Aerial Lidar Report

Kansas Lidar (AOI 1)

15115

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Section 1: Lidar Acquisition

1.1 Acquisition

The Atlantic Group, LLC (Atlantic) has successfully completed lidar acquisition for the Kansas Lidar (AOI 1). Lidar for this AOI was acquired in eight (8) flight lifts completed on March 6th, 2015. The project area encompasses 1,707 square miles or 4,421 square kilometers.

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 seventy eight (78) 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. At least two (2) GPS reference station(s) were in operation during all missions, sampling positions at 1 Hz or higher frequently. Differential GPS baseline lengths did not exceed 40 km, unless otherwise approved. Differential GPS unit in aircraft recorded sample positions at 2 Hz or more frequently. Lidar data was only acquired when GPS PDOP was ≤ 4 and at least 6 satellites were in view.

Atlantic monitored weather and atmospheric conditions and conducted lidar missions only when conditions existed that would not degrade sensor ability in the collection of data. These conditions included no snow, rain, fog, smoke, mist and/or low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Atlantic accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

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

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

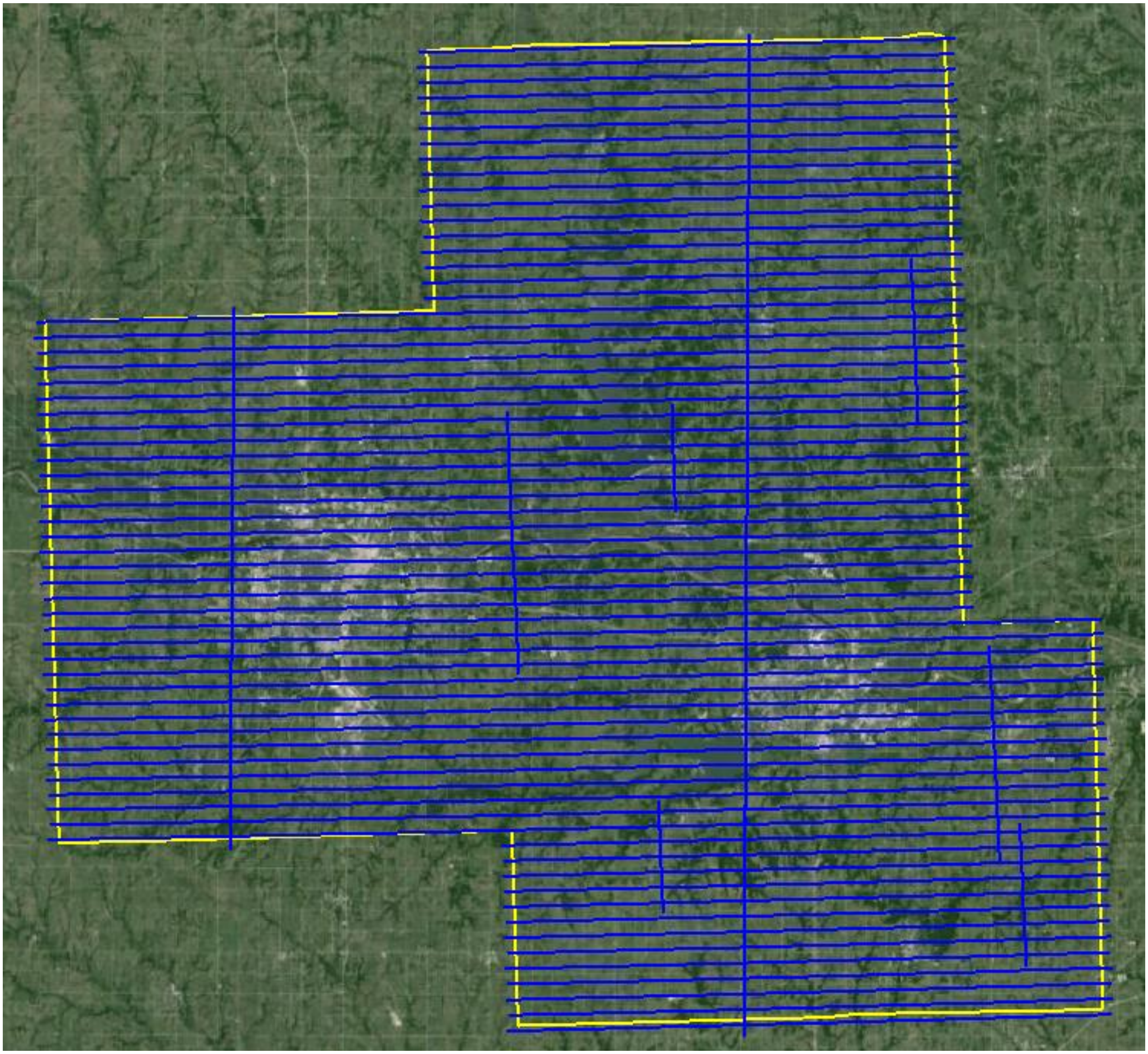


Figure 1: Trajectories as flown by Atlantic

1.5 Acquisition Equipment

Atlantic operated a Partenavia S.P.A. P 68 C/TC (N775MW) outfitted with 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

1.6 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)	0.6
Nominal Pulse Density (pls/m²)	2.5
Nominal Flight Height (AGL meters)	2318
Nominal Flight Speed (kts)	130
Pass Heading (degree)	90
Sensor Scan Angle (degree)	40
Scan Frequency (Hz)	35.8
Pulse Rate of Scanner (kHz)	256.8
Line Spacing (m)	286
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)	0.15
Nominal Swath With (m)	1536
Nominal Swath Overlap (%)	20
Scan Pattern	Triangle

Table 2: Atlantic Lidar System Acquisition Parameters

1.7 GPS Reference Station(s)

Four (4) CORS stations, and one (1) dedicated station set by Atlantic 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	**PID**	**Latitude (N)**	**Longitude (W)**	**Height**
KST5	DJ3671	39°02'40.55423"	096°02'20.77601"	303.970
KST6	DJ3673	39°02'39.66728"	096°02'20.83134"	303.813
MOPL	DN5836	39°23'04.09613"	094°47'00.08215"	211.995
ZKC1	DF9221	38°52'48.55022"	094°47'26.96359"	306.538
SP1	n/a	39°00'19.52791"	095°12'55.38246"	219.974

Table 3: GPS Reference Station Coordinates

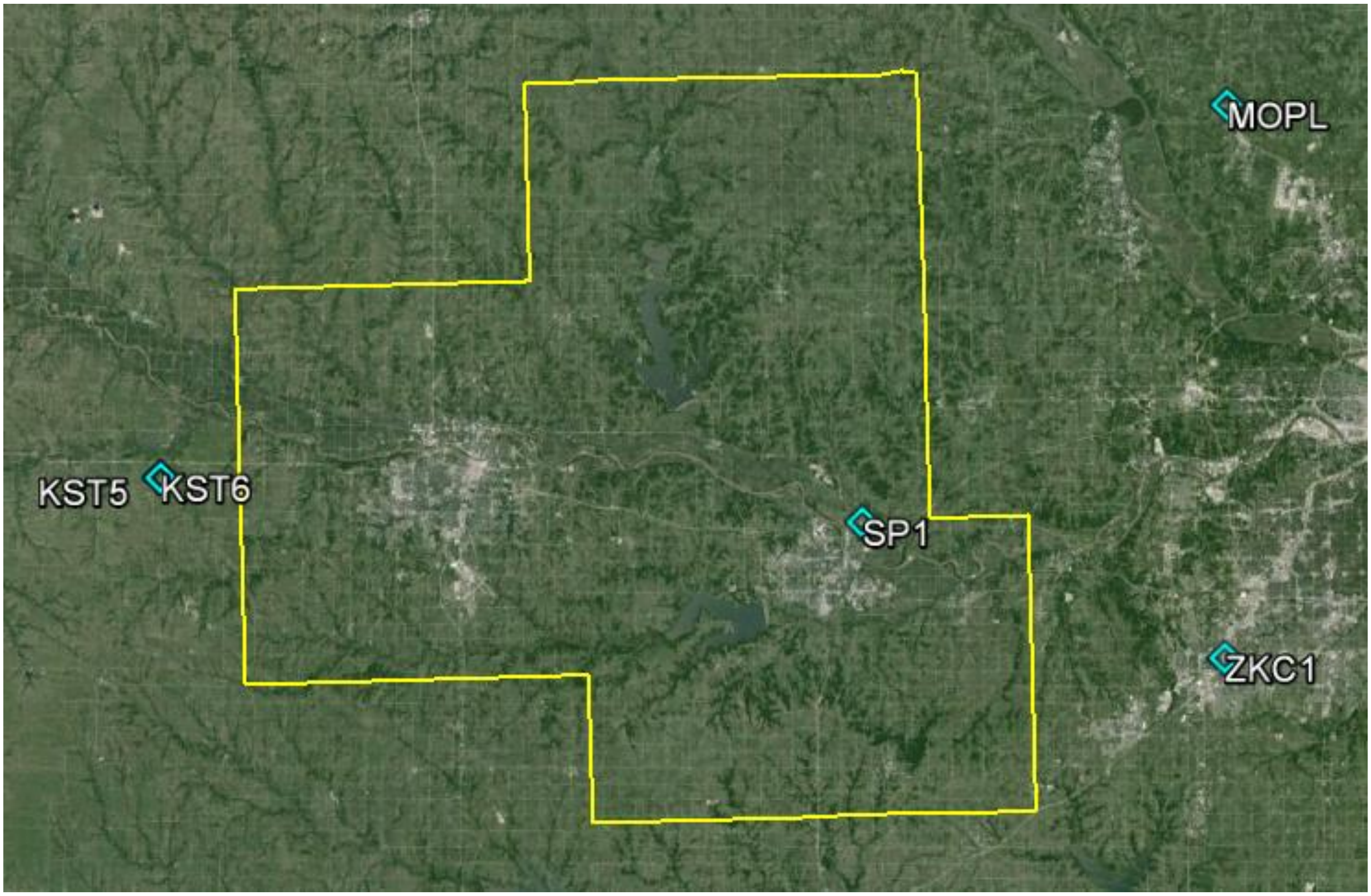


Figure 2: GPS Reference Station(s)

1.8 Airborne GPS Kinematic

Differential GPS unit in aircraft collected positions at 2 Hz. Airborne GPS data was processed using the Inertial Explorer (version 8.5.4320) software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of ≤4 when laser online. Distances from base station to aircraft were kept to a maximum of 40km.

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 and Calibration of Laser Points

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete. Subsequently, the mission points are output using Leica's CloudPro post processor with the most recent boresight values. The initial point generation for each mission calibration is verified within TerraScan using distance colored points to identify errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. Once validated each output mission is imported into the GeoCue software package. Here a project level supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

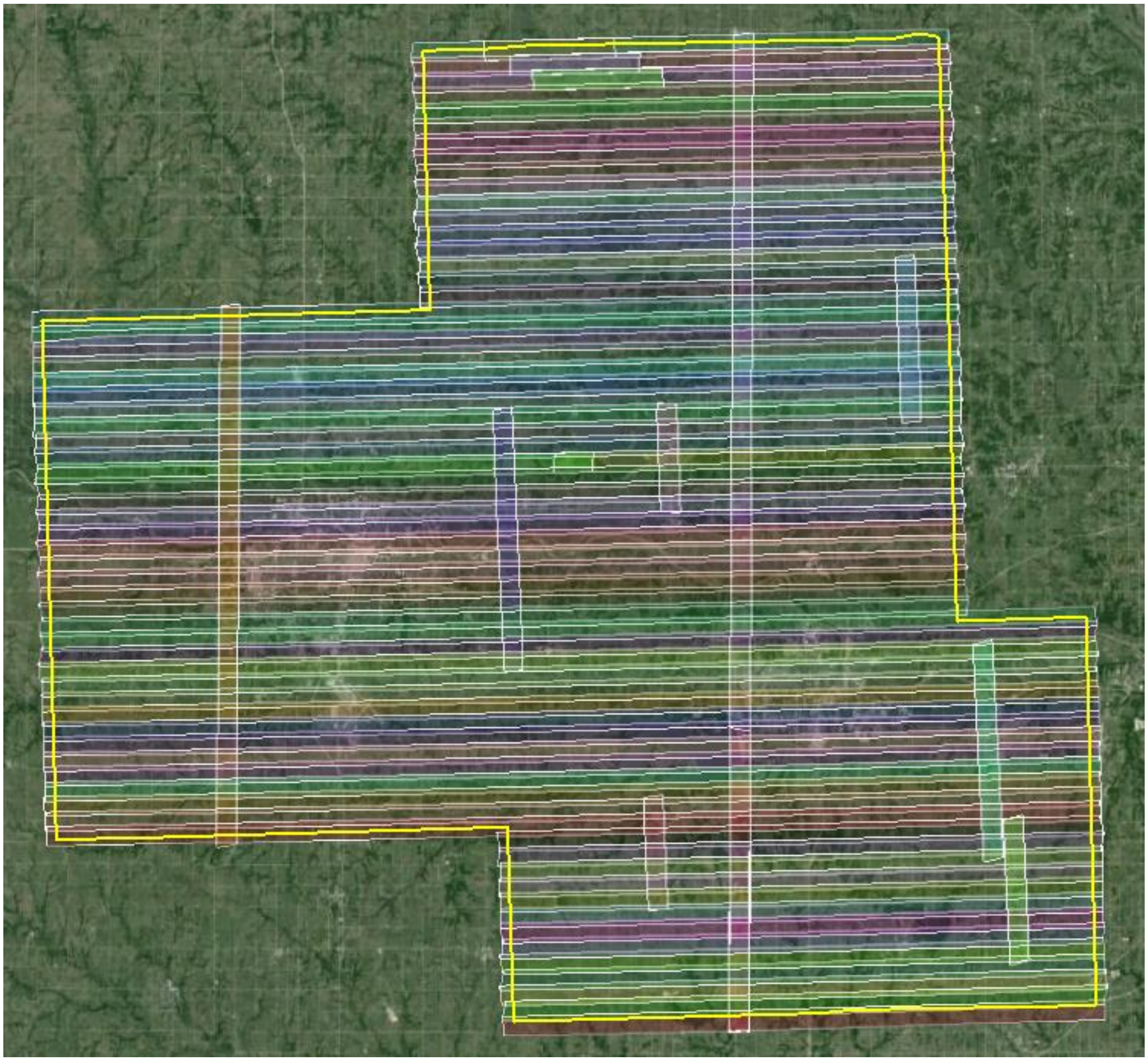


Figure 3: Lidar swath data showing complete coverage

2.2 Reference Systems

Horizontal Datum:	North American Datum of 1983 (HARN)
Coordinate System:	Universal Transverse Mercator Northern Zone 15
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12A
Units:	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	18,109,370,370
Aggregate Nominal Pulse Spacing (m)	0.6131
Aggregate Nominal Pulse Density (pls/m^2)	2.7

Table 4: Lidar Point Cloud Statistics

2.4 Relative Accuracy

For effective data management, each imported mission is tiled out in GeoCue to a project specific tile scheme or index. Relative accuracy and internal quality are then checked using a number of carefully selected tiles in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed by the generation of Z-Difference colored intensity orthos in GeoCue. The color scale of these orthos are adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission alignment. When available, surveyed control points are used to supplement and verify the calibration of the data.

