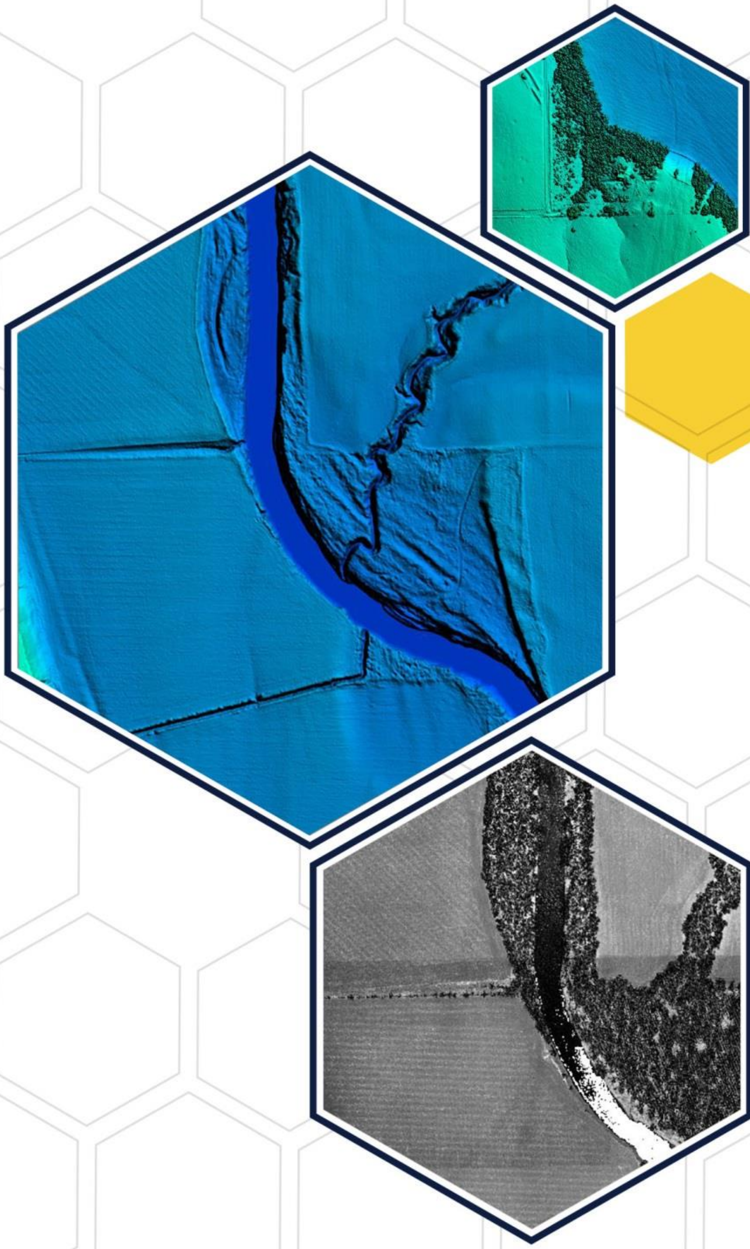

Aerial Lidar Report

16113
United States Geological Survey, 2017 Alabama 25 Counties Lidar (Block 2)
February 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 Alabama 25 County Lidar Block 2 Area of Interest (AOI). Lidar for this AOI was acquired in eleven (11) flight missions completed on March 9th, 2017. The project area encompasses 1,253,871 acres, 5,074 square kilometers or 1,959 square miles.

1.2 Acquisition Status Report

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. Atlantic's Director of Flight Operations 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 the GNSS constellations, and performed the first QC 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 at an optimal time.

1.3 Acquisition Details

Atlantic acquired one-hundred and forty-one (141) passes of the AOI as a series of perpendicular and/or adjacent flight-lines. Differential GNSS unit in aircraft recorded sample positions at 2 Hz or more frequency. Lidar data was only acquired when a minimum of 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.

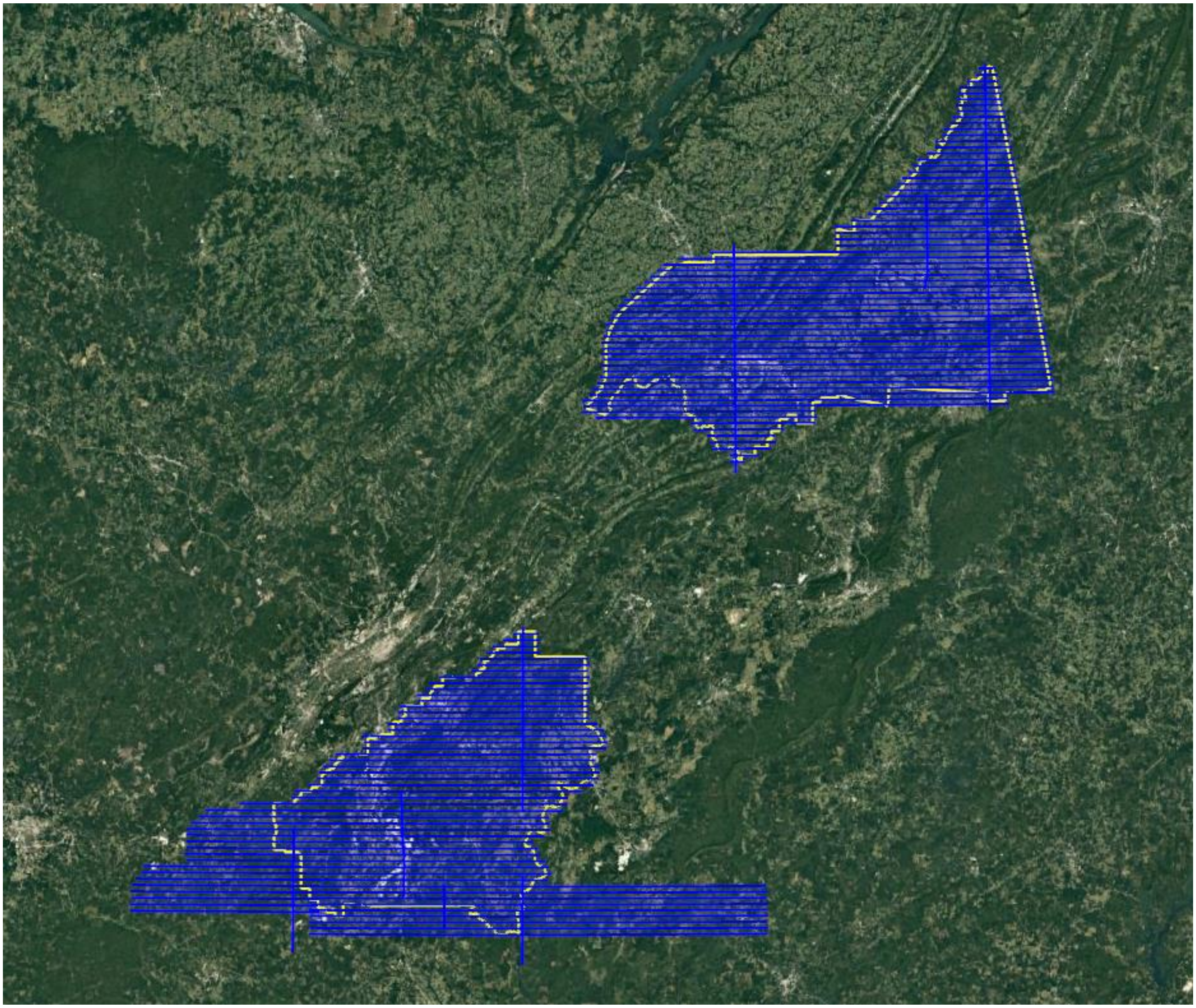


Figure 1: Trajectories as flown by Atlantic

1.6 Acquisition Equipment

Atlantic operated a Partenavia S.P.A P 68 C/TC (N775MW), a Cessna T210L (N732JE), and a Piper PA-31-350 Chieftain (N1872H) all 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)	2,000
Nominal Flight Speed (kts)	130
Pass Heading (degree)	Varies
Sensor Scan Angle (degree)	45
Scan Frequency (Hz)	35.1
Pulse Rate of Scanner (kHz)	264.8
Line Spacing (m)	1,141
Pulse Duration of Scanner (ns)	4
Pulse Width of Scanner (m)	0.44
Central Wavelength of Sensor Laser (nm)	1064
Sensor Operated with Multiple Pulses	Yes
Beam Divergence (mrad)	0.22
Nominal Swath Width (m)	1,663
Nominal Swath Overlap (%)	20
Scan Pattern	Triangle

Table 2: Atlantic Lidar System Acquisition Parameters

1.8 GNSS Reference Station(s)

Nine (9) Continuously Operating Reference Stations (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**
ALCN	CORS	DM3491	34 09 46.98035	085 39 31.04169	164.916
ALHL	CORS	DM3969	33 53 15.27574	086 23 52.59565	332.083
AL30	CORS	DI2226	33 31 56.44064	086 51 12.26529	149.807
ALTA	CORS	DM3977	33 25 24.57365	086 07 16.28680	149.933
ALA1	CORS	DM2678	32 35 55.86421	085 30 14.10823	185.476
ALLA	CORS	DM5373	32 55 02.64002	085 24 01.77791	238.544
HGIS	CORS	DK7412	34 43 41.17629	086 35 12.06178	177.731
GTAC	CORS	DG5771	34 42 39.82636	086 39 12.28466	194.331
ALNC	CORS	DM2662	34 40 52.58348	087 18 33.99419	158.085

Table 3: GNSS Reference Station Coordinates

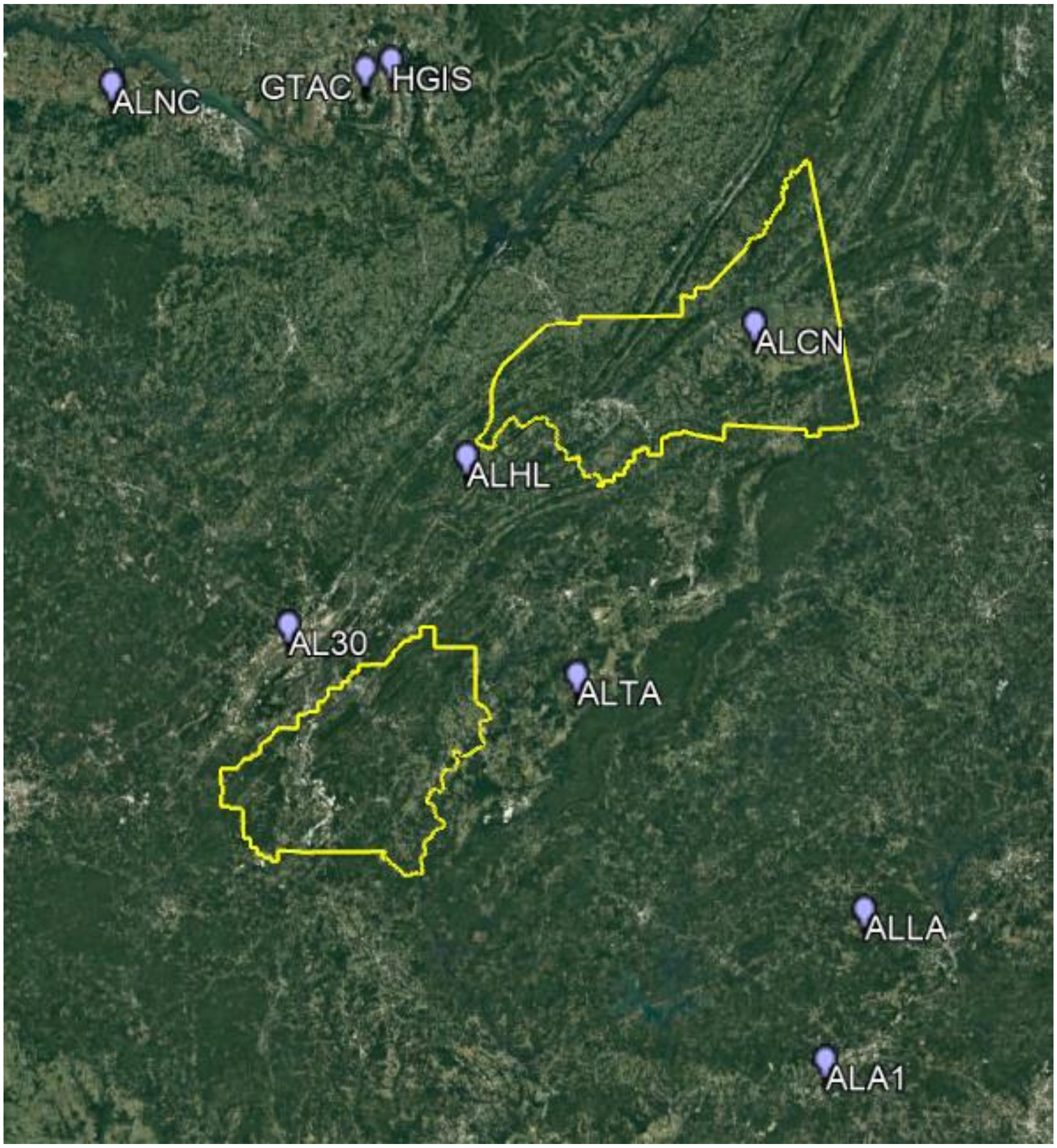


Figure 2: GNSS Reference Station(s)

1.9 Airborne GNSS Kinematic

Differential GNSS unit in aircraft collected positions at 2 Hz. Airborne GNSS data was processed using the Inertial Explorer (version 8.60.6717) software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon).

For all flights, the GNSS data can be classified as good, with 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 GNSS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

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

Section 2: Lidar Processing

2.1 Lidar Point Cloud Generation

Atlantic used Leica software products to download the IPAS ABGNSS/IMU data and raw laser scan files from the airborne system. Waypoint Inertial Explorer is used to extract the raw IPAS ABGNSS/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 Lidar ASCII Standard (*.las) formatted swath point clouds.

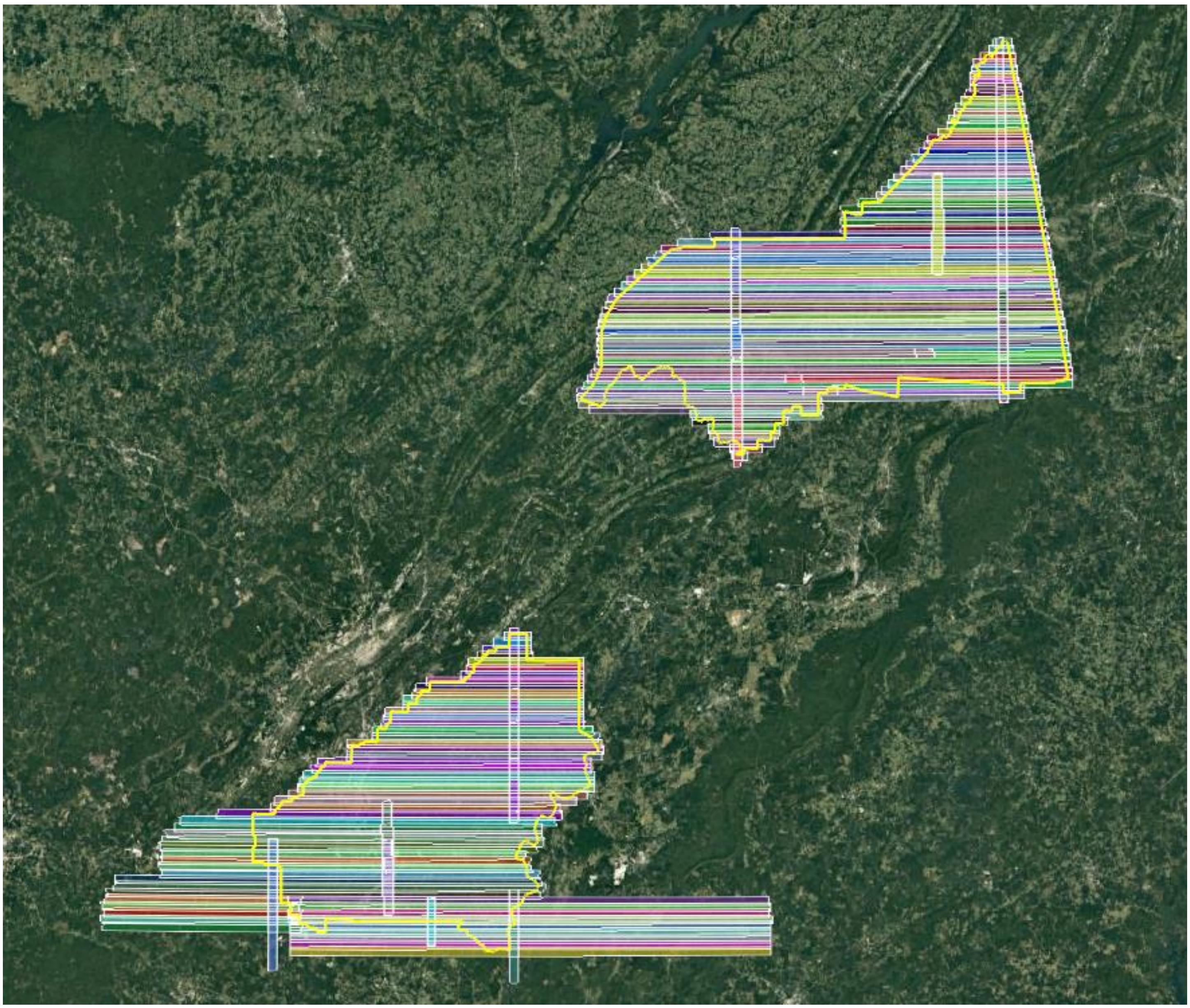


Figure 3: Lidar swath data showing complete coverage

2.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Coordinate System:	Universal Transverse Mercator Zone 16 North
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units of Reference:	Meters

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	38,493,882,629
Nominal Pulse Spacing (m)	0.6282
Nominal Pulse Density (pls/m²)	2.53
Nominal Pulse Spacing (ft)	2.0611
Nominal Pulse Density (pls/ft²)	0.24
Aggregate Total Points	26,990,765,236
Aggregate Nominal Pulse Spacing (m)	0.5467
Aggregate Nominal Pulse Density (pls/m²)	3.35
Aggregate Nominal Pulse Spacing (ft)	1.7935
Aggregate Nominal Pulse Density (pls/ft²)	0.31

Table 4: Lidar Point Cloud Statistics

2.4 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 2,000m; the expected radial horizontal positional error will be RMSEz = 29.0cm.

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 rasters (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.

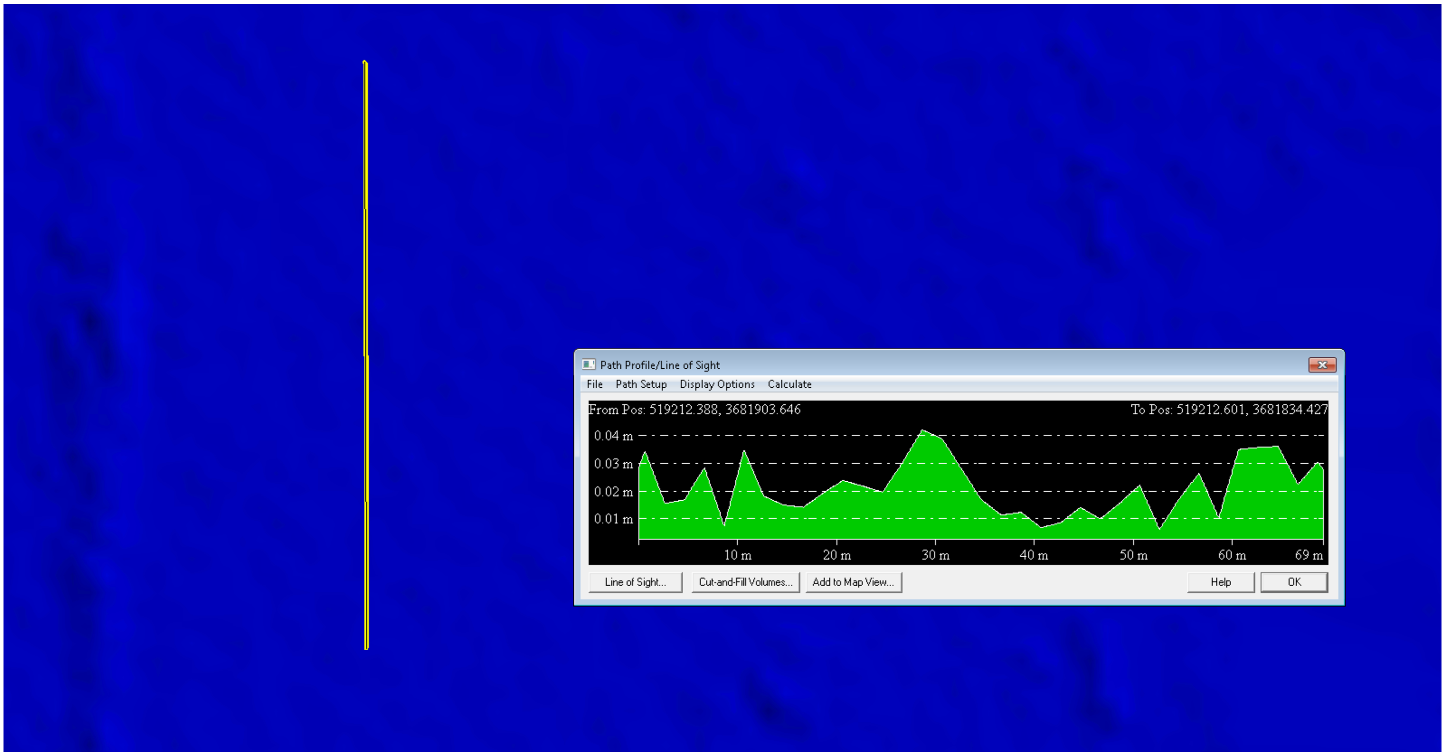


Figure 4: Smooth Surface Repeatability of ≤6cm

2.6 Lidar Calibration

Lidar ranging data were initially calibrated using previous best parameters for this instrument and aircraft. Using a combination of GeoCue, 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 ≤2cm. A final analysis of the calibrated lidar is preformed using a TerraMatch Tie Line report for an overall statistical model of the project area.

Upon completion of the data calibration, Atlantic runs a complete set of elevation difference intensity rasters (dZ Orthos). 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 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	0m to 0.04m	0.04m to 0.08m	0.08m to 0.12m	> 0.12m

Figure 5: Swath Overlap Difference of ≤8cm, Maximum of ±16cm

2.7 Overlap Consistency (Interswath)

An overall statistical assessment of the relative accuracy using TerraMatch Tie Line Report between lidar swaths can be found in Tables 5, 6, 7, and 8 below. The values provided are in meters.

Average Magnitudes Per Line											
Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1115	0.032	0.032	0.023	1208	0.03	0.031	0.016	1343	0.024	0.025	0.016
1116	0.028	0.031	0.016	1209	0.032	0.032	0.015	1344	0.026	0.028	0.015
1117	0.029	0.032	0.017	1210	0.025	0.03	0.015	1345	0.027	0.029	0.015
1118	0.037	0.03	0.016	1211	0.022	0.028	0.015	1346	0.028	0.033	0.015
1119	0.034	0.025	0.015	1212	0.023	0.027	0.015	1347	0.02	0.026	0.021
1120	0.025	0.02	0.016	1213	0.03	0.032	0.015	1348	0.028	0.027	0.020
1121	0.03	0.033	0.016	1214	0.028	0.027	0.014	1349	0.033	0.041	0.016
1122	0.038	0.038	0.016	1215	0.028	0.029	0.016	1350	0.027	0.036	0.016
1123	0.038	0.04	0.016	1216	0.028	0.03	0.018	1351	0.027	0.037	0.015
1124	0.033	0.039	0.017	1217	0.021	0.019	0.023	1352	0.027	0.037	0.014
1125	0.028	0.042	0.016	1218	0.024	0.025	0.017	1353	0.034	0.038	0.016
1126	0.032	0.04	0.016	1219	0.023	0.022	0.021	1354	0.038	0.045	0.016
1127	0.021	0.038	0.017	1246	0.022	0.023	0.016	1355	0.032	0.039	0.015
1128	0.023	0.026	0.017	1247	0.023	0.025	0.017	1356	0.03	0.035	0.016
1129	0.04	0.043	0.017	1248	0.03	0.023	0.018	1357	0.029	0.034	0.018
1130	0.027	0.022	0.016	1249	0.016	0.015	0.015	1358	0.029	0.028	0.021
1131	0.024	0.033	0.016	1250	0.012	0.035	0.024	1359	0.022	0.025	0.025
1132	0.025	0.036	0.017	1252	0.04	0.044	0.027	1360	0.017	0.027	0.015
1133	0.023	0.031	0.016	1253	0.049	0.042	0.022	1361	0.029	0.026	0.015
1134	0.021	0.028	0.017	1254	0.06	0.016	0.020	1362	0.015	0.019	0.014
1135	0.03	0.028	0.017	1255	0.029	0.031	0.019	1363	0.015	0.021	0.014
1136	0.035	0.026	0.017	1256	0.025	0.031	0.016	1364	0.019	0.023	0.015
1137	0.027	0.032	0.017	1260	0.042	0.041	0.040	1365	0.016	0.019	0.015
1138	0.026	0.032	0.018	1319	0.031	0.035	0.021	1366	0.014	0.017	0.016
1139	0.032	0.03	0.018	1320	0.03	0.038	0.016	1367	0.016	0.016	0.015
1161	0.027	0.039	0.016	1321	0.025	0.034	0.016	1368	0.018	0.018	0.015
1162	0.031	0.042	0.016	1322	0.027	0.035	0.015	1369	0.014	0.014	0.014
1163	0.029	0.044	0.015	1323	0.028	0.036	0.016	1370	0.016	0.015	0.015
1164	0.034	0.046	0.016	1324	0.027	0.032	0.017	1371	0.016	0.016	0.015
1165	0.042	0.05	0.015	1325	0.029	0.037	0.017	1372	0.016	0.015	0.015
1166	0.029	0.043	0.017	1326	0.025	0.033	0.017	1373	0.015	0.014	0.015
1167	0.027	0.027	0.017	1327	0.021	0.029	0.018	1374	0.013	0.012	0.016
1168	0.026	0.028	0.024	1328	0.031	0.042	0.020	1375	0.02	0.019	0.016
1188	0.028	0.016	0.016	1329	0.041	0.041	0.025	1376	0.017	0.017	0.015
1189	0.022	0.016	0.016	1330	0.026	0.023	0.020	1377	0.013	0.013	0.016
1190	0.022	0.019	0.014	1331	0.031	0.04	0.019	1378	0.014	0.013	0.014
1191	0.025	0.026	0.015	1332	0.028	0.031	0.016	1379	0.023	0.023	0.017
1192	0.017	0.016	0.015	1333	0.031	0.031	0.016	1380	0.02	0.026	0.029

1193	0.017	0.017	0.016	**1334**	0.017	0.021	0.017	**1381**	0.015	0.016	0.015
1194	-	-	0.018	**1335**	0.022	0.029	0.015	**1382**	0.019	0.019	0.015
1195	-	-	0.018	**1336**	0.035	0.042	0.017	**1383**	0.019	0.021	0.014
1196	0.01	0.033	0.019	**1337**	0.032	0.038	0.015	**1384**	0.018	0.024	0.015
1197	0.014	0.015	0.015	**1338**	0.023	0.031	0.016	**1385**	0.02	0.029	0.015
1198	0.001	0.002	0.015	**1339**	0.026	0.033	0.016	**1386**	0.015	0.014	0.014
1205	0.019	0.029	0.021	**1340**	0.025	0.026	0.021	**1387**	0.012	0.012	0.014
1206	0.017	0.014	0.020	**1341**	0.039	0.025	0.016	**1388**	0.015	0.016	0.015
1207	0.023	0.024	0.016	**1342**	0.026	0.028	0.014	**1389**	0.012	0.02	0.021

Table 5: Average Tie Line Magnitudes per Line

Internal Observation Statistics			
Category	**X**	**Y**	**Z**
Average Magnitude	0.027	0.032	0.016
RMS Values	0.04	0.046	0.022
Maximum Values	0.159	0.204	0.162
Observation Weight	53678.0	53678.0	53678.0

Table 6: Tie Line Observation Statistics

Overall Relative Accuracy	
Category	**Mismatch**
Average 3D Mismatch	0.01942
Average XY Mismatch	0.04966
Average Z Mismatch	0.01627

Table 7: Relative Accuracy Results

TerraMatch Tie Lines	
Category	**Observations**
Section Lines	450,176
Roof Lines	47,906

Table 8: Total Tie Lines

2.8 Lidar Classification

Atlantic uses multiple automated filtering routines on the calibrated lidar point cloud identifying and extracting bare-earth and above ground features. GeoCue, TerraScan, and TerraModeler software was used for the initial batch processing and manual editing of the lidar point clouds. Atlantic utilized collected breakline data to preform classification for classes' 9-Water and 10-Ignored Ground in LP360. Outlined in Table 9 are the classification codes utilized for this project.

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

Table 9: Point Cloud Classification Scheme

Section 3: Lidar Accuracy

3.1 Ground Surveyed Check Points

Atlantic established a total of sixty-three (63) check points for this project (33 NVA + 30 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.

3.2 Vertical Accuracy Requirements

Below are the vertical accuracy reporting requirements for this project:

Vertical Accuracy Reporting Requirements in Meters:

$RMSE_Z \leq$ 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:

$RMSE_Z \leq$ 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).

