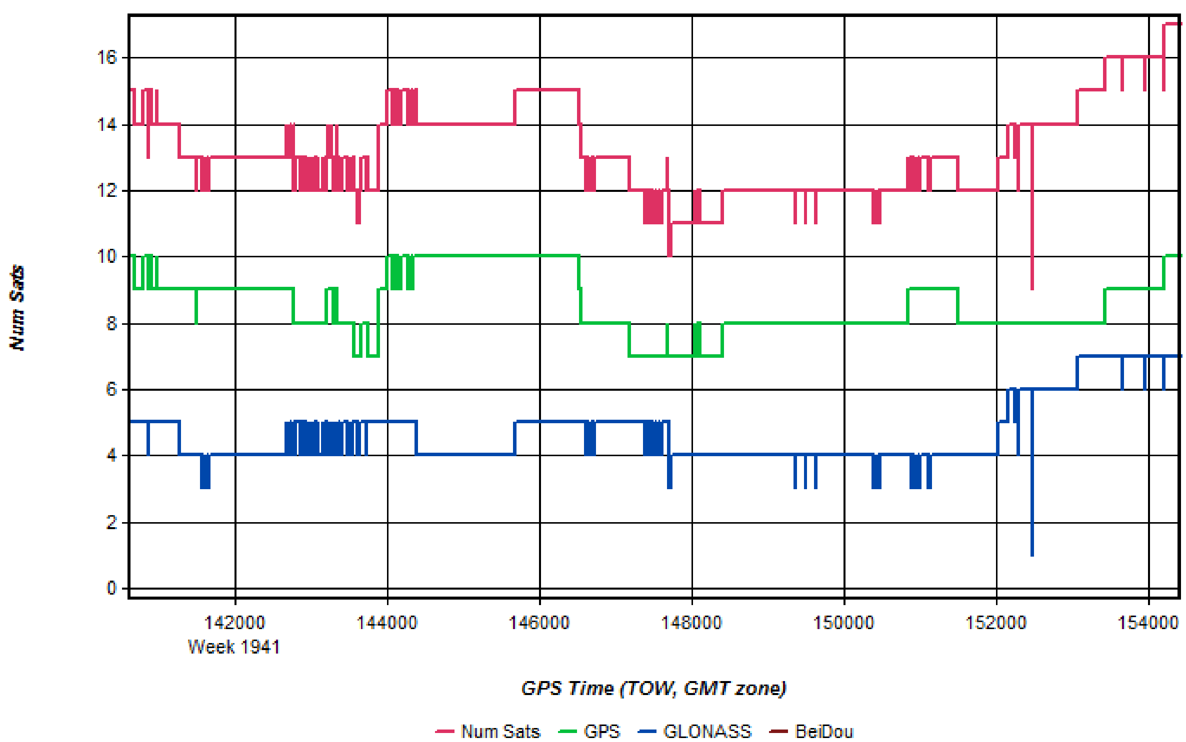

0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
Separation (m)
562000
Week 1940
564000
566000
568000
570000
572000
GPS Time (TOW, GMT zone)
East
North
Up