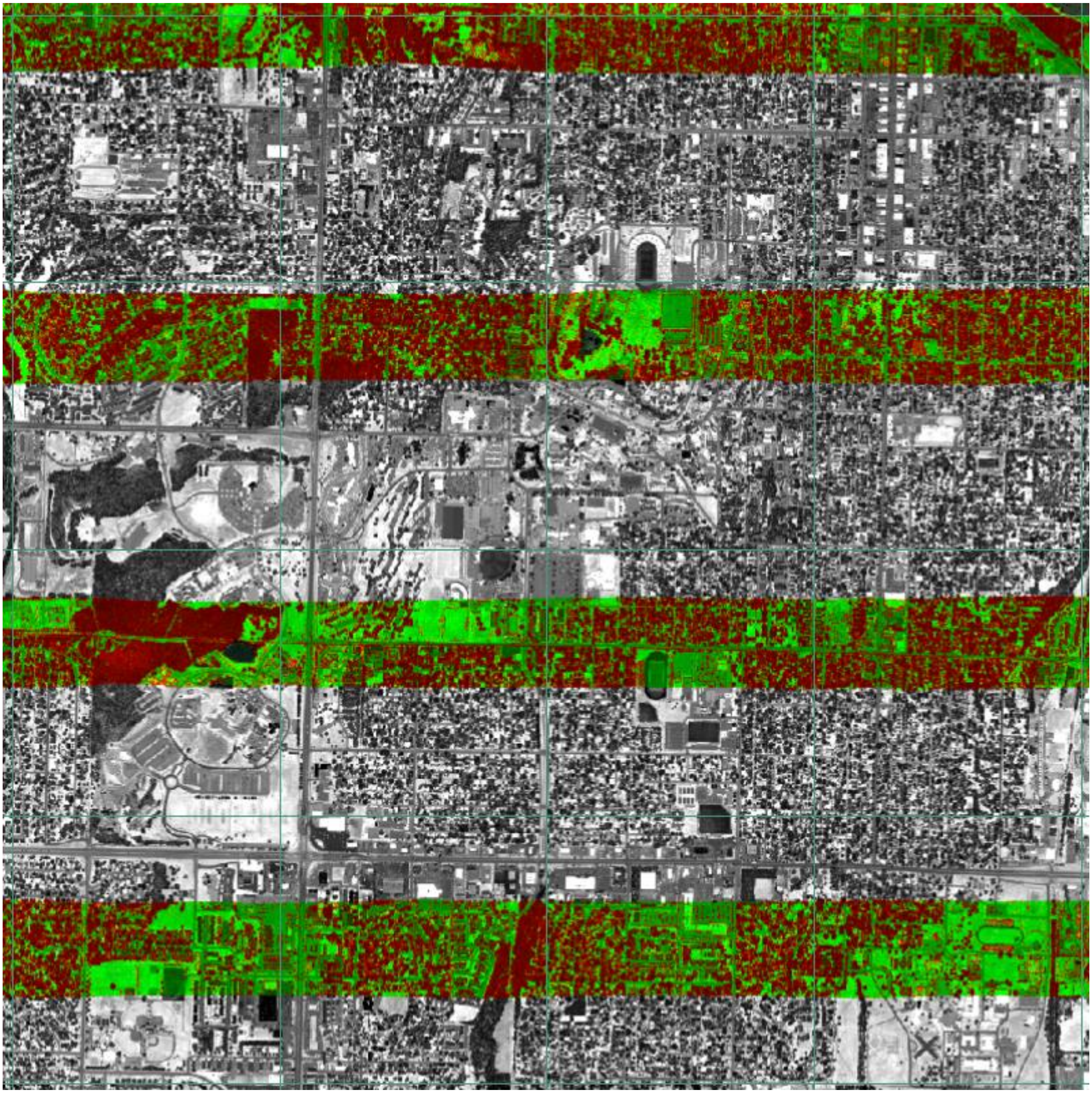


Figure 4: dZ ortho sub-sample

2.5 Relative Accuracy Results

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
2	0.027	0.036	0.01	25	0.029	0.034	0.011	52	0.014	0.022	0.011
3	0.024	0.037	0.012	26	0.028	0.033	0.011	53	0.02	0.023	0.011
4	0.022	0.034	0.013	27	0.021	0.037	0.011	54	0.016	0.017	0.011
5	0.037	0.049	0.011	28	0.024	0.032	0.011	56	0.018	0.018	0.011
6	0.026	0.036	0.011	29	0.023	0.028	0.013	57	0.022	0.022	0.011
7	0.015	0.034	0.01	32	0.03	0.019	0.009	58	0.023	0.032	0.011
8	0.014	0.023	0.01	33	0.027	0.026	0.01	59	0.018	0.028	0.011
9	0.028	0.02	0.011	34	0.027	0.025	0.011	60	0.017	0.029	0.011
10	0.037	0.022	0.01	35	0.028	0.027	0.012	62	0.018	0.028	0.011
11	0.032	0.027	0.011	36	0.022	0.025	0.011	63	0.019	0.028	0.011
12	0.043	0.042	0.011	37	0.018	0.032	0.011	64	0.017	0.021	0.011
13	0.037	0.037	0.011	38	0.022	0.028	0.012	65	0.016	0.018	0.009
14	0.026	0.023	0.01	39	0.022	0.032	0.011	66	0.026	0.026	0.011
15	0.029	0.031	0.011	40	0.03	0.037	0.011	67	0.038	0.039	0.011
16	0.035	0.03	0.011	42	0.03	0.039	0.013	68	0.021	0.03	0.011
17	0.024	0.023	0.01	43	0.039	0.045	0.012	69	0.025	0.028	0.01
18	0.023	0.018	0.013	45	0.019	0.031	0.012	70	0.026	0.029	0.012
19	0.029	0.018	0.011	46	0.015	0.02	0.013	71	0.021	0.033	0.011
20	0.016	0.017	0.01	47	0.021	0.025	0.013	73	0.026	0.041	0.01
21	0.023	0.022	0.011	48	0.024	0.033	0.012	74	0.031	0.049	0.011
22	0.024	0.03	0.01	49	0.023	0.026	0.011	75	0.03	0.042	0.011
23	0.021	0.034	0.011	50	0.021	0.024	0.011	76	0.022	0.02	0.011
24	0.018	0.033	0.011	51	0.019	0.031	0.012	77	0.026	0.052	0.013

Table 5: Average Tie Line Magnitudes per Line

Internal Observation Statistics			
Category	X	Y	Z
Average Magnitude	0.020	0.026	0.011
RMS Values	0.033	0.038	0.014
Maximum Values	0.150	0.150	0.120
Observation Weight	59020.0	59020.0	447512.0

Table 6: Tie Line Observation Statistics

Overall Relative Accuracy	
Category	**Mismatch**
Average 3D Mismatch	0.01554
Average XY Mismatch	0.04103
Average Z Mismatch	0.01105

Table 7: Relative Accuracy Results

TerraMatch Tie Lines	
Category	**Observations**
Section Lines	179,715
Roof Lines	29,498

Table 8: Total Tie Lines

2.6 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.

2.7 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-Rail (breakline buffer) in LP360. Outlined in Table 9 are the classification codes utilized for this project.

ASPRS Standard Lidar Point Classes		
Code	**Description**	**Utilized**
0	Created, never classified	
1	Unclassified[3]	X
2	Ground	X
3	Low Vegetation	
4	Medium Vegetation	
5	High Vegetation	
6	Building	
7	Low Point (noise)	X
8	Reserved	
9	Water	X
10	Rail (breakline buffer)	X
11	Road Surface	
12	Reserved	
13	Wire – Guard (Shield)	
14	Wire – Conductor (Phase)	
15	Transmission Tower	
16	Wire-structure Connector (e.g. Insulator)	
17	Bridge Deck	X
18	High Noise	X
19-63	Reserved	
64-255	User Definable	

Table 9: Point Cloud Classification Scheme

Section 3: Vertical Accuracy Assessment

3.1 Ground Surveyed Check Points

Atlantic established a total of one hundred and ten (110) checkpoints for this project (58 NVA + 52 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

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 graphic(s) depicts the location and distribution of NVA and VVA Check Points established for this project.

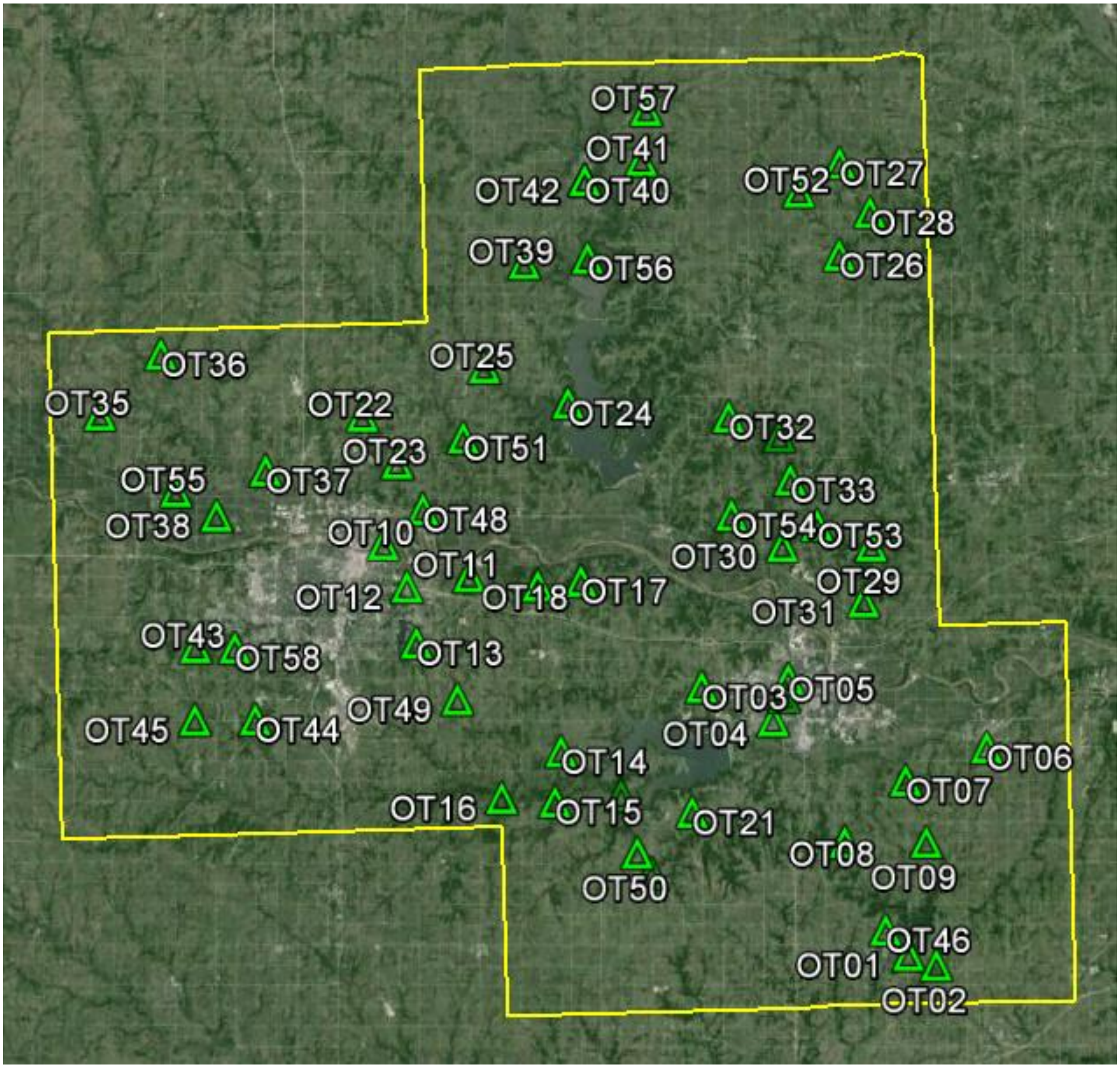


Figure 5: Non-vegetated Vertical Accuracy (NVA) Check Point Distribution

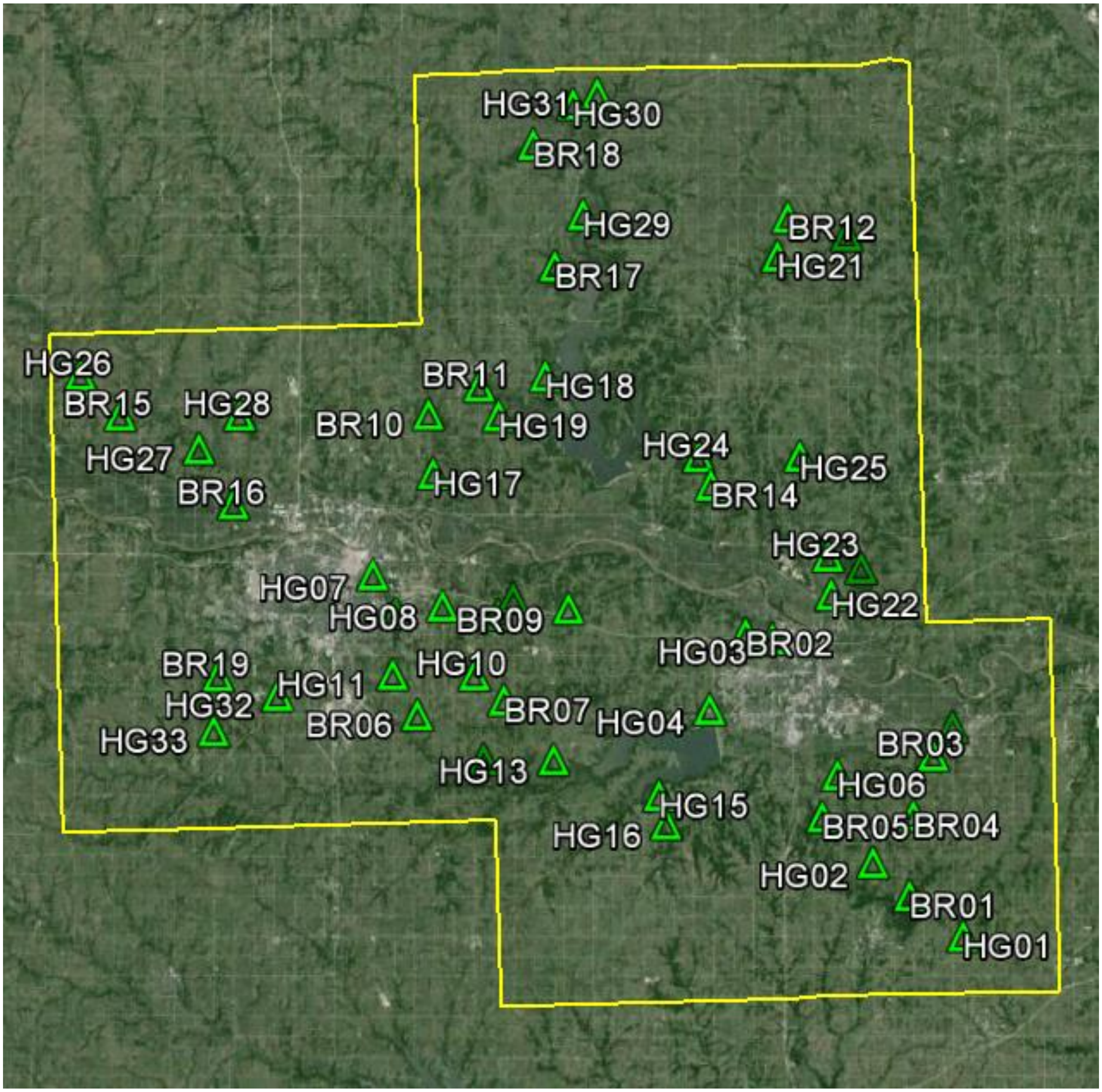


Figure 6: Vegetated Vertical Accuracy (VVA) Check Point Distribution

3.4 Check Point Assessment

A vertical accuracy assessment of the NVA & VVA checkpoints against the lidar point cloud swath data and bare-earth surface DEM's can be found in Tables 10, 11, and 12 below. The coordinates provided are in NAD83 (HARN), UTM Zone 15N, NAVD88 (Geoid12A), Meters.

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Swath)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
OT01	311886.486	4294001.043	333.709	333.737	Open Terrain/Bare Earth	0.028
OT02	314064.580	4293151.841	326.774	326.840	Open Terrain/Bare Earth	0.066
OT03	296061.698	4315607.480	331.775	331.751	Open Terrain/Bare Earth	-0.024
OT04	301662.378	4312809.742	263.173	263.174	Open Terrain/Bare Earth	0.001
OT05	302938.306	4316060.706	300.965	300.984	Open Terrain/Bare Earth	0.019
OT06	318513.575	4310229.694	271.285	271.278	Open Terrain/Bare Earth	-0.007
OT07	312021.767	4307794.663	277.499	277.477	Open Terrain/Bare Earth	-0.022
OT08	307064.542	4303057.432	274.393	274.364	Open Terrain/Bare Earth	-0.029
OT09	313526.353	4302884.988	274.397	274.391	Open Terrain/Bare Earth	-0.006
OT10	271161.083	4327558.503	270.060	270.040	Open Terrain/Bare Earth	-0.020
OT11	277889.565	4324832.449	287.948	287.929	Open Terrain/Bare Earth	-0.019
OT12	272940.190	4324151.281	301.091	301.035	Open Terrain/Bare Earth	-0.056
OT13	273566.116	4319704.169	312.167	312.196	Open Terrain/Bare Earth	0.029
OT14	284782.156	4310830.985	305.619	305.611	Open Terrain/Bare Earth	-0.008
OT15	284209.687	4306882.643	284.239	284.288	Open Terrain/Bare Earth	0.049
OT16	279990.110	4307282.648	285.865	285.832	Open Terrain/Bare Earth	-0.033
OT17	286727.393	4324239.879	321.763	321.732	Open Terrain/Bare Earth	-0.031
OT18	283302.042	4323967.035	332.474	332.398	Open Terrain/Bare Earth	-0.076
OT19	289441.648	4307221.737	303.581	303.606	Open Terrain/Bare Earth	0.025
OT20	291706.280	4301028.278	317.729	317.710	Open Terrain/Bare Earth	-0.019
OT21	295040.054	4305761.263	309.828	309.876	Open Terrain/Bare Earth	0.048
OT22	269781.308	4337725.594	308.344	308.369	Open Terrain/Bare Earth	0.025
OT23	272439.454	4333934.760	309.272	309.226	Open Terrain/Bare Earth	-0.046
OT24	286091.817	4338306.084	311.876	311.895	Open Terrain/Bare Earth	0.019
OT25	279556.400	4341289.808	288.716	288.732	Open Terrain/Bare Earth	0.016
OT26	307887.568	4349394.103	334.064	334.063	Open Terrain/Bare Earth	-0.001
OT27	308118.243	4356666.052	349.838	349.822	Open Terrain/Bare Earth	-0.016
OT28	310422.195	4352715.211	328.786	328.806	Open Terrain/Bare Earth	0.020
OT29	309794.611	4326393.002	329.532	329.485	Open Terrain/Bare Earth	-0.047
OT30	302766.241	4326543.153	298.204	298.072	Open Terrain/Bare Earth	-0.132
OT31	309073.719	4322003.731	267.016	266.964	Open Terrain/Bare Earth	-0.052
OT32	298768.319	4336868.983	358.488	358.517	Open Terrain/Bare Earth	0.029
OT33	303521.090	4331764.780	315.189	315.155	Open Terrain/Bare Earth	-0.034
OT34	302748.572	4335214.292	321.223	321.191	Open Terrain/Bare Earth	-0.032
OT35	248939.367	4338406.175	325.215	325.198	Open Terrain/Bare Earth	-0.017