3.3 Check Point Distribution

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

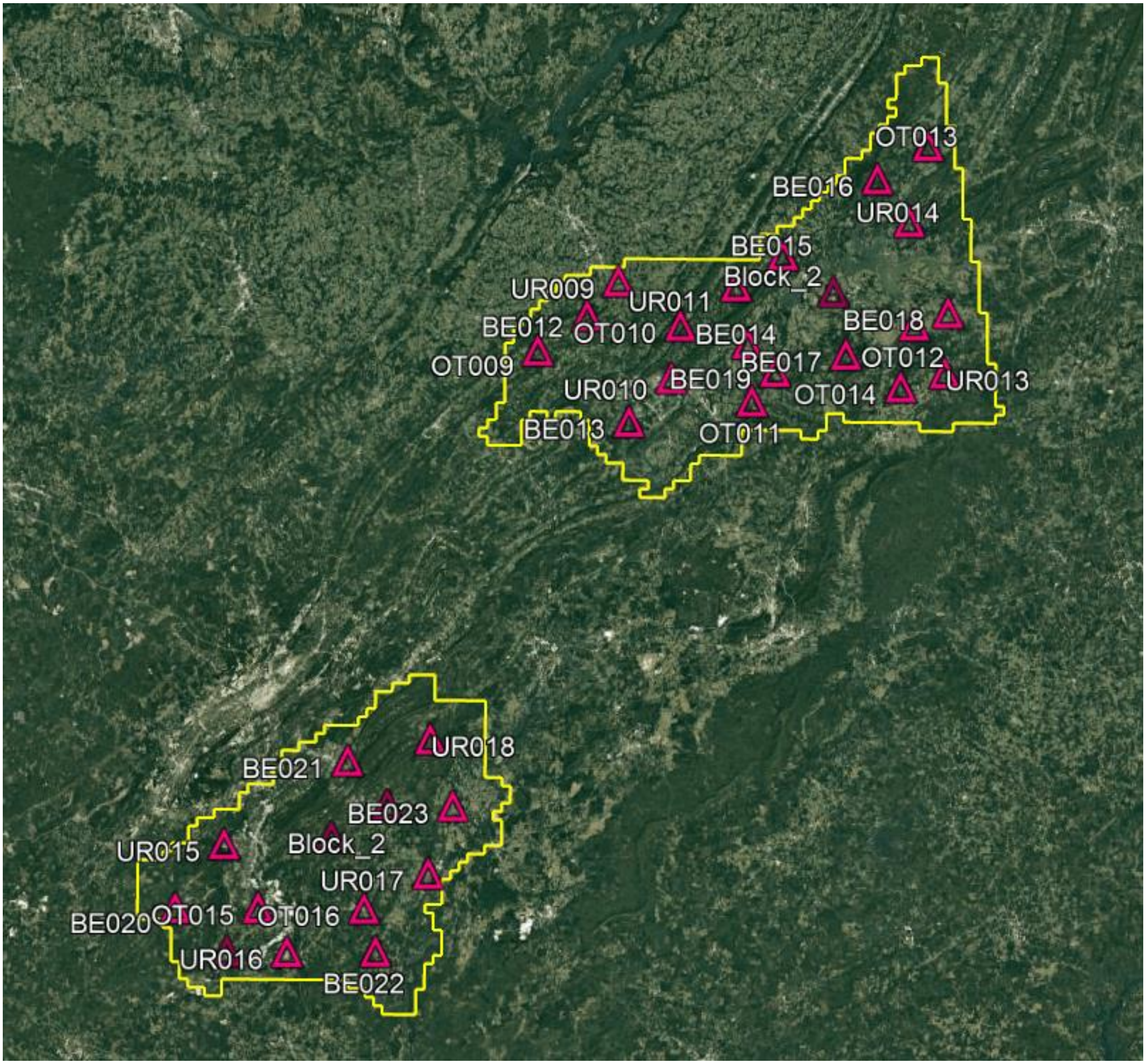


Figure 6: Non-vegetated Vertical Accuracy (NVA) Check Point Distribution

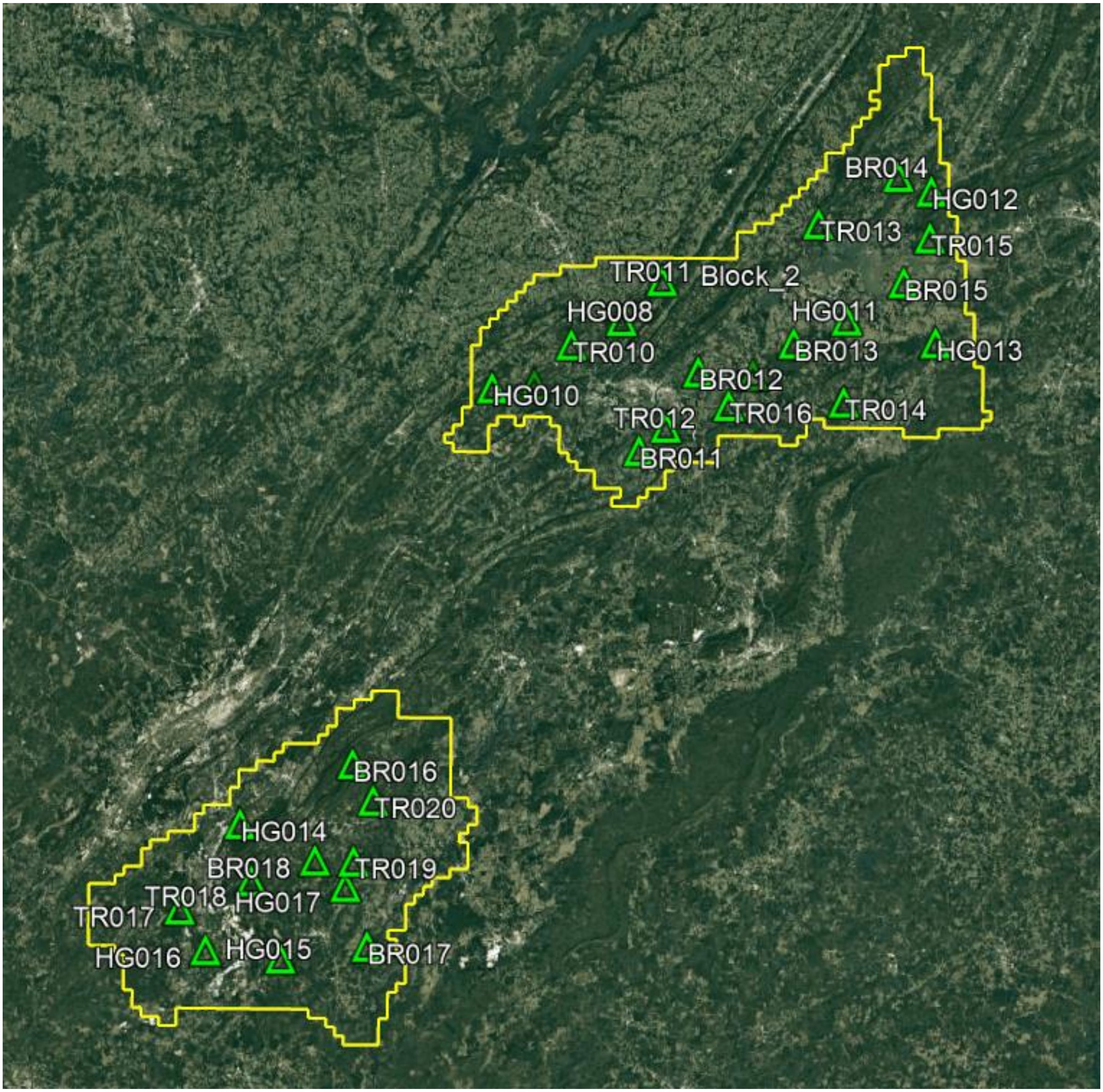


Figure 7: Vegetated Vertical Accuracy (VVA) Check Point Distribution

3.4 Vertical Accuracy Results

An overall statistical assessment of the check points can be found in Tables 10 and 11 below. The values provided are in meters.

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	33	0.071	0.138	
NVA of Bare Earth	33	0.071	0.139	
NVA of DEM	33	0.074	0.146	
VVA of Bare Earth	28	0.084		0.157

Table 10: Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)

Vegetated Vertical Accuracy (VVA) 5% Outliers > 95th Percentile (0.169m)						
PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
HG014	522309.352	3689827.250	146.161	146.331	High Grass	0.170
HG009	608939.769	3766324.576	167.303	167.477	High Grass	0.174

Table 11: 5% Outlier Check Points

3.5 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 12, 13, 14, and 15 below. The coordinates provided are in NAD83 (2011), UTM Zone 16 North, NAVD88 (Geoid12B), Meters.

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Point Cloud)						
PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
BE012	575535.109	3775952.539	273.463	273.454	Open Terrain/Bare Earth	-0.009
BE013	583097.750	3757313.063	162.061	162.055	Open Terrain/Bare Earth	-0.006
BE014	604008.097	3771264.599	178.876	178.952	Open Terrain/Bare Earth	0.076
BE015	610163.188	3786898.319	263.549	263.488	Open Terrain/Bare Earth	-0.061
BE016	626837.335	3800451.735	223.454	223.423	Open Terrain/Bare Earth	-0.031
BE017	621437.645	3769426.331	181.283	181.382	Open Terrain/Bare Earth	0.099
BE018	639575.637	3776971.053	184.771	184.859	Open Terrain/Bare Earth	0.088
BE019	608921.279	3766326.192	167.356	167.429	Open Terrain/Bare Earth	0.073
BE020	503289.604	3671022.270	205.579	205.554	Open Terrain/Bare Earth	-0.025
BE021	533750.839	3697262.318	254.464	254.468	Open Terrain/Bare Earth	0.004
BE022	538871.821	3663617.652	148.239	148.254	Open Terrain/Bare Earth	0.015
BE023	552405.160	3689401.041	139.006	139.083	Open Terrain/Bare Earth	0.077
OT009	566871.607	3769742.768	269.579	269.593	Open Terrain/Bare Earth	0.014
OT010	592063.762	3774306.733	191.060	191.167	Open Terrain/Bare Earth	0.107
OT011	604825.061	3761090.368	178.144	178.157	Open Terrain/Bare Earth	0.013
OT012	633578.653	3774705.240	193.523	193.580	Open Terrain/Bare Earth	0.057
OT013	635824.069	3806445.680	200.196	200.153	Open Terrain/Bare Earth	-0.043
OT014	631220.842	3763801.731	190.556	190.610	Open Terrain/Bare Earth	0.054
OT015	517987.744	3671178.288	156.028	156.061	Open Terrain/Bare Earth	0.033

OT016	536783.566	3671183.653	163.127	163.174	Open Terrain/Bare Earth	0.047
OT017	512499.783	3663433.164	123.107	123.198	Open Terrain/Bare Earth	0.091
OT018	540785.813	3689554.609	149.510	149.555	Open Terrain/Bare Earth	0.045
OT019	530924.048	3683867.320	162.811	162.953	Open Terrain/Bare Earth	0.142
UR009	581051.352	3782013.032	325.058	324.897	Urban	-0.161
UR010	590524.454	3765027.858	166.416	166.337	Urban	-0.079
UR011	601906.416	3781347.888	254.372	254.342	Urban	-0.030
UR012	619140.859	3780502.920	176.251	176.169	Urban	-0.082
UR013	639016.933	3766295.607	224.242	224.215	Urban	-0.027
UR014	632594.466	3792966.450	184.029	183.975	Urban	-0.054
UR015	511886.903	3682380.813	132.057	132.047	Urban	-0.010
UR016	523169.356	3663398.422	156.290	156.295	Urban	0.005
UR017	548109.328	3677459.400	130.033	129.916	Urban	-0.117
UR018	548333.021	3701161.994	157.815	157.700	Urban	-0.115

Table 12: Lidar Point Cloud NVA Assessment

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Bare-Earth)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
BE012	575535.109	3775952.539	273.463	273.454	Open Terrain/Bare Earth	-0.009
BE013	583097.750	3757313.063	162.061	162.055	Open Terrain/Bare Earth	-0.006
BE014	604008.097	3771264.599	178.876	178.952	Open Terrain/Bare Earth	0.076
BE015	610163.188	3786898.319	263.549	263.488	Open Terrain/Bare Earth	-0.061
BE016	626837.335	3800451.735	223.454	223.423	Open Terrain/Bare Earth	-0.031
BE017	621437.645	3769426.331	181.283	181.382	Open Terrain/Bare Earth	0.099
BE018	639575.637	3776971.053	184.771	184.859	Open Terrain/Bare Earth	0.088
BE019	608921.279	3766326.192	167.356	167.429	Open Terrain/Bare Earth	0.073
BE020	503289.604	3671022.270	205.579	205.554	Open Terrain/Bare Earth	-0.025
BE021	533750.839	3697262.318	254.464	254.468	Open Terrain/Bare Earth	0.004
BE022	538871.821	3663617.652	148.239	148.248	Open Terrain/Bare Earth	0.009
BE023	552405.160	3689401.041	139.006	139.067	Open Terrain/Bare Earth	0.061
OT009	566871.607	3769742.768	269.579	269.593	Open Terrain/Bare Earth	0.014
OT010	592063.762	3774306.733	191.060	191.167	Open Terrain/Bare Earth	0.107
OT011	604825.061	3761090.368	178.144	178.157	Open Terrain/Bare Earth	0.013
OT012	633578.653	3774705.240	193.523	193.602	Open Terrain/Bare Earth	0.079
OT013	635824.069	3806445.680	200.196	200.153	Open Terrain/Bare Earth	-0.043
OT014	631220.842	3763801.731	190.556	190.610	Open Terrain/Bare Earth	0.054
OT015	517987.744	3671178.288	156.028	155.998	Open Terrain/Bare Earth	-0.030
OT016	536783.566	3671183.653	163.127	163.174	Open Terrain/Bare Earth	0.047
OT017	512499.783	3663433.164	123.107	123.151	Open Terrain/Bare Earth	0.044
OT018	540785.813	3689554.609	149.510	149.555	Open Terrain/Bare Earth	0.045
OT019	530924.048	3683867.320	162.811	162.953	Open Terrain/Bare Earth	0.142
UR009	581051.352	3782013.032	325.058	324.897	Urban	-0.161
UR010	590524.454	3765027.858	166.416	166.337	Urban	-0.079

UR011	601906.416	3781347.888	254.372	254.342	Urban	-0.030
UR012	619140.859	3780502.920	176.251	176.169	Urban	-0.082
UR013	639016.933	3766295.607	224.242	224.215	Urban	-0.027
UR014	632594.466	3792966.450	184.029	183.923	Urban	-0.106
UR015	511886.903	3682380.813	132.057	132.047	Urban	-0.010
UR016	523169.356	3663398.422	156.290	156.295	Urban	0.005
UR017	548109.328	3677459.400	130.033	129.916	Urban	-0.117
UR018	548333.021	3701161.994	157.815	157.700	Urban	-0.115

Table 13: Bare-Earth Lidar NVA Assessment

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (DEM)						
PointID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
BE012	575535.109	3775952.539	273.463	273.448	Open Terrain/Bare Earth	0.015
BE013	583097.750	3757313.063	162.061	161.969	Open Terrain/Bare Earth	0.092
BE014	604008.097	3771264.599	178.876	178.942	Open Terrain/Bare Earth	-0.066
BE015	610163.188	3786898.319	263.549	263.475	Open Terrain/Bare Earth	0.074
BE016	626837.335	3800451.735	223.454	223.411	Open Terrain/Bare Earth	0.043
BE017	621437.645	3769426.331	181.283	181.398	Open Terrain/Bare Earth	-0.115
BE018	639575.637	3776971.053	184.771	184.834	Open Terrain/Bare Earth	-0.063
BE019	608921.279	3766326.192	167.356	167.427	Open Terrain/Bare Earth	-0.071
BE020	503289.604	3671022.270	205.579	205.505	Open Terrain/Bare Earth	0.074
BE021	533750.839	3697262.318	254.464	254.468	Open Terrain/Bare Earth	-0.004
BE022	538871.821	3663617.652	148.239	148.217	Open Terrain/Bare Earth	0.022
BE023	552405.160	3689401.041	139.006	139.030	Open Terrain/Bare Earth	-0.024
OT009	566871.607	3769742.768	269.579	269.590	Open Terrain/Bare Earth	-0.011
OT010	592063.762	3774306.733	191.060	191.131	Open Terrain/Bare Earth	-0.071
OT011	604825.061	3761090.368	178.144	178.162	Open Terrain/Bare Earth	-0.018
OT012	633578.653	3774705.240	193.523	193.574	Open Terrain/Bare Earth	-0.051
OT013	635824.069	3806445.680	200.196	200.144	Open Terrain/Bare Earth	0.052
OT014	631220.842	3763801.731	190.556	190.578	Open Terrain/Bare Earth	-0.022
OT015	517987.744	3671178.288	156.028	155.964	Open Terrain/Bare Earth	0.064
OT016	536783.566	3671183.653	163.127	163.167	Open Terrain/Bare Earth	-0.040
OT017	512499.783	3663433.164	123.107	123.151	Open Terrain/Bare Earth	-0.044
OT018	540785.813	3689554.609	149.510	149.553	Open Terrain/Bare Earth	-0.043
OT019	530924.048	3683867.320	162.811	162.945	Open Terrain/Bare Earth	-0.134
UR009	581051.352	3782013.032	325.058	324.877	Urban	0.181
UR010	590524.454	3765027.858	166.416	166.329	Urban	0.087
UR011	601906.416	3781347.888	254.372	254.324	Urban	0.048
UR012	619140.859	3780502.920	176.251	176.120	Urban	0.131
UR013	639016.933	3766295.607	224.242	224.189	Urban	0.053
UR014	632594.466	3792966.450	184.029	183.930	Urban	0.099
UR015	511886.903	3682380.813	132.057	132.036	Urban	0.021
UR016	523169.356	3663398.422	156.290	156.318	Urban	-0.028

UR017	548109.328	3677459.400	130.033	129.927	Urban	0.106
UR018	548333.021	3701161.994	157.815	157.714	Urban	0.101

Table 14: Bare=Earth DEM NVA Assessment

Vegetated Vertical Accuracy (VVA) Check Point Assessment (Bare Earth)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
BR010	571768.262	3764325.828	232.952	233.054	Brush	0.102
BR011	589635.803	3753385.932	175.661	175.756	Brush	0.095
BR012	599625.040	3766783.142	185.169	185.166	Brush	-0.003
BR013	615825.822	3771758.475	172.404	172.468	Brush	0.064
BR014	633523.850	3800136.515	200.624	200.718	Brush	0.094
BR015	634516.701	3782164.027	173.267	173.435	Brush	0.168
BR016	541390.036	3700134.572	155.719	155.845	Brush	0.126
BR017	544017.344	3669229.281	125.945	126.104	Brush	0.159
BR018	535078.053	3683740.778	164.228	164.380	Brush	0.152
HG008	586530.411	3775341.809	187.687	187.825	High Grass	0.138
HG010	564608.742	3763792.929	275.214	275.303	High Grass	0.089
HG011	624837.148	3775739.767	178.278	178.328	High Grass	0.050
HG012	639117.288	3797651.361	187.843	187.801	High Grass	-0.042
HG013	639999.424	3772029.360	224.639	224.651	High Grass	0.012
HG015	529296.663	3667093.408	158.564	158.639	High Grass	0.075
HG016	516528.771	3668393.037	157.348	157.439	High Grass	0.091
HG017	540290.938	3679324.118	158.589	158.670	High Grass	0.081
TR010	578012.234	3771200.895	293.594	293.662	Trees	0.068
TR011	593359.739	3782133.469	220.657	220.620	Trees	-0.037
TR012	594204.840	3757379.371	171.524	171.528	Trees	0.004
TR013	619905.168	3792008.466	175.387	175.405	Trees	0.018
TR014	624395.081	3761849.437	220.973	221.003	Trees	0.030
TR015	638910.324	3789758.954	188.571	188.517	Trees	-0.054
TR016	604817.823	3761105.518	178.456	178.442	Trees	-0.014
TR017	512104.613	3675250.851	151.391	151.331	Trees	-0.060
TR018	524269.293	3680176.145	173.753	173.788	Trees	0.035
TR019	541632.318	3683649.376	154.856	154.853	Trees	-0.003
TR020	544912.088	3693955.505	156.277	156.336	Trees	0.059

Table 15: Bare-Earth Lidar VVA Assessment

Section 4: Certification

4.1 Limitations of Use

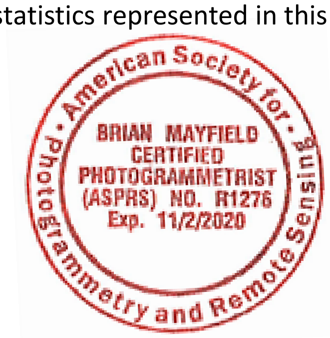
The accuracy assessment confirms that the data may be used for the intended applications stated in the **Project Purpose** section of this document. The dataset may also be used as a topographic input for other applications but the user should be aware that this lidar dataset was designed with a specific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

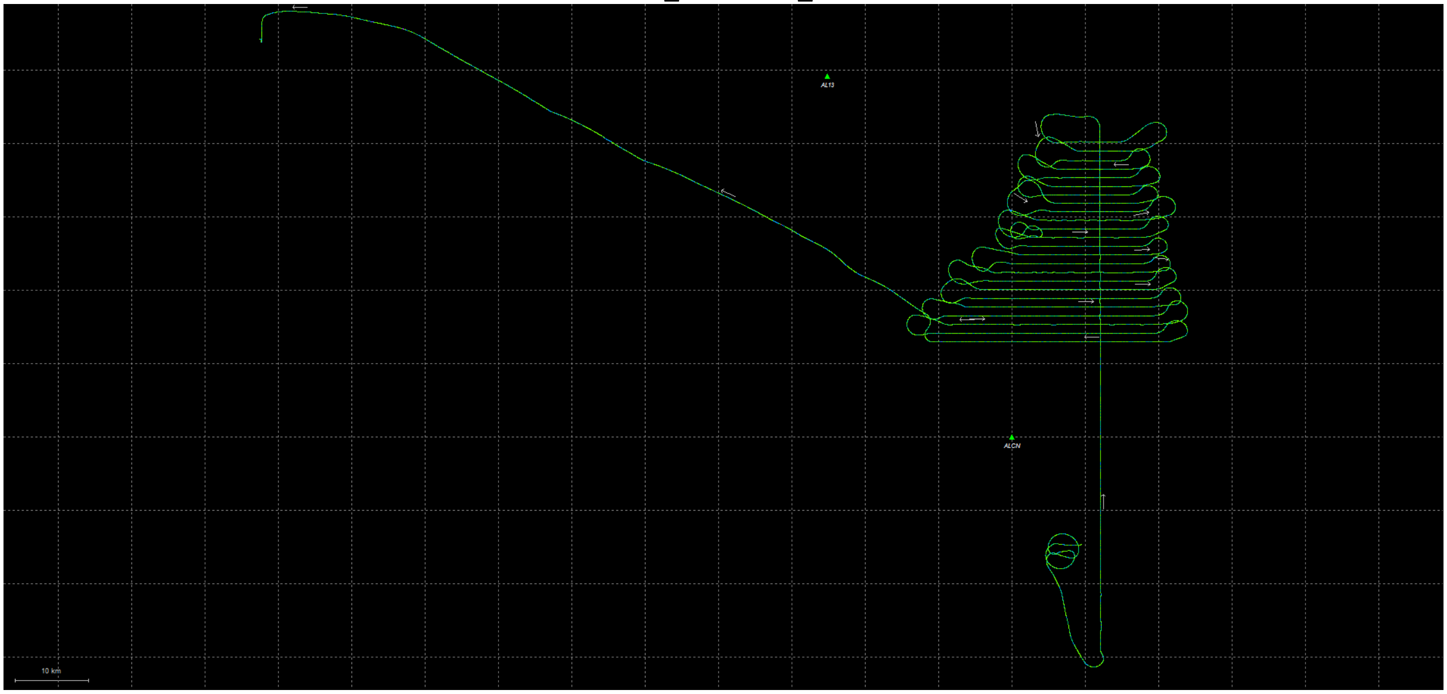
Section 5: GNSS Processing

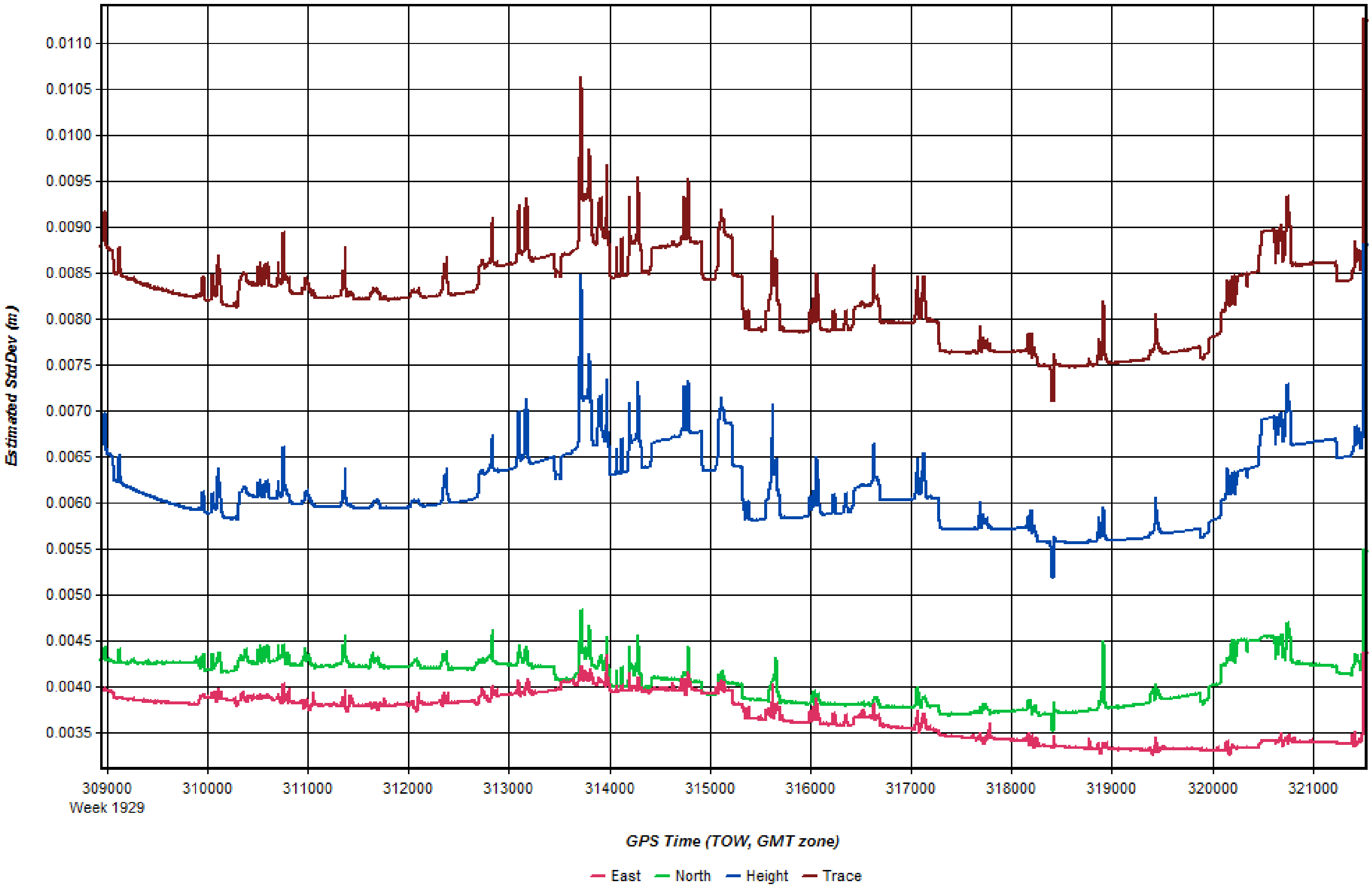
Inertial Explorer version 8.60.6717

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

Coverage Map	The Coverage Map plot shows the Aircraft GNSS-IMU Trajectory in reference to localized GNSS 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_20161228_1