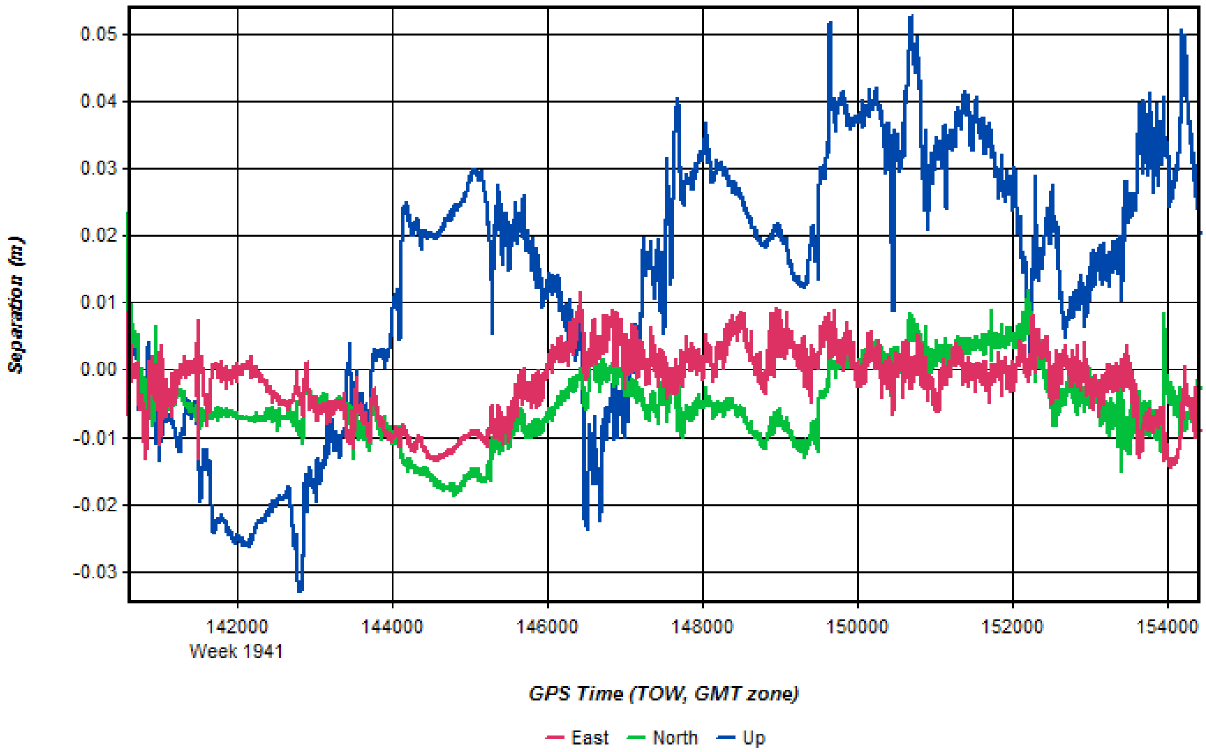


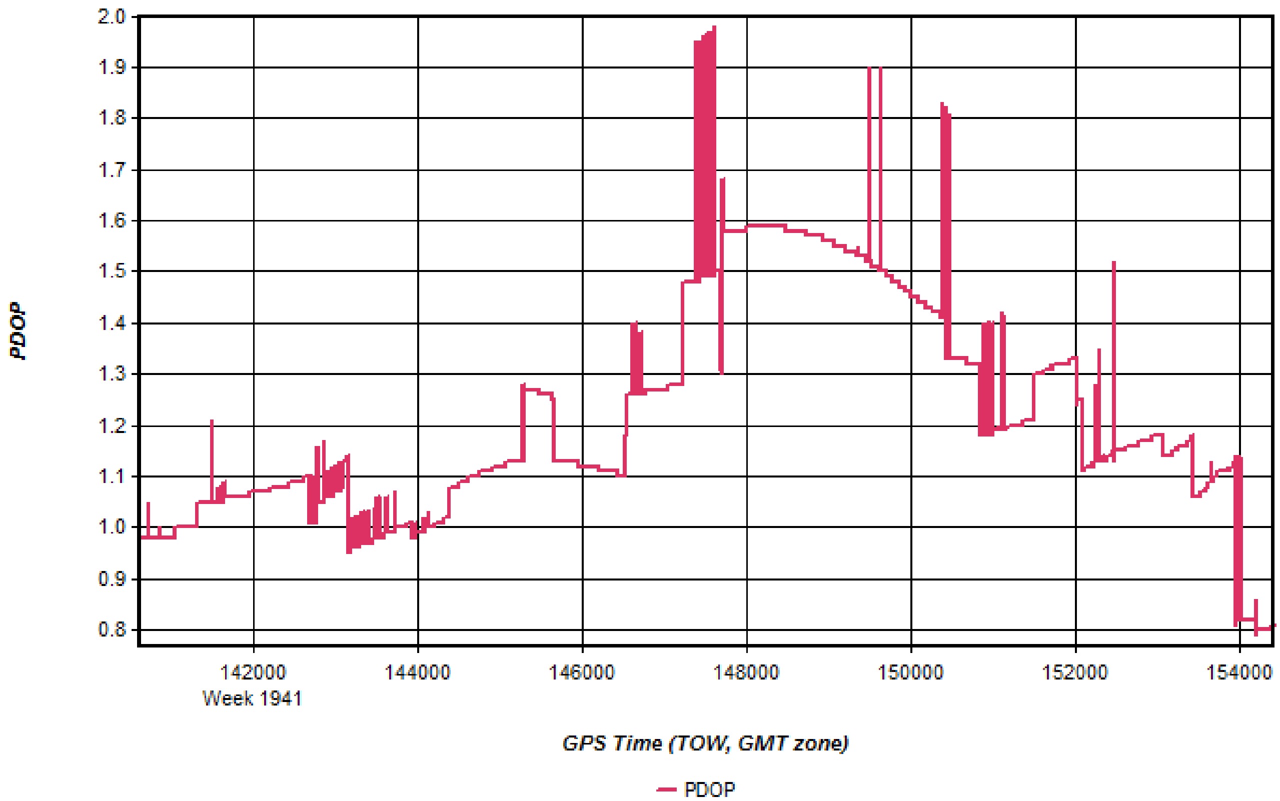
123_20170320_1



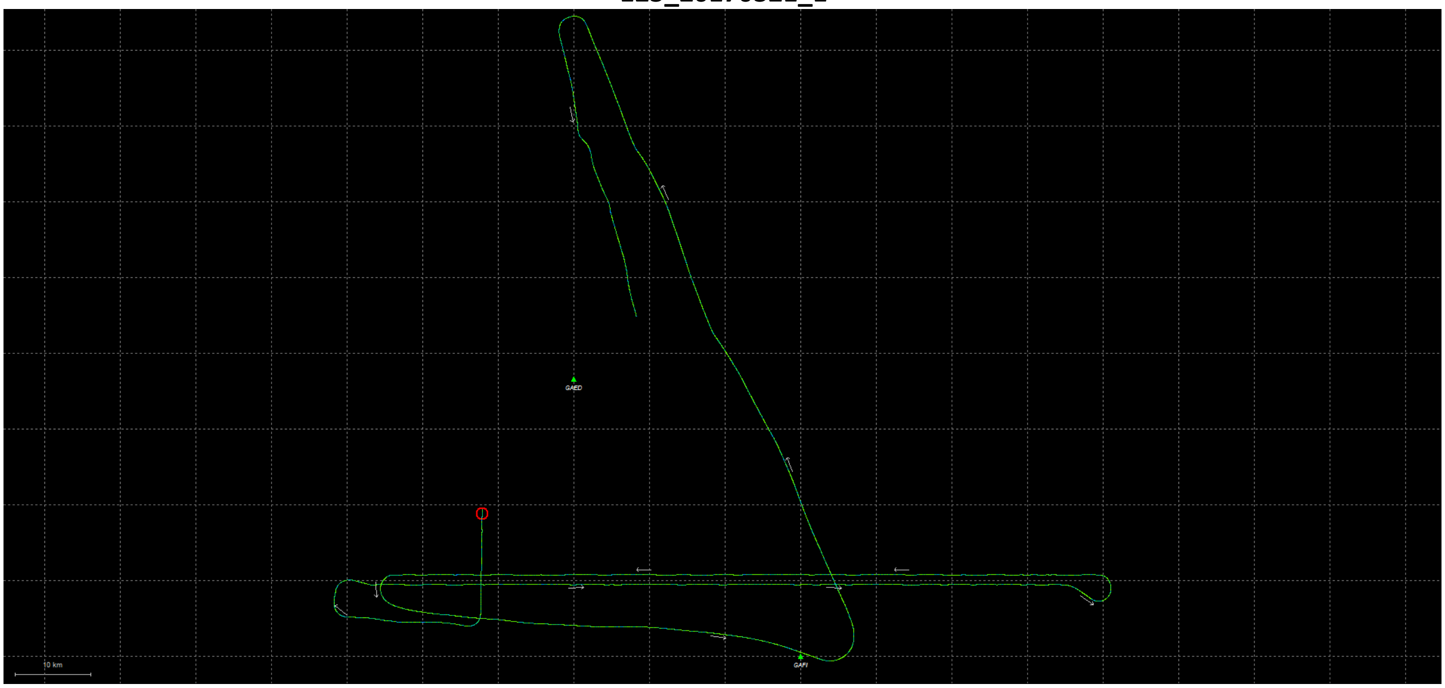

Estimated StdDev (m)
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
142000
Week 1941
144000
146000
148000
150000
152000
154000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