OT36	253916.218	4343058.654	320.015	319.985	Open Terrain/Bare Earth	-0.030
OT37	261989.054	4333640.363	300.293	300.212	Open Terrain/Bare Earth	-0.081
OT38	257996.754	4330168.638	276.085	276.120	Open Terrain/Bare Earth	0.035
OT39	282920.458	4349435.491	294.110	294.206	Open Terrain/Bare Earth	0.096
OT40	287894.586	4355852.318	293.519	293.544	Open Terrain/Bare Earth	0.025
OT41	292426.777	4357309.391	304.420	304.366	Open Terrain/Bare Earth	-0.054
OT42	287894.571	4355852.277	293.552	293.544	Open Terrain/Bare Earth	-0.008
OT43	256058.224	4319830.587	345.769	345.765	Open Terrain/Bare Earth	-0.004
OT44	260625.841	4313995.843	337.744	337.728	Open Terrain/Bare Earth	-0.016
OT45	255843.635	4314100.019	342.823	342.783	Open Terrain/Bare Earth	-0.040
OT46	310122.226	4296036.934	322.824	322.875	Open Terrain/Bare Earth	0.051
OT47	302572.445	4314655.770	299.034	299.148	Open Terrain/Bare Earth	0.114
OT48	274369.951	4330232.526	284.092	284.081	Open Terrain/Bare Earth	-0.011
OT49	276699.060	4315167.305	336.818	336.855	Open Terrain/Bare Earth	0.037
OT50	290610.218	4302659.774	331.610	331.586	Open Terrain/Bare Earth	-0.024
OT51	277720.407	4335786.379	301.174	301.159	Open Terrain/Bare Earth	-0.015
OT52	304849.954	4354490.894	357.724	357.710	Open Terrain/Bare Earth	-0.014
OT53	305554.553	4328118.140	279.720	279.705	Open Terrain/Bare Earth	-0.015
OT54	298791.509	4329102.151	269.423	269.420	Open Terrain/Bare Earth	-0.003
OT55	254821.751	4332190.846	276.707	276.693	Open Terrain/Bare Earth	-0.014
OT56	287955.134	4349701.803	293.652	293.748	Open Terrain/Bare Earth	0.096
OT57	292910.880	4361276.785	321.286	321.314	Open Terrain/Bare Earth	0.028
OT58	259160.419	4319709.353	325.428	325.419	Open Terrain/Bare Earth	-0.009

Table 10: Lidar Point Cloud Swath Data Assessment

Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (DEM)						
PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
OT01	311886.486	4294001.043	333.709	333.725	Open Terrain/Bare Earth	0.016
OT02	314064.580	4293151.841	326.774	326.840	Open Terrain/Bare Earth	0.066
OT03	296061.698	4315607.480	331.775	331.741	Open Terrain/Bare Earth	-0.034
OT04	301662.378	4312809.742	263.173	263.169	Open Terrain/Bare Earth	-0.004
OT05	302938.306	4316060.706	300.965	300.950	Open Terrain/Bare Earth	-0.015
OT06	318513.575	4310229.694	271.285	271.271	Open Terrain/Bare Earth	-0.014
OT07	312021.767	4307794.663	277.499	277.466	Open Terrain/Bare Earth	-0.033
OT08	307064.542	4303057.432	274.393	274.359	Open Terrain/Bare Earth	-0.034
OT09	313526.353	4302884.988	274.397	274.386	Open Terrain/Bare Earth	-0.011
OT10	271161.083	4327558.503	270.060	269.985	Open Terrain/Bare Earth	-0.075
OT11	277889.565	4324832.449	287.948	287.887	Open Terrain/Bare Earth	-0.061
OT12	272940.190	4324151.281	301.091	300.988	Open Terrain/Bare Earth	-0.103
OT13	273566.116	4319704.169	312.167	312.175	Open Terrain/Bare Earth	0.008
OT14	284782.156	4310830.985	305.619	305.579	Open Terrain/Bare Earth	-0.040

OT15	284209.687	4306882.643	284.239	284.246	Open Terrain/Bare Earth	0.007
OT16	279990.110	4307282.648	285.865	285.831	Open Terrain/Bare Earth	-0.034
OT17	286727.393	4324239.879	321.763	321.701	Open Terrain/Bare Earth	-0.062
OT18	283302.042	4323967.035	332.474	332.397	Open Terrain/Bare Earth	-0.077
OT19	289441.648	4307221.737	303.581	303.606	Open Terrain/Bare Earth	0.025
OT20	291706.280	4301028.278	317.729	317.710	Open Terrain/Bare Earth	-0.019
OT21	295040.054	4305761.263	309.828	309.857	Open Terrain/Bare Earth	0.029
OT22	269781.308	4337725.594	308.344	308.342	Open Terrain/Bare Earth	-0.002
OT23	272439.454	4333934.760	309.272	309.226	Open Terrain/Bare Earth	-0.046
OT24	286091.817	4338306.084	311.876	311.864	Open Terrain/Bare Earth	-0.012
OT25	279556.400	4341289.808	288.716	288.732	Open Terrain/Bare Earth	0.016
OT26	307887.568	4349394.103	334.064	334.048	Open Terrain/Bare Earth	-0.016
OT27	308118.243	4356666.052	349.838	349.822	Open Terrain/Bare Earth	-0.016
OT28	310422.195	4352715.211	328.786	328.806	Open Terrain/Bare Earth	0.020
OT29	309794.611	4326393.002	329.532	329.406	Open Terrain/Bare Earth	-0.126
OT30	302766.241	4326543.153	298.204	298.039	Open Terrain/Bare Earth	-0.165
OT31	309073.719	4322003.731	267.016	266.962	Open Terrain/Bare Earth	-0.054
OT32	298768.319	4336868.983	358.488	358.517	Open Terrain/Bare Earth	0.029
OT33	303521.090	4331764.780	315.189	315.116	Open Terrain/Bare Earth	-0.073
OT34	302748.572	4335214.292	321.223	321.191	Open Terrain/Bare Earth	-0.032
OT35	248939.367	4338406.175	325.215	325.198	Open Terrain/Bare Earth	-0.017
OT36	253916.218	4343058.654	320.015	319.979	Open Terrain/Bare Earth	-0.036
OT37	261989.054	4333640.363	300.293	300.202	Open Terrain/Bare Earth	-0.091
OT38	257996.754	4330168.638	276.085	276.051	Open Terrain/Bare Earth	-0.034
OT39	282920.458	4349435.491	294.110	294.206	Open Terrain/Bare Earth	0.096
OT40	287894.586	4355852.318	293.519	293.514	Open Terrain/Bare Earth	-0.005
OT41	292426.777	4357309.391	304.420	304.346	Open Terrain/Bare Earth	-0.074
OT42	287894.571	4355852.277	293.552	293.514	Open Terrain/Bare Earth	-0.038
OT43	256058.224	4319830.587	345.769	345.747	Open Terrain/Bare Earth	-0.022
OT44	260625.841	4313995.843	337.744	337.728	Open Terrain/Bare Earth	-0.016
OT45	255843.635	4314100.019	342.823	342.783	Open Terrain/Bare Earth	-0.040
OT46	310122.226	4296036.934	322.824	322.857	Open Terrain/Bare Earth	0.033
OT47	302572.445	4314655.770	299.034	299.105	Open Terrain/Bare Earth	0.071
OT48	274369.951	4330232.526	284.092	284.030	Open Terrain/Bare Earth	-0.062
OT49	276699.060	4315167.305	336.818	336.855	Open Terrain/Bare Earth	0.037
OT50	290610.218	4302659.774	331.610	331.586	Open Terrain/Bare Earth	-0.024
OT51	277720.407	4335786.379	301.174	301.138	Open Terrain/Bare Earth	-0.036
OT52	304849.954	4354490.894	357.724	357.710	Open Terrain/Bare Earth	-0.014
OT53	305554.553	4328118.140	279.720	279.694	Open Terrain/Bare Earth	-0.026
OT54	298791.509	4329102.151	269.423	269.418	Open Terrain/Bare Earth	-0.005
OT55	254821.751	4332190.846	276.707	276.659	Open Terrain/Bare Earth	-0.048
OT56	287955.134	4349701.803	293.652	293.748	Open Terrain/Bare Earth	0.096

OT57	292910.880	4361276.785	321.286	321.314	Open Terrain/Bare Earth	0.028
OT58	259160.419	4319709.353	325.428	325.354	Open Terrain/Bare Earth	-0.074

Table 11: Bare-Earth Surface NVA Assessment

Vegetated Vertical Accuracy (VVA) Check Point Assessment (DEM)						
PointID	**Easting**	**Northing**	**KnownZ**	**LaserZ**	**Description**	**DeltaZ**
BR01	313101.272	4298045.493	291.561	291.609	Brush	0.048
BR02	300477.915	4319432.167	269.241	269.219	Brush	-0.022
BR03	315310.758	4309251.824	266.067	266.105	Brush	0.038
BR04	313573.609	4304475.260	284.243	284.360	Brush	0.117
BR05	306243.085	4304572.056	276.081	276.194	Brush	0.113
BR06	273879.805	4313638.902	322.667	322.694	Brush	0.027
BR07	280879.411	4314628.724	326.049	326.231	Brush	0.182
BR08	280618.632	4321506.409	309.541	309.524	Brush	-0.017
BR09	286279.051	4321847.723	332.637	332.570	Brush	-0.067
BR10	275438.106	4337727.928	300.761	300.910	Brush	0.149
BR11	279587.872	4339867.185	293.674	293.822	Brush	0.148
BR12	304791.787	4352736.941	344.765	344.762	Brush	-0.003
BR13	309920.917	4324436.342	327.351	327.234	Brush	-0.117
BR14	298007.540	4331407.023	303.792	303.786	Brush	-0.006
BR15	250582.740	4338343.702	304.175	304.177	Brush	0.002
BR16	259534.364	4330977.920	274.645	274.592	Brush	-0.053
BR17	285926.656	4349341.942	309.149	309.220	Brush	0.071
BR18	284452.463	4359153.537	281.208	281.244	Brush	0.036
BR19	257910.506	4317202.603	353.751	353.672	Brush	-0.079
HG01	317341.682	4294687.744	325.946	326.041	High Grass	0.095
HG02	310235.467	4300798.195	272.185	272.196	High Grass	0.011
HG03	302611.675	4318955.611	263.063	263.053	High Grass	-0.010
HG04	297418.101	4313445.701	300.720	300.790	High Grass	0.070
HG05	316932.220	4311494.150	268.724	268.678	High Grass	-0.046
HG06	307558.146	4307903.041	268.312	268.313	High Grass	0.001
HG07	270604.533	4324977.226	276.629	276.592	High Grass	-0.037
HG08	276147.985	4322319.543	291.549	291.549	High Grass	0.000
HG09	272351.420	4321842.826	279.978	279.906	High Grass	-0.072
HG10	278557.802	4316716.339	334.753	334.725	High Grass	-0.028
HG11	271987.530	4316932.433	309.770	309.756	High Grass	-0.014
HG12	279111.324	4309937.701	296.036	296.135	High Grass	0.099
HG13	284752.519	4309747.950	283.626	283.640	High Grass	0.014
HG14	281852.538	4322770.208	315.515	315.590	High Grass	0.075
HG15	293148.487	4306634.931	310.112	310.128	High Grass	0.016
HG16	293671.469	4304332.850	307.638	307.719	High Grass	0.081

HG17	275667.856	4332962.125	279.313	279.254	High Grass	-0.059
HG18	284916.869	4340533.563	313.098	313.098	High Grass	0.000
HG19	281074.377	4337446.240	295.510	295.572	High Grass	0.062
HG20	309488.261	4351164.111	297.615	297.690	High Grass	0.075
HG21	303864.953	4349643.336	344.367	344.394	High Grass	0.027
HG22	307443.344	4322373.718	253.536	253.529	High Grass	-0.007
HG23	307294.941	4325465.252	315.806	315.820	High Grass	0.014
HG24	297075.629	4333722.997	334.970	334.997	High Grass	0.027
HG25	305218.310	4333532.777	324.399	324.369	High Grass	-0.030
HG26	247451.128	4341680.297	303.223	303.292	High Grass	0.069
HG27	256856.943	4335471.977	279.128	279.109	High Grass	-0.019
HG28	260218.806	4338074.547	303.624	303.684	High Grass	0.060
HG29	288304.993	4353405.385	302.792	302.800	High Grass	0.008
HG30	287748.324	4362304.580	312.379	312.448	High Grass	0.069
HG31	289715.069	4363100.376	312.558	312.620	High Grass	0.062
HG32	262670.649	4315510.385	349.095	349.087	High Grass	-0.008
HG33	257434.749	4312811.957	351.295	351.312	High Grass	0.017

Table 12: Bare-Earth Surface VVA Assessment

3.5 Vertical Accuracy Results

An overall statistical assessment of the check points can be found in Tables 13, 14, 15, and 16 below. The values provided are in meters.

Check Points Error Statistics								
Category	**# of**	**Min**	**Max**	**Mean**	**Median**	**Skew**	**Std Dev**	**$RMSE_Z$**
Open Terrain/Bare Earth	58	-0.165	0.096	-0.021	-0.021	-0.039	0.049	0.053
High Grass	33	-0.072	0.099	0.019	0.014	0.037	0.046	0.049
Brush	19	-0.117	0.182	0.030	0.027	0.202	0.084	0.087
Consolidated	110	-0.165	0.182	0.000	-0.008	0.400	0.059	0.059

Table 13: Check Points Error Statistics

Check Points Vertical Accuracy Assessment				
Land Cover Category	**# of Points**	**FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600)**	**CVA — Consolidated Vertical Accuracy (95th Percentile)**	**SVA — Supplemental Vertical Accuracy (95th Percentile)**
Open Terrain/Bare Earth	58	0.103		
High Grass	33			0.087
Brush	19			0.152
Consolidated	110		0.098	

Table 14: Check Points Vertical Accuracy Assessment

Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)				
Broad Land Cover Type	**# of Points**	**$RMSE_Z$ (m)**	**95% Confidence Level (m)**	**95th Percentile (m)**
NVA of Point Cloud	58	0.043	0.084	
NVA of DEM	58	0.053	0.103	
VVA of DEM	52	0.065		0.131

Table 15: Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)

Comparison of NSSDA, NDEP, and ASPRS Statistics					
Land Cover Category	**NSSDA $Accuracy_Z$ at 95% confidence level based on $RMSE_Z$ * 1.9600 (m)**	**NDEP FVA, plus SVAs and CVA based on 95th Percentile (m)**	**NDEP Accuracy Term**	**ASPRS Vertical Accuracy (m)**	**ASPRS Accuracy Term**
Bare Earth/Open Terrain	0.103	0.067	FVA	0.103	NVA
High Grass	0.096	0.087	SVA	0.131	VVA
Brush	0.170	0.152	SVA		
Consolidated	0.116	0.098	CVA	N/A	N/A

Table 16: Comparison of NSSDA, NDEP, and ASPRS Statistics

3.6 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 Kansas Department of Agriculture.

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.

Section 4: Certification

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

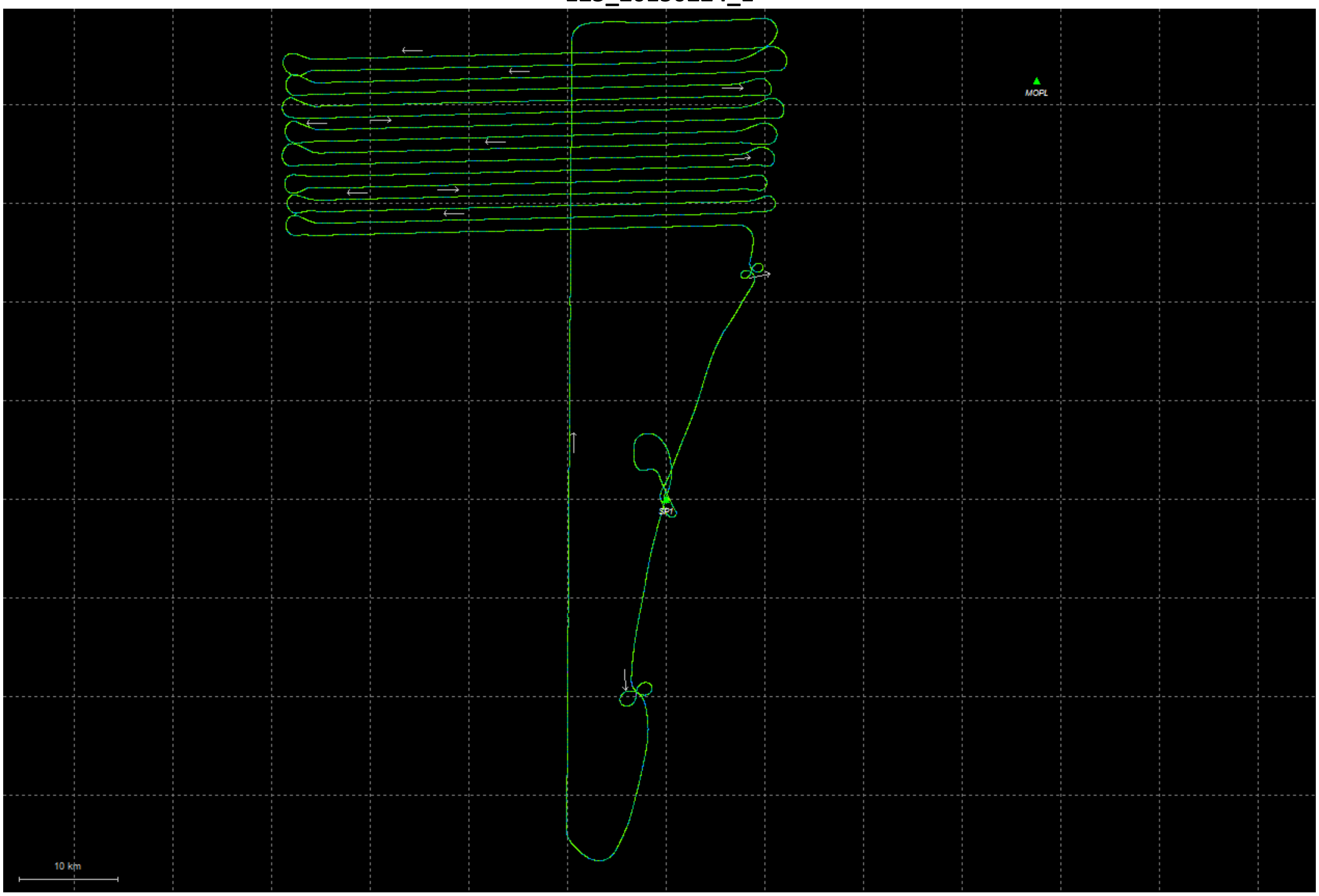
Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