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0.0050
0.0045
0.0040
0.0035
Estimated StdDev (m)
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Week 1929
310000
311000
312000
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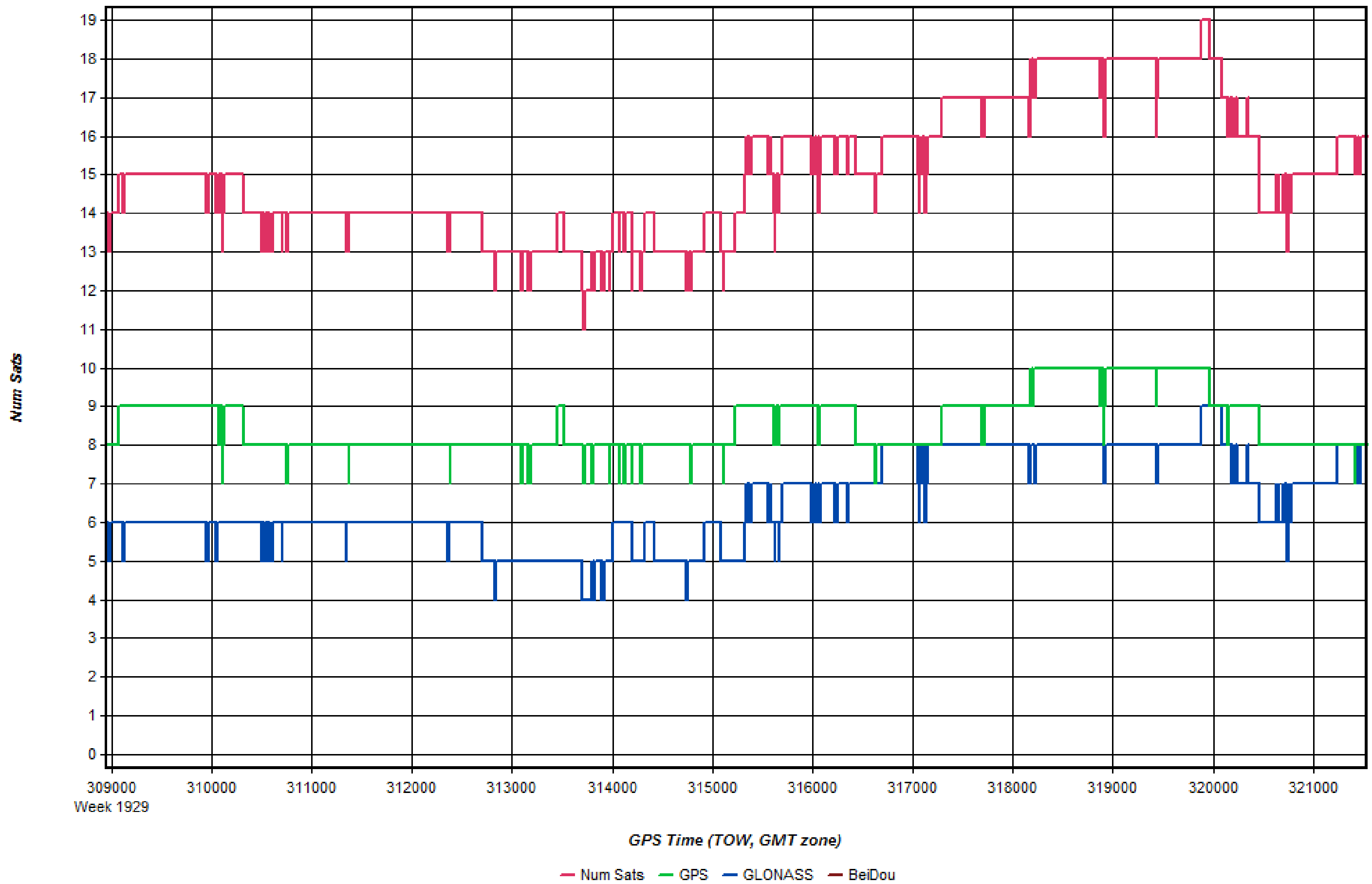
GPS Time (TOW, GMT zone)
East
North
Height
Trace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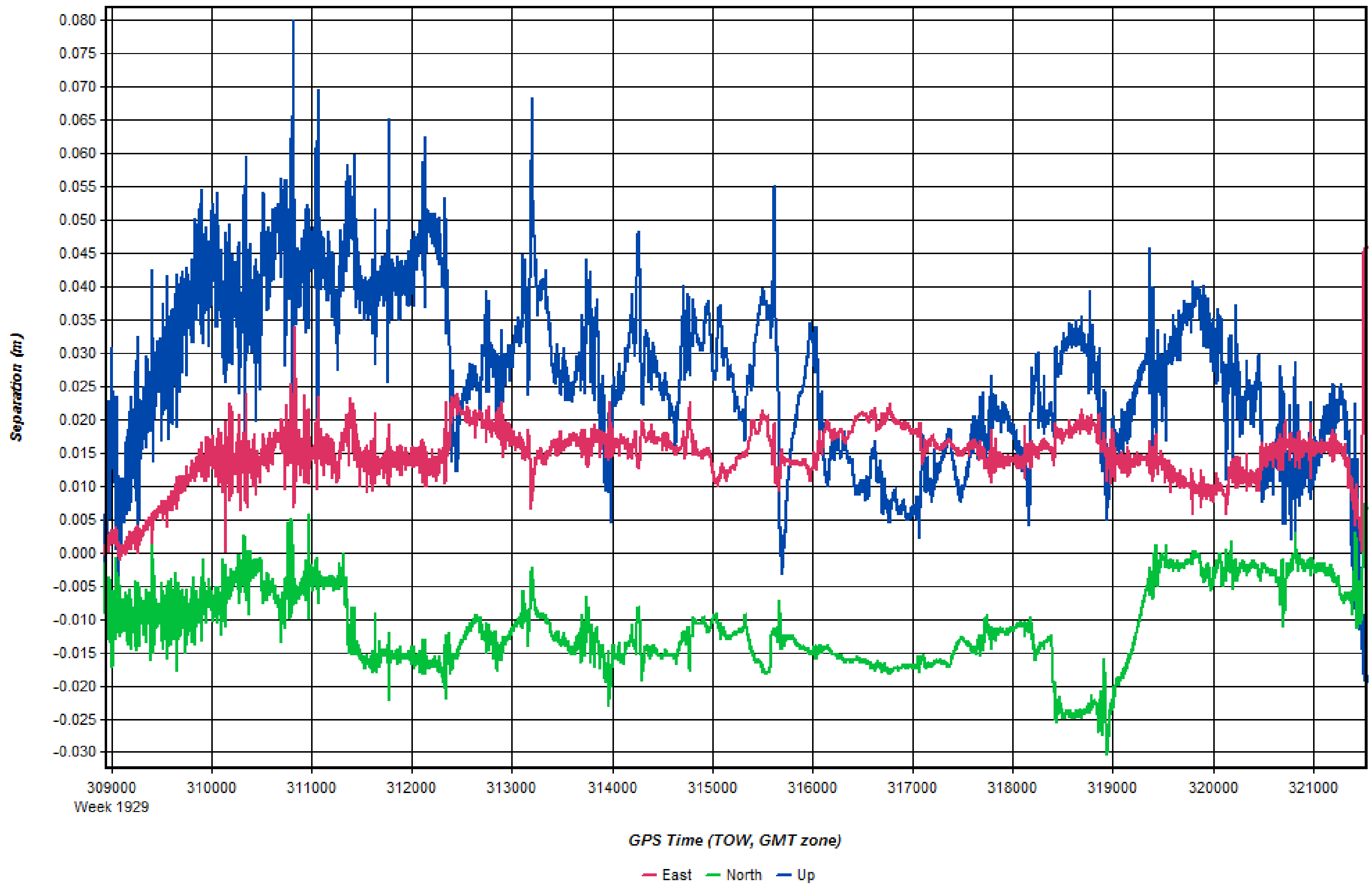
GPS
GLONASS
BeiDou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0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
Separation (m)
309000
Week 1929
310000
311000
312000
313000
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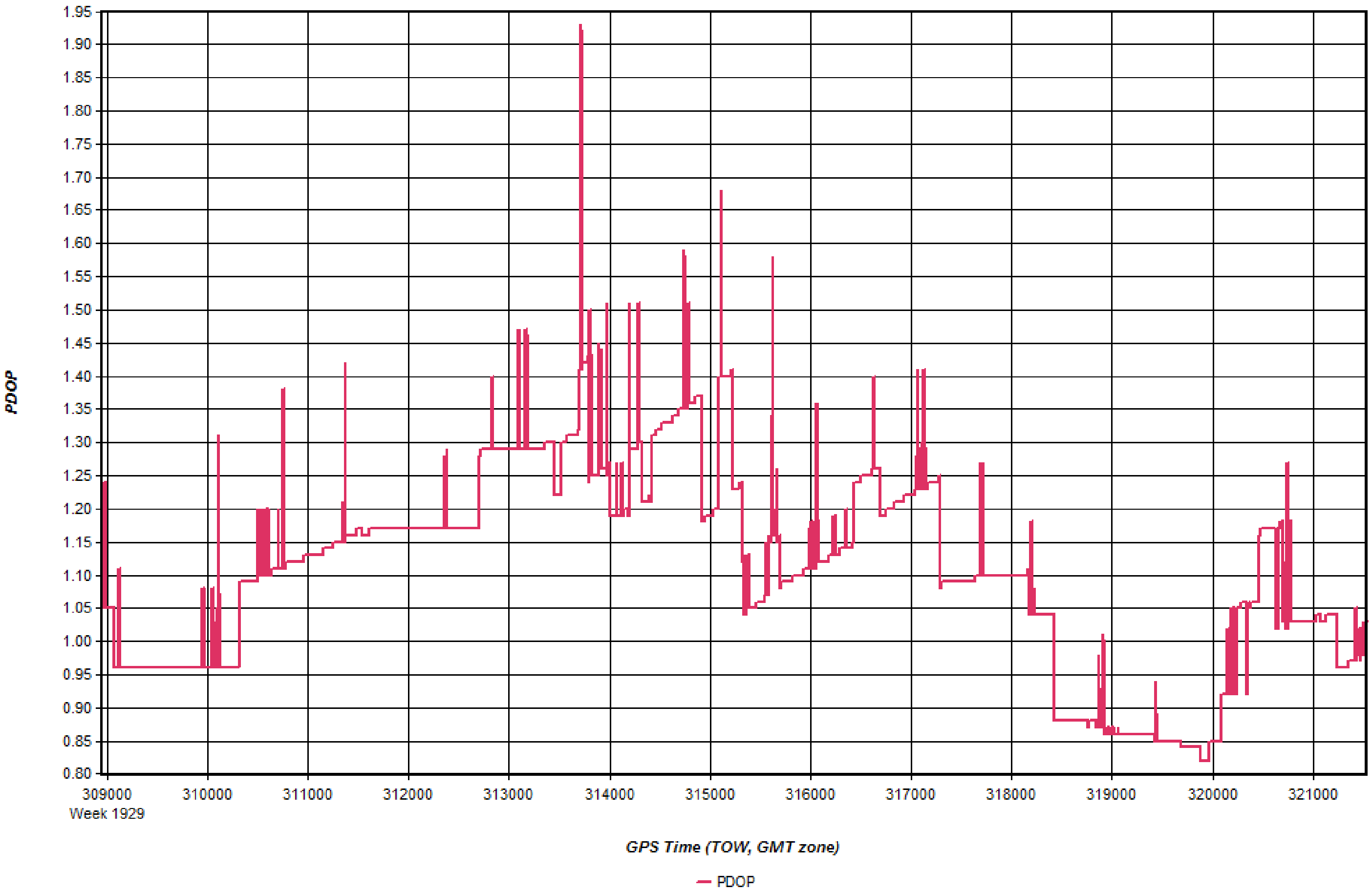
East
North
Up



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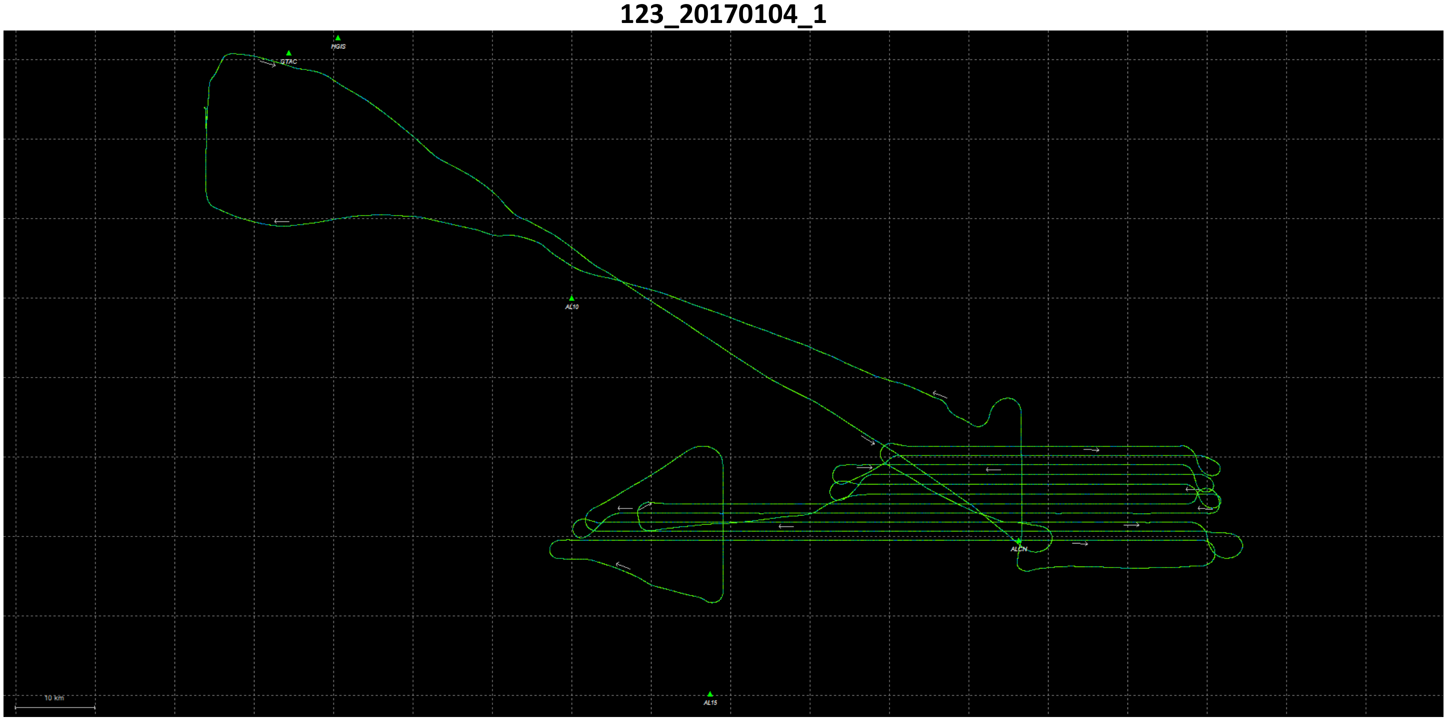

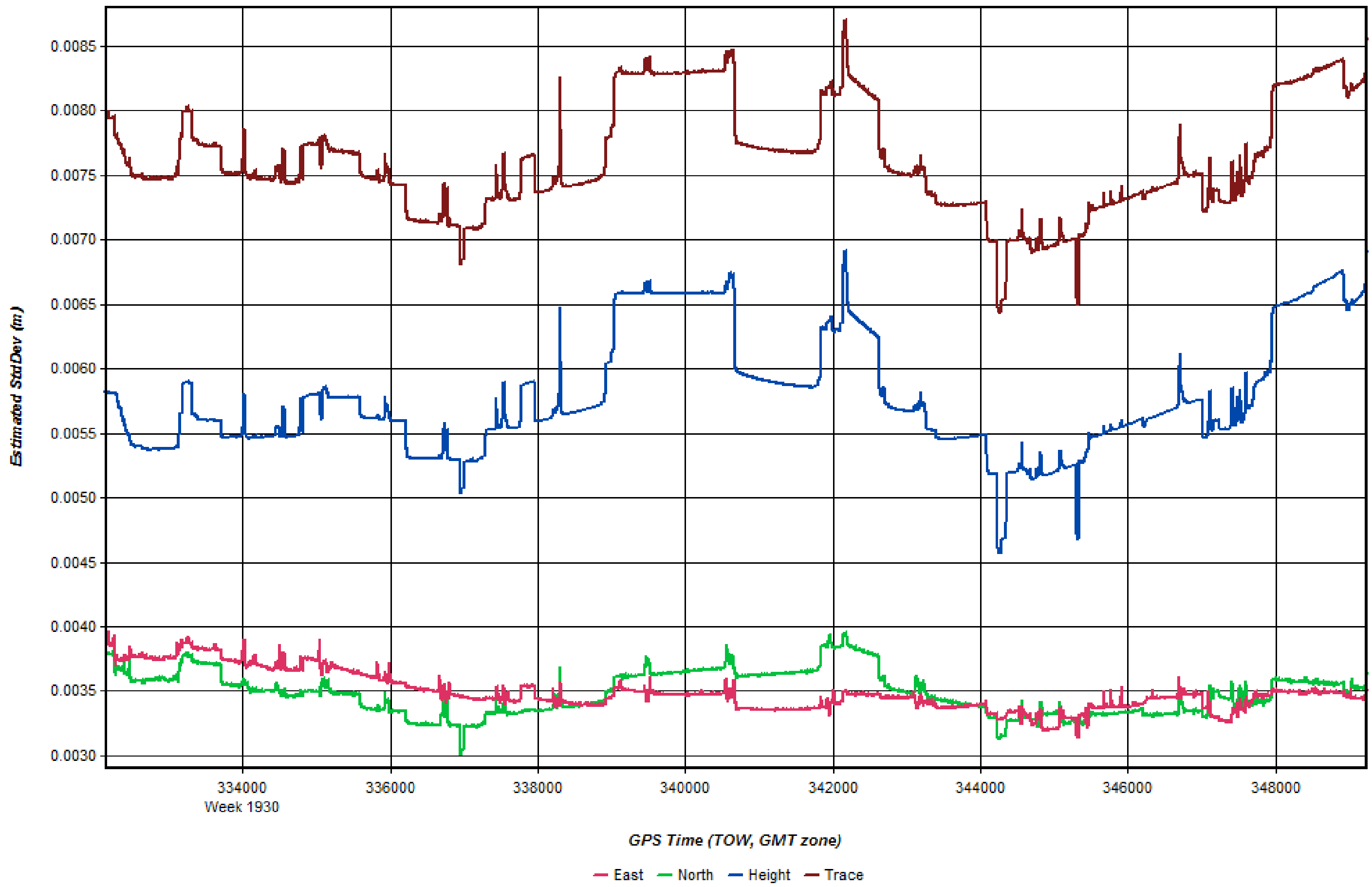
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Week 1930
336000
338000
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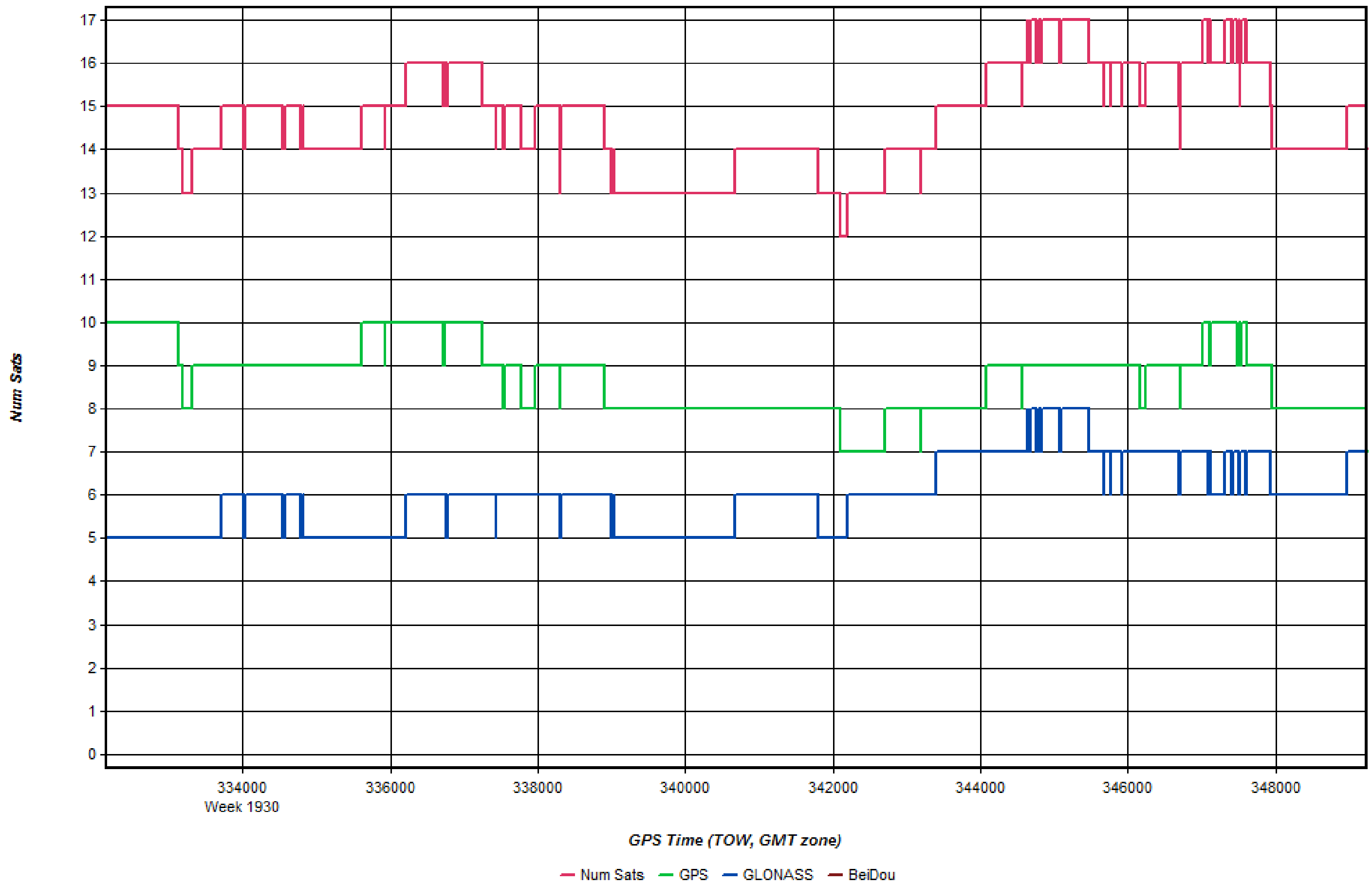
346000
348000
GPS Time (TOW, GMT zone)
East
North
Height
Trace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Week 1930
336000
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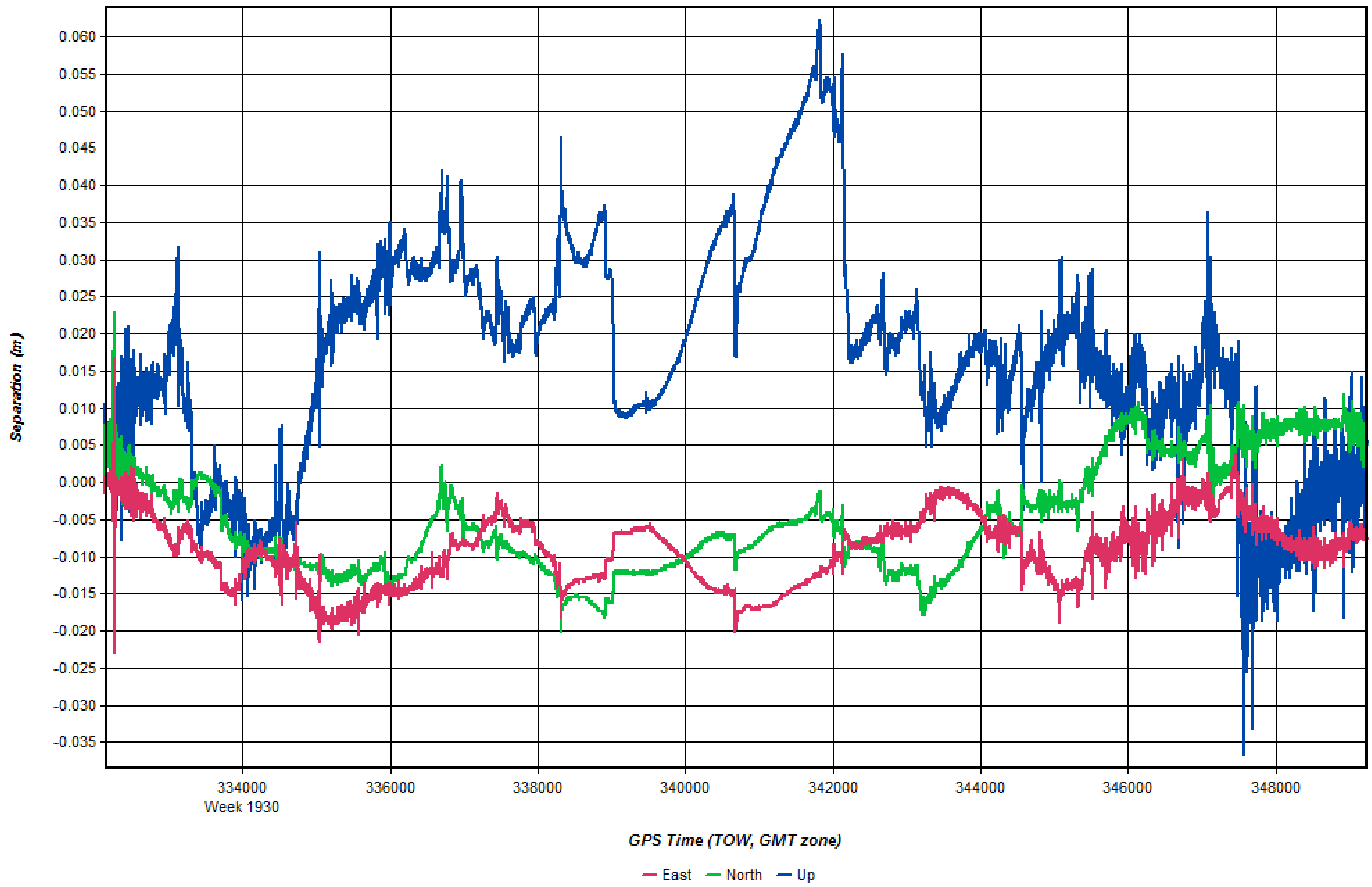
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou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0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
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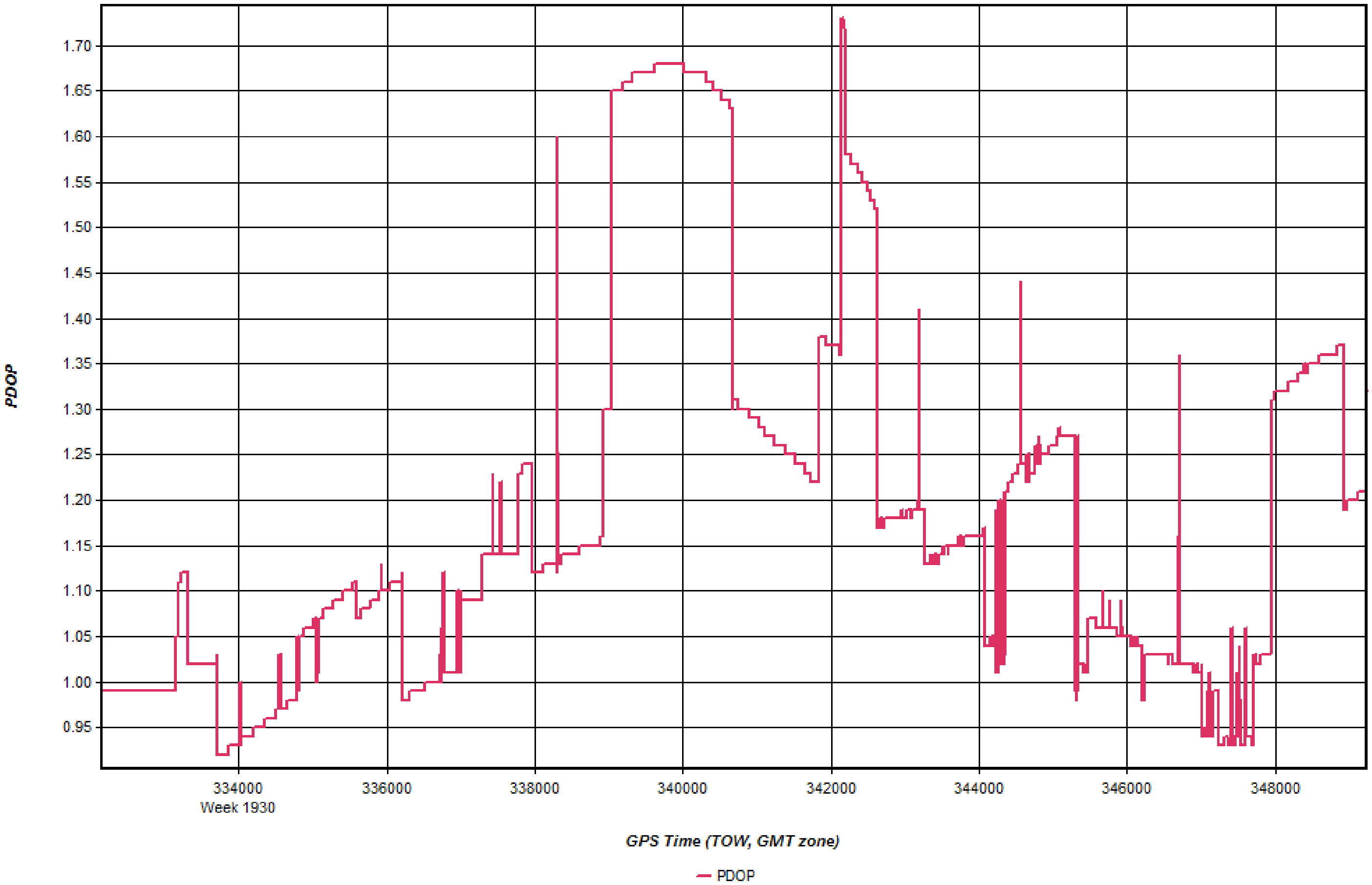
348000
GPS Time (TOW, GMT zone)
East
North
Up



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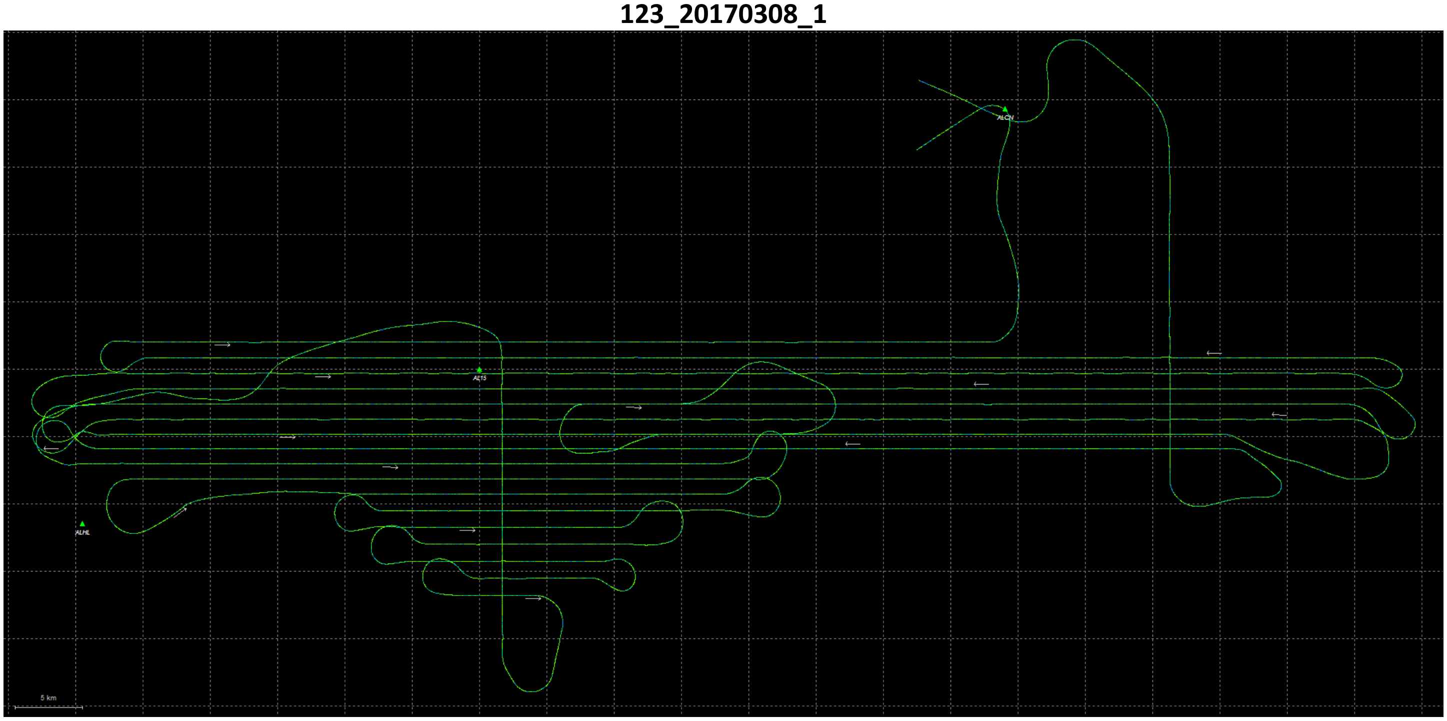