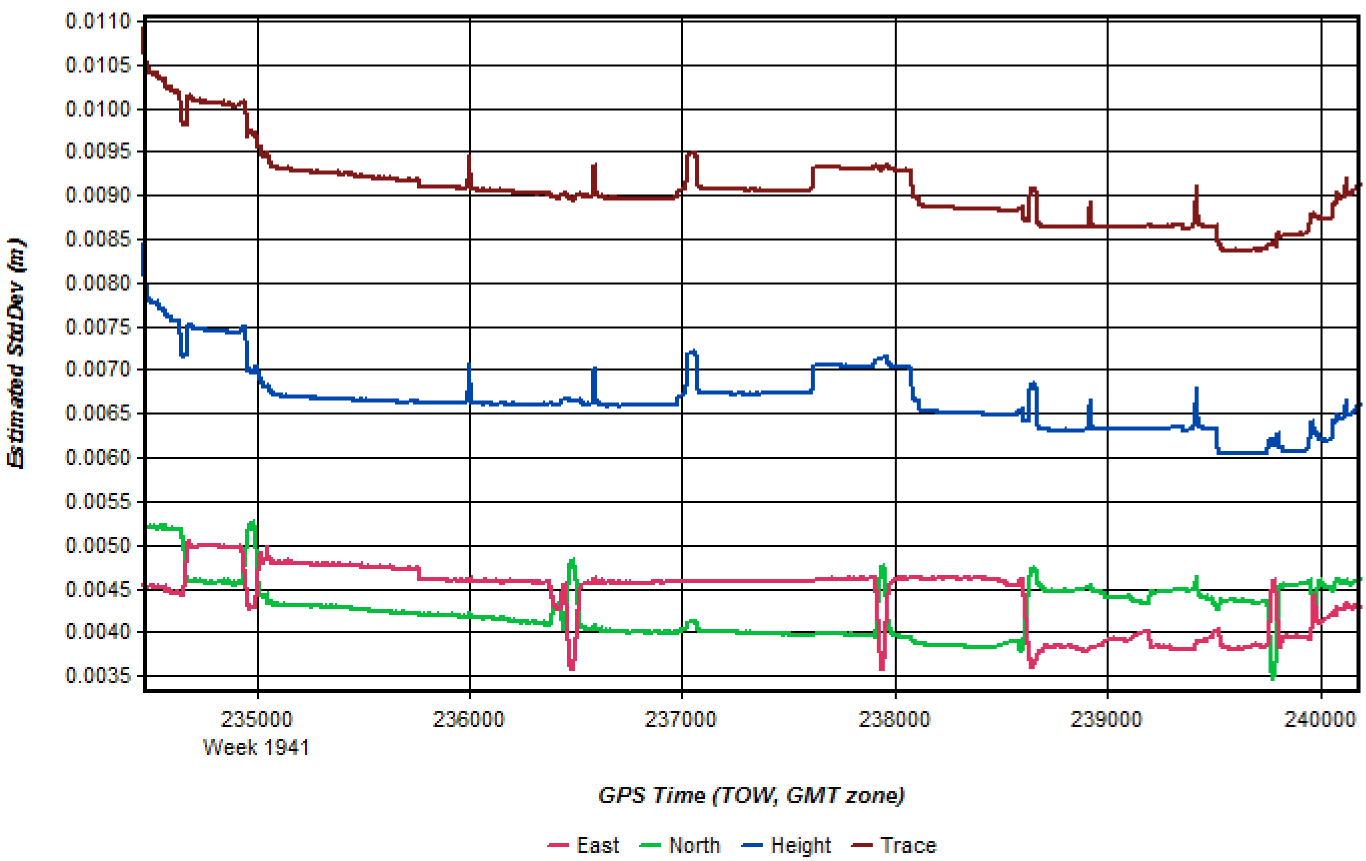

Num Sats
16
14
12
10
8
6
4
2
0
142000
Week 1941
144000
146000
148000
150000
152000
154000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

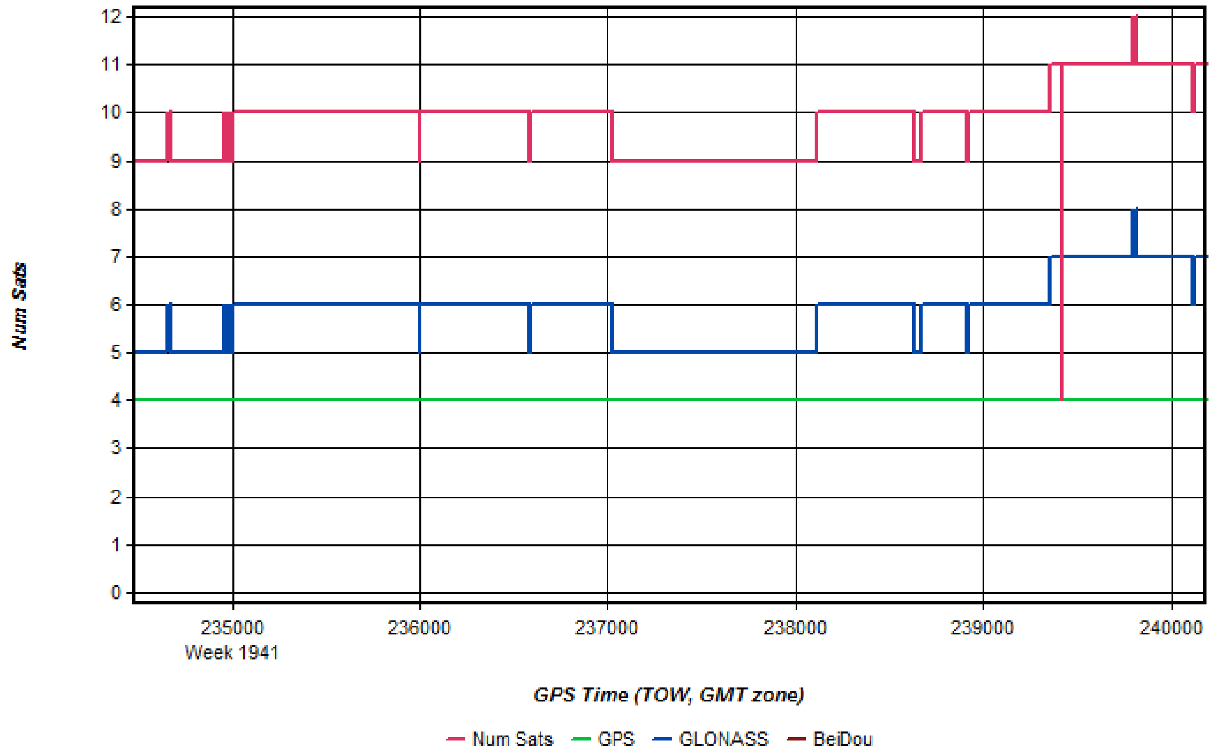

Separation (m)
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
142000
Week 1941
144000
146000
148000
150000
152000
154000
GPS Time (TOW, GMT zone)
East
North
Up