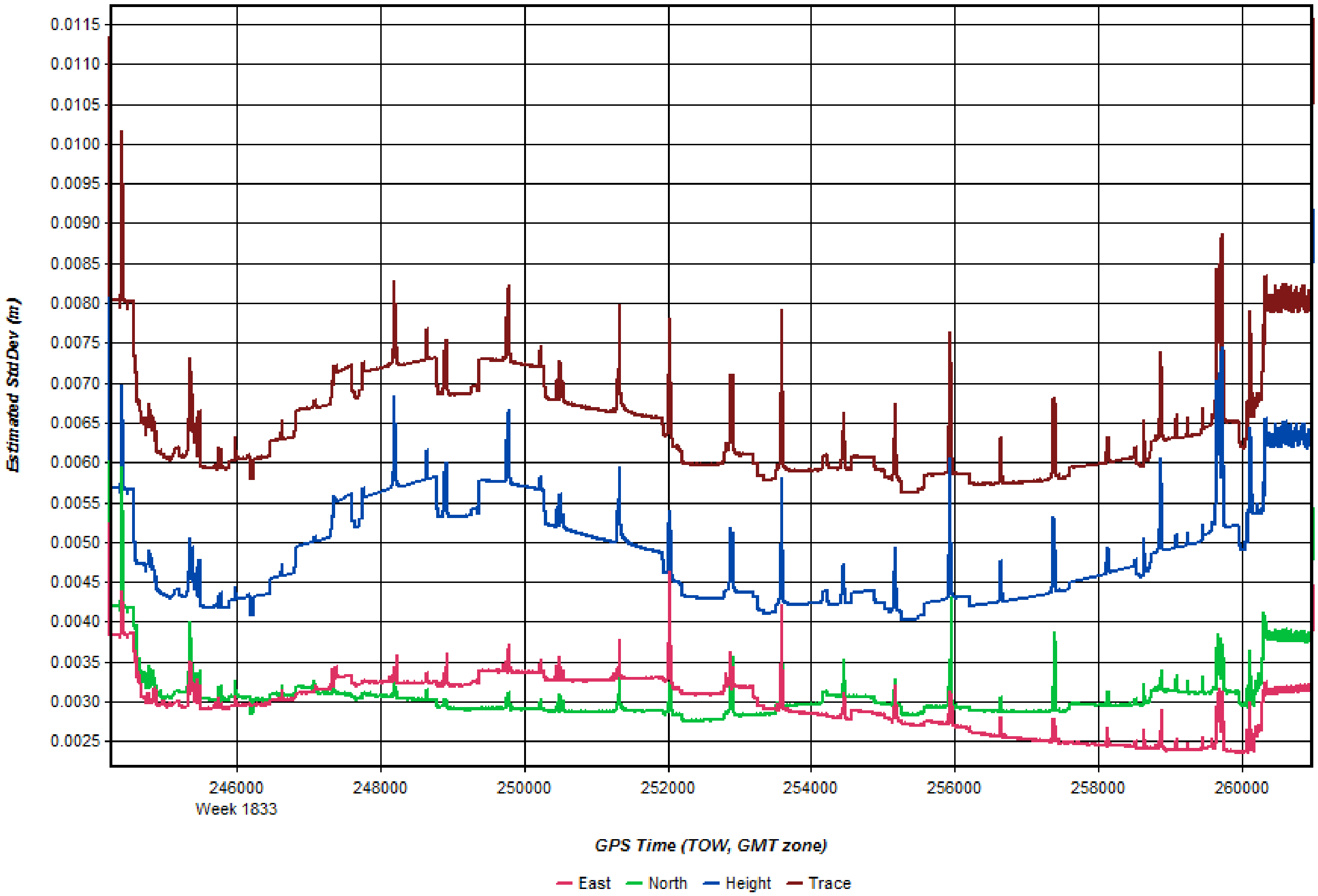
Section 5: GPS Processing

Inertial Explorer Version 8.50.4320

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

123_20150224_1

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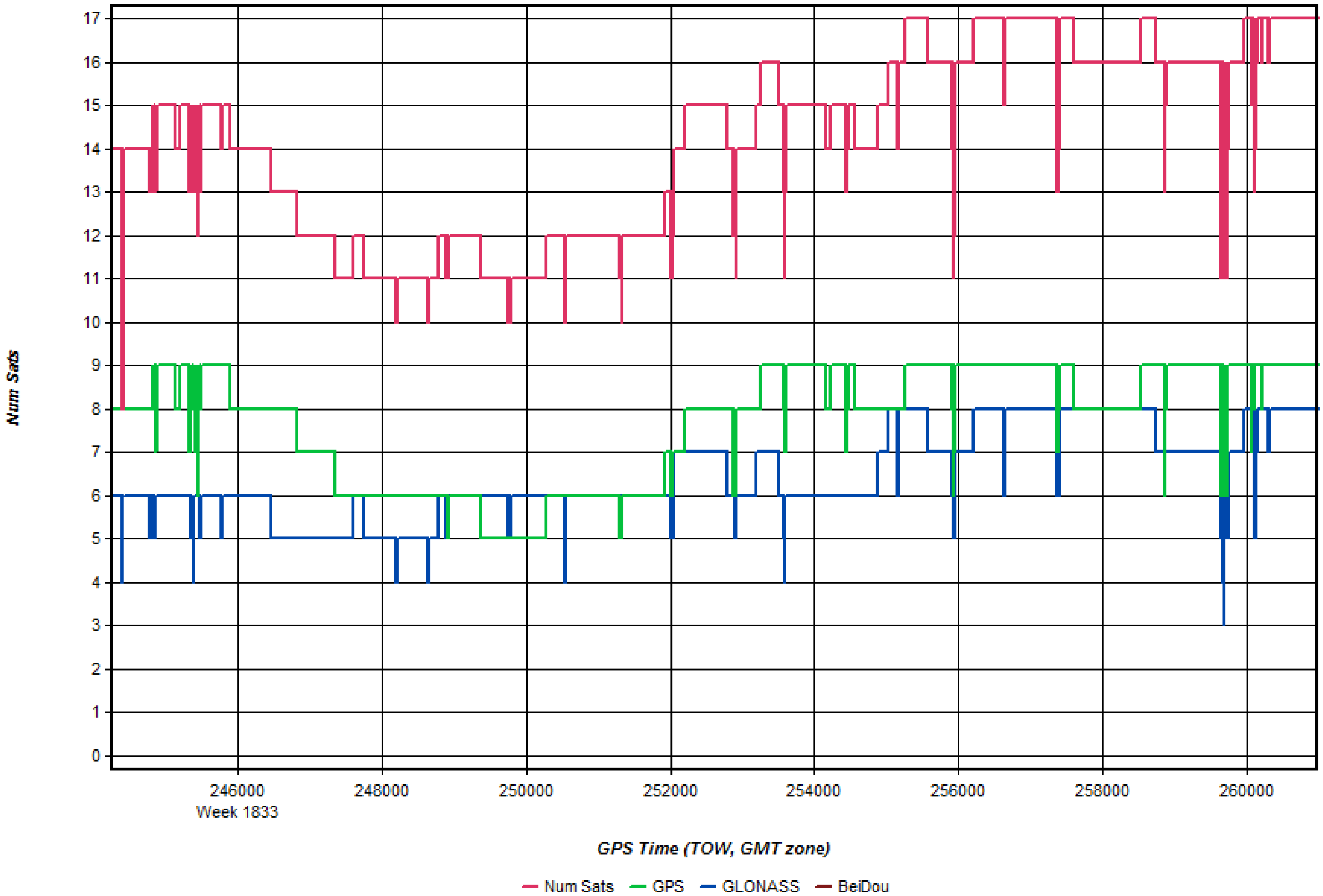
East
North
Height
Trace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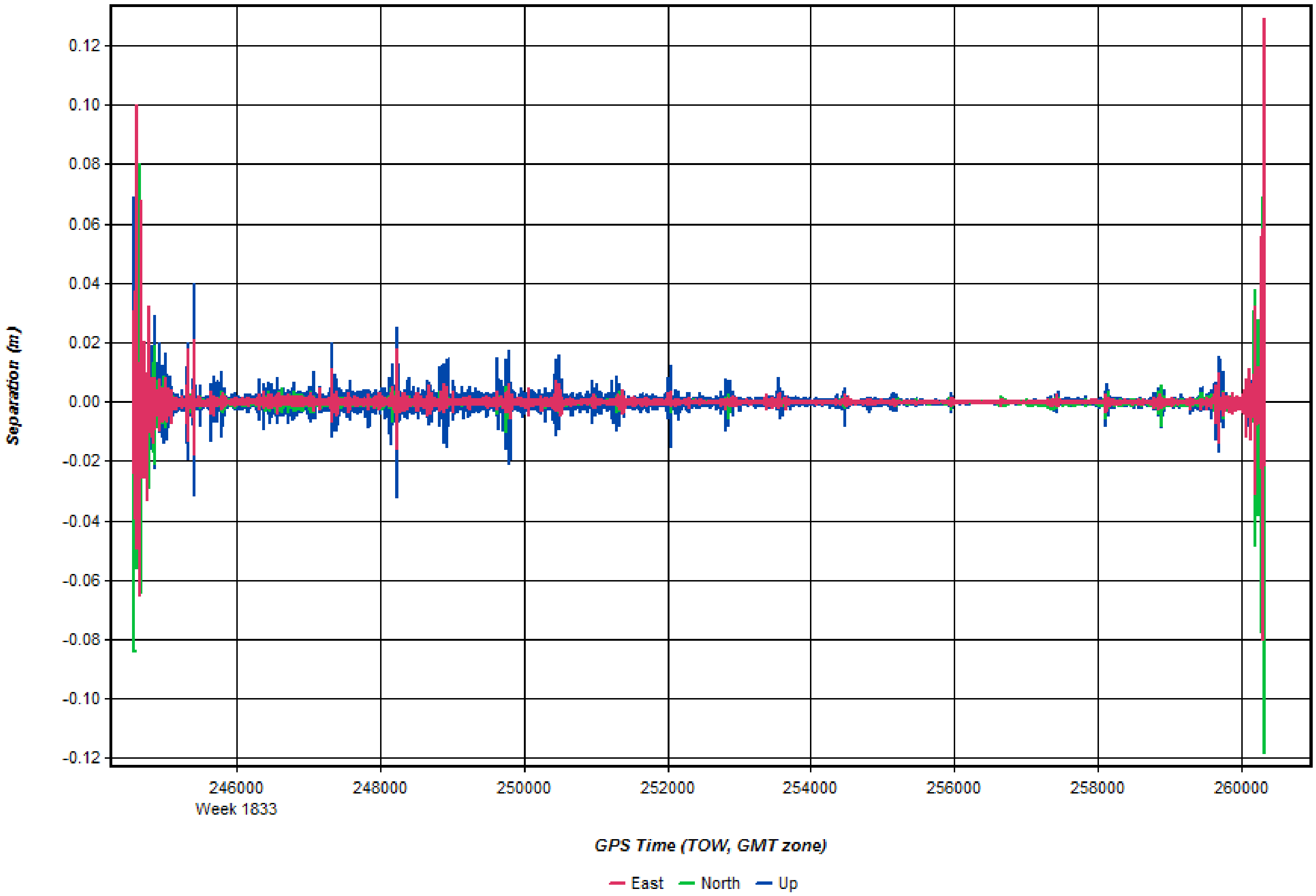
Num Sats
GPS
GLONASS
BeiDou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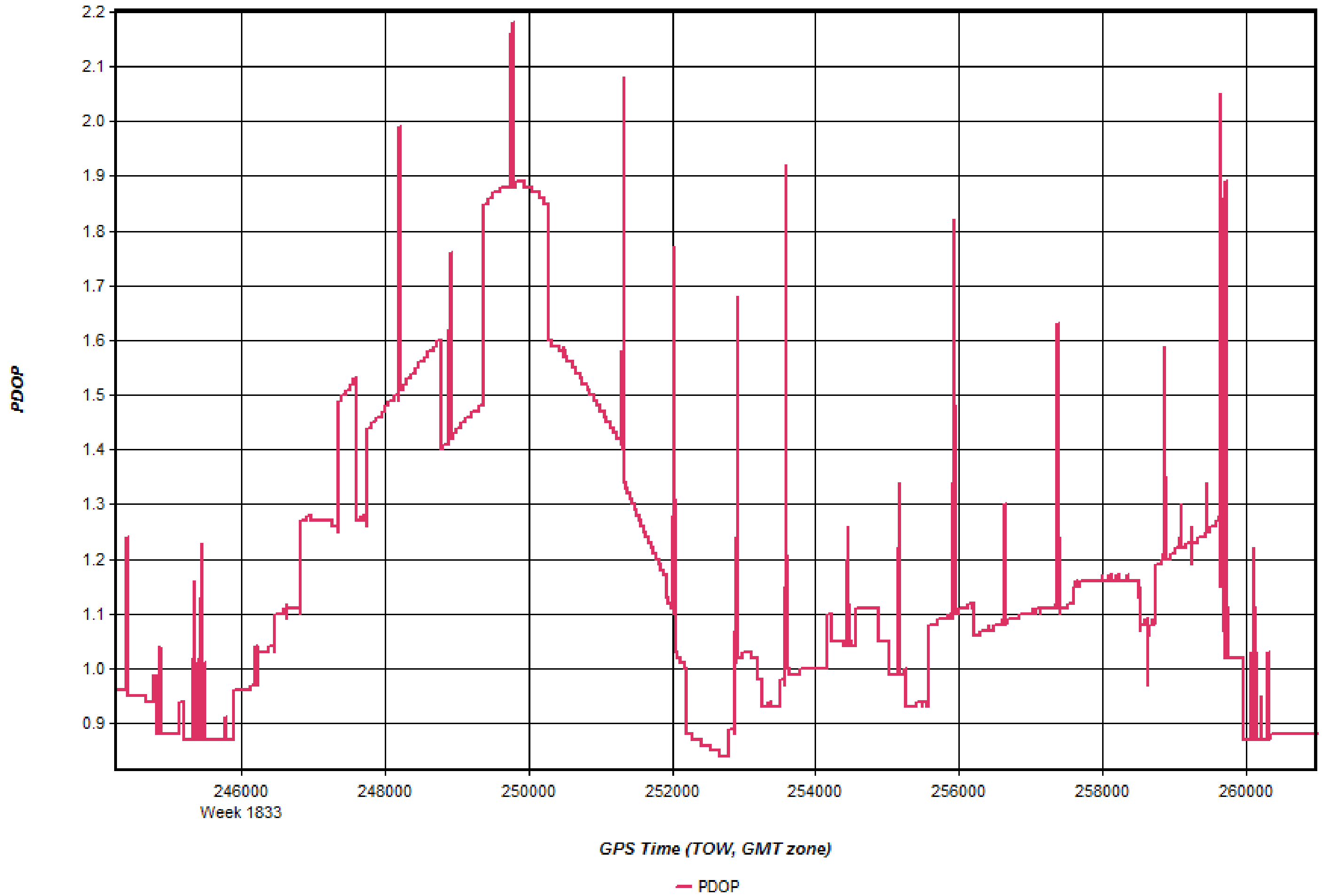
North
Up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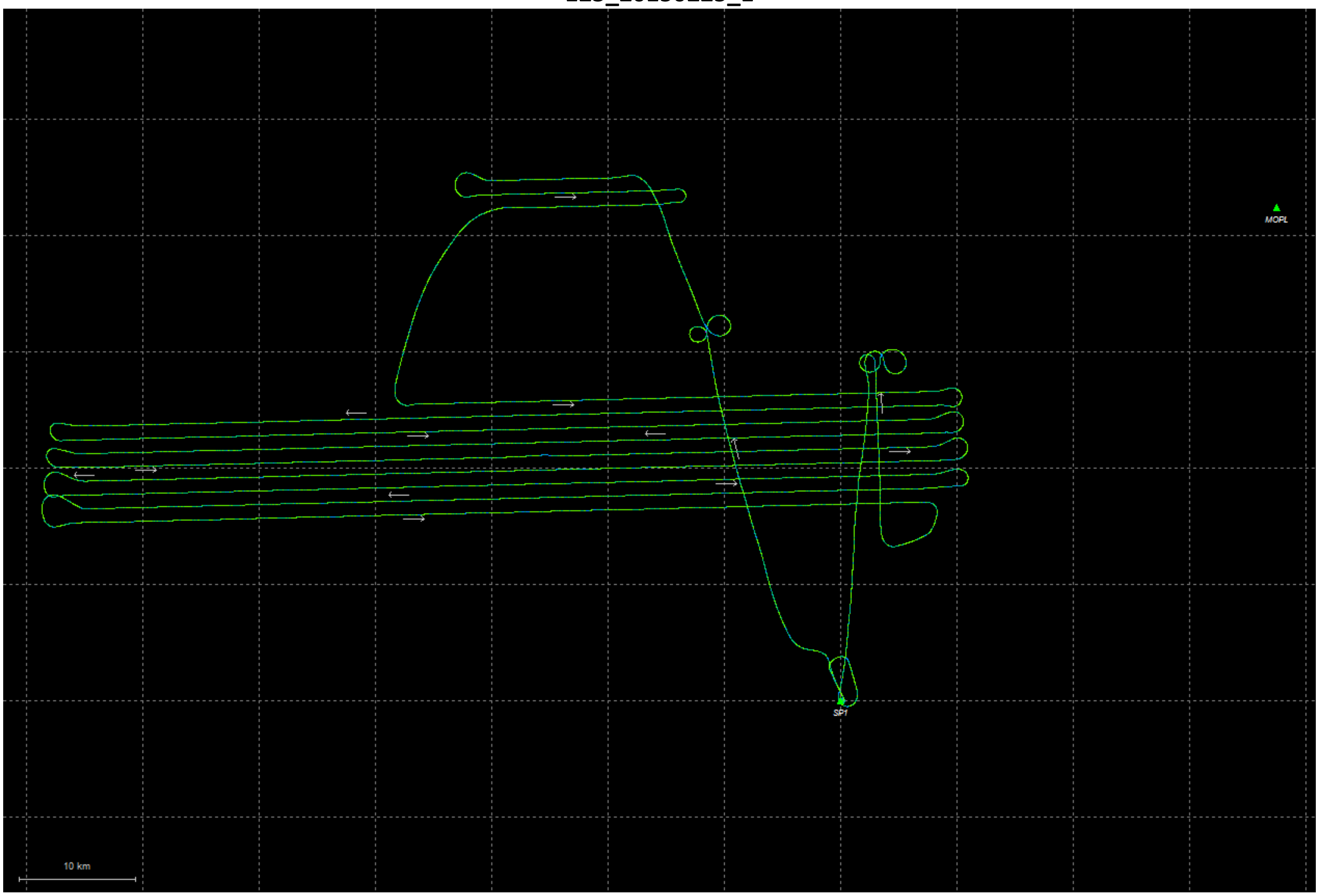