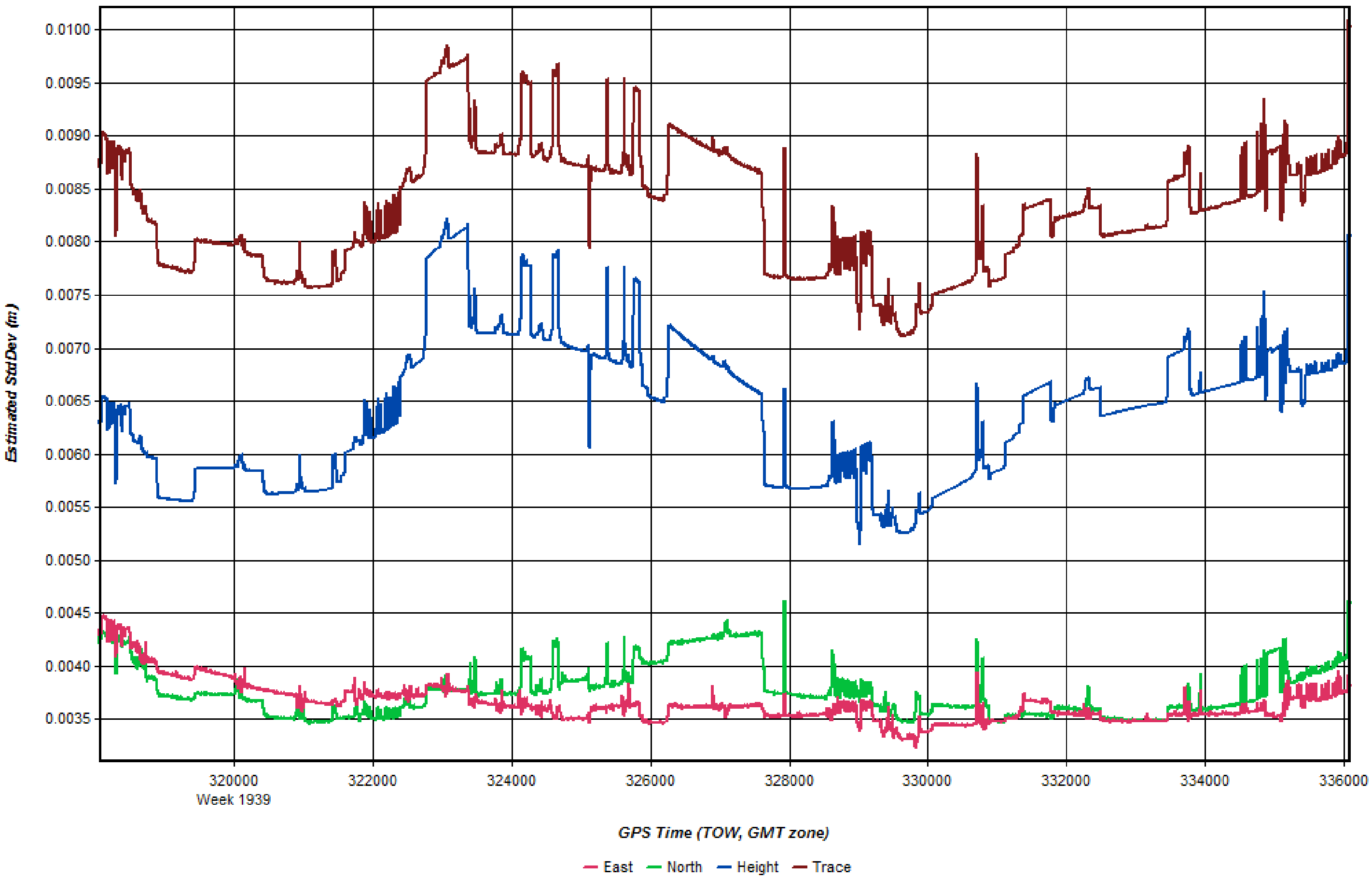
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0.0045
0.0040
0.0035
320000
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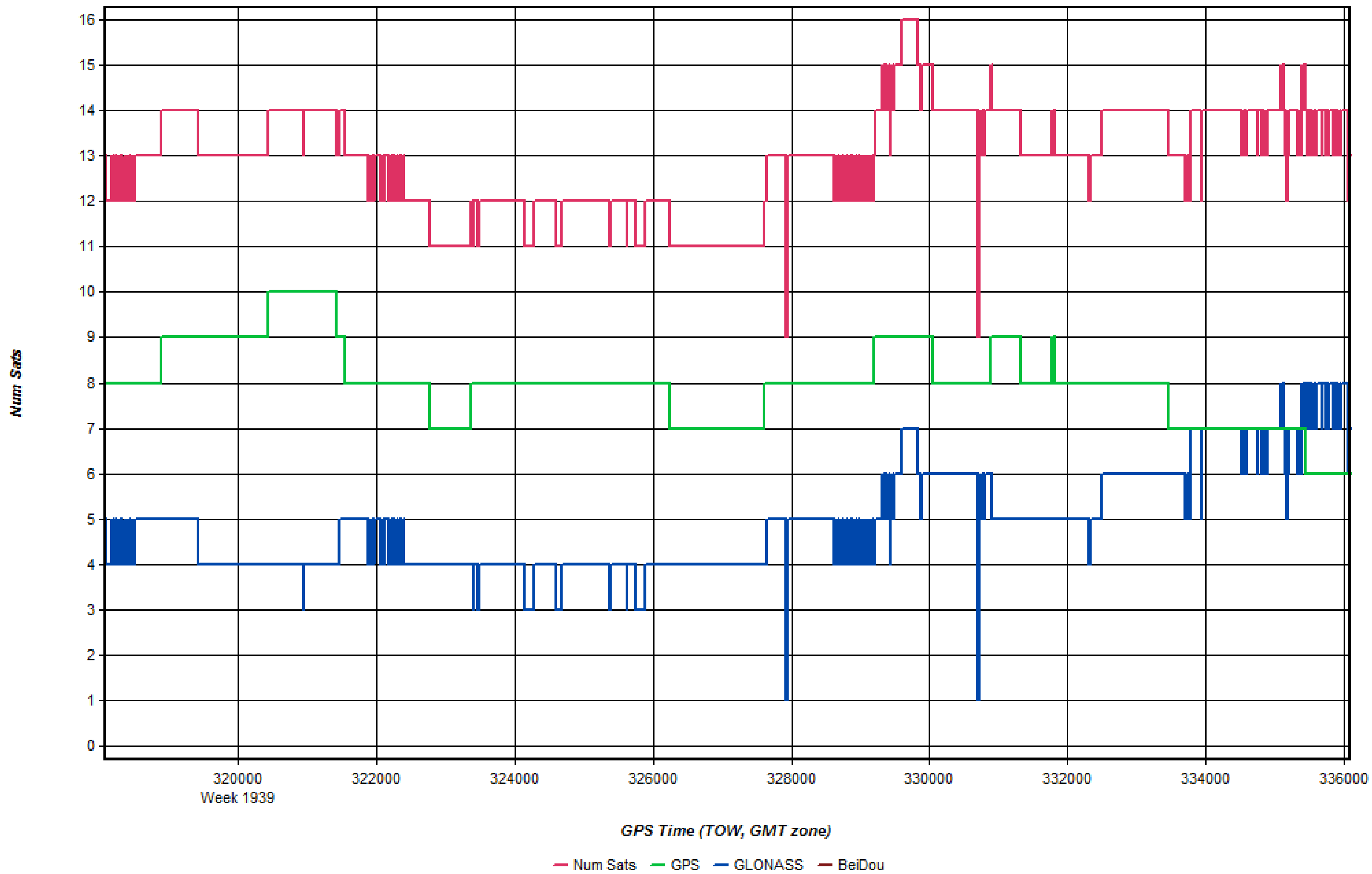
East
North
Height
Trace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GPS
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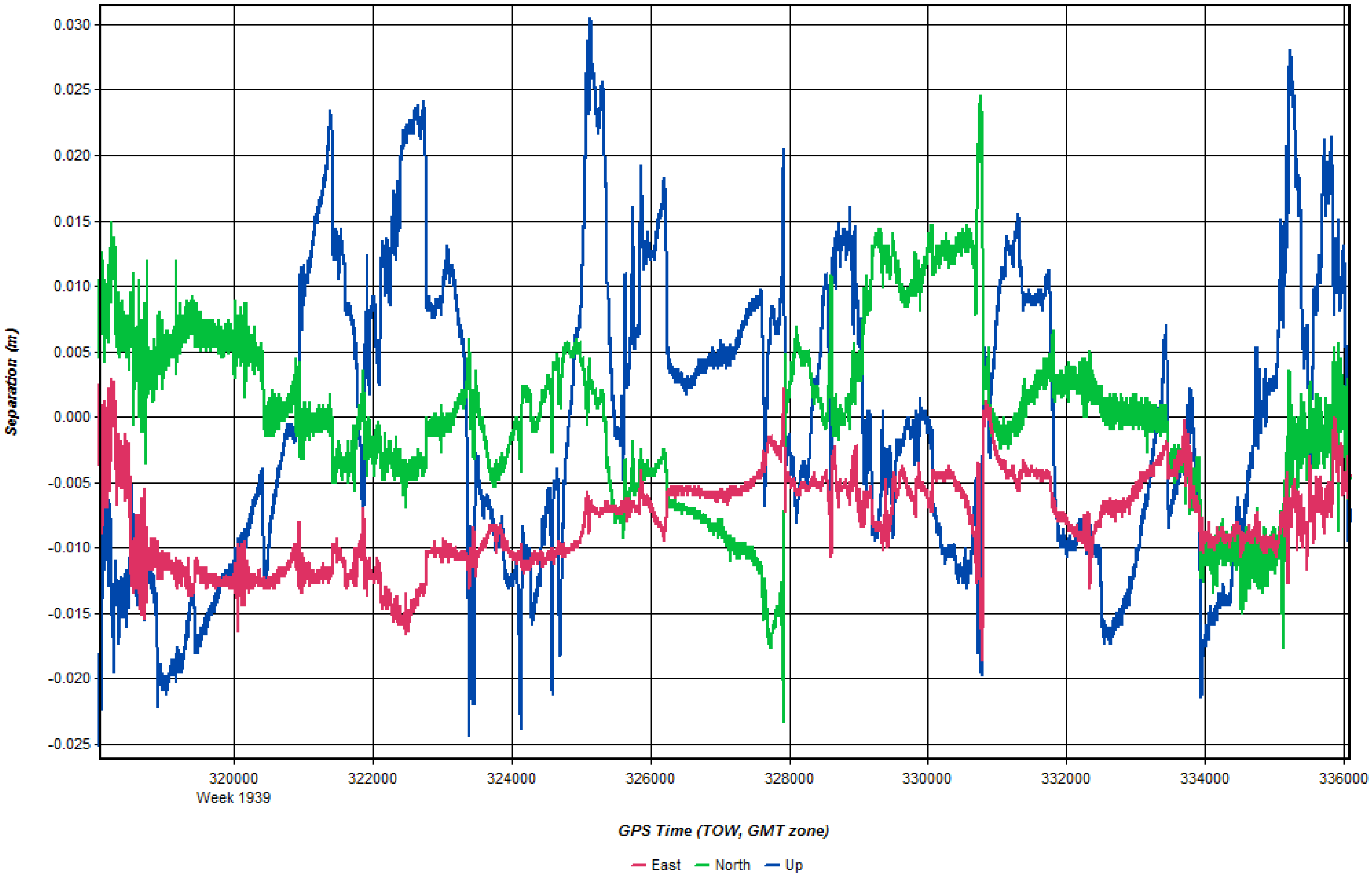
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Separation (m)
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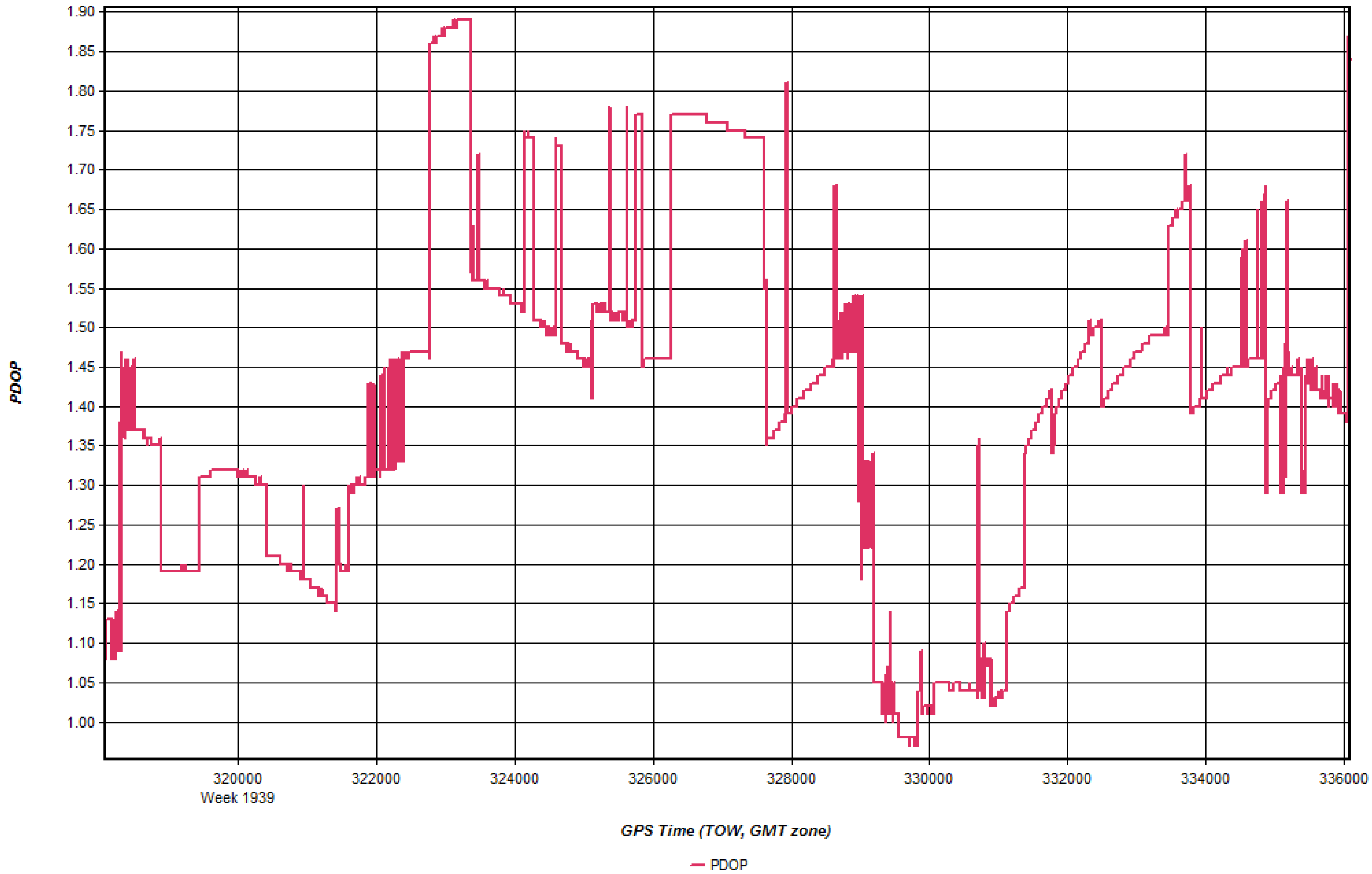
GPS Time (TOW, GMT zone)
East
North
Up



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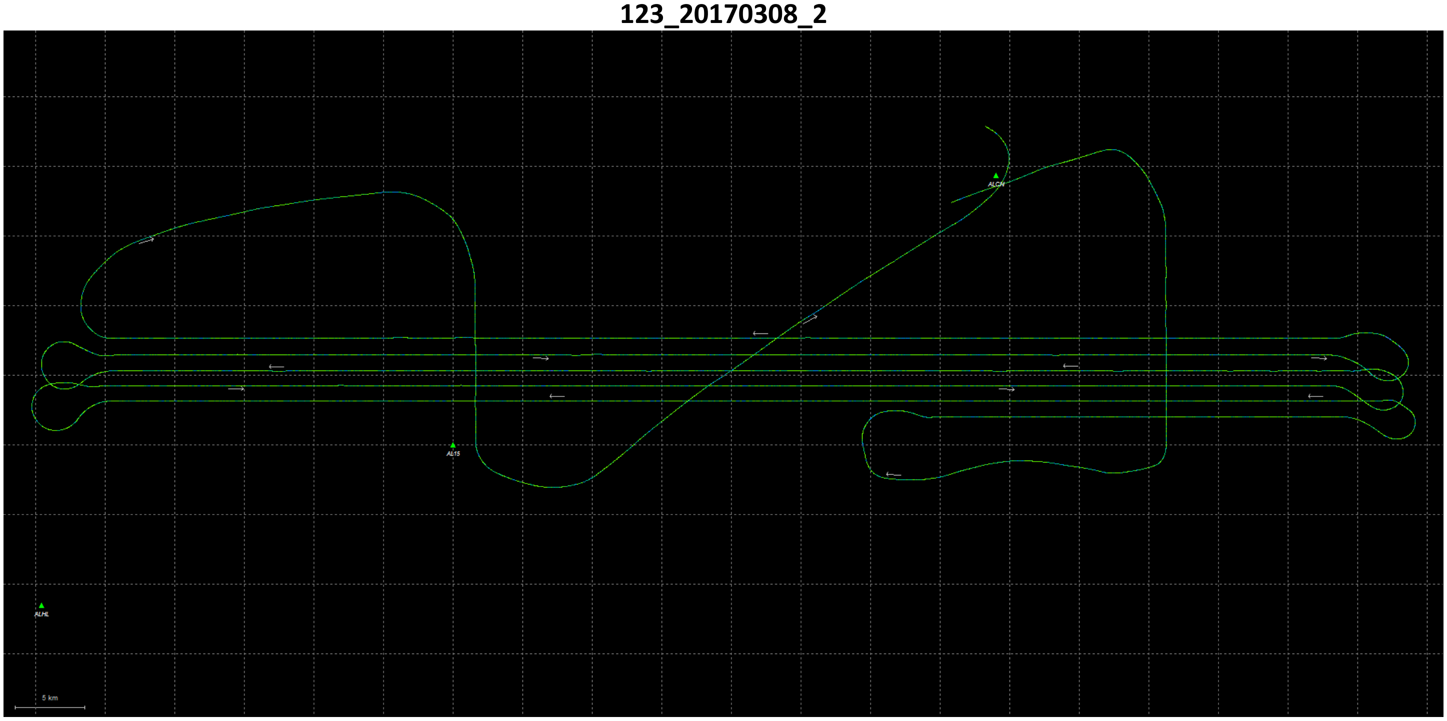
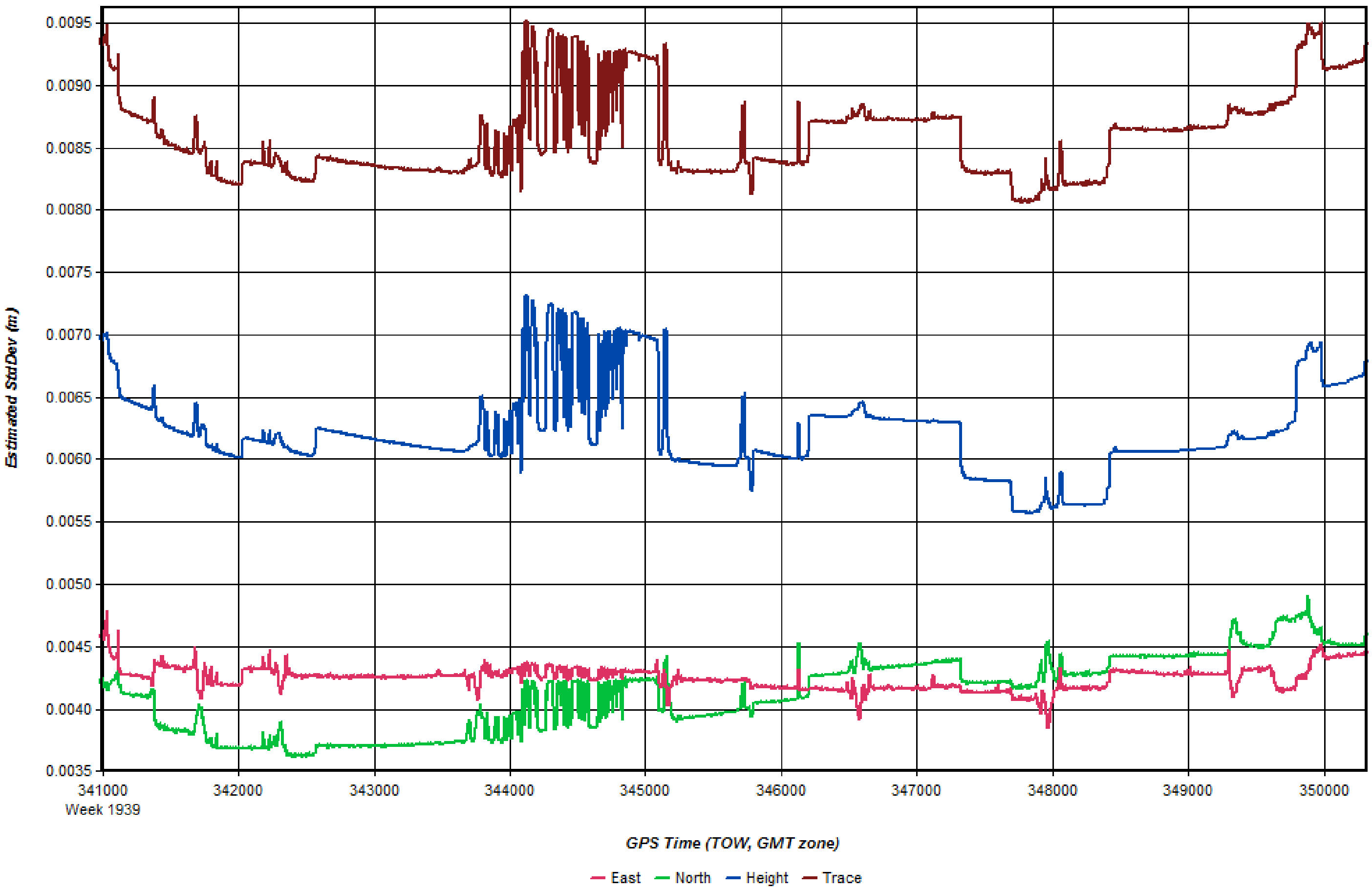
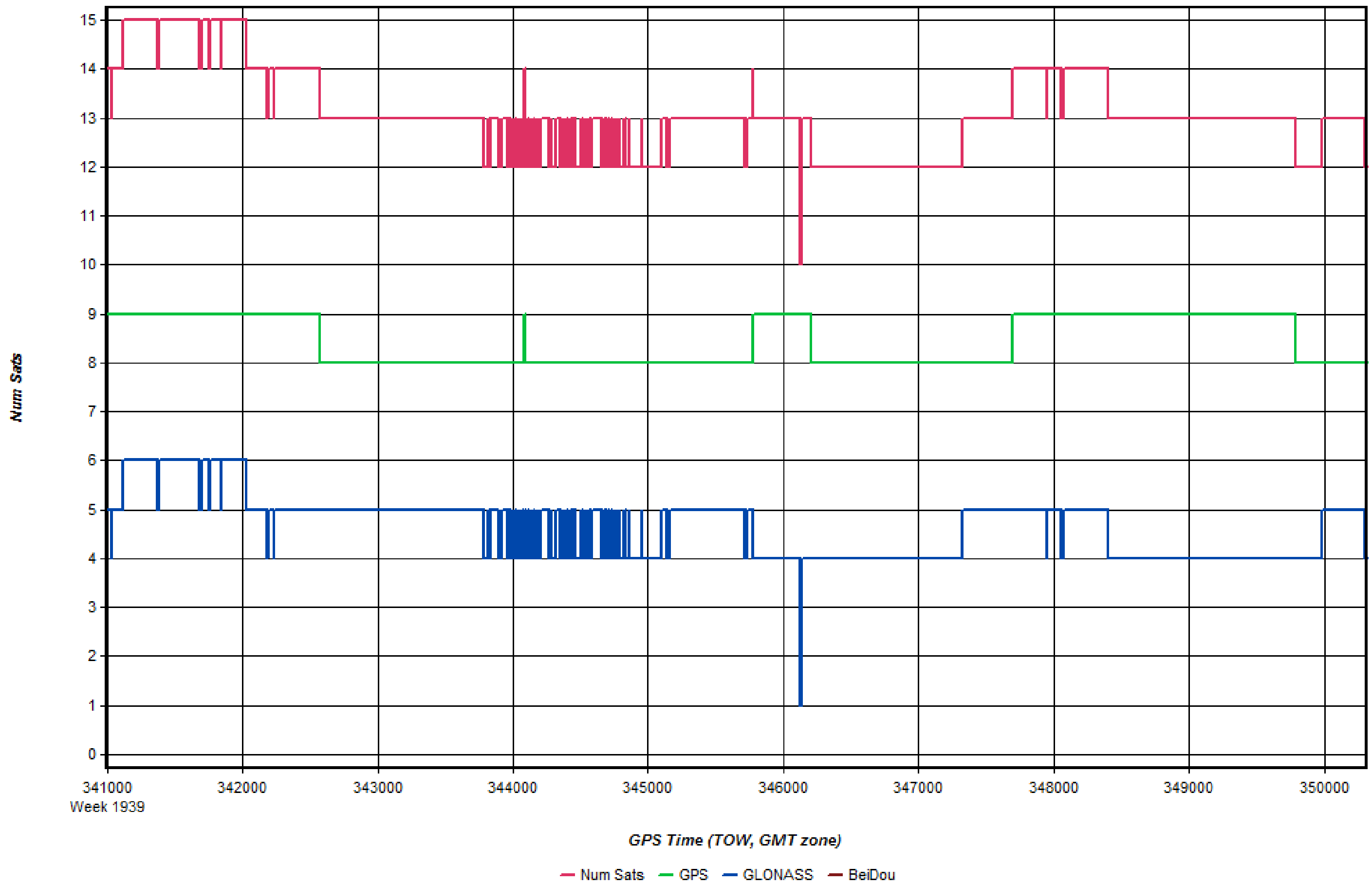