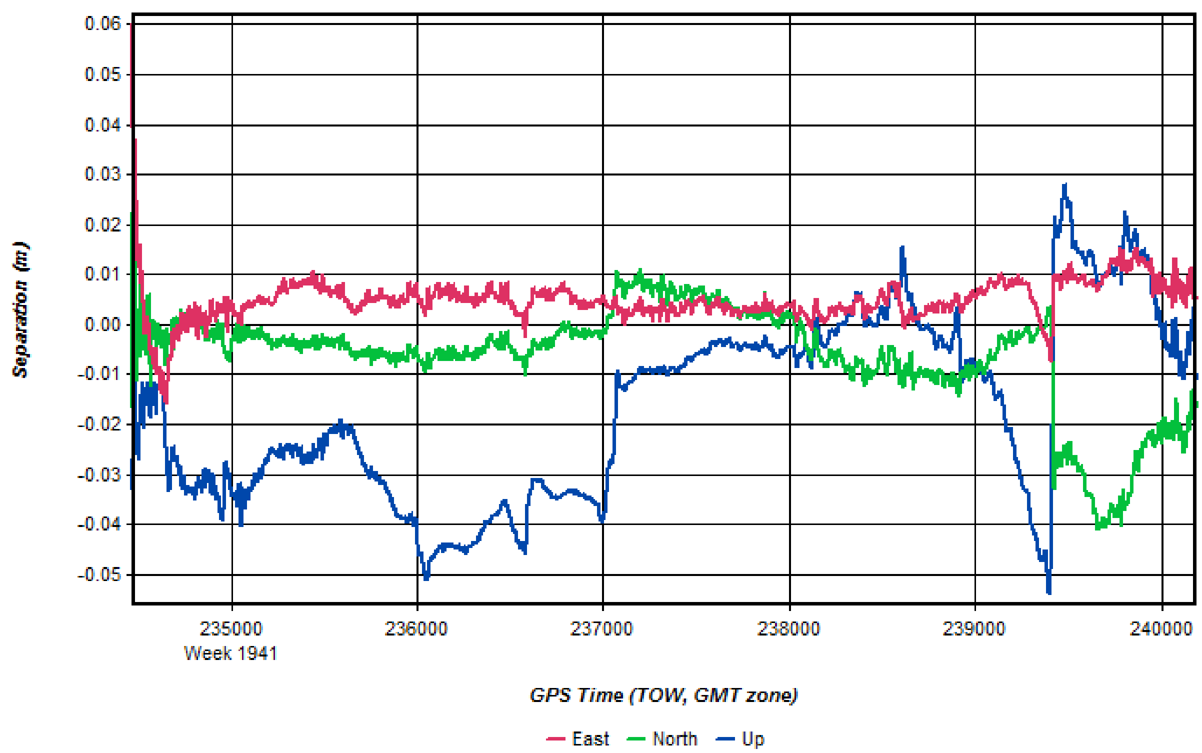

PDOP
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
142000
Week 1941
144000
146000
148000
150000
152000
154000
GPS Time (TOW, GMT zone)
PDOP