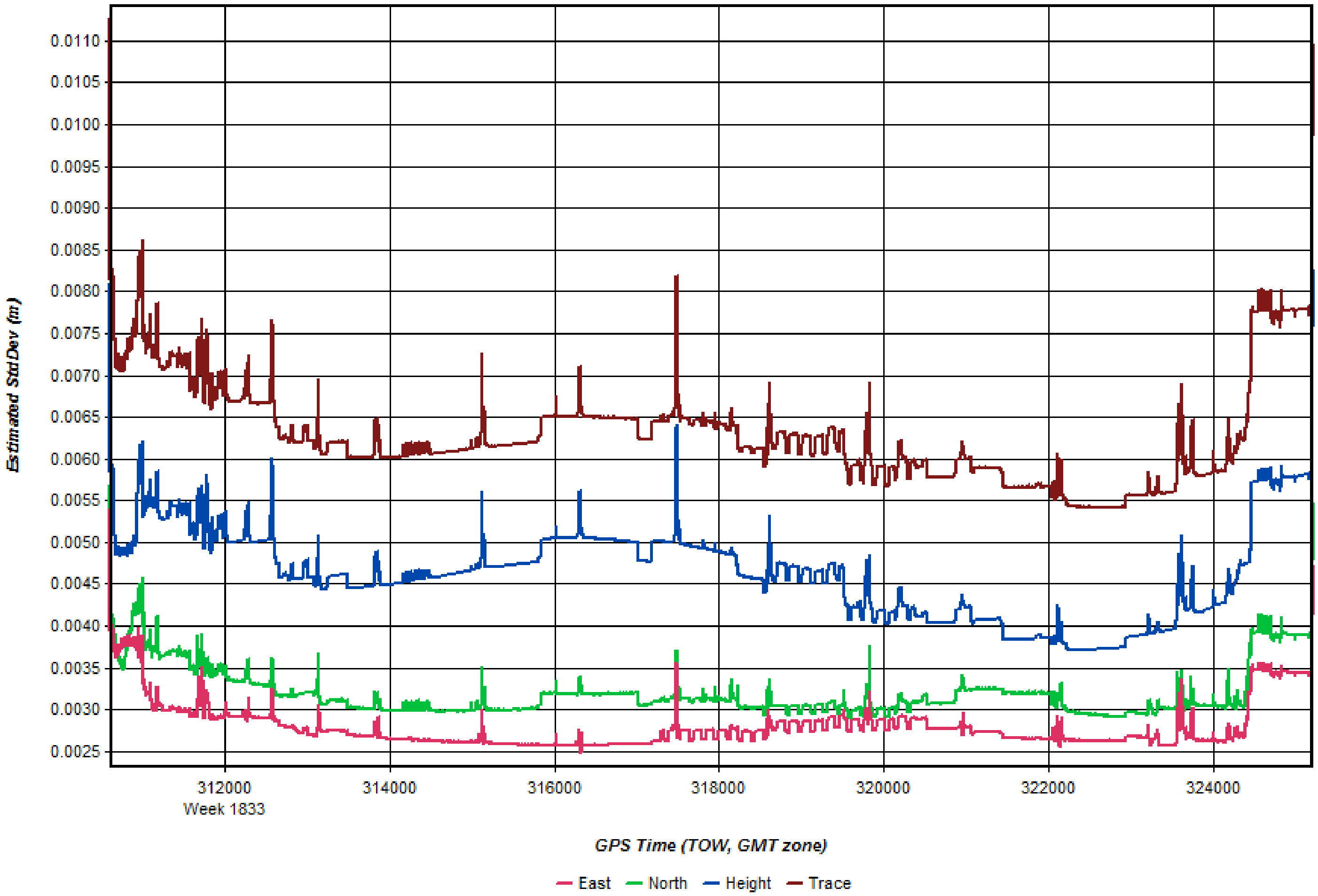
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North
Height
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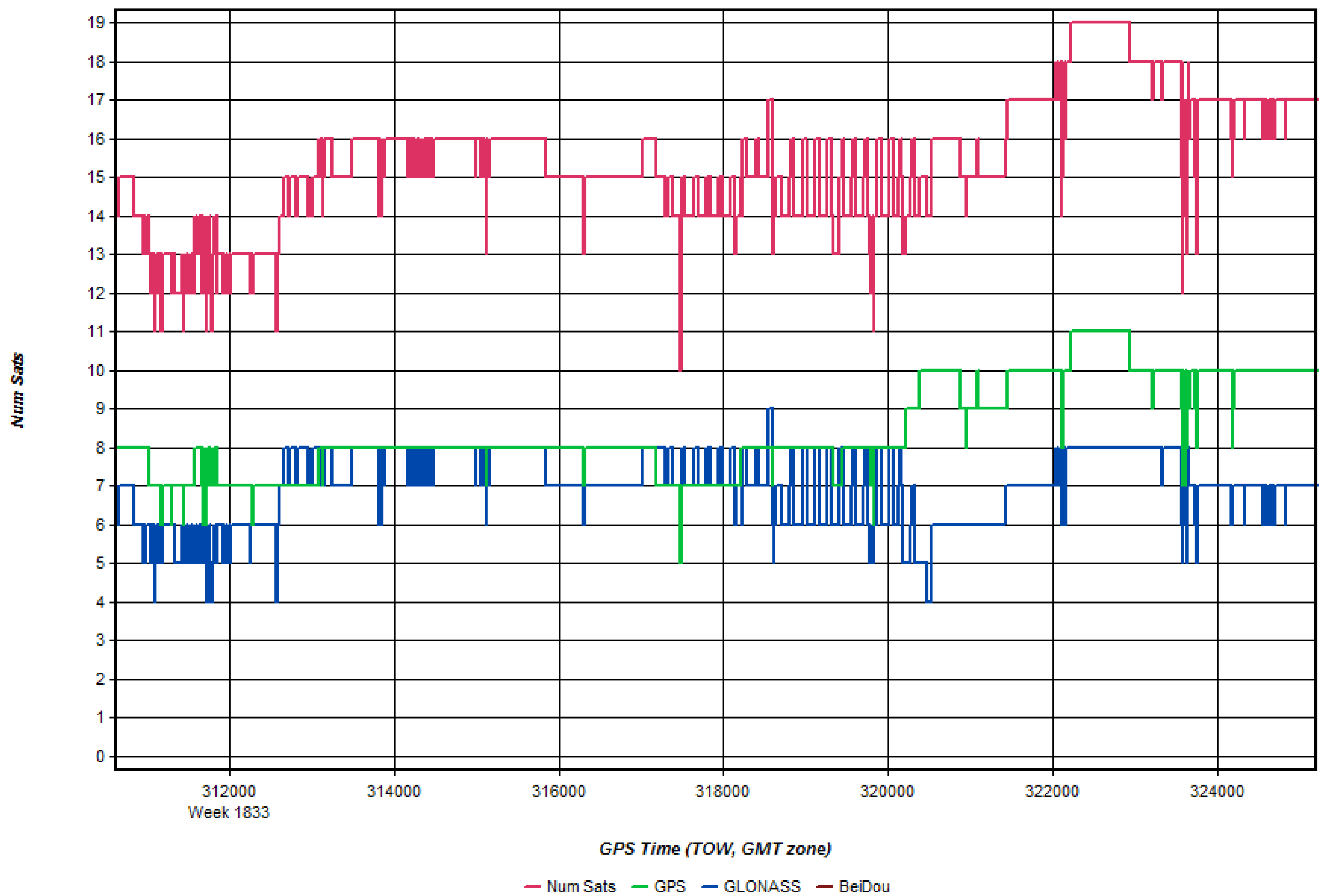
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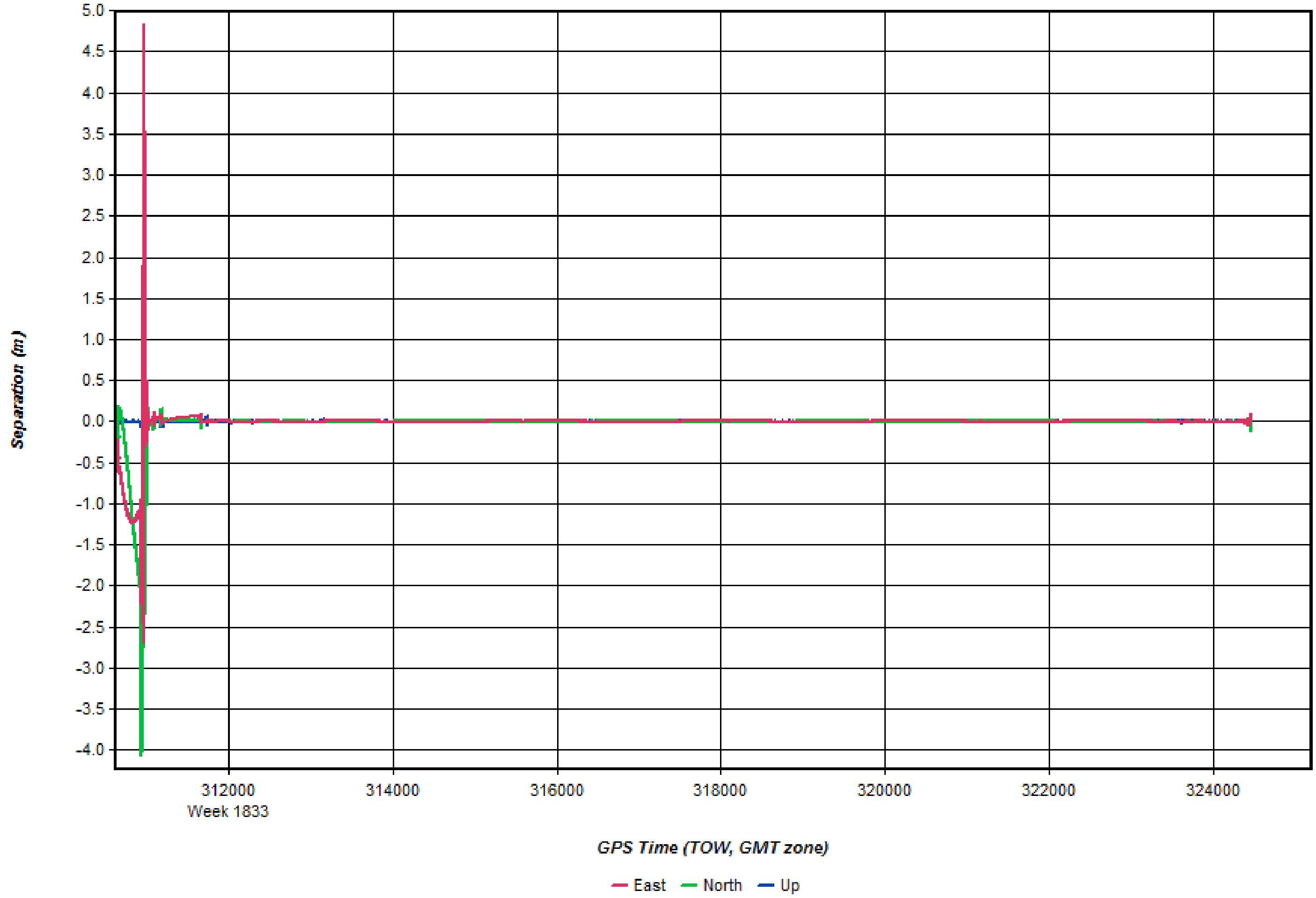
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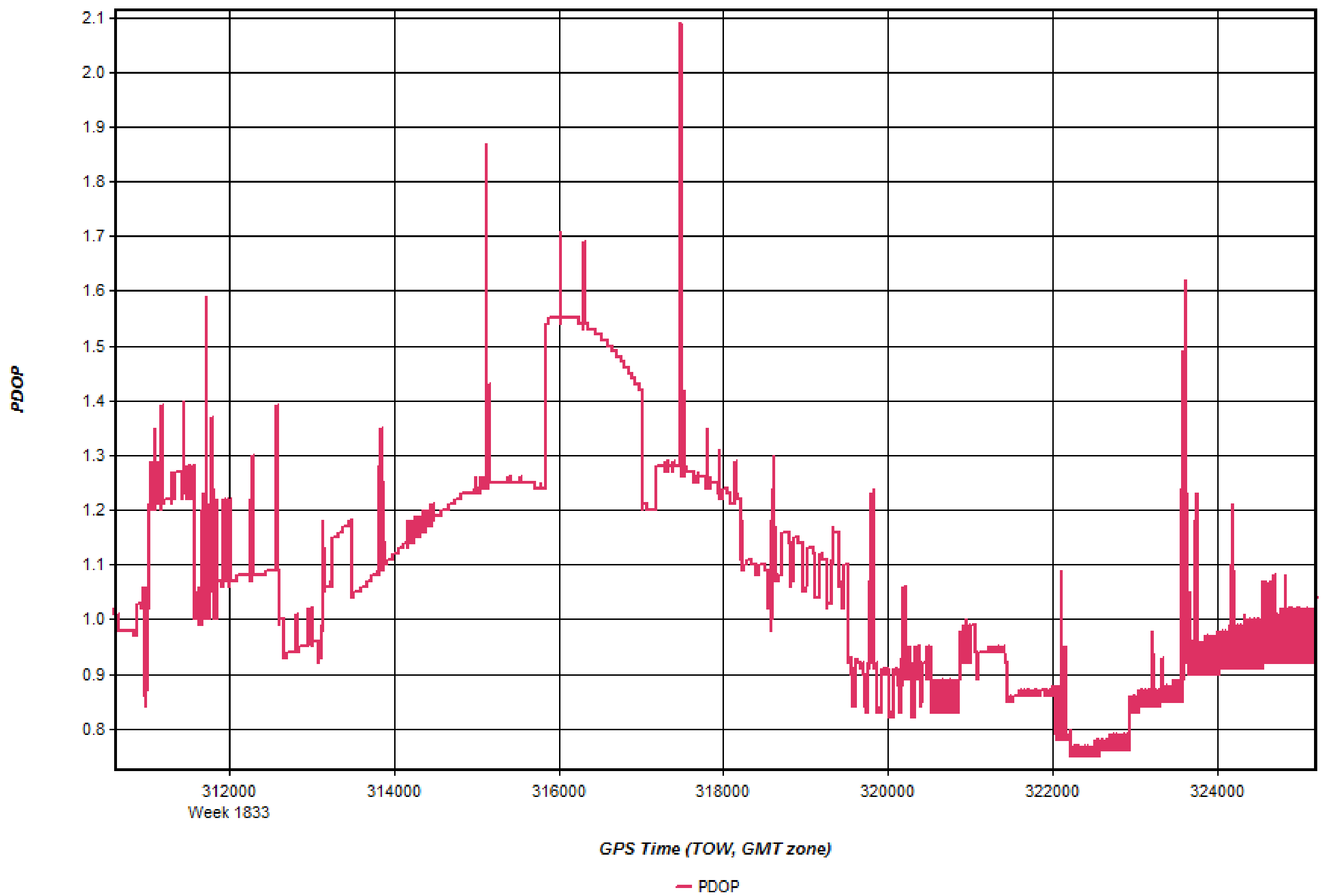
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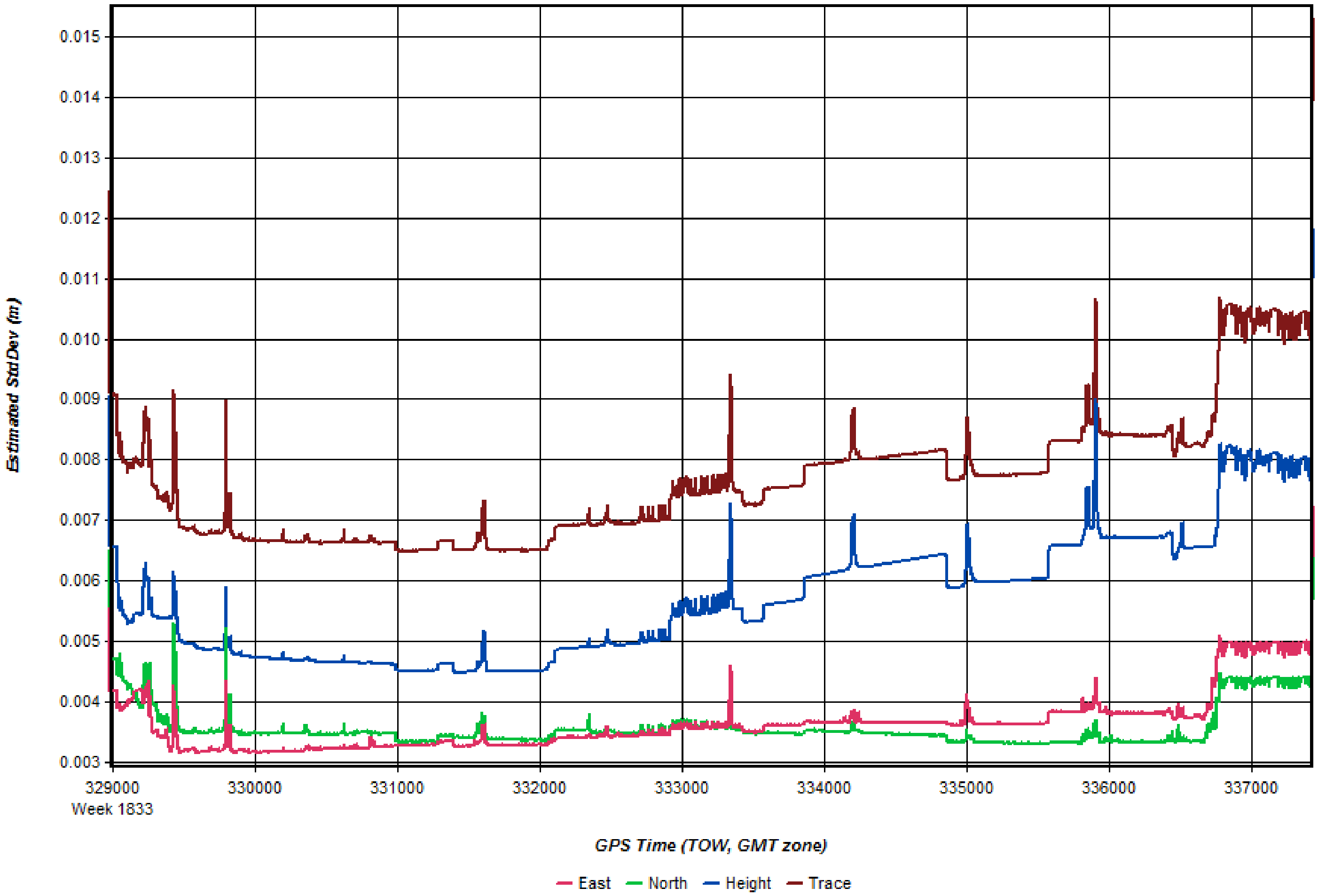
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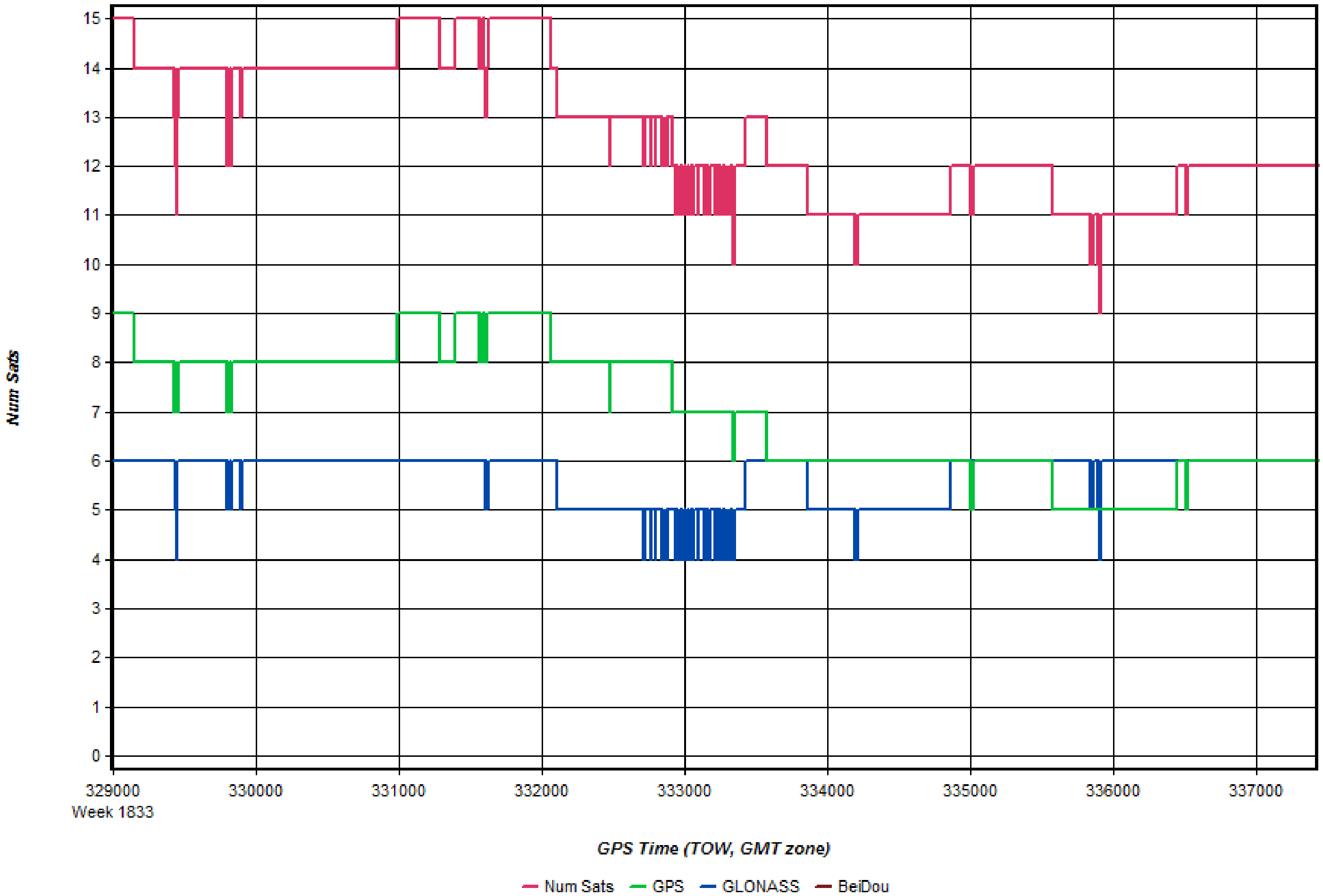