Estimated StdDev (m)
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
341000
Week 1939
342000
343000
344000
345000
346000
347000
348000
349000
350000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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14
13
12
11
10
9
8
7
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5
4
3
2
1
0
341000
Week 1939
342000
343000
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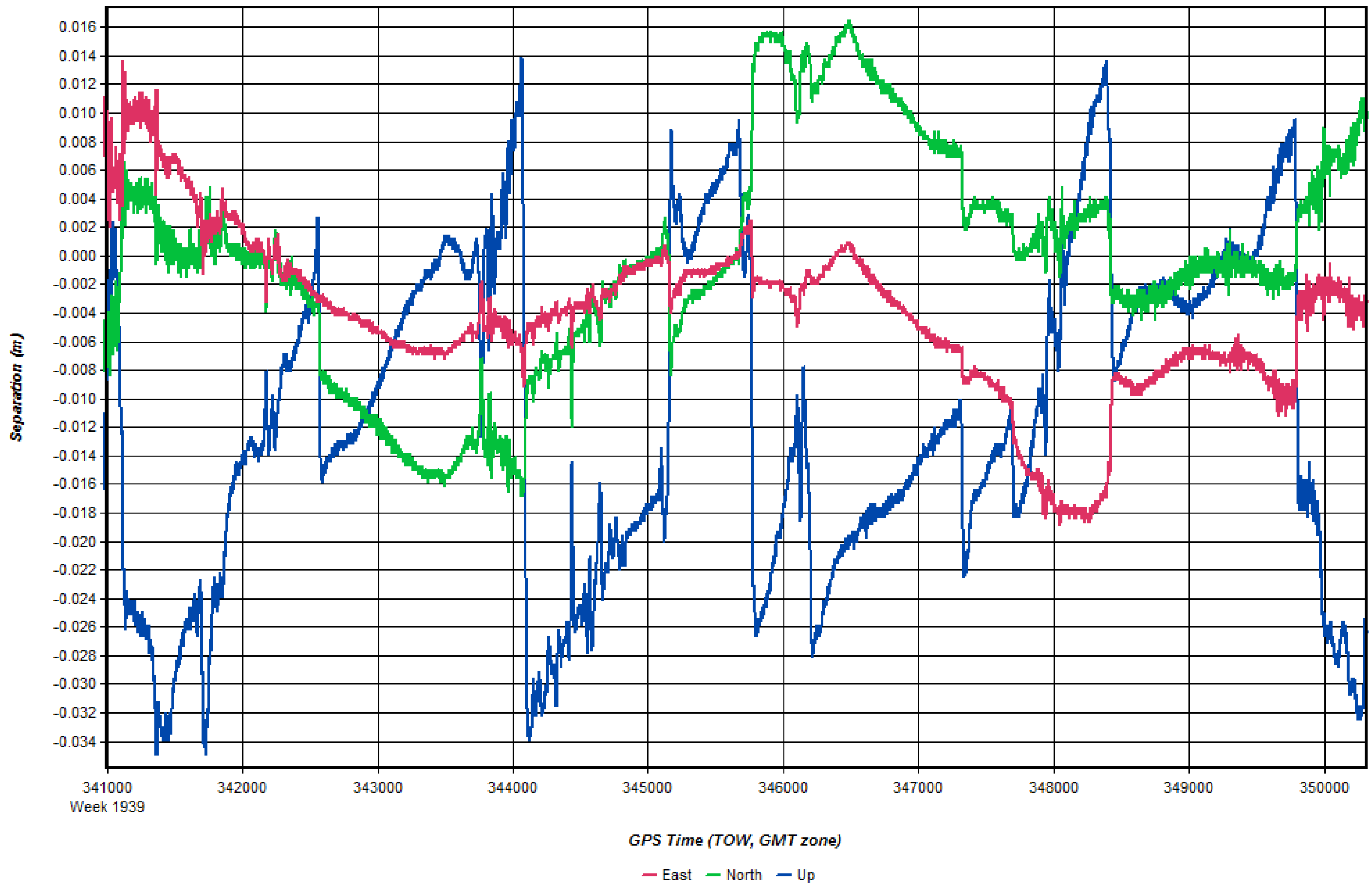
348000
349000
350000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


Separation (m)
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0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
-0.014
-0.016
-0.018
-0.020
-0.022
-0.024
-0.026
-0.028
-0.030
-0.032
-0.034
341000
Week 1939
342000
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344000
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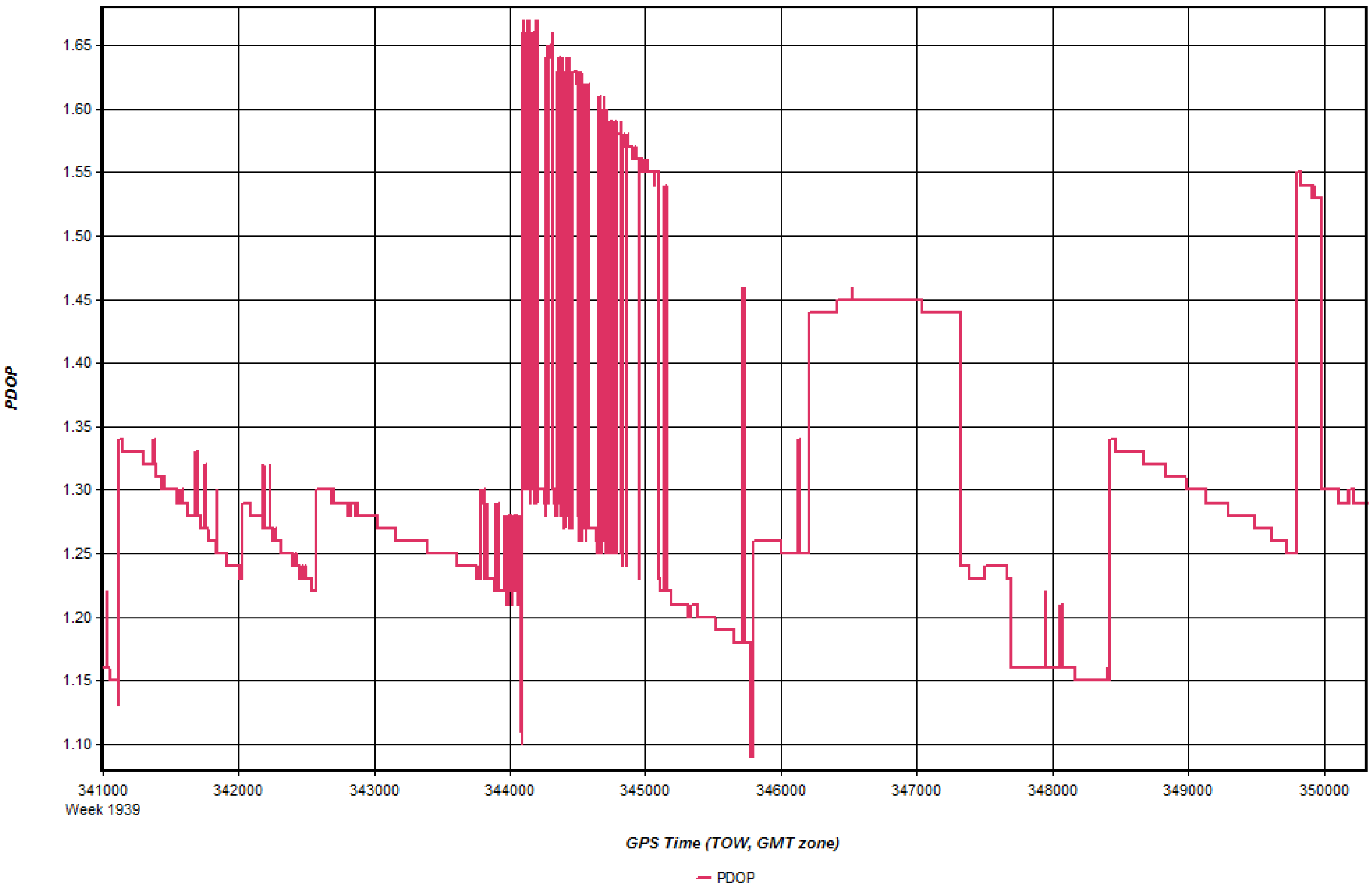
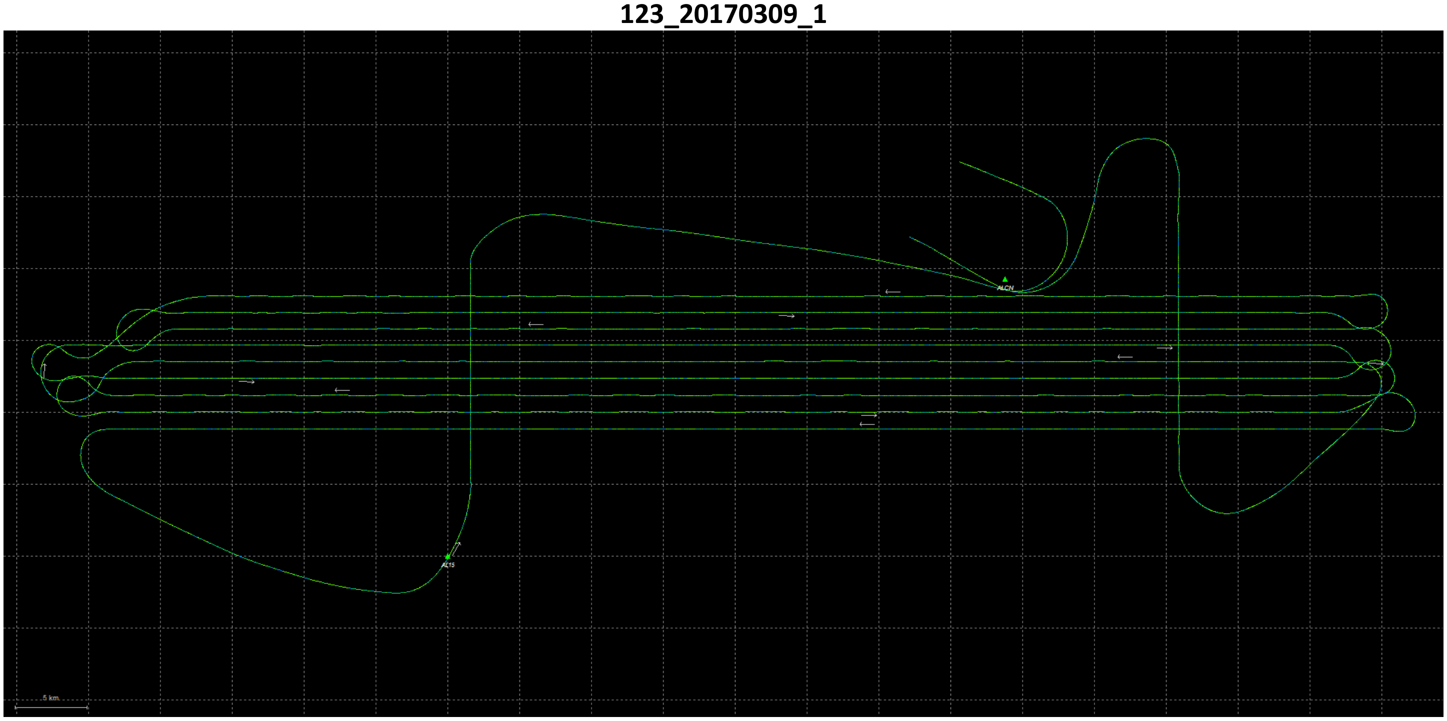
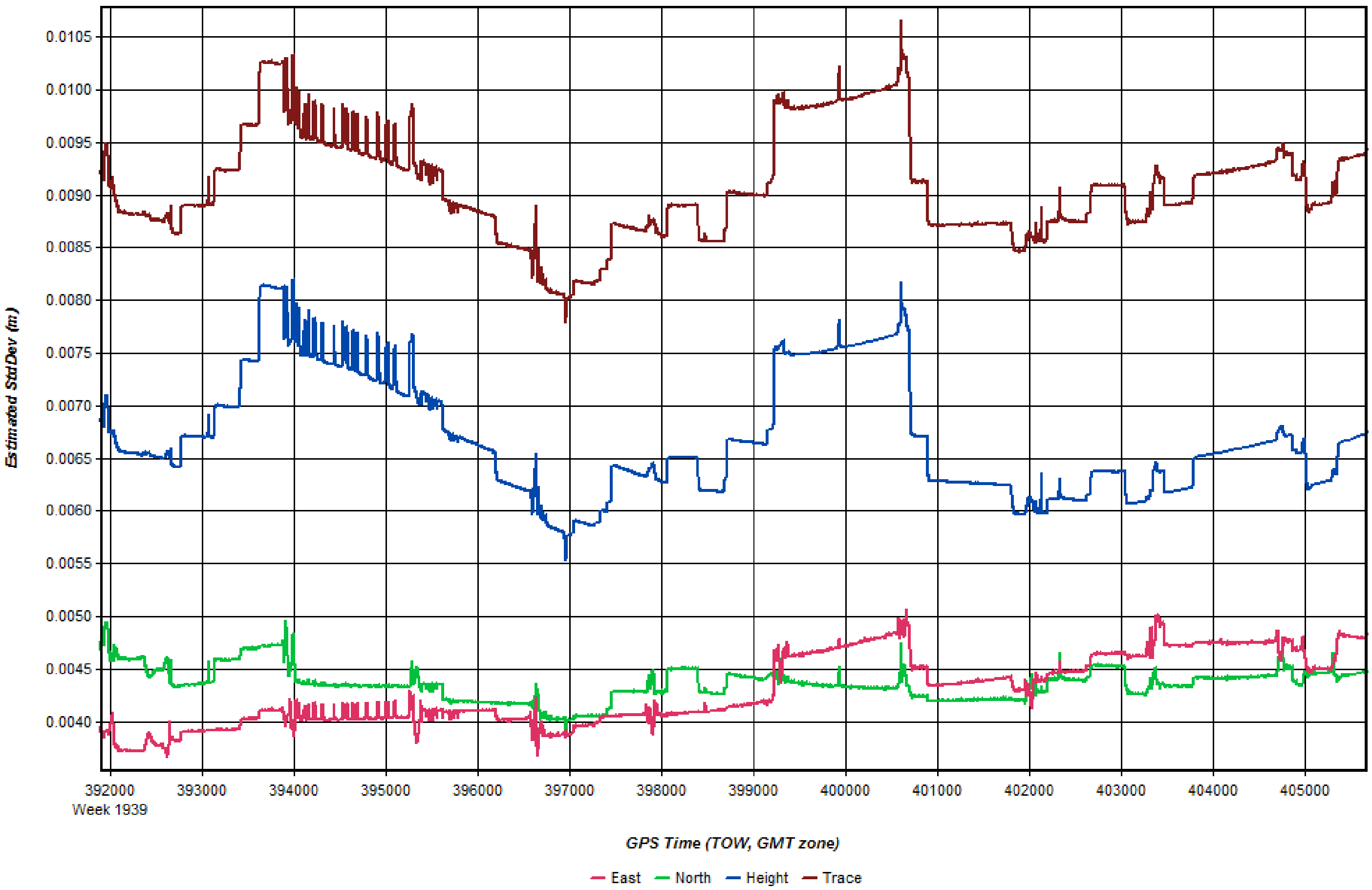
347000
348000
349000
350000
GPS Time (TOW, GMT zone)
East
North
Up



123_20170309_1

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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
Estimated StdDev (m)
392000
Week 1939
393000
394000
395000
396000
397000
398000
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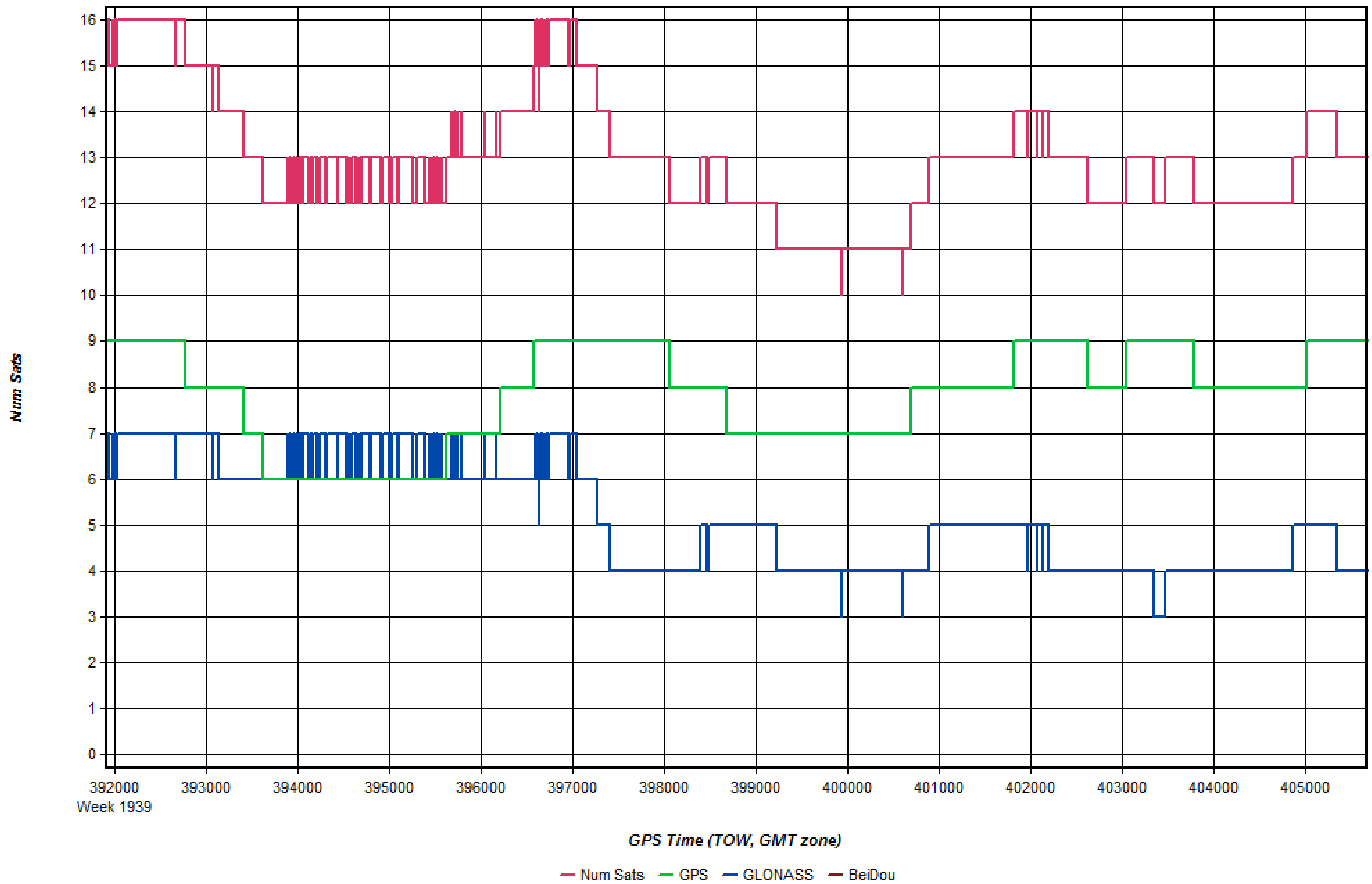
400000
401000
402000
403000
404000
405000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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Week 1939
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394000
395000
396000
397000
398000
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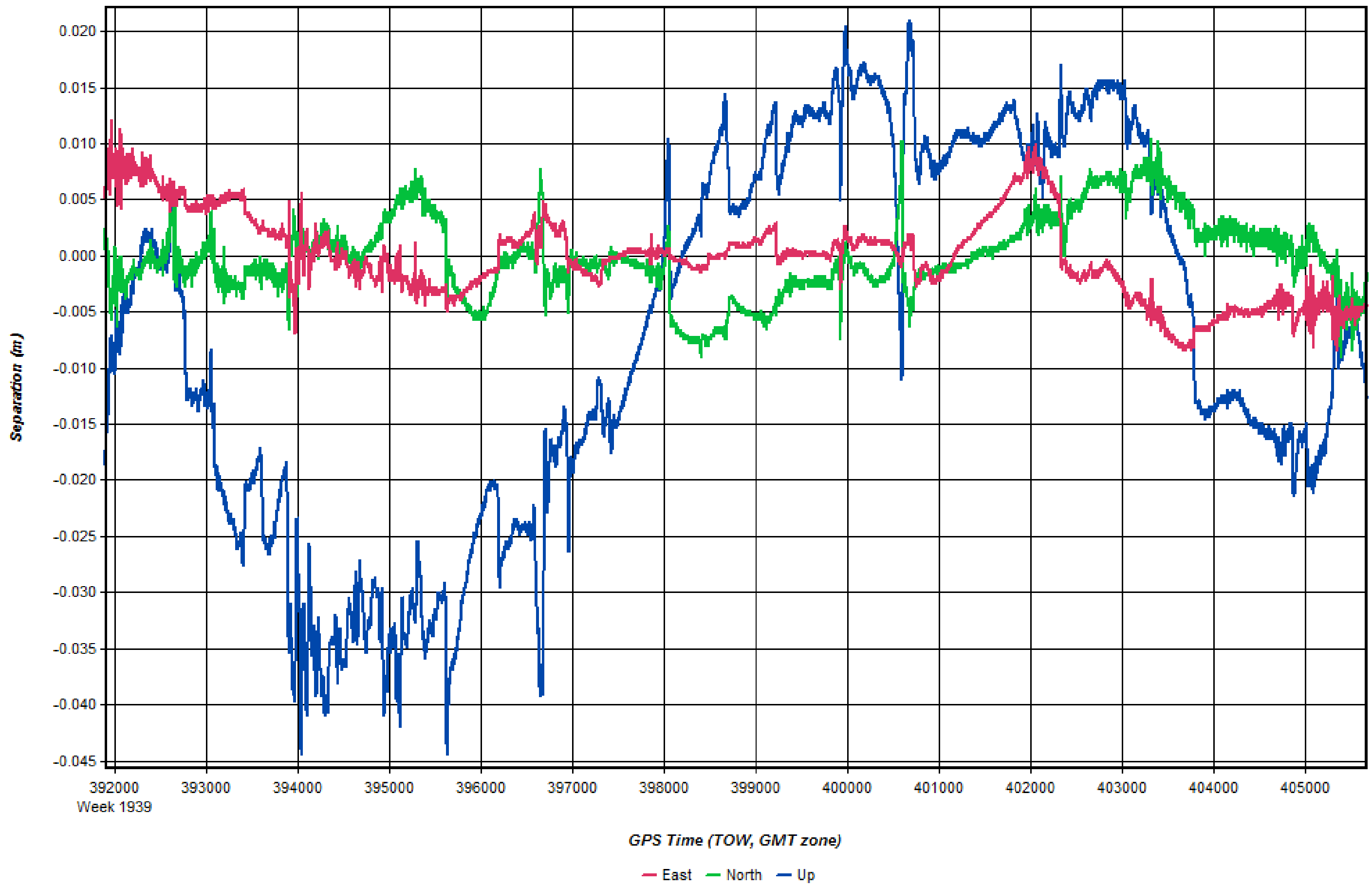
400000
401000
402000
403000
404000
405000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


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
-0.045
Separation (m)
392000
Week 1939
393000
394000
395000
396000
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398000
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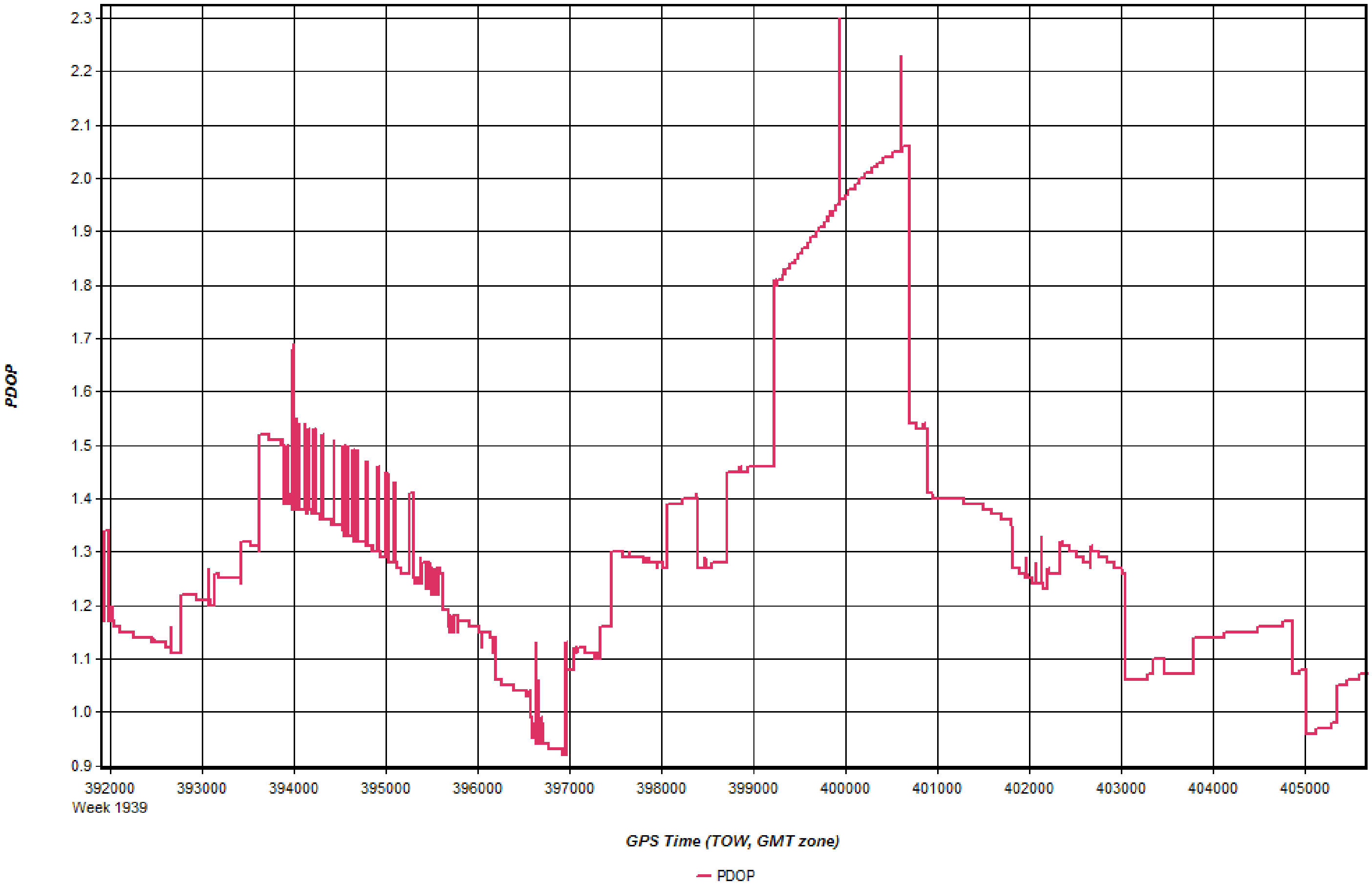
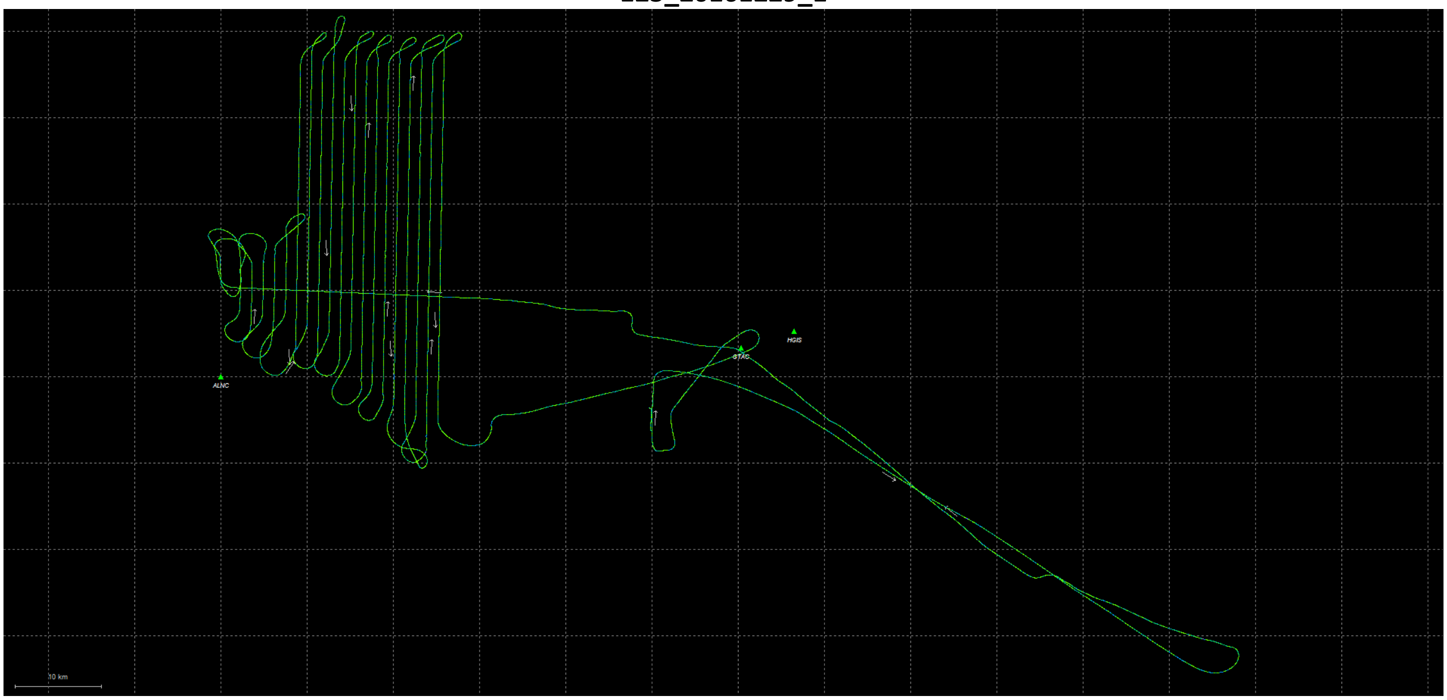
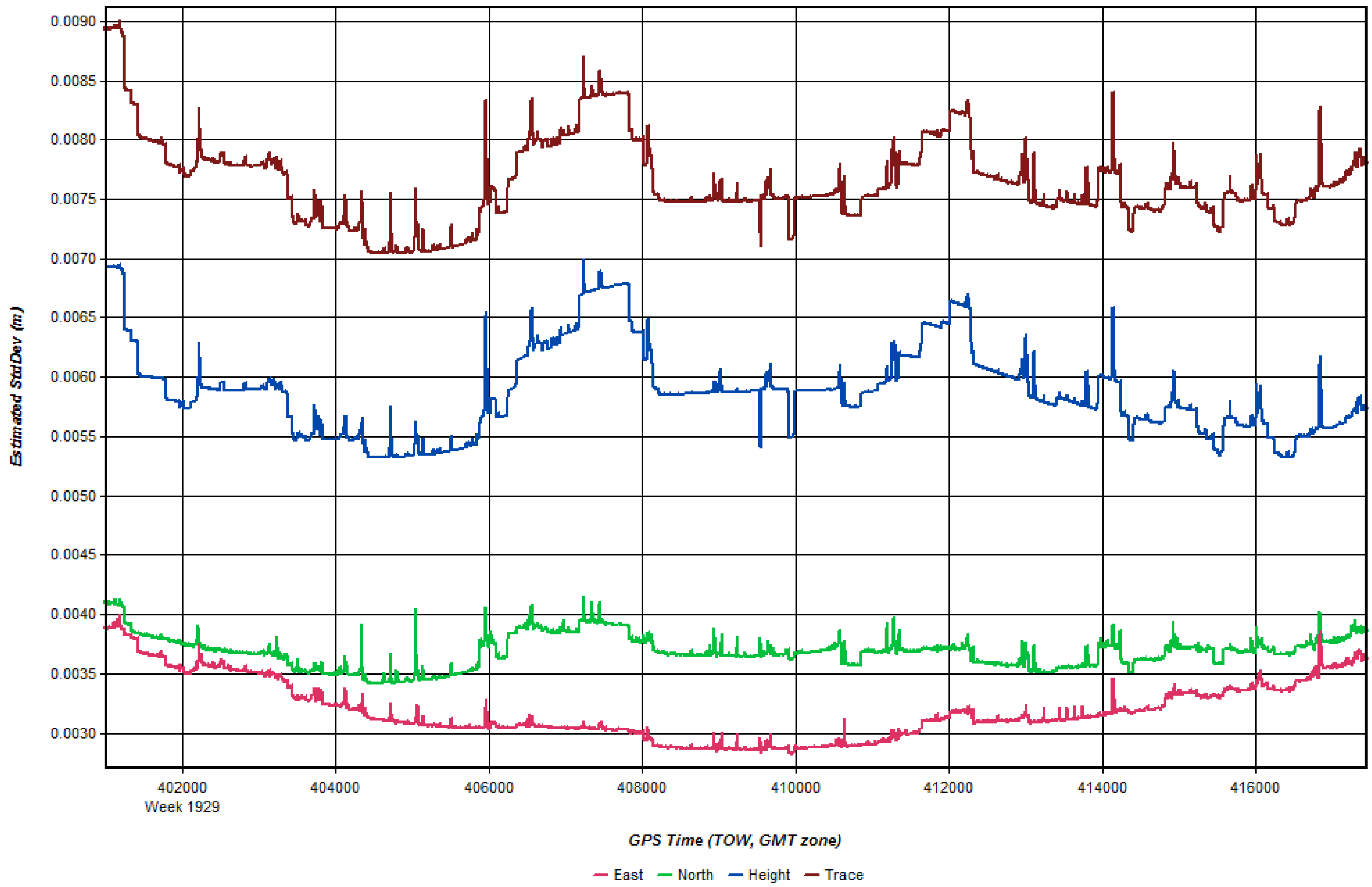
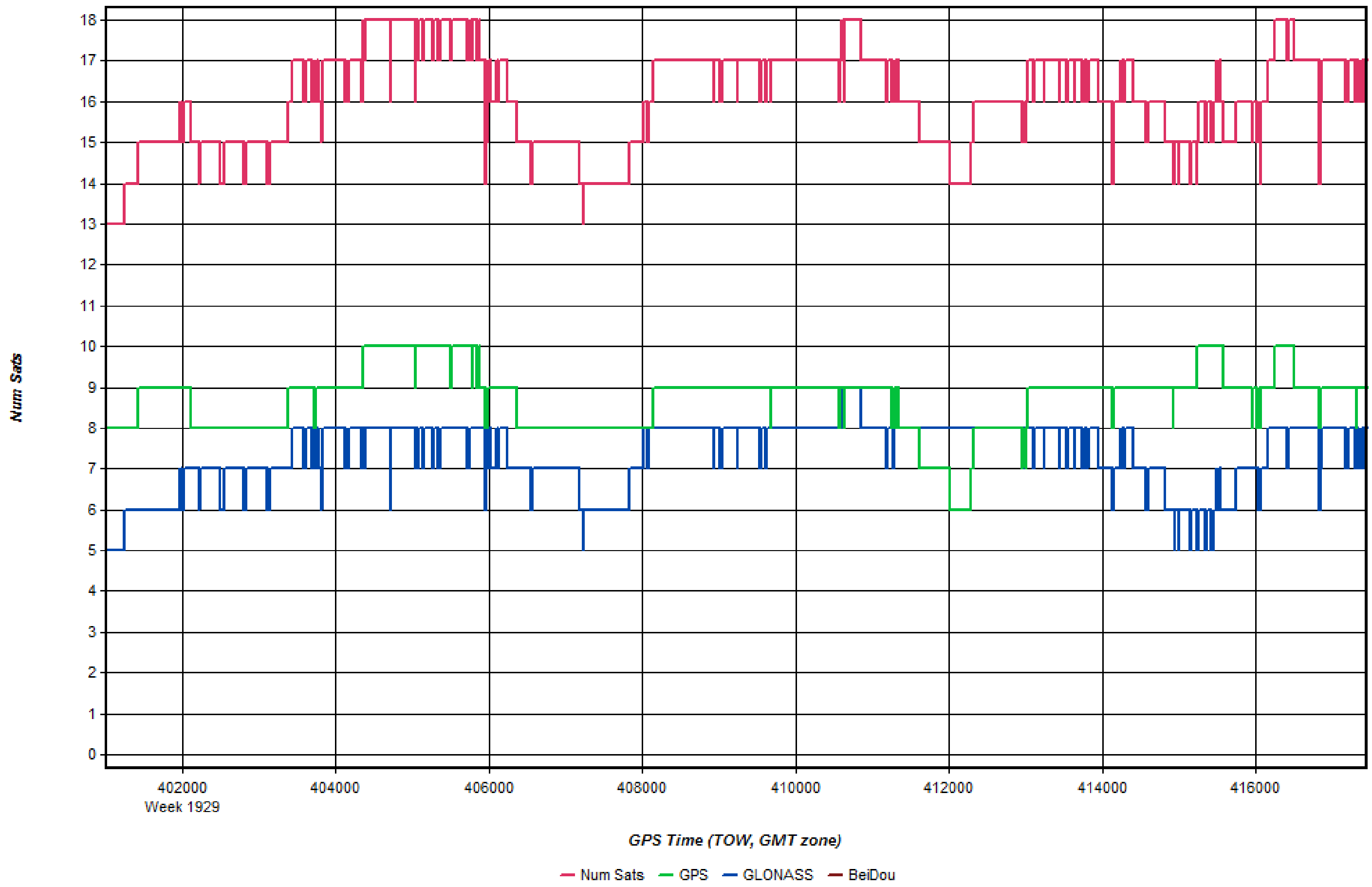
400000
401000
402000
403000
404000
405000
GPS Time (TOW, GMT zone)
East
North
Up