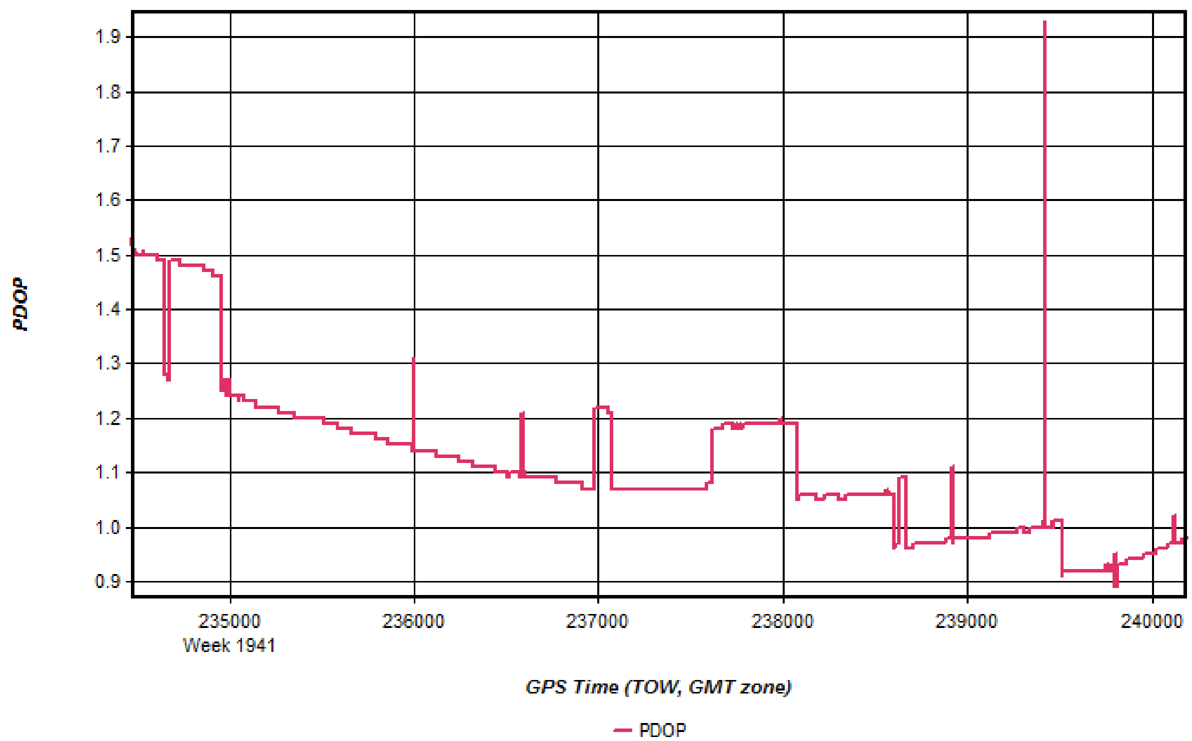
123_20170321_1



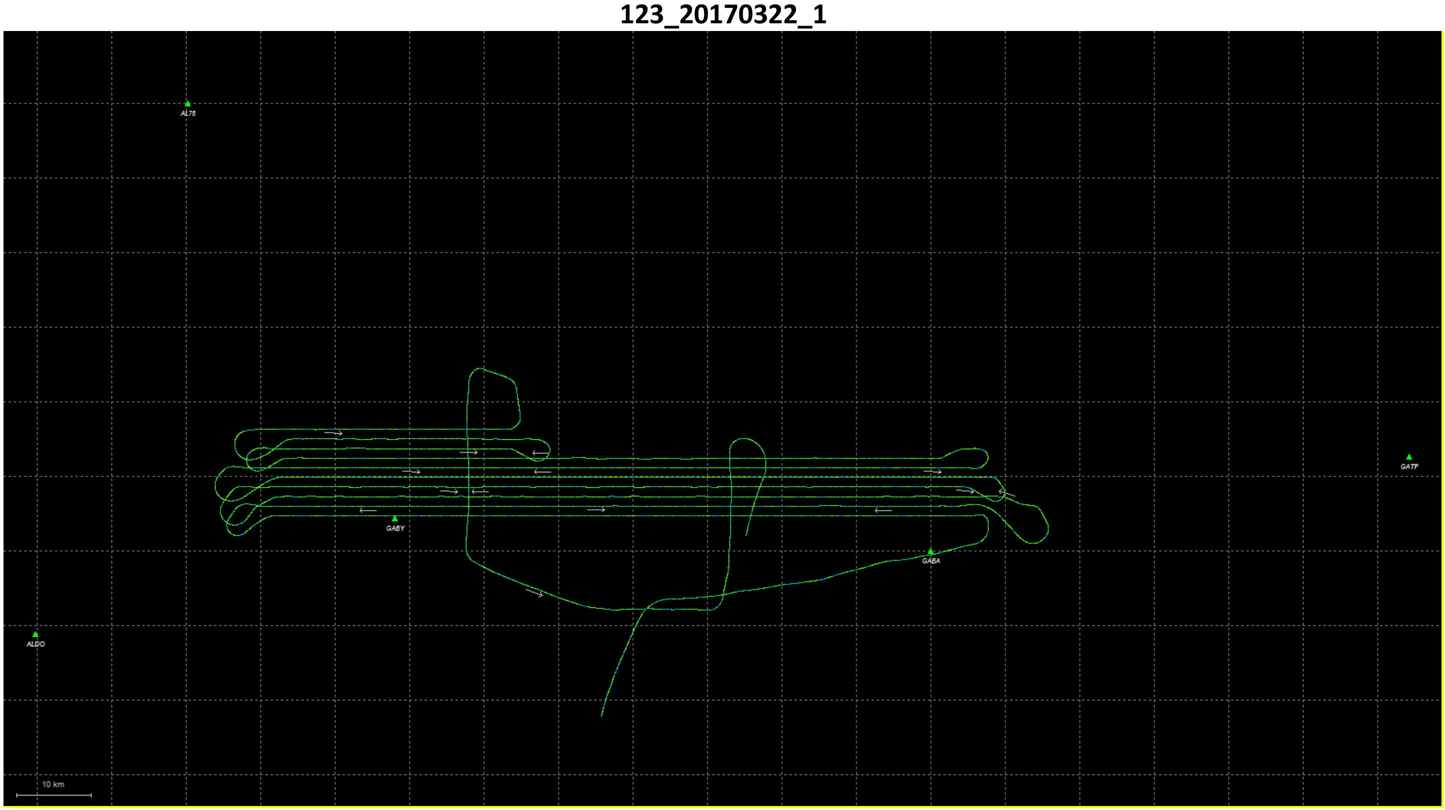


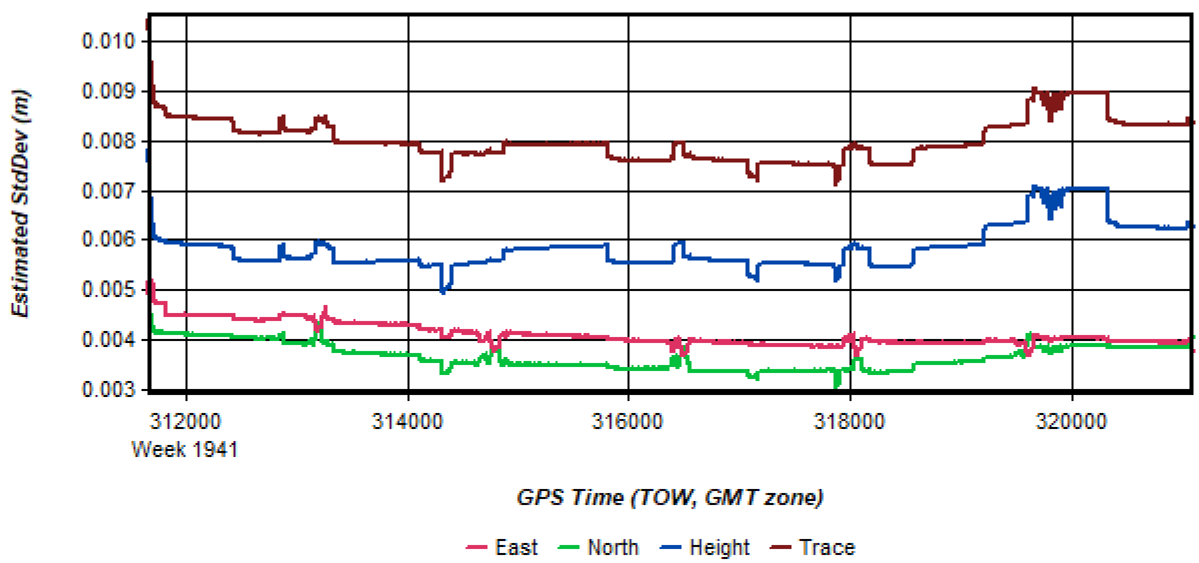

12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
235000
Week 1941
236000
237000
238000
239000
240000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

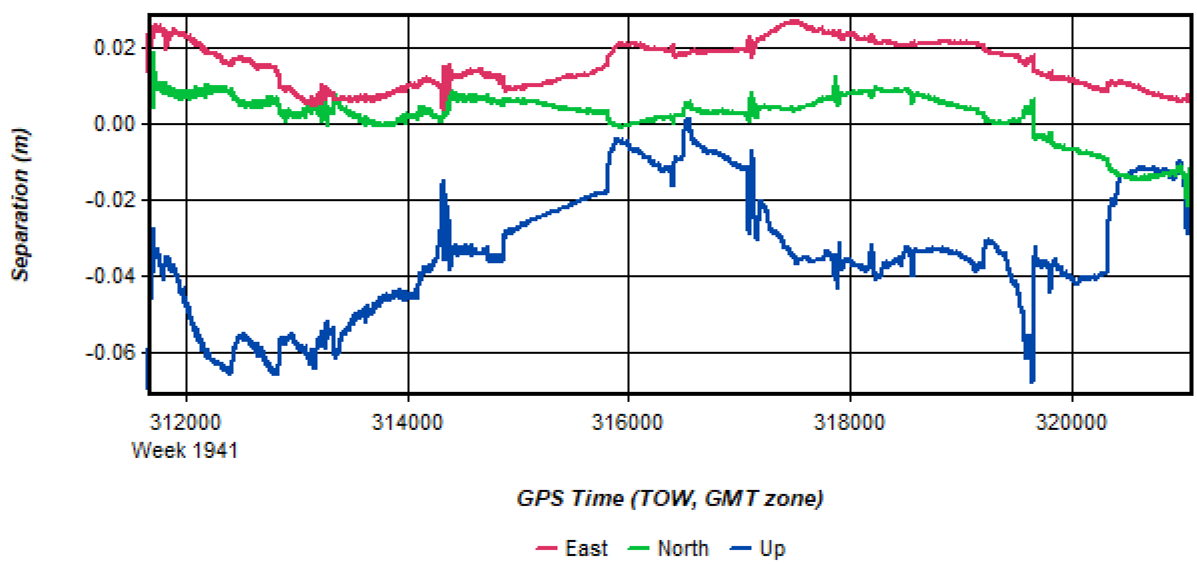

0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
Separation (m)
235000
Week 1941
236000
237000
238000
239000
240000
GPS Time (TOW, GMT zone)
East
North
Up