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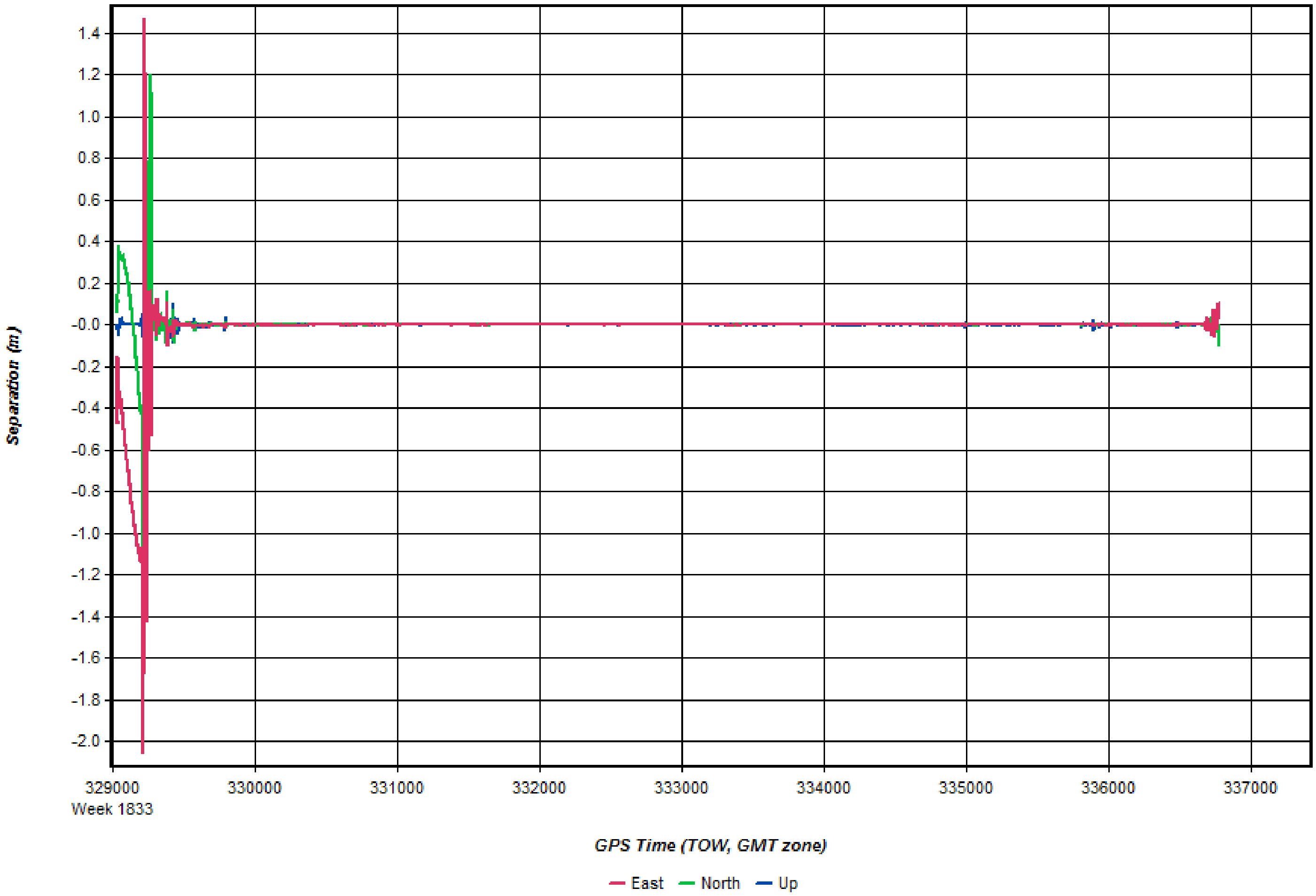
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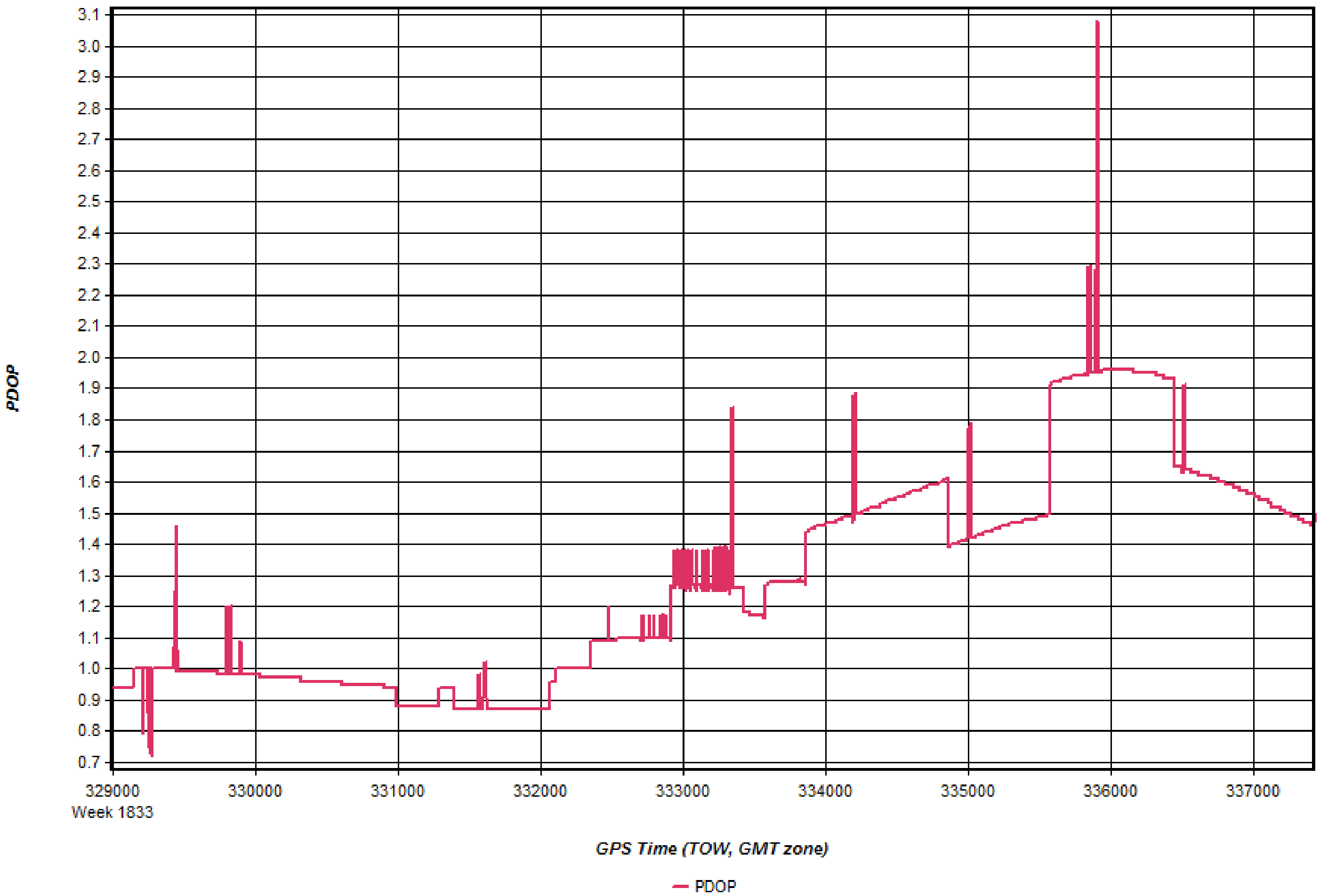
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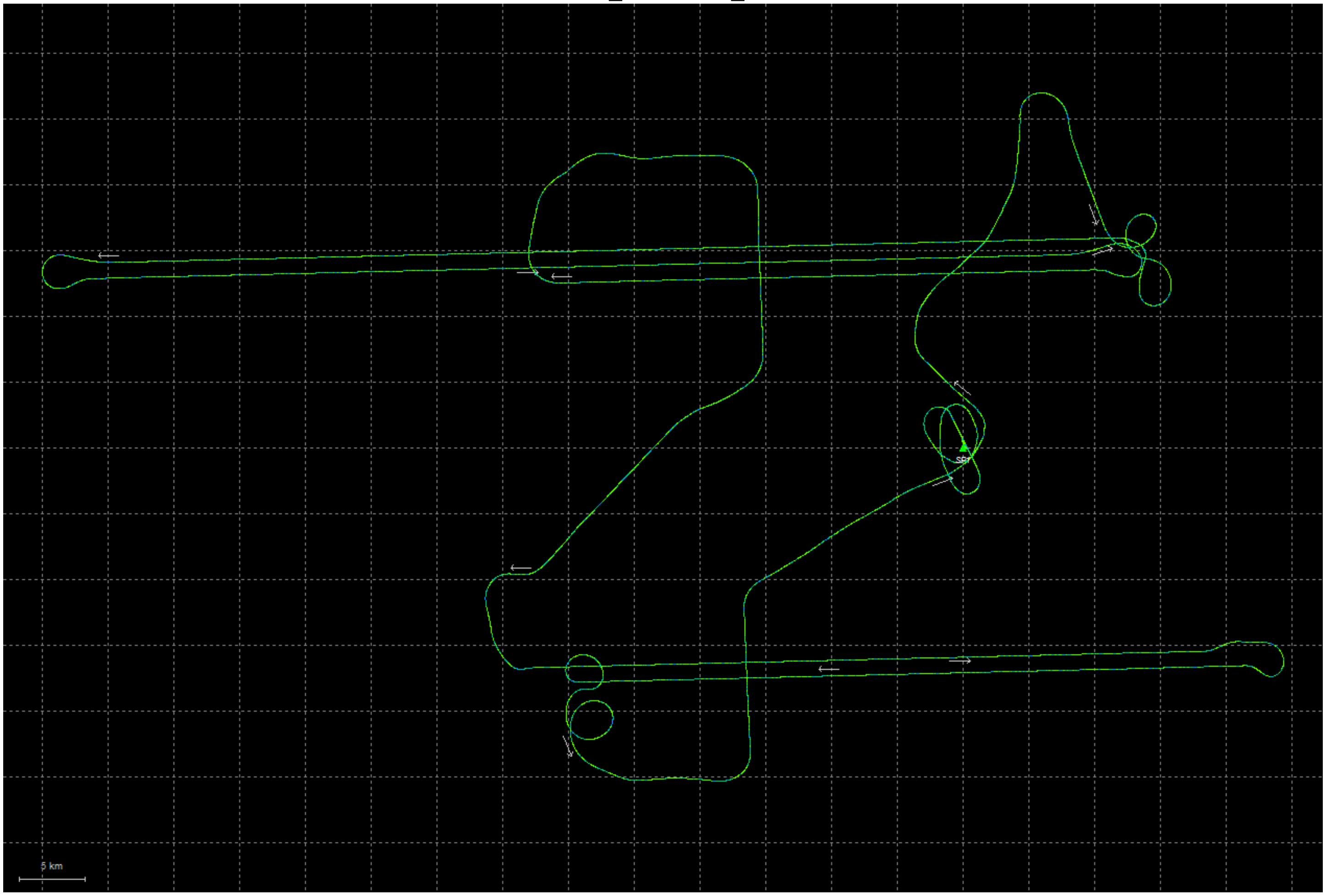
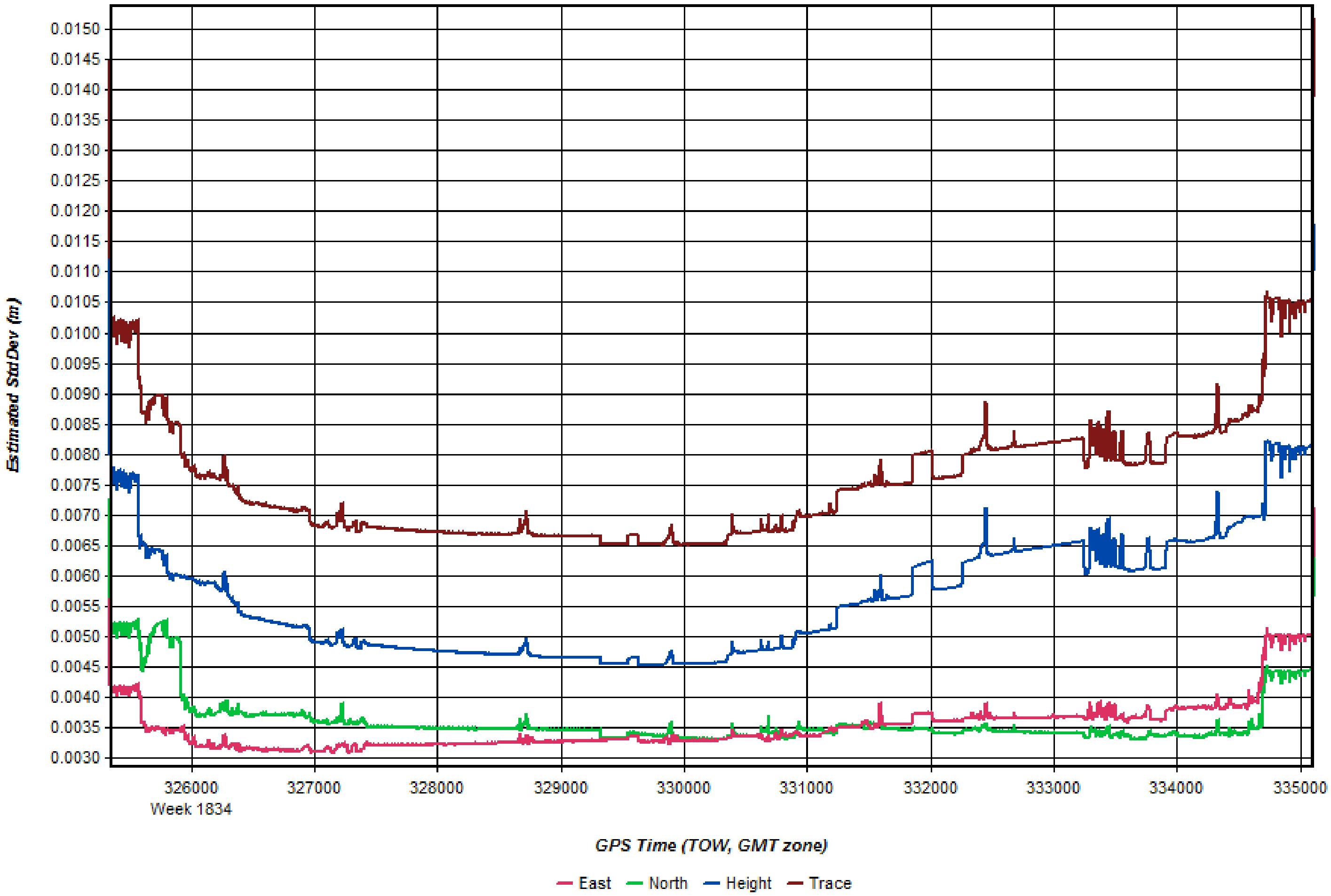
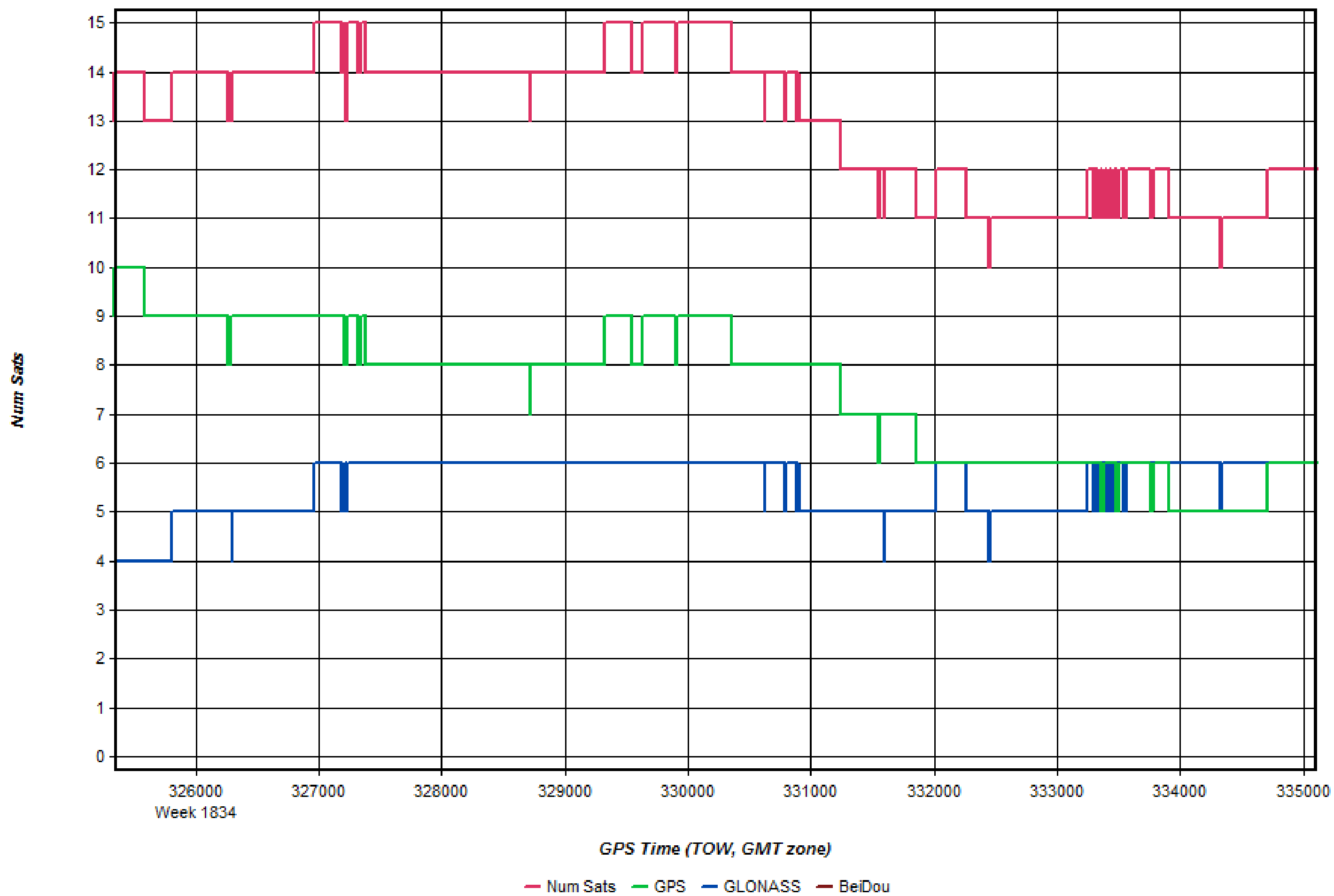
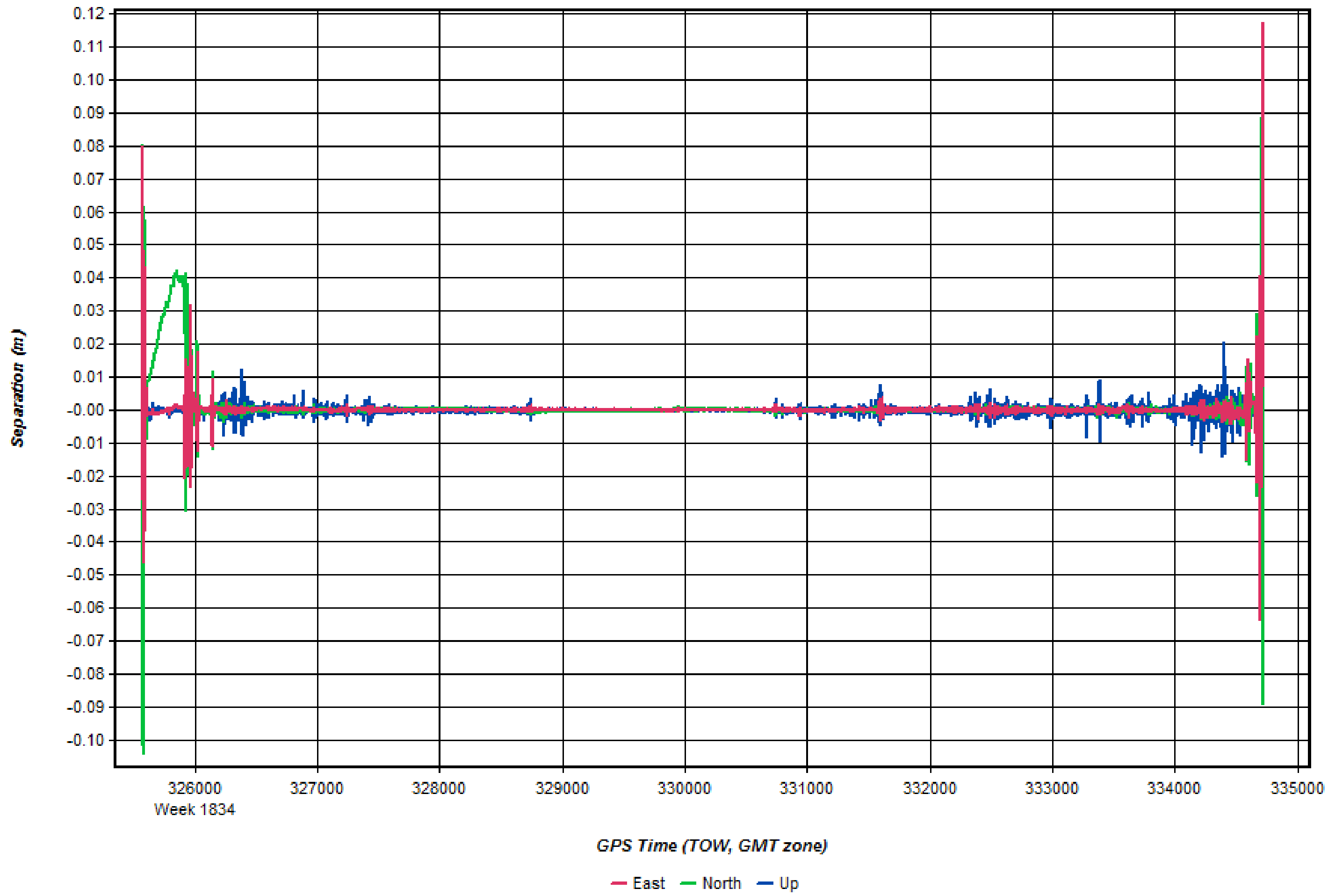
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
329000
Week 1833
330000
331000
332000
333000
334000
335000
336000
337000
GPS Time (TOW, GMT zone)
PDOP