123_20161229_1




0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
Estimated StdDev (m)
402000
Week 1929
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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18
402000
Week 1929
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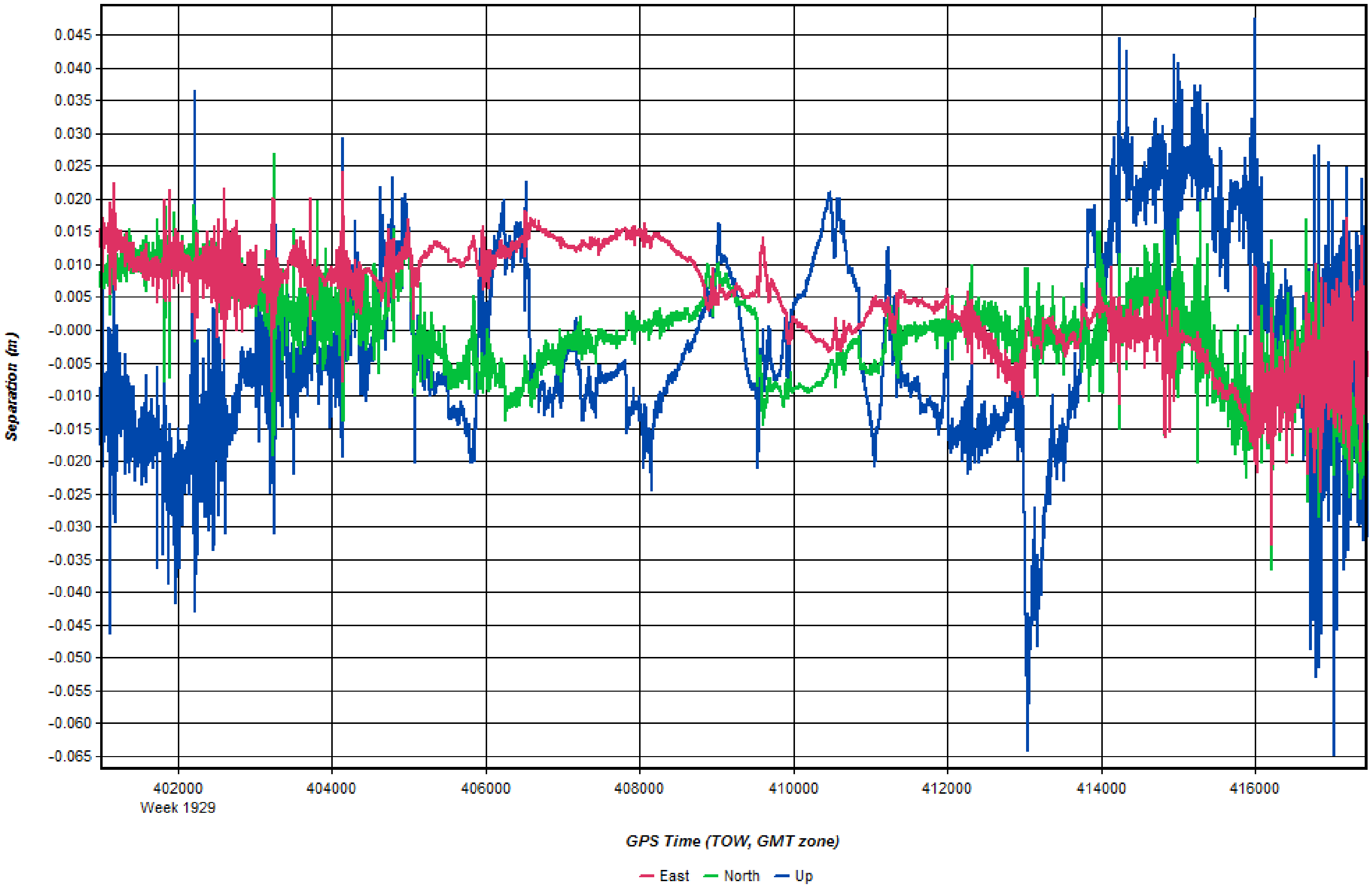
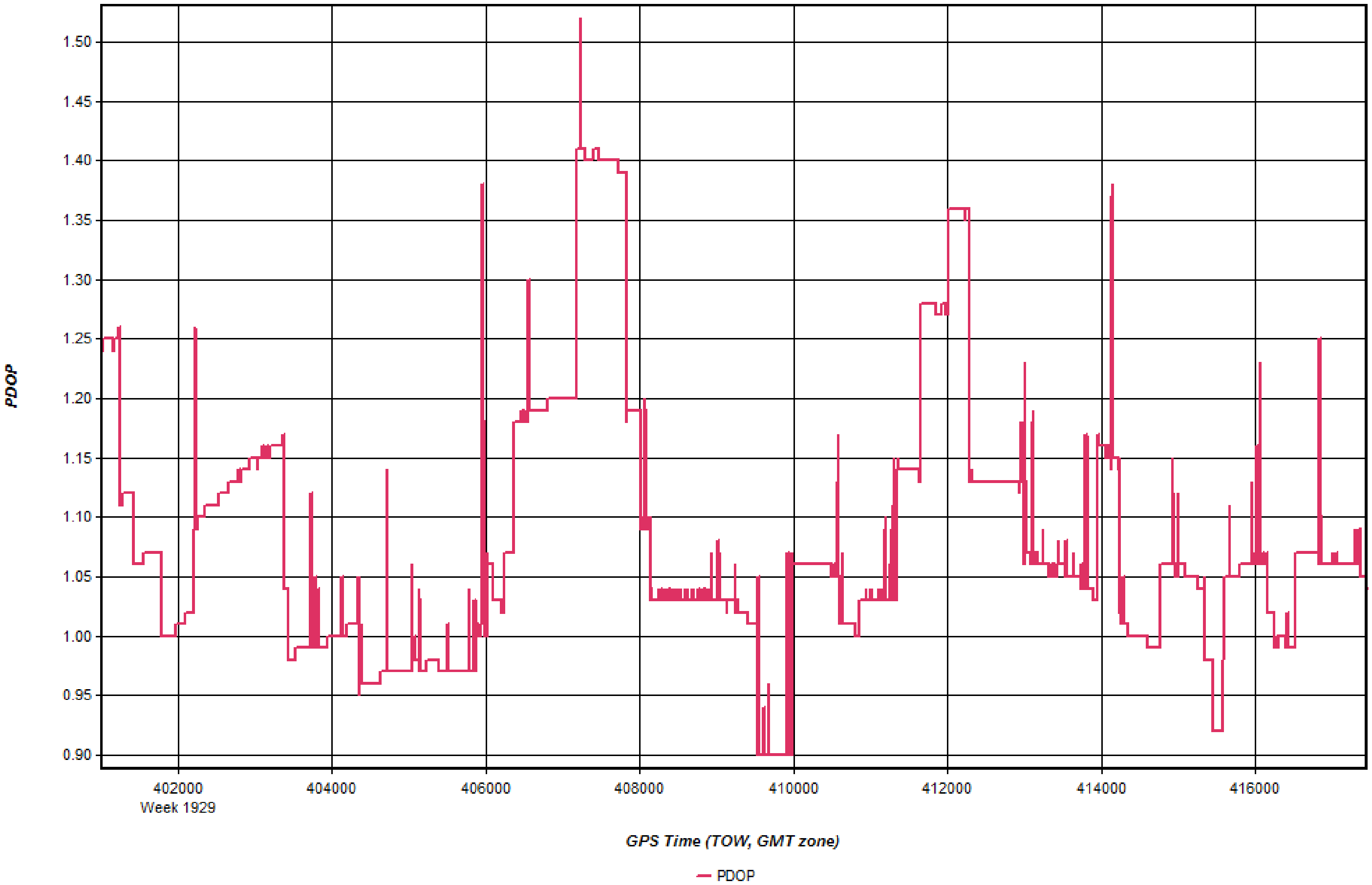
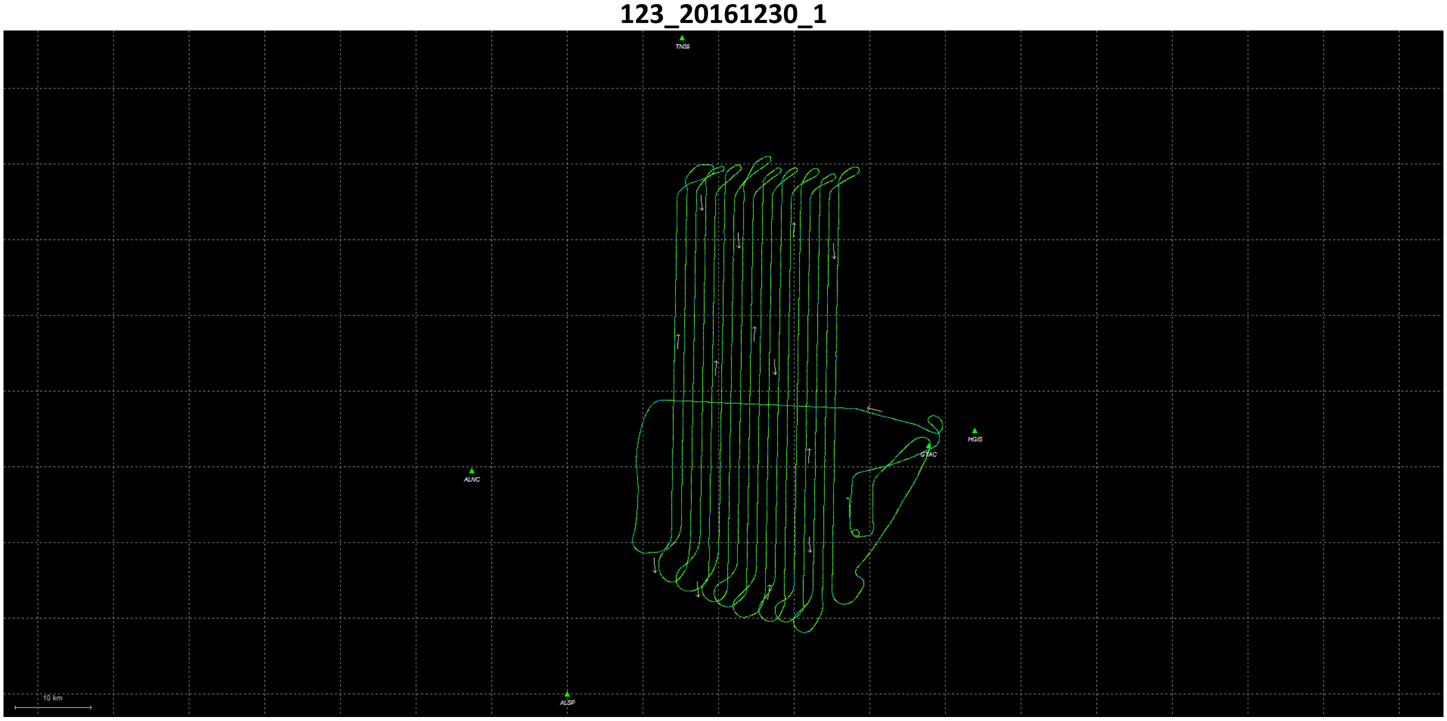
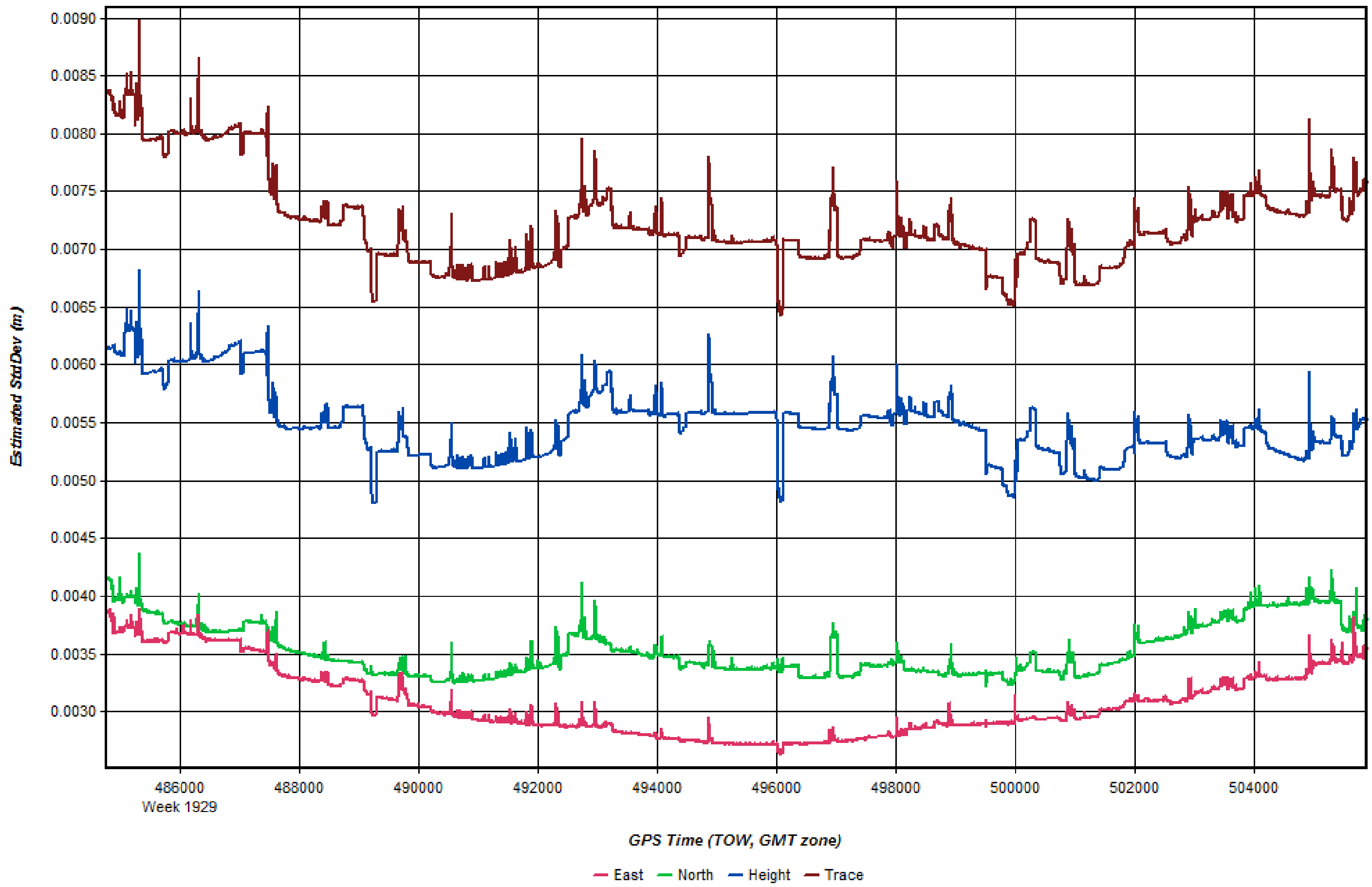
412000
414000
416000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


0.045
0.040
0.035
0.030
0.025
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
-0.045
-0.050
-0.055
-0.060
-0.065
Separation (m)
402000
Week 1929
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
East
North
Up