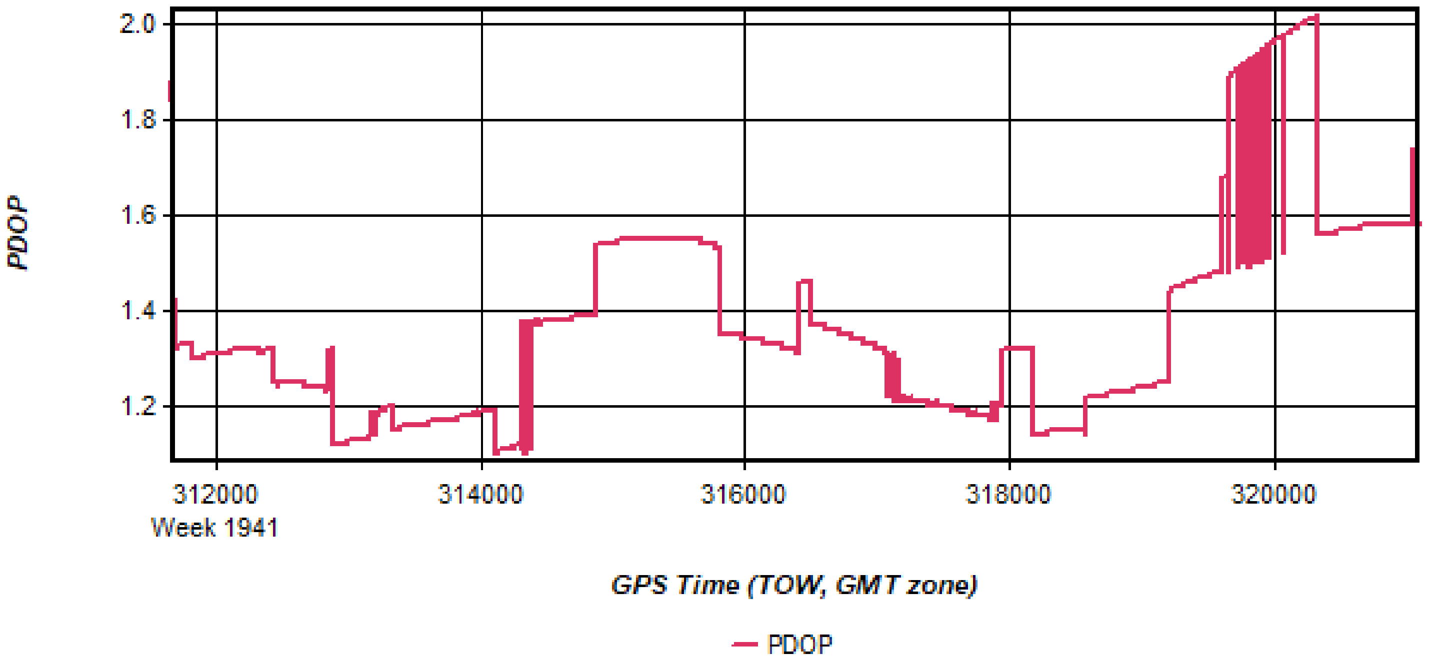


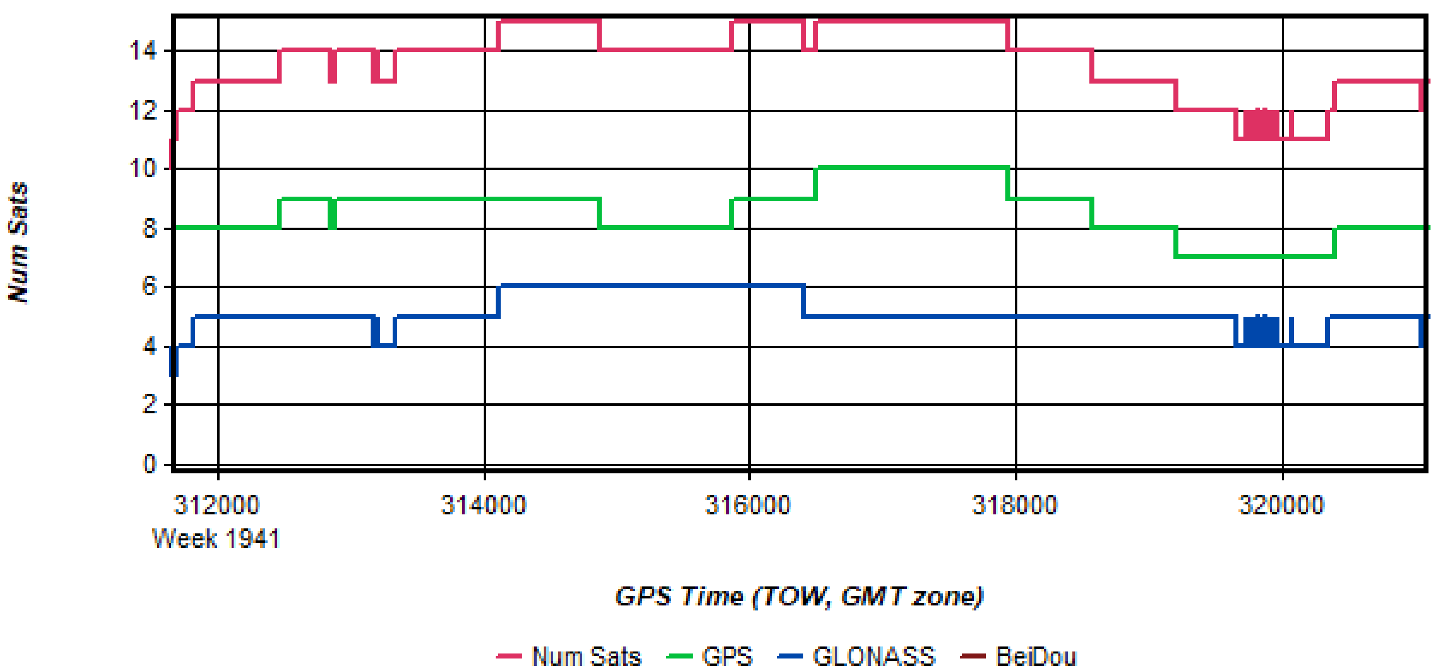
123_20170322_1



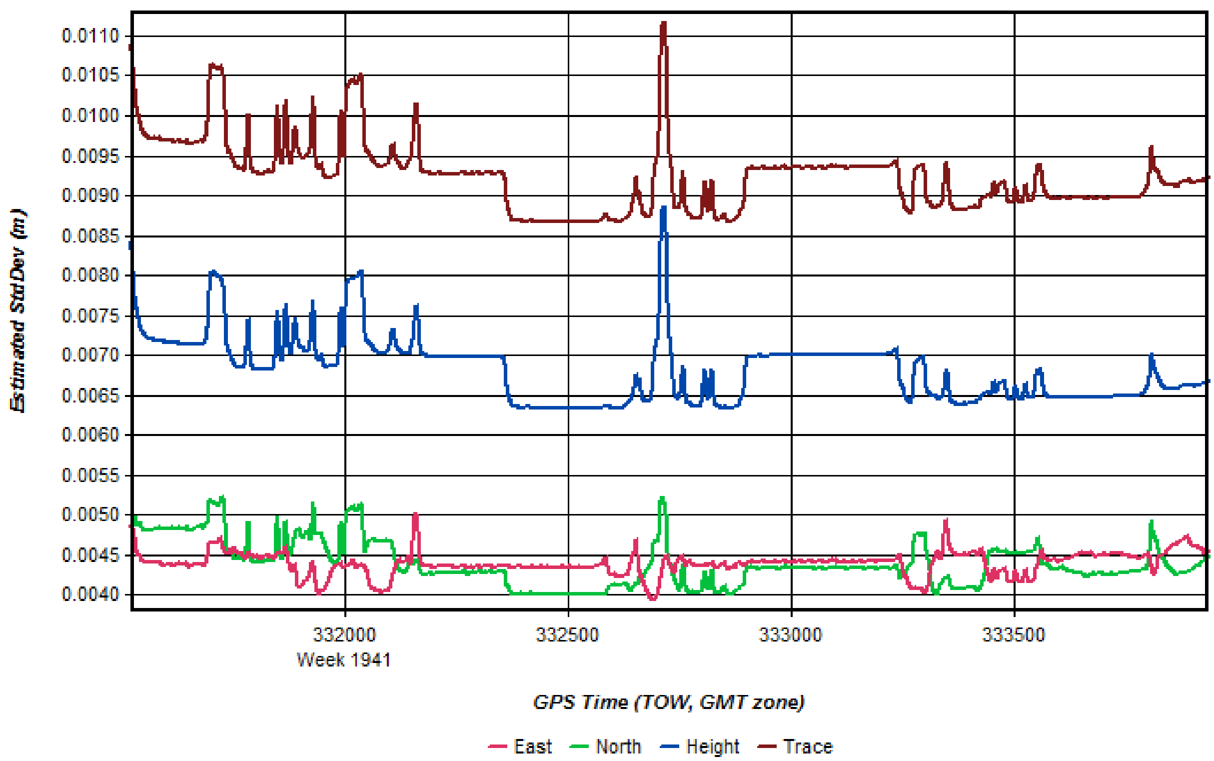

Estimated StdDev (m)
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
312000
Week 1941
314000