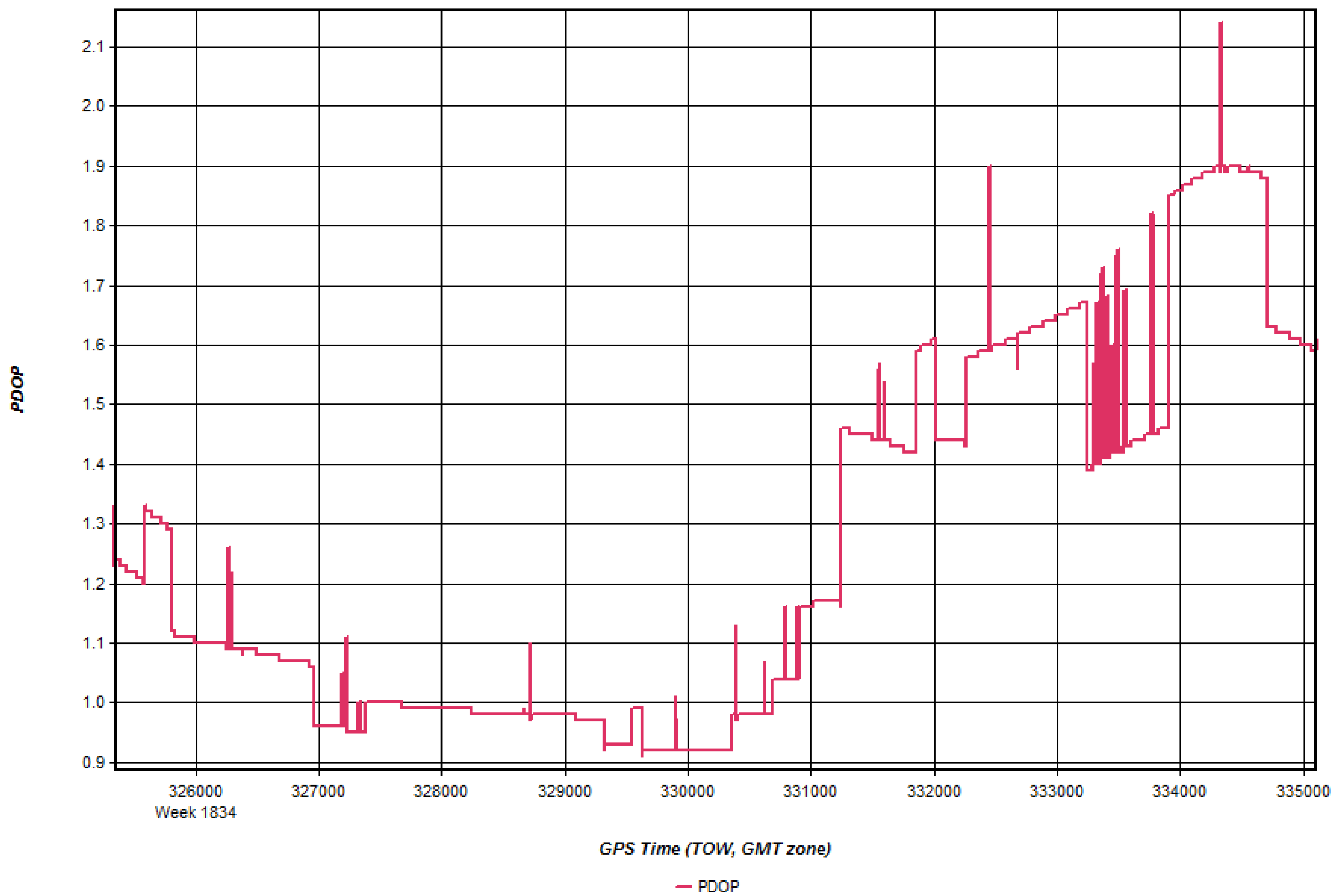
123_20150304_1



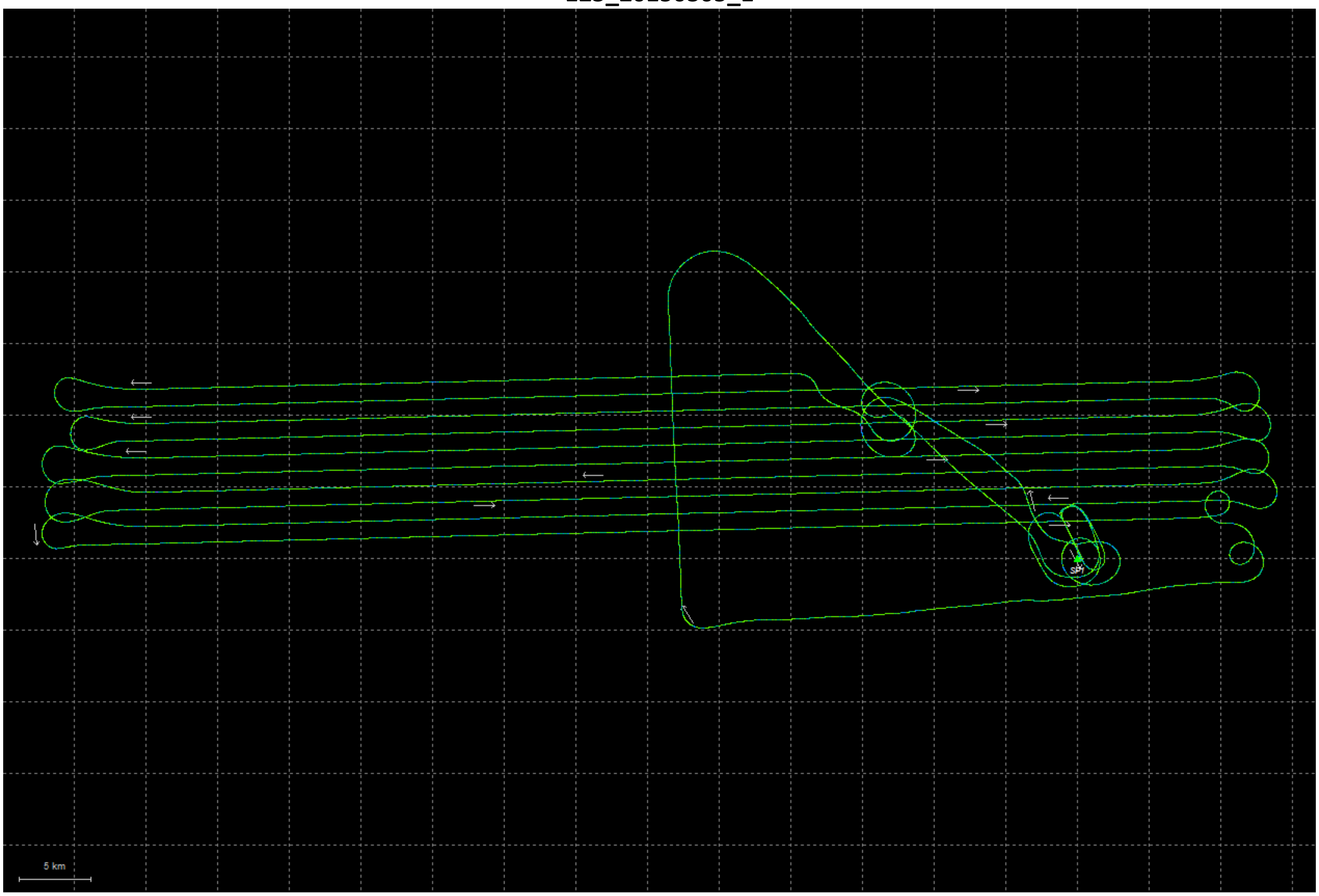

Estimated Std Dev (m)
0.0150
0.0145
0.0140
0.0135
0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
326000
Week 1834
327000
328000
329000
330000
331000
332000
333000
334000
335000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