123_20161230_1




0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
Estimated StdDev (m)
486000
Week 1929
488000
490000
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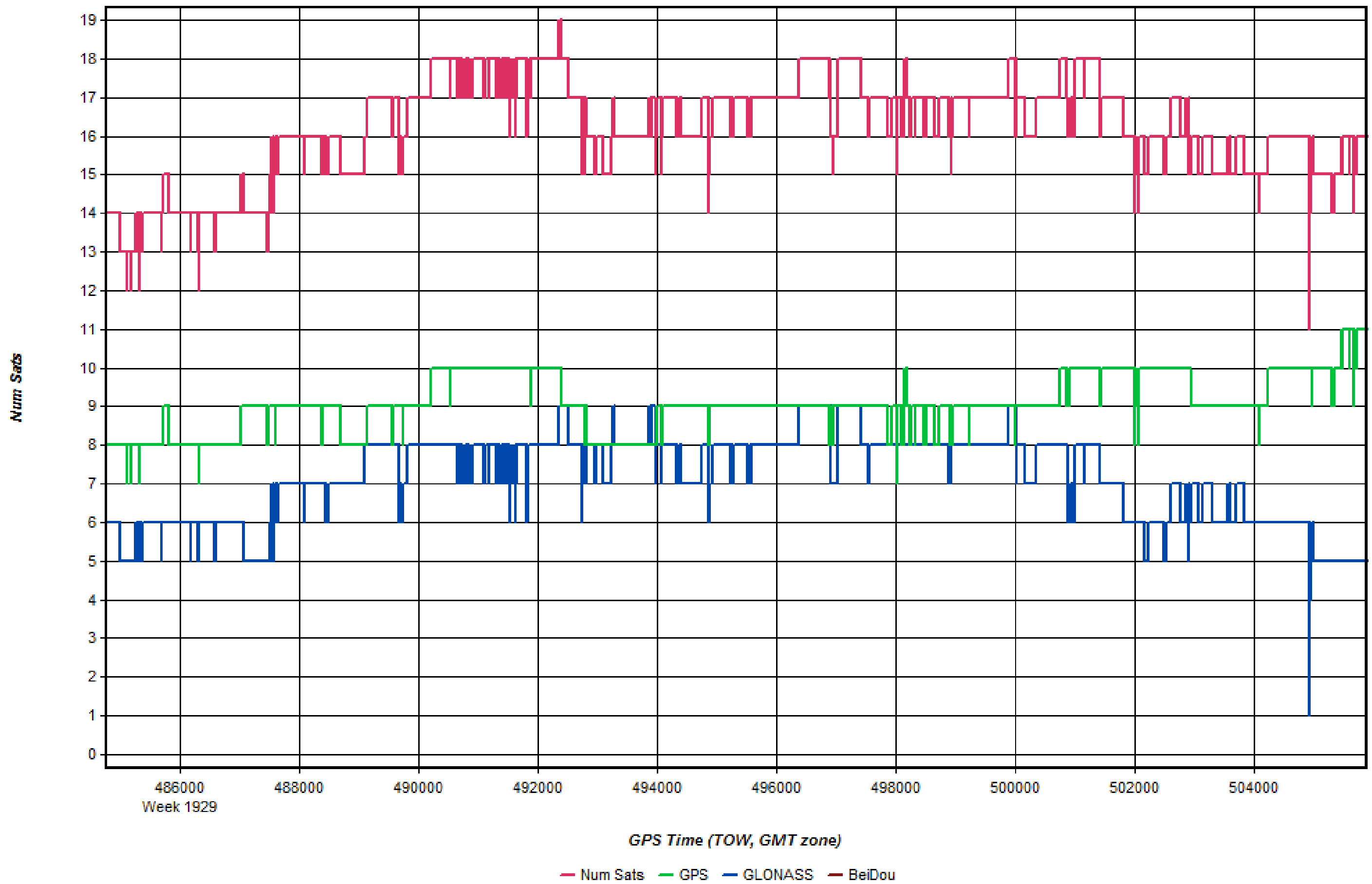
494000
496000
498000
500000
502000
504000
GPS Time (TOW, GMT zone)
East
North
Height
Trace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14
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16
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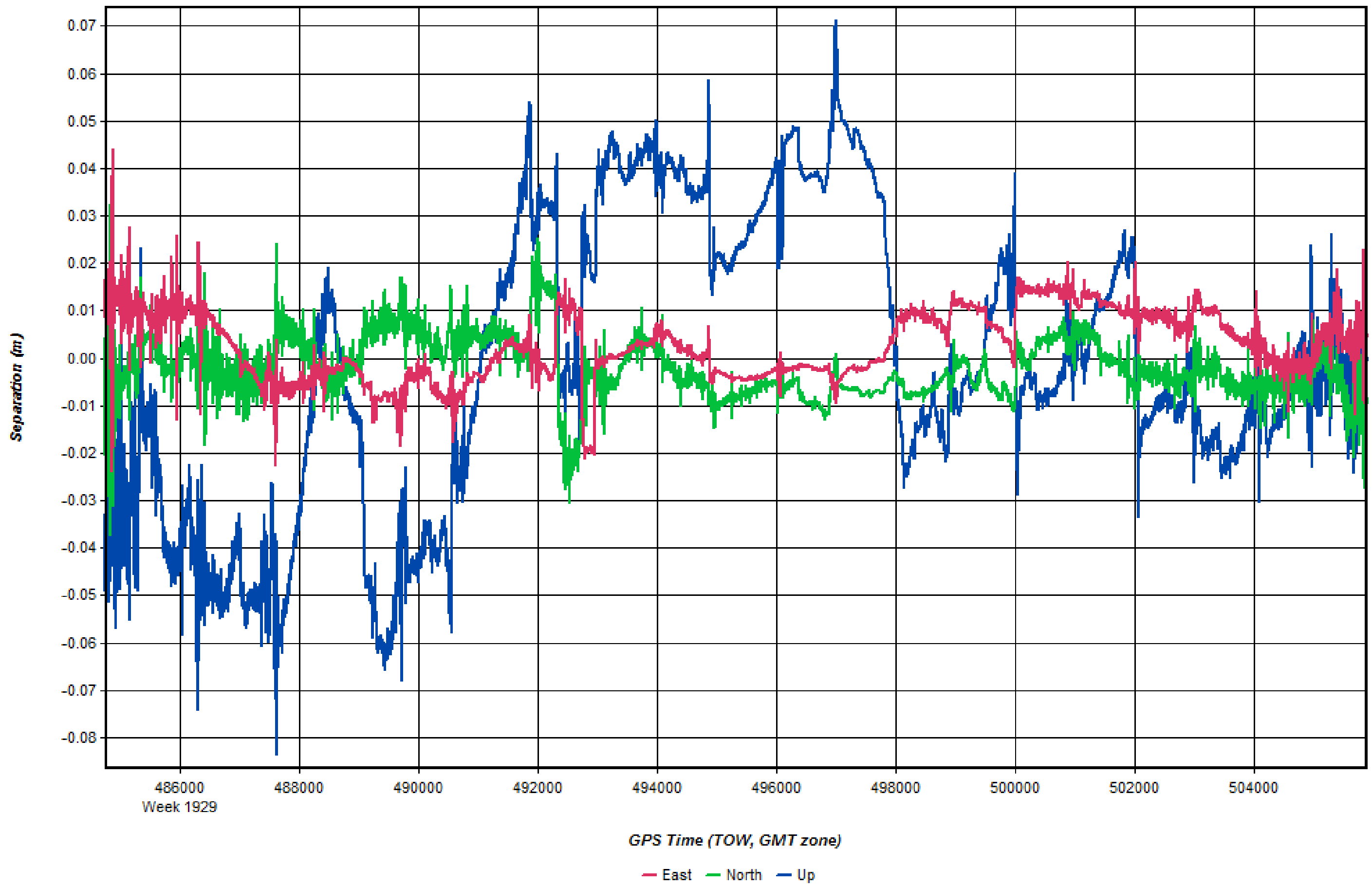
Week 1929
488000
490000
492000
494000
496000
498000
500000
502000
504000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou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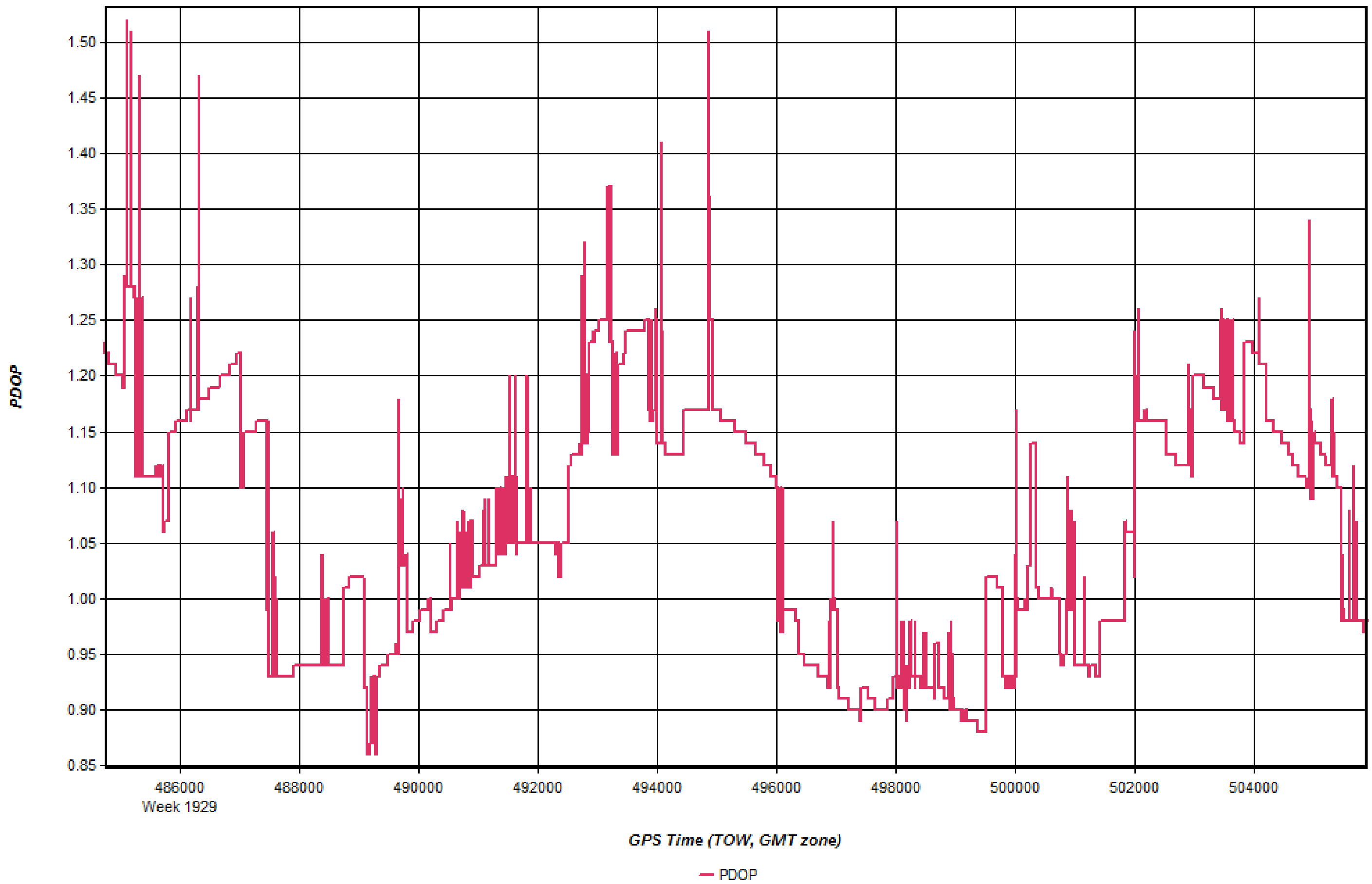
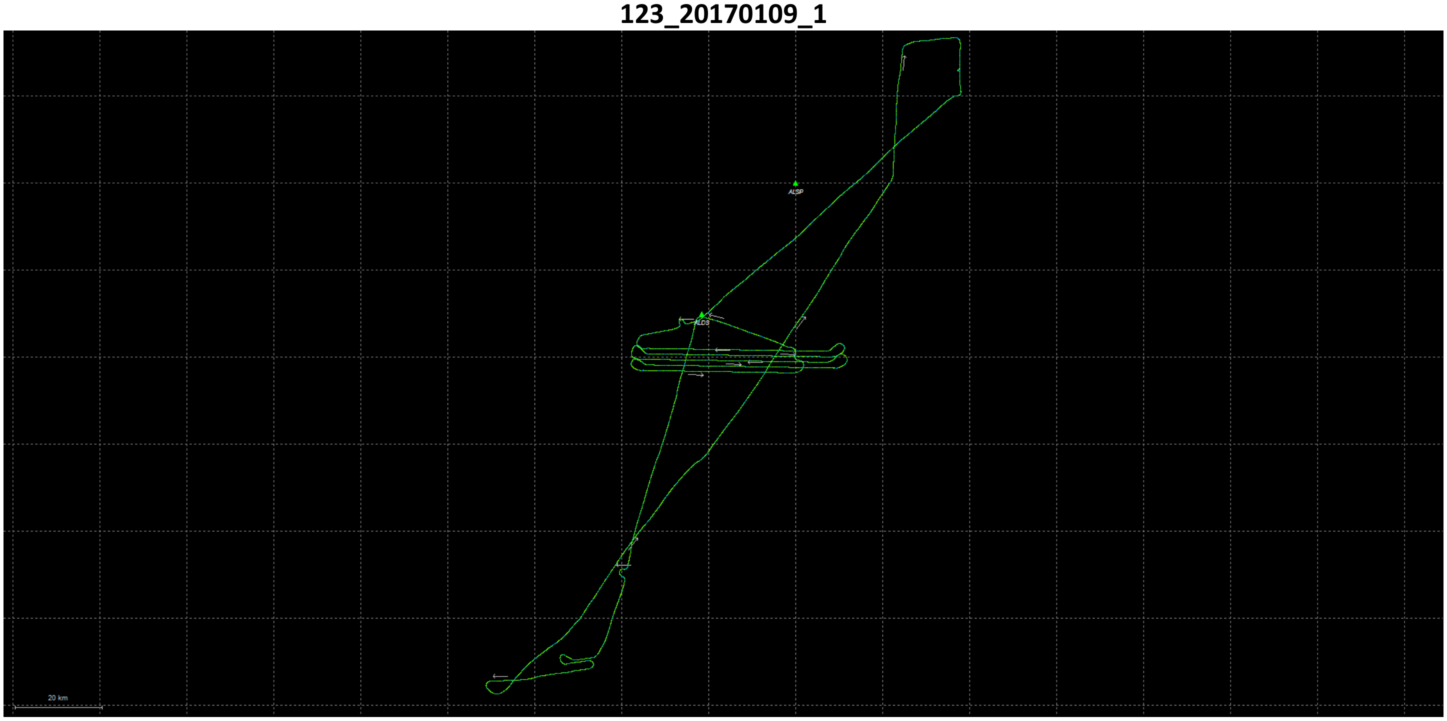
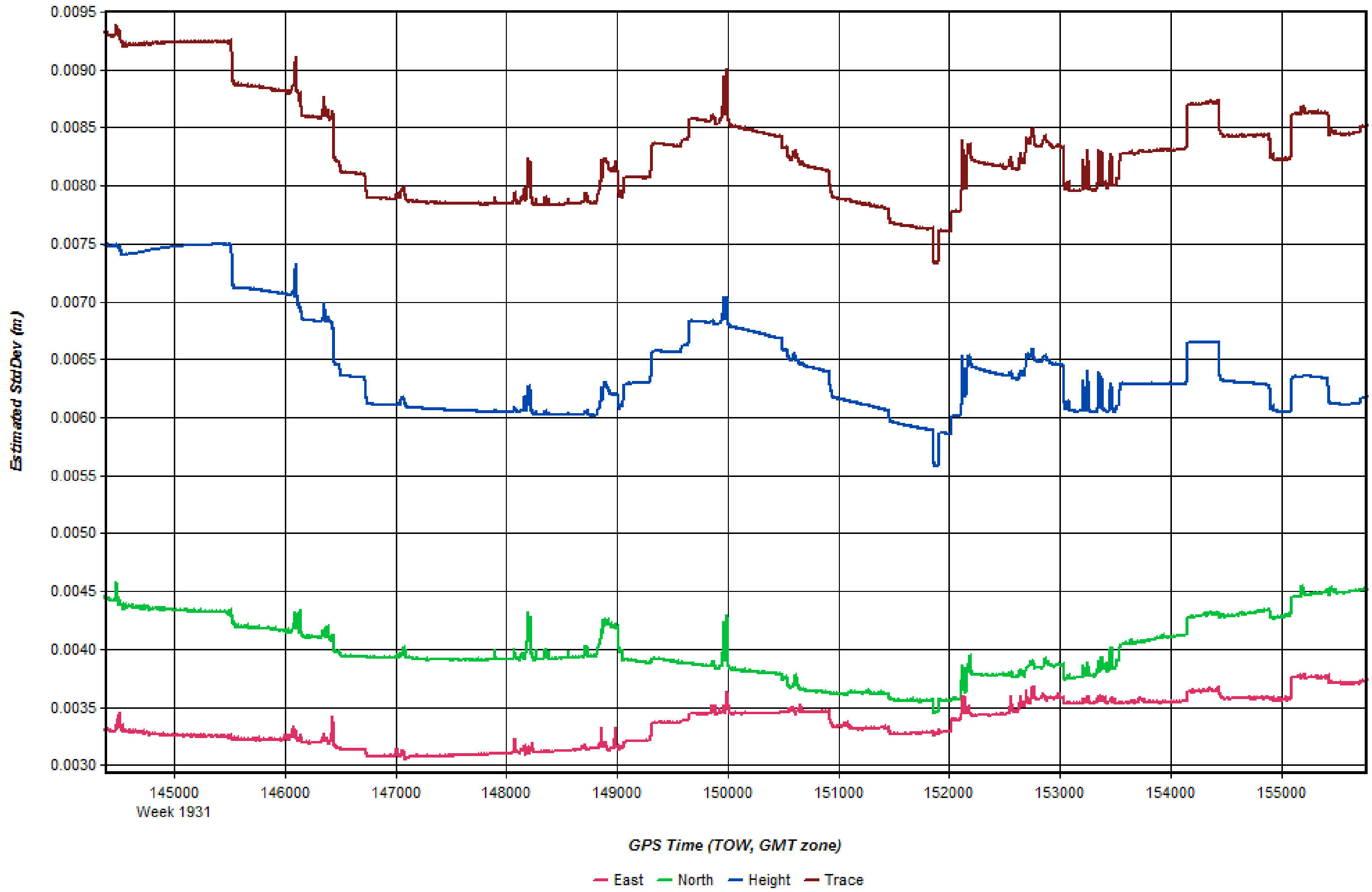
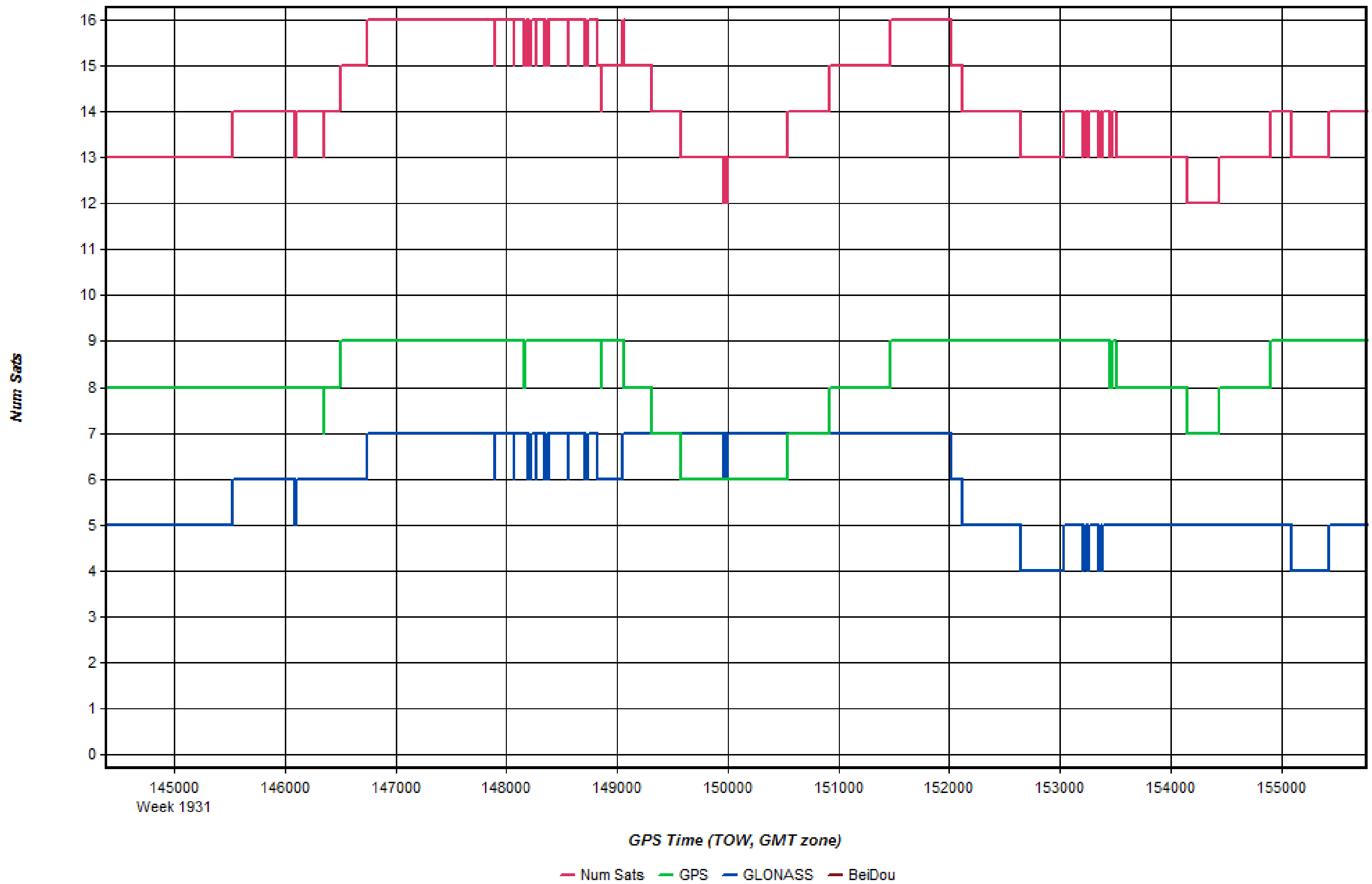
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
Separation (m)
486000
Week 1929
488000
490000
492000
494000
496000
498000
500000
502000
504000
GPS Time (TOW, GMT zone)
East
North
Up



123_20170109_1




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
0.0030
Estimated StdDev (m)
145000
Week 1931
146000
147000
148000
149000
150000
151000
152000
153000
154000
155000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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3
2
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0
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Week 1931
146000
147000
148000
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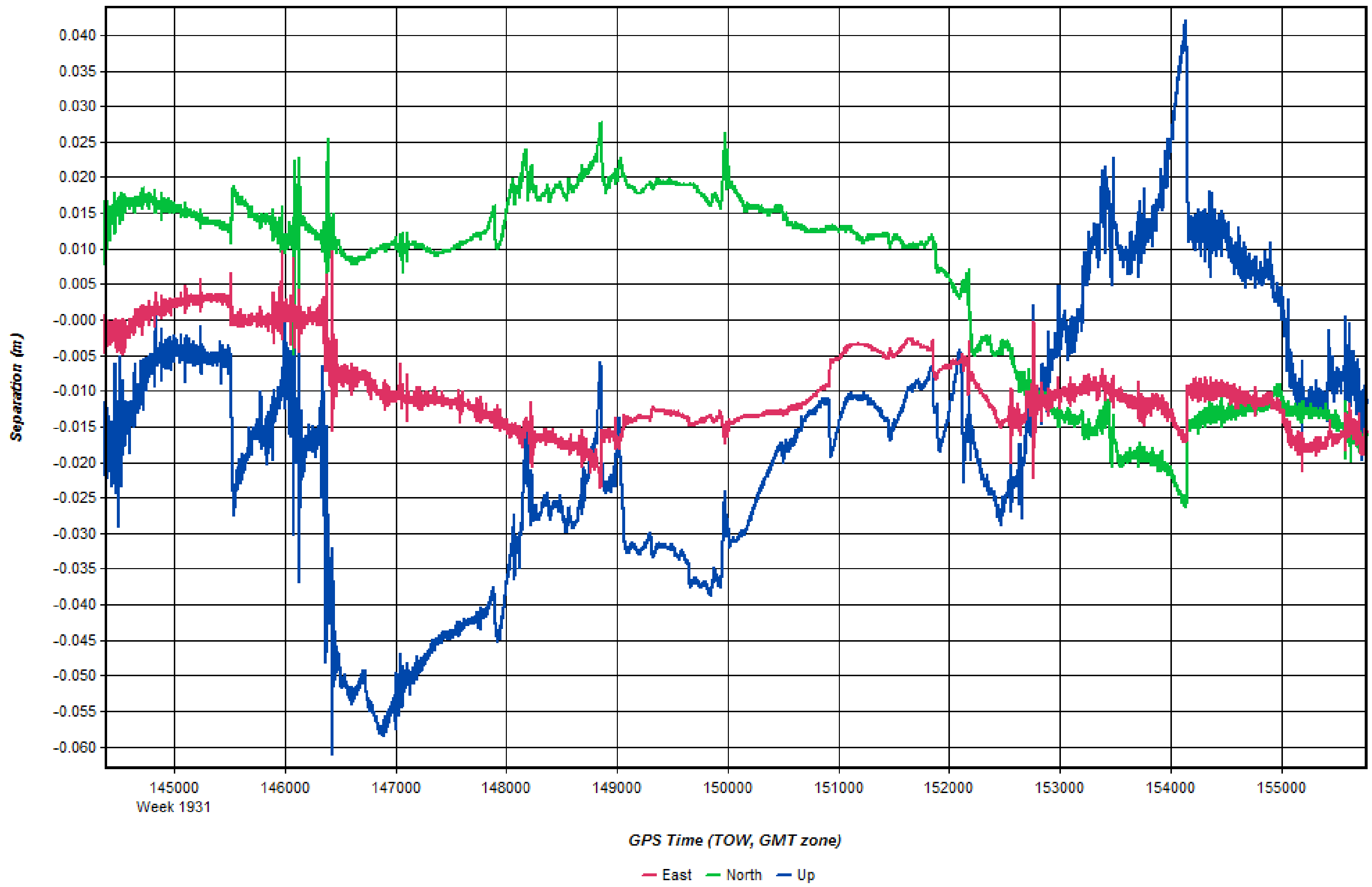
153000
154000
155000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


0.040
0.035
0.030
0.025
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
-0.045
-0.050
-0.055
-0.060
Separation (m)
145000
Week 1931
146000
147000
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149000
150000
151000
152000
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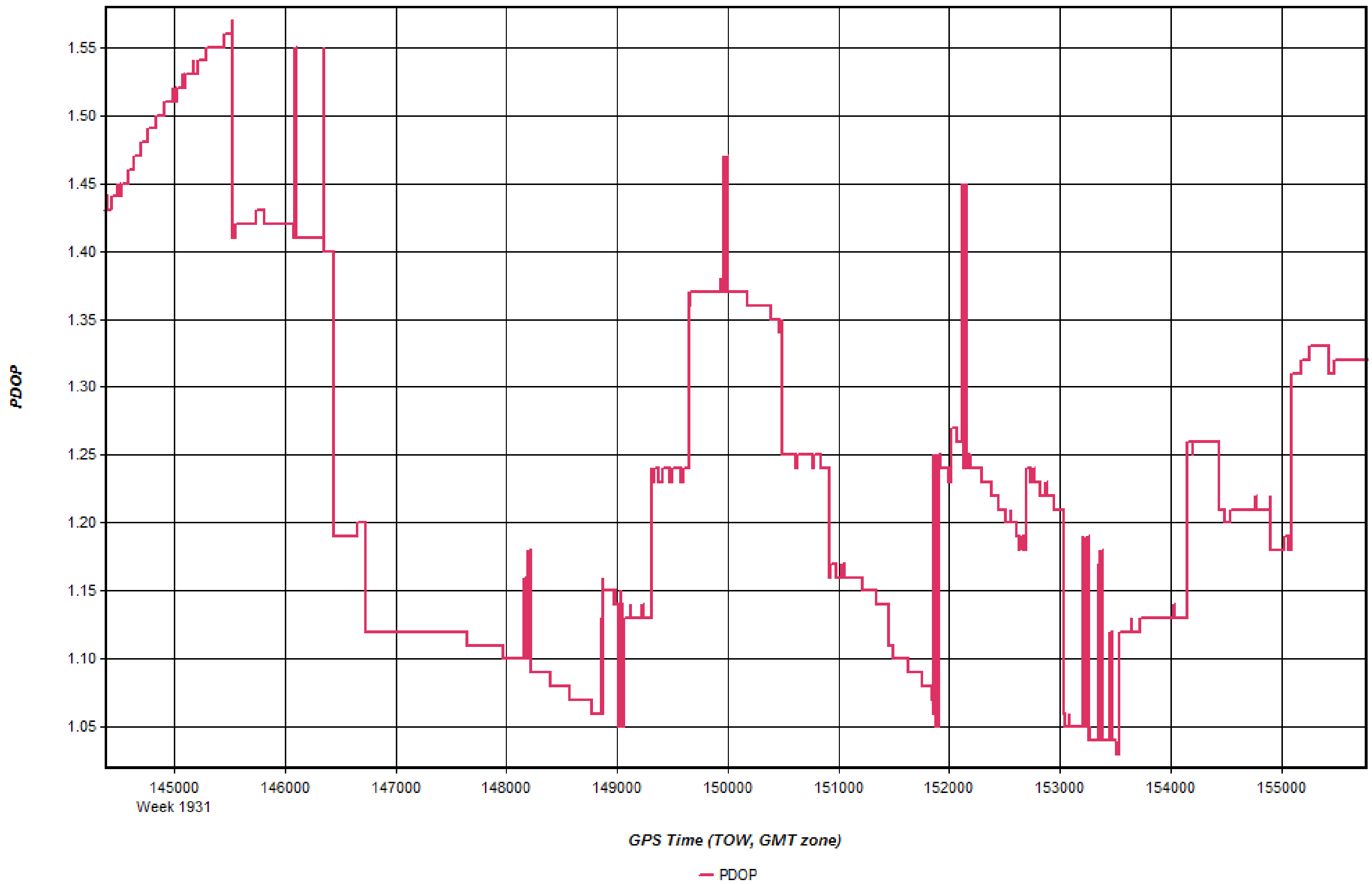
154000
155000
GPS Time (TOW, GMT zone)
East
North
Up


PDOP
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
145000
Week 1931
146000
147000
148000
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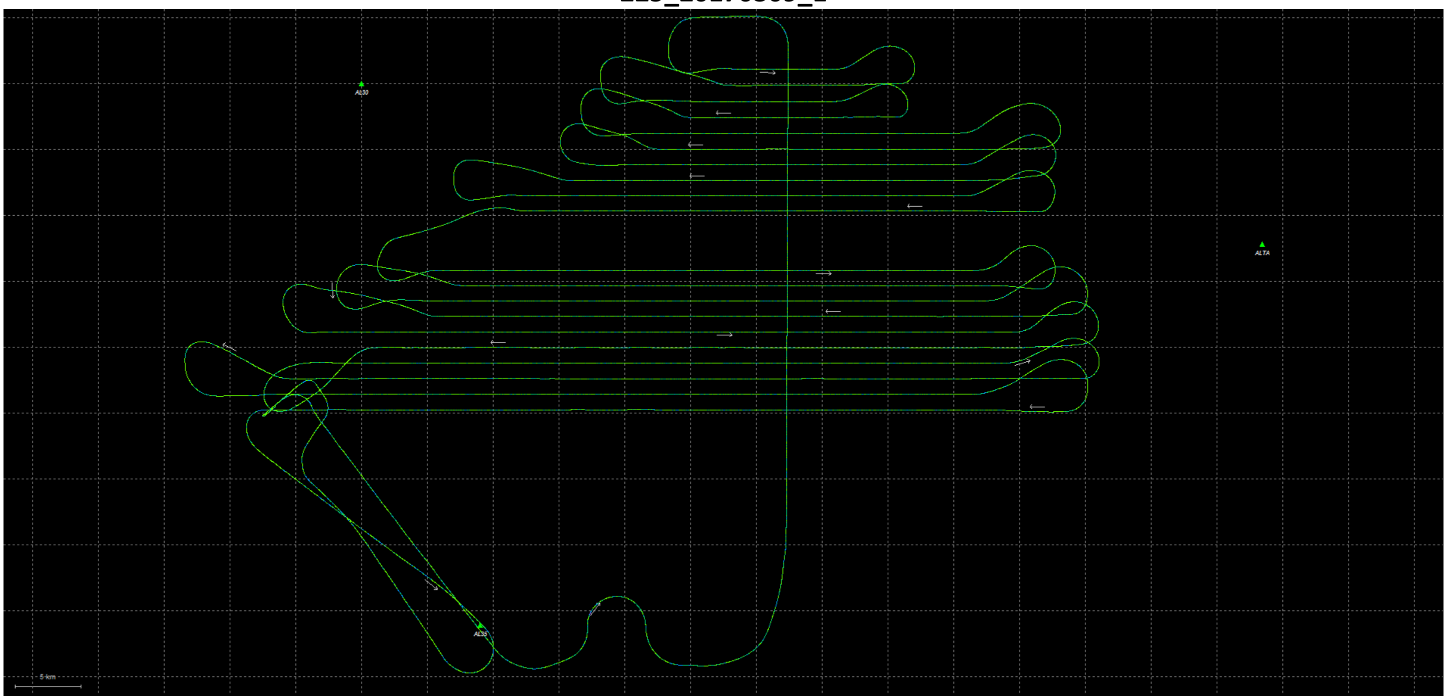
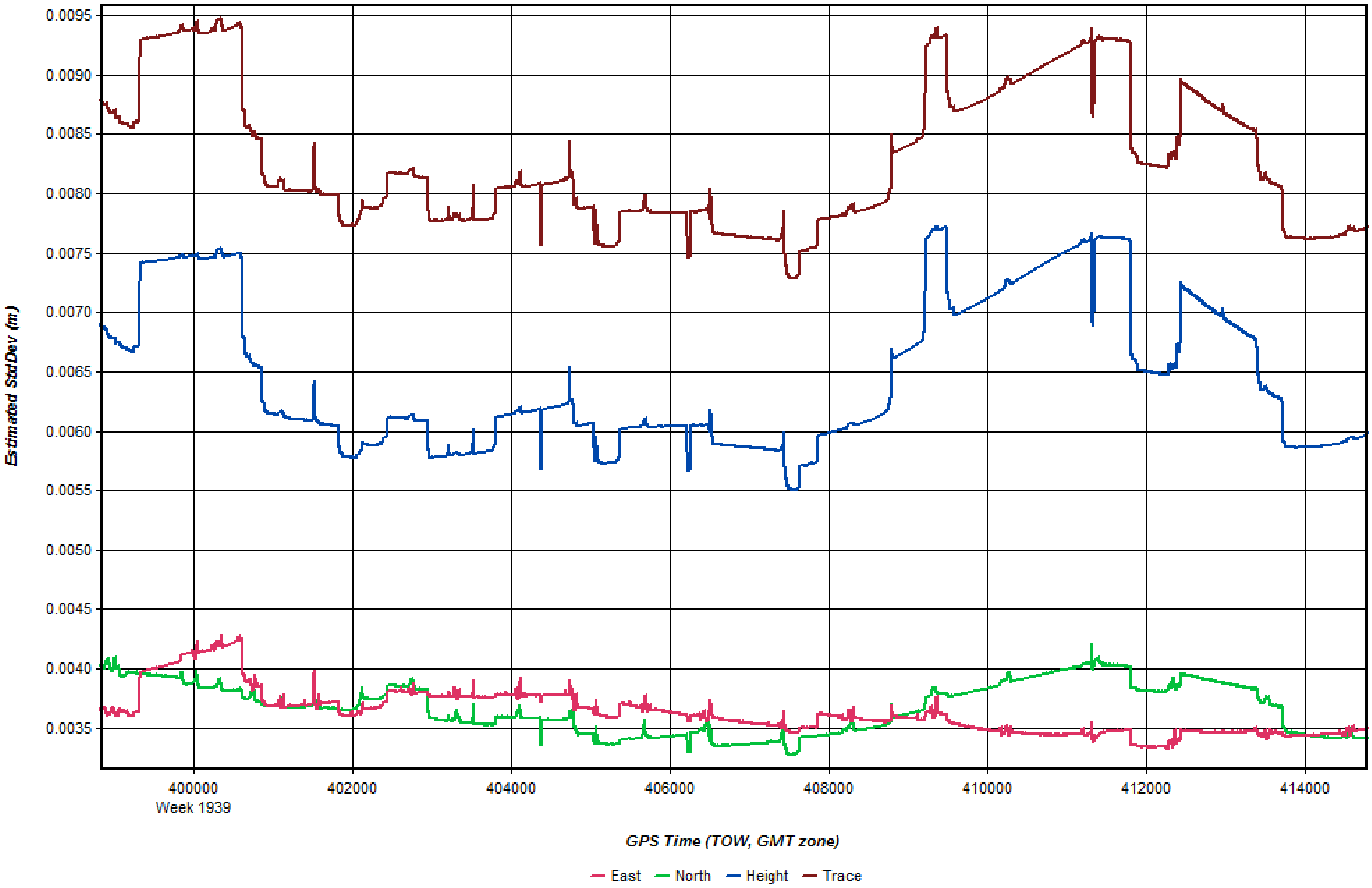
151000
152000
153000
154000
155000
GPS Time (TOW, GMT zone)
PDOP