316000
318000
320000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

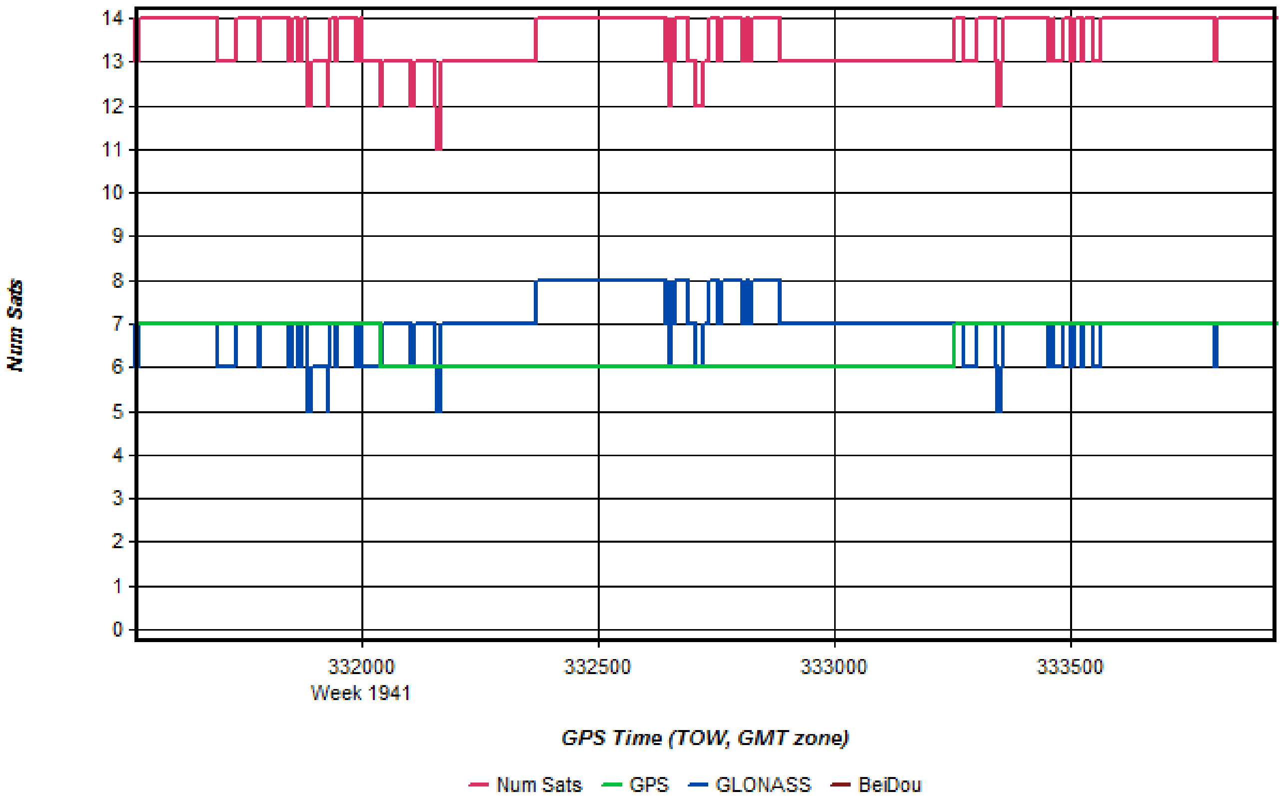

Separation (m)
0.02
0.00
-0.02
-0.04
-0.06
312000
Week 1941
314000
316000
318000
320000
GPS Time (TOW, GMT zone)
East
North
Up