225_20170309_1




Estimated StdDev (m)
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
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Week 1939
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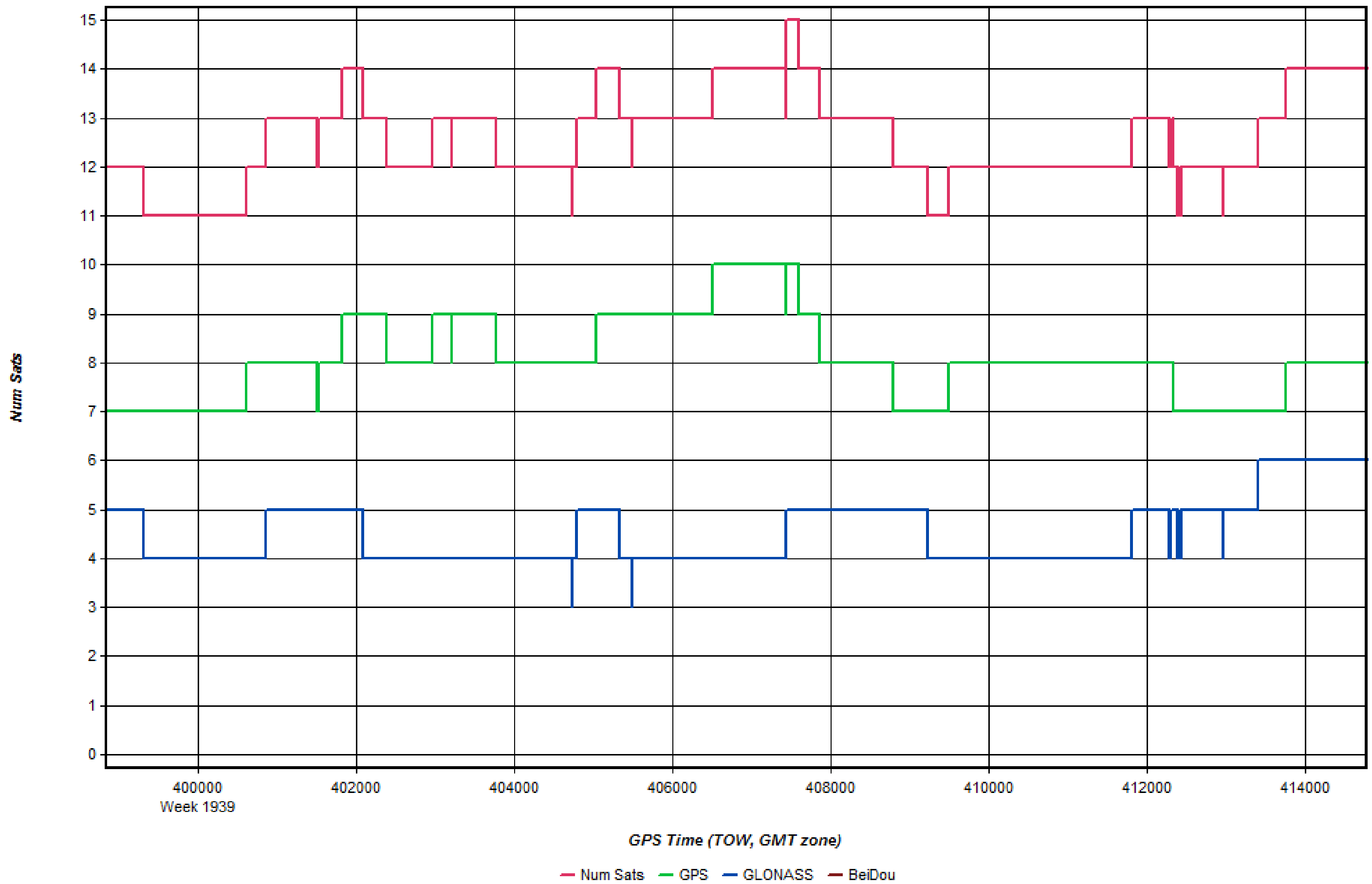
406000
408000
410000
412000
414000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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4
3
2
1
0
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Week 1939
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408000
410000
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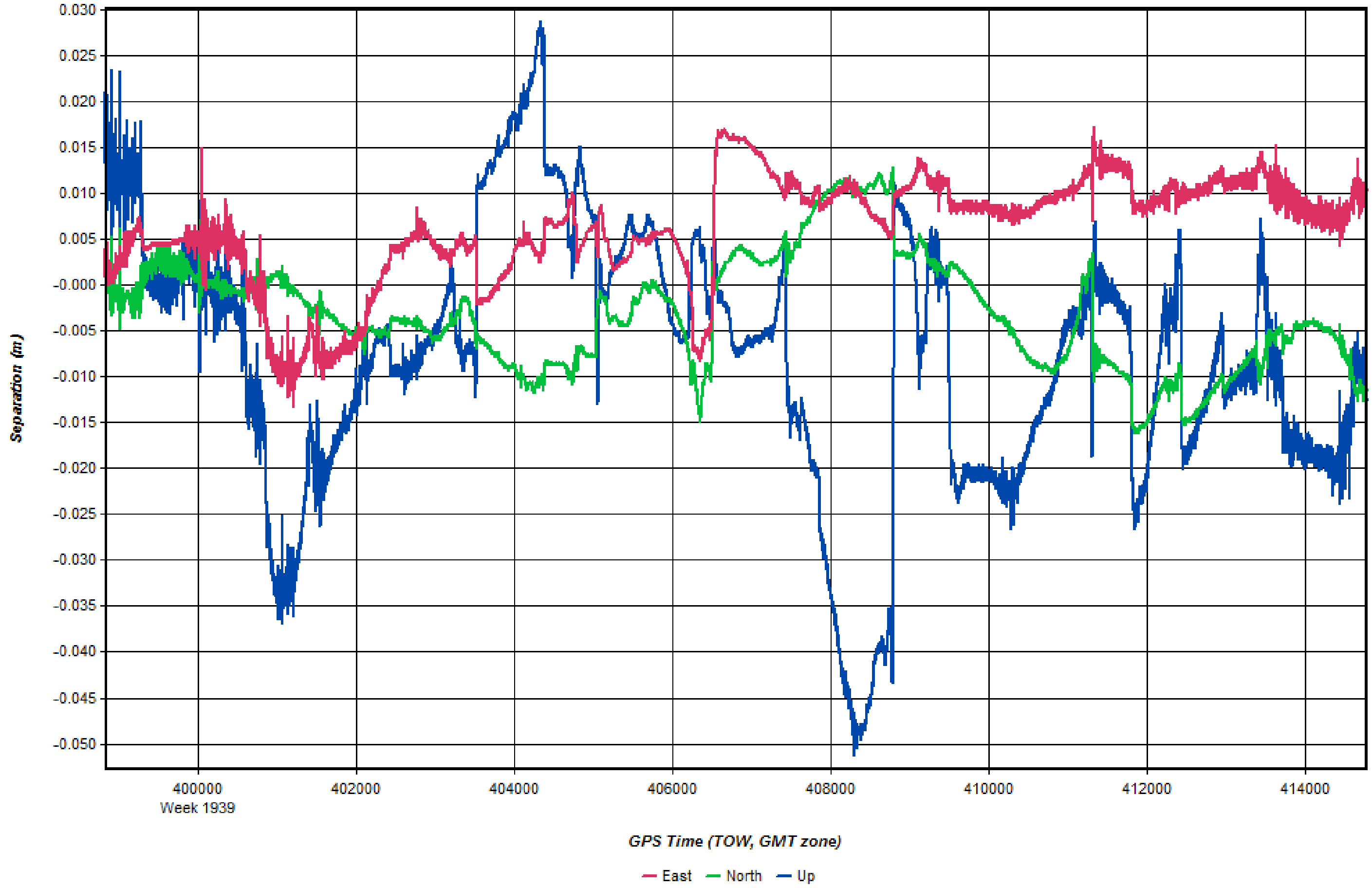
414000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou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0.020
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0.010
0.005
-0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
Separation (m)
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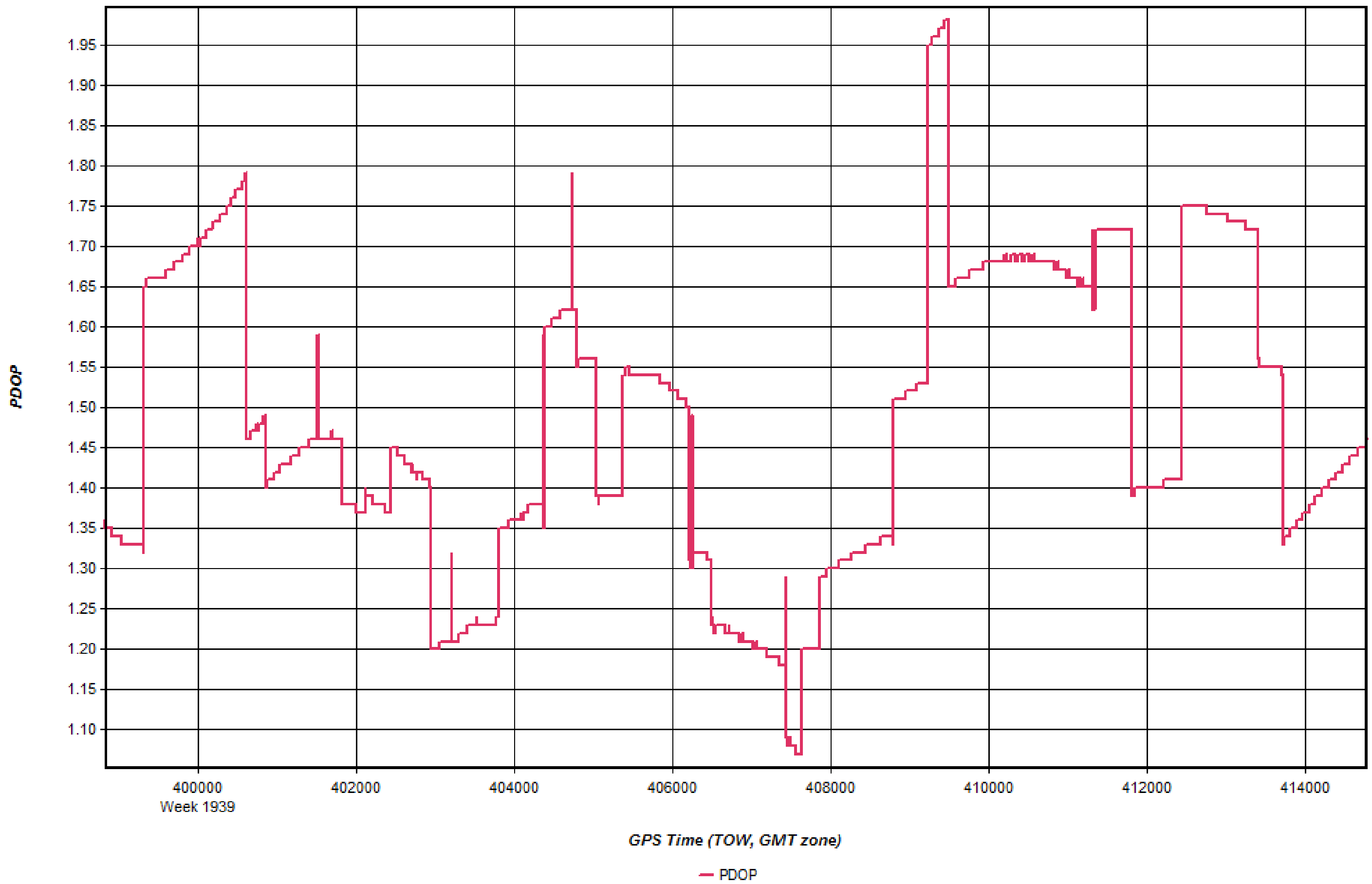
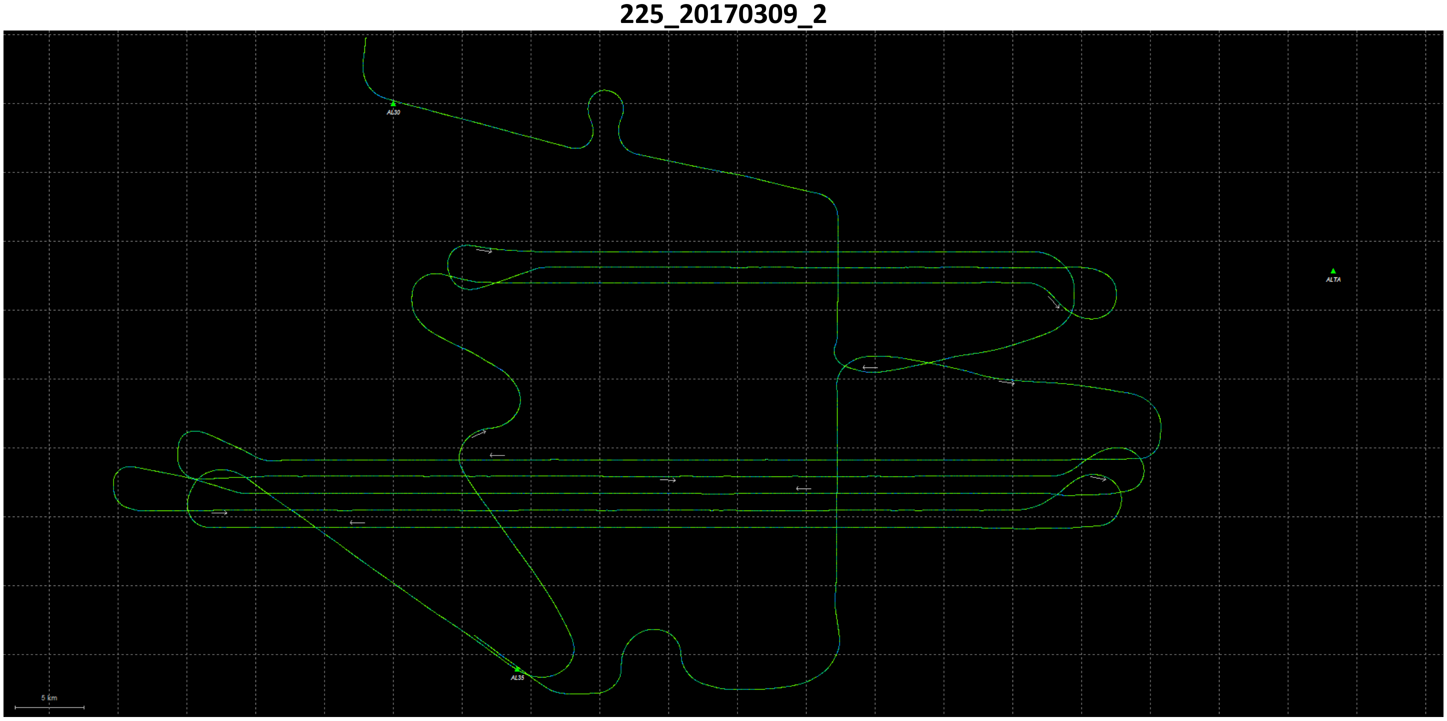
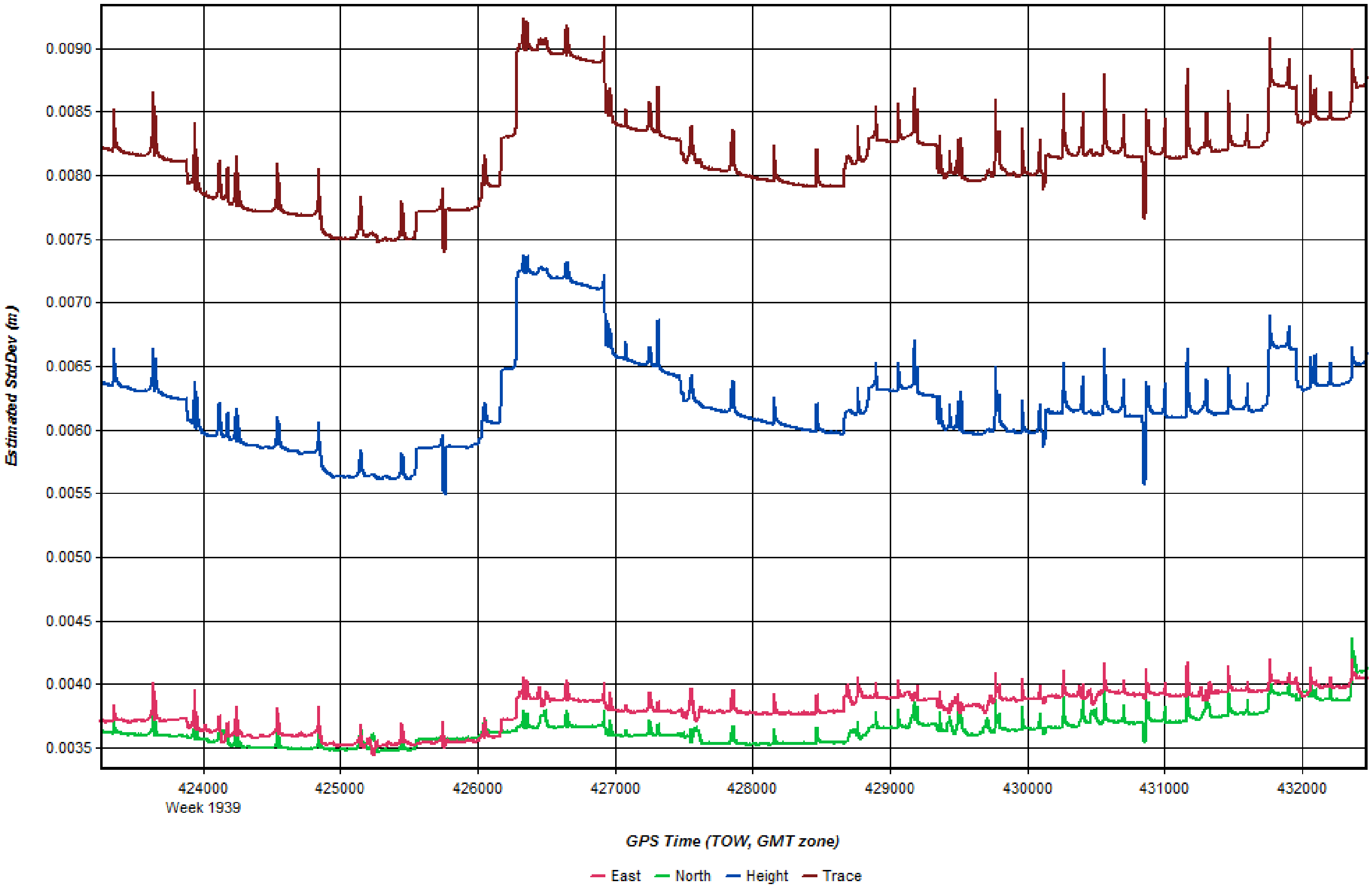
Week 1939
402000
404000
406000
408000
410000
412000
414000
GPS Time (TOW, GMT zone)
East
North
Up



225_20170309_2




0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
Estimated StdDev (m)
424000
Week 1939
425000
426000
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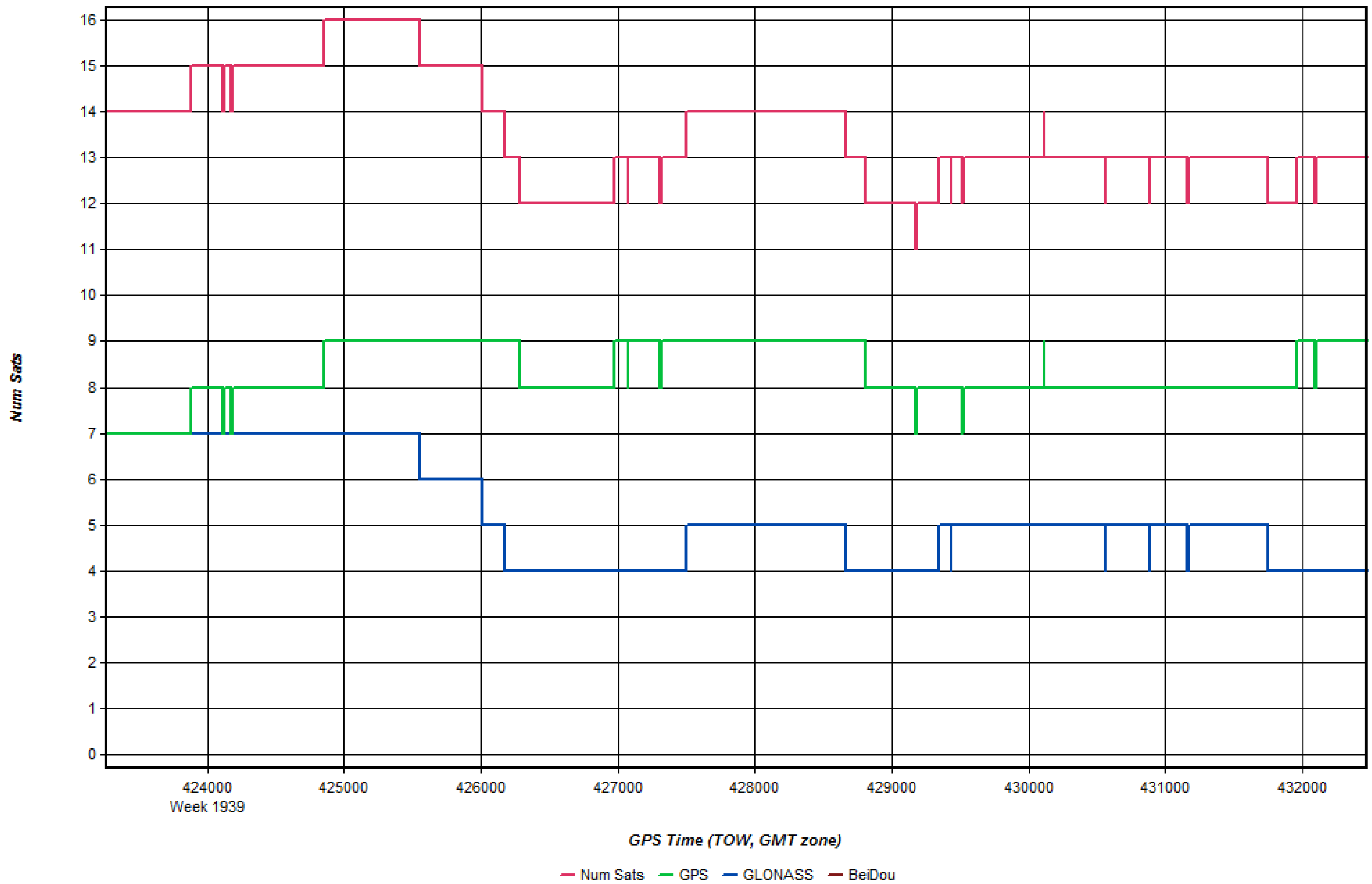
428000
429000
430000
431000
432000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


16
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12
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6
5
4
3
2
1
0
Num Sats
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Week 1939
425000
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430000
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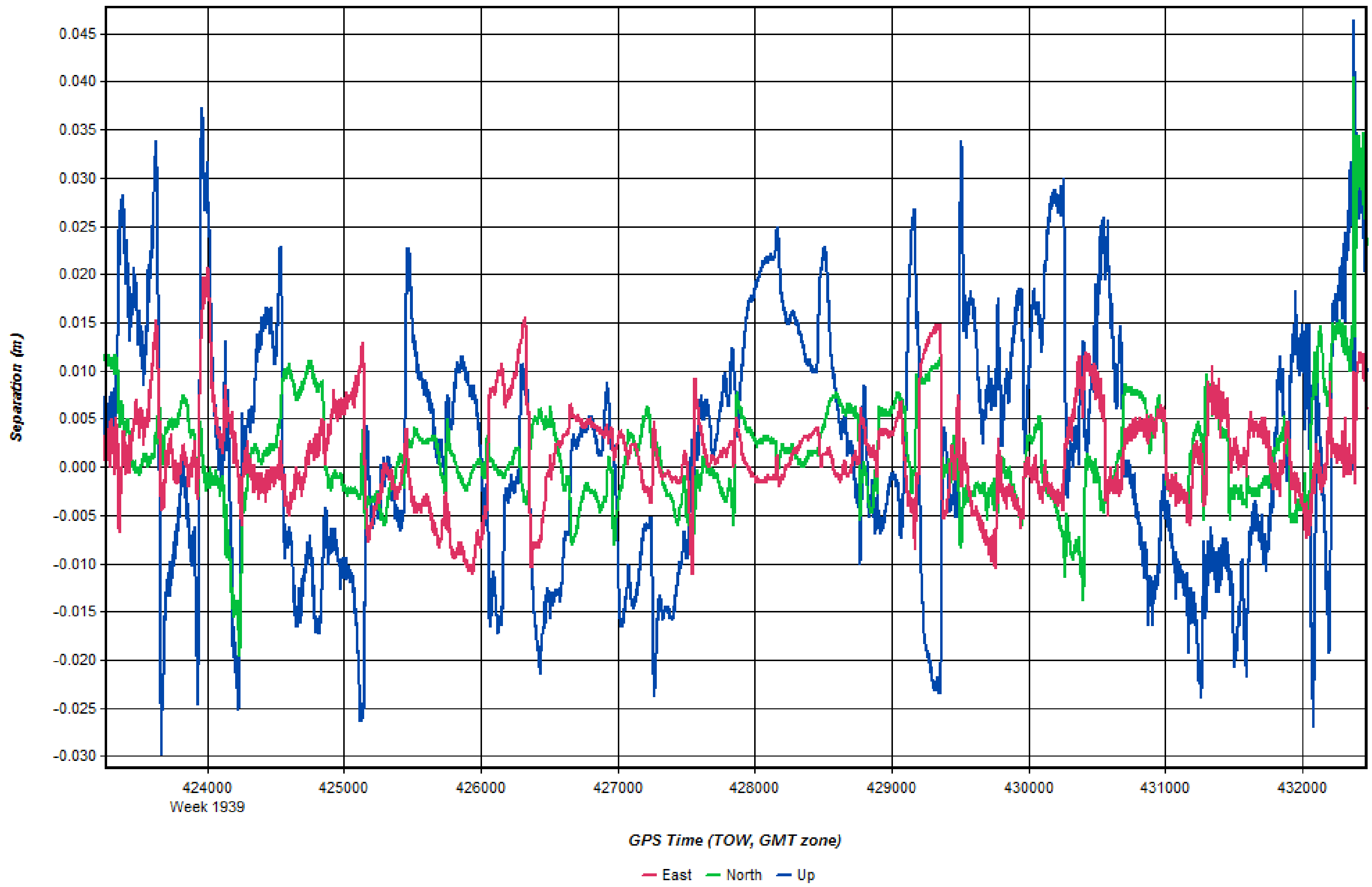
432000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou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0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
Separation (m)
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Week 1939
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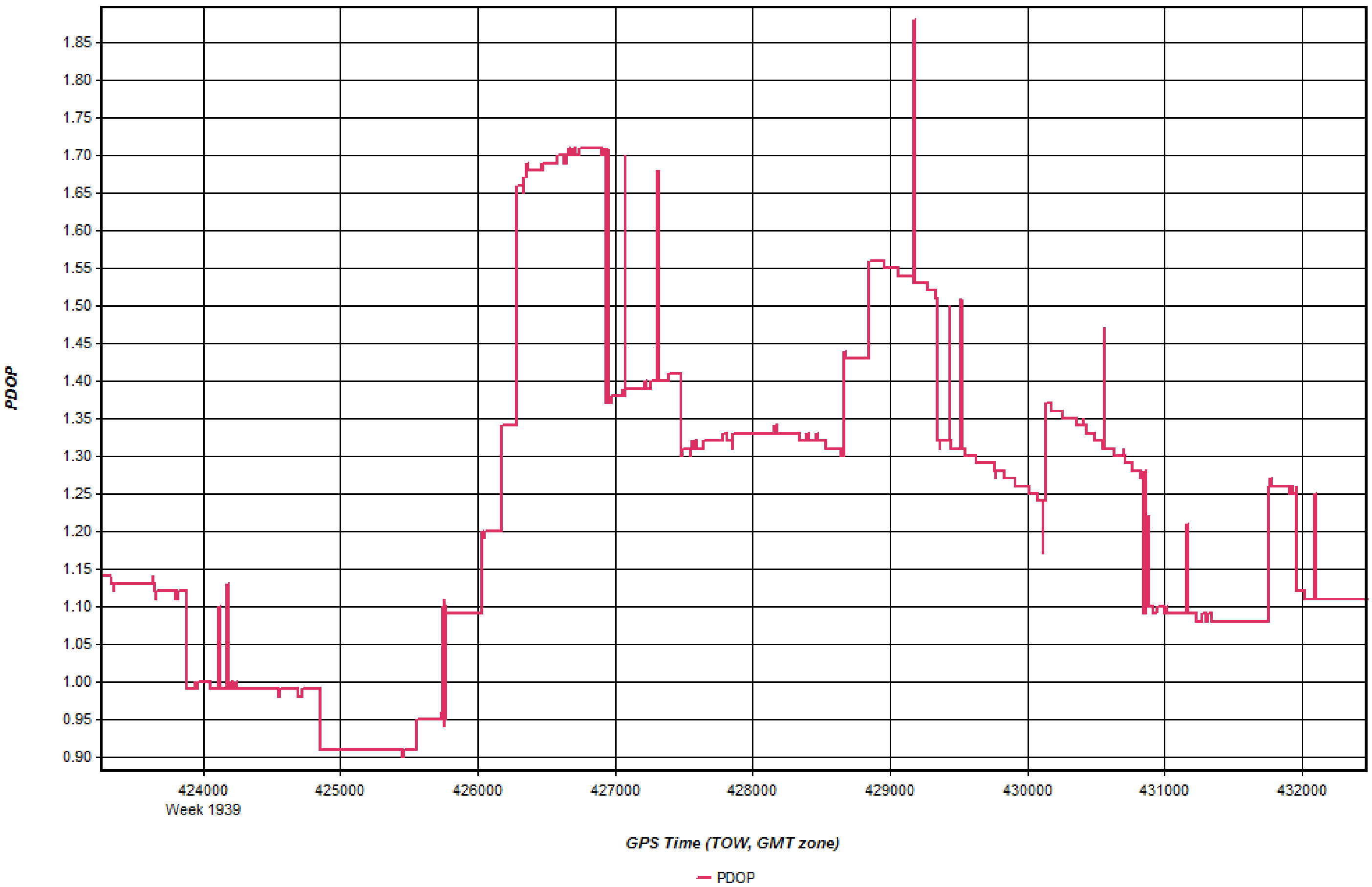
429000
430000
431000
432000
GPS Time (TOW, GMT zone)
East
North
Up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1.50
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1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
PDOP
424000
Week 1939
425000
426000
427000
428000
429000
430000
431000
432000
GPS Time (TOW, GMT zone)
PDOP