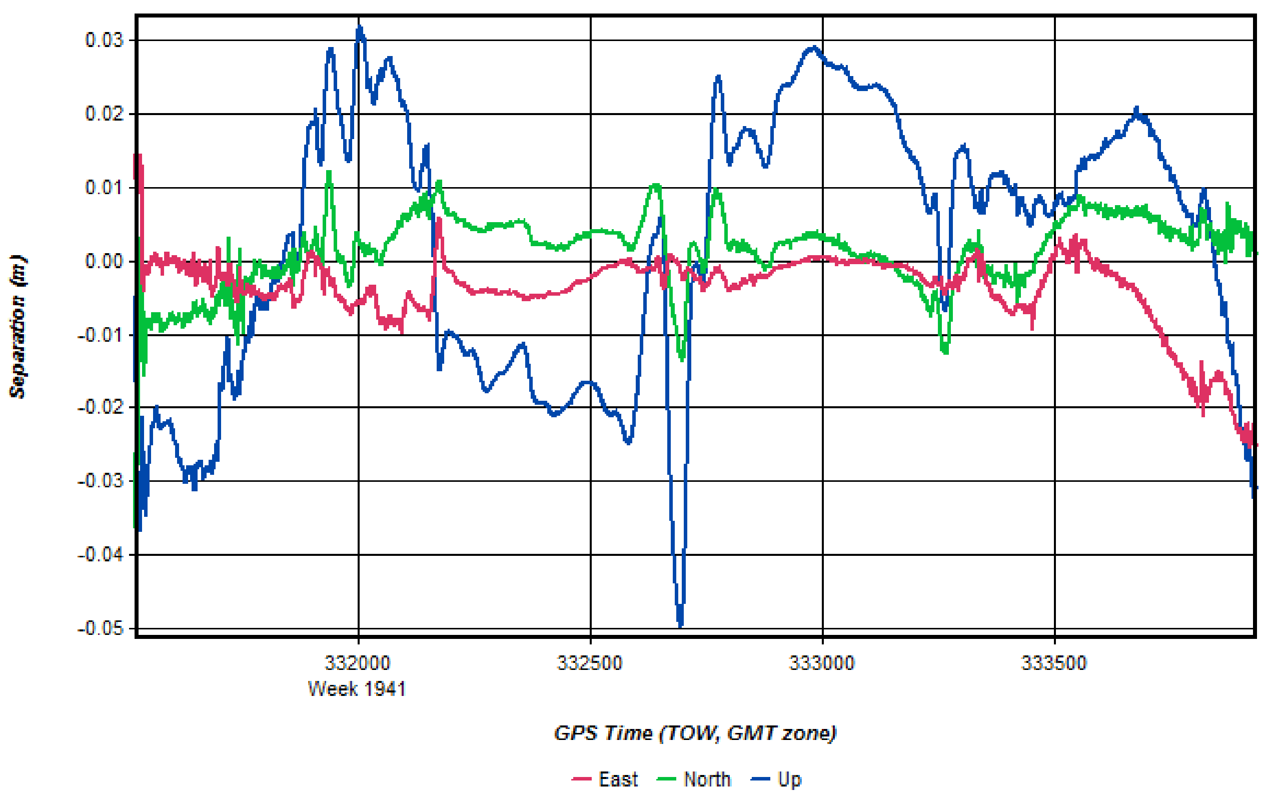

PDOP
2.0
1.8
1.6
1.4
1.2
312000
Week 1941
314000
316000
318000
320000
GPS Time (TOW, GMT zone)
PDOP

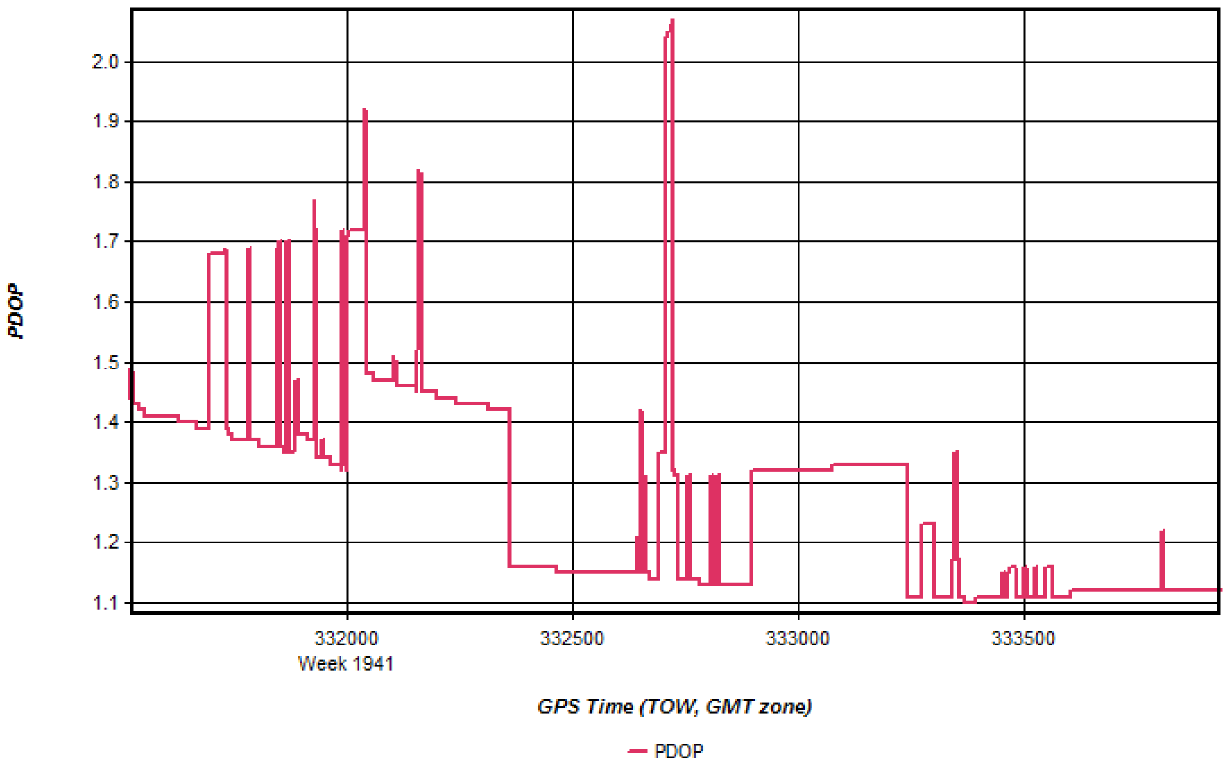

Num Sats
14
12
10
8
6
4
2
0
312000
Week 1941
314000
316000
318000
320000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

123_20170322_2A




Num Sats
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
332000
Week 1941
332500
333000
333500
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


Separation (m)
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
332000
Week 1941
332500
333000
333500
GPS Time (TOW, GMT zone)
East
North
Up


PDOP
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
332000
Week 1941
332500
333000
333500
GPS Time (TOW, GMT zone)
PDOP