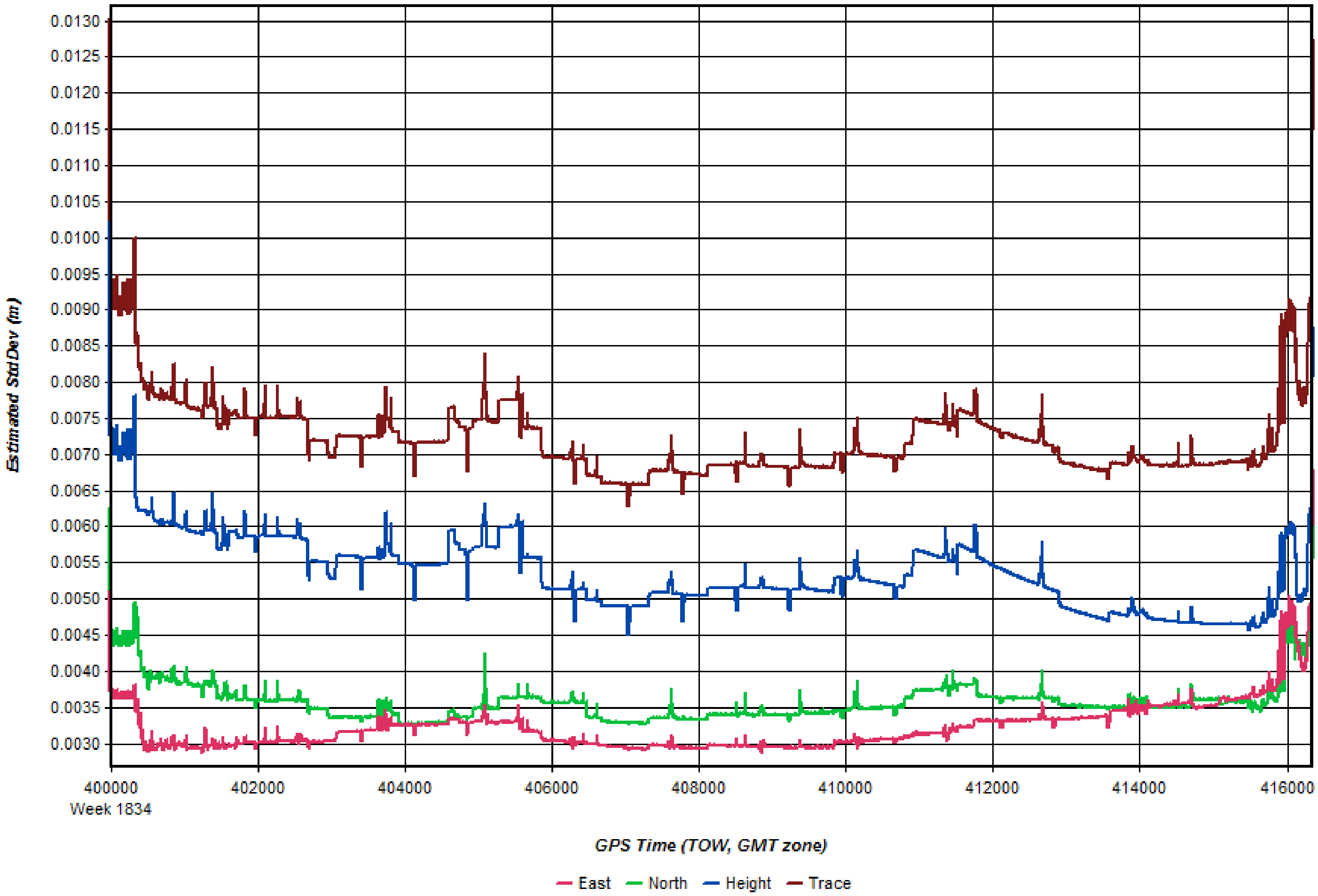

15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
326000
Week 1834
327000
328000
329000
330000
331000
332000
333000
334000
335000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

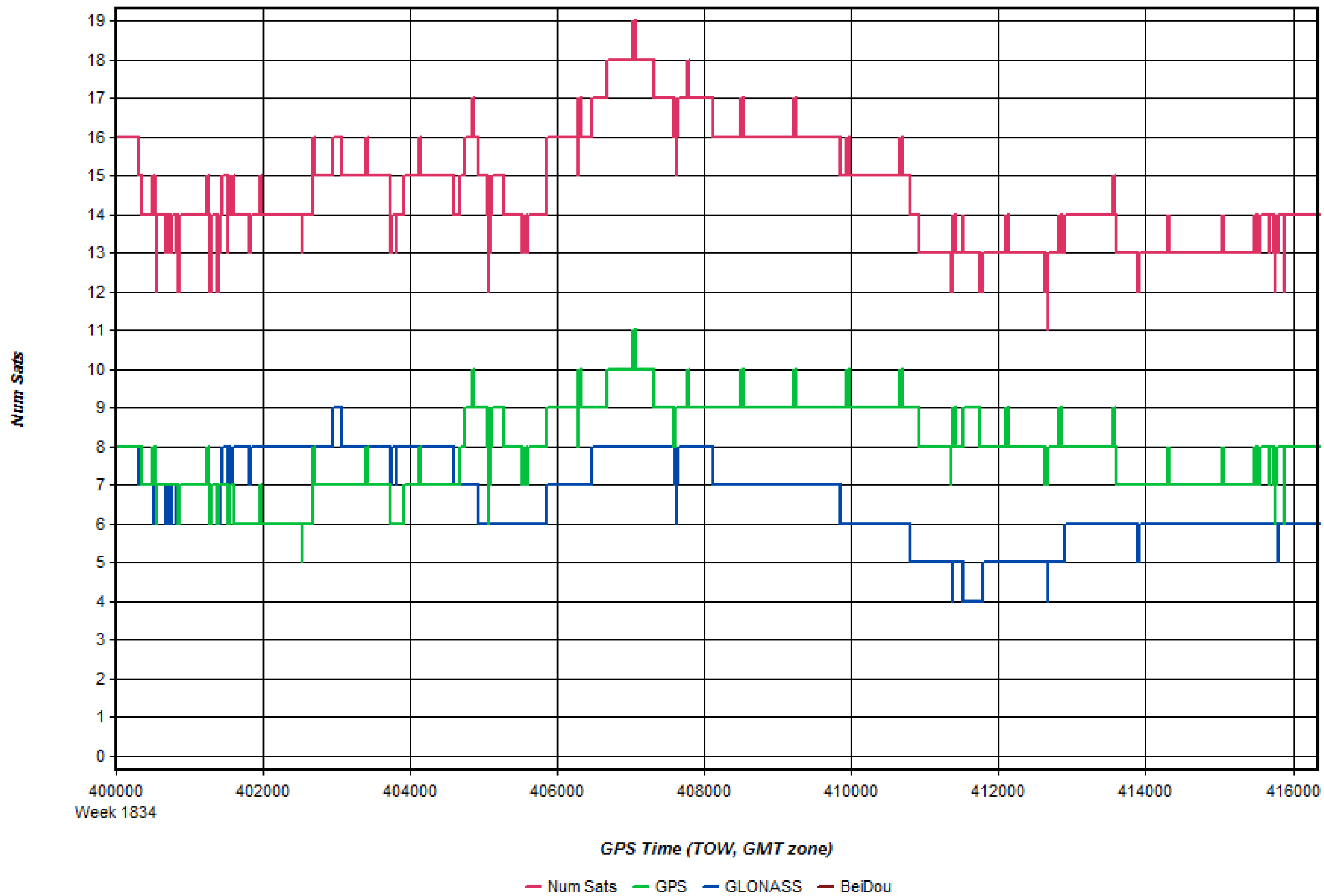

Separation (m)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
326000
Week 1834
327000
328000
329000
330000
331000
332000
333000
334000
335000
GPS Time (TOW, GMT zone)
East
North
Up

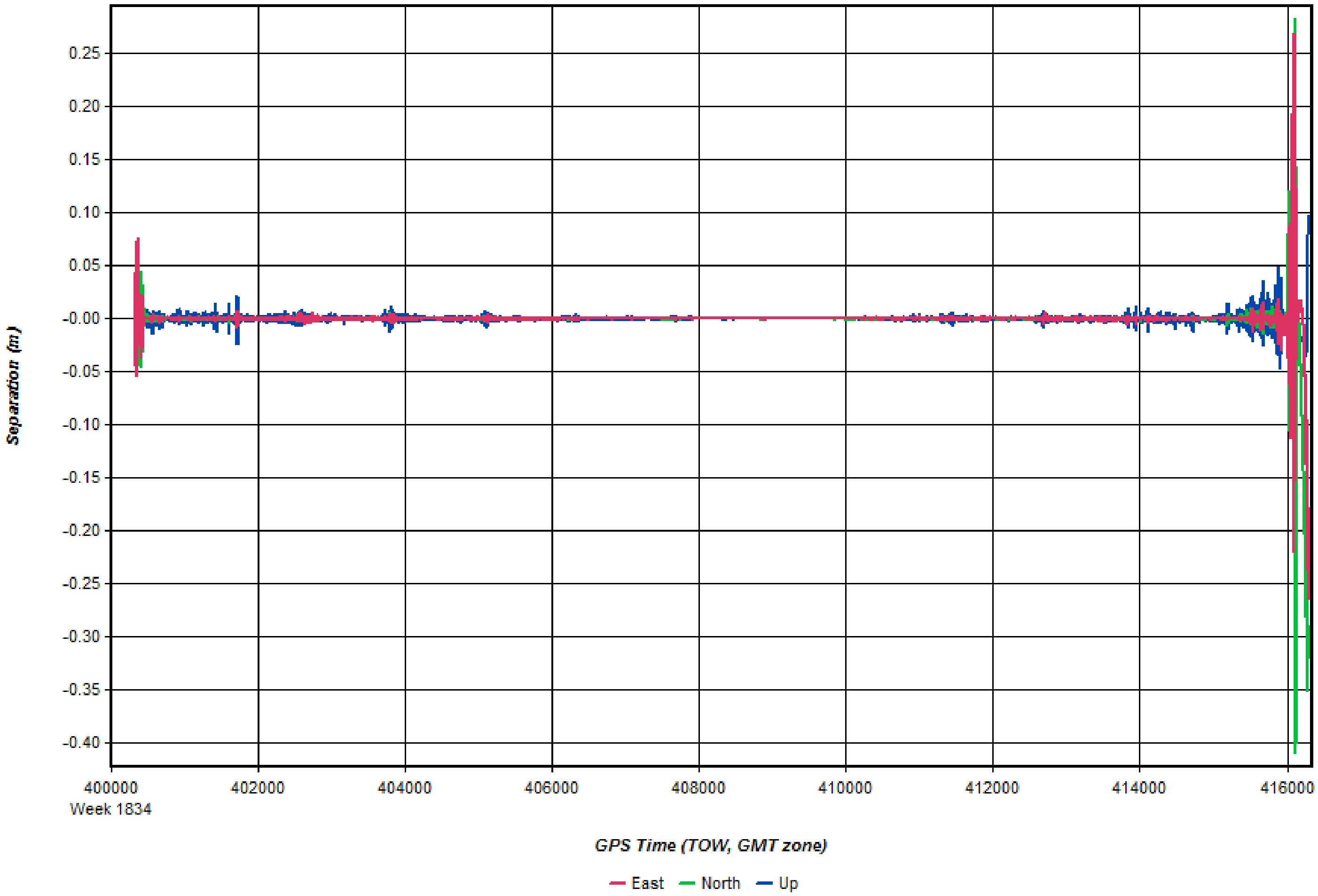

2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
PDOP
326000
Week 1834
327000
328000
329000
330000
331000
332000
333000
334000
335000
GPS Time (TOW, GMT zone)
PDOP

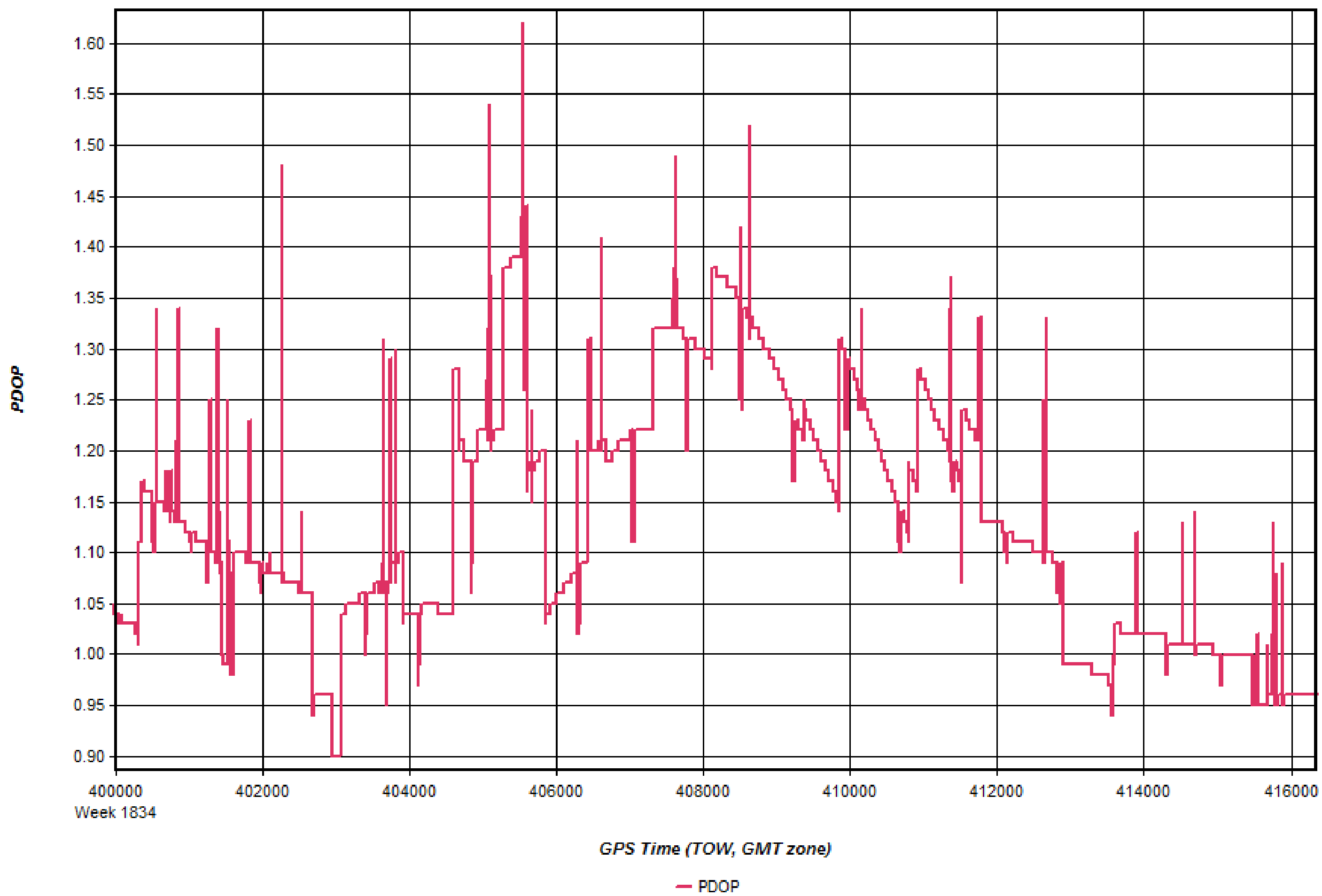
123_20150305_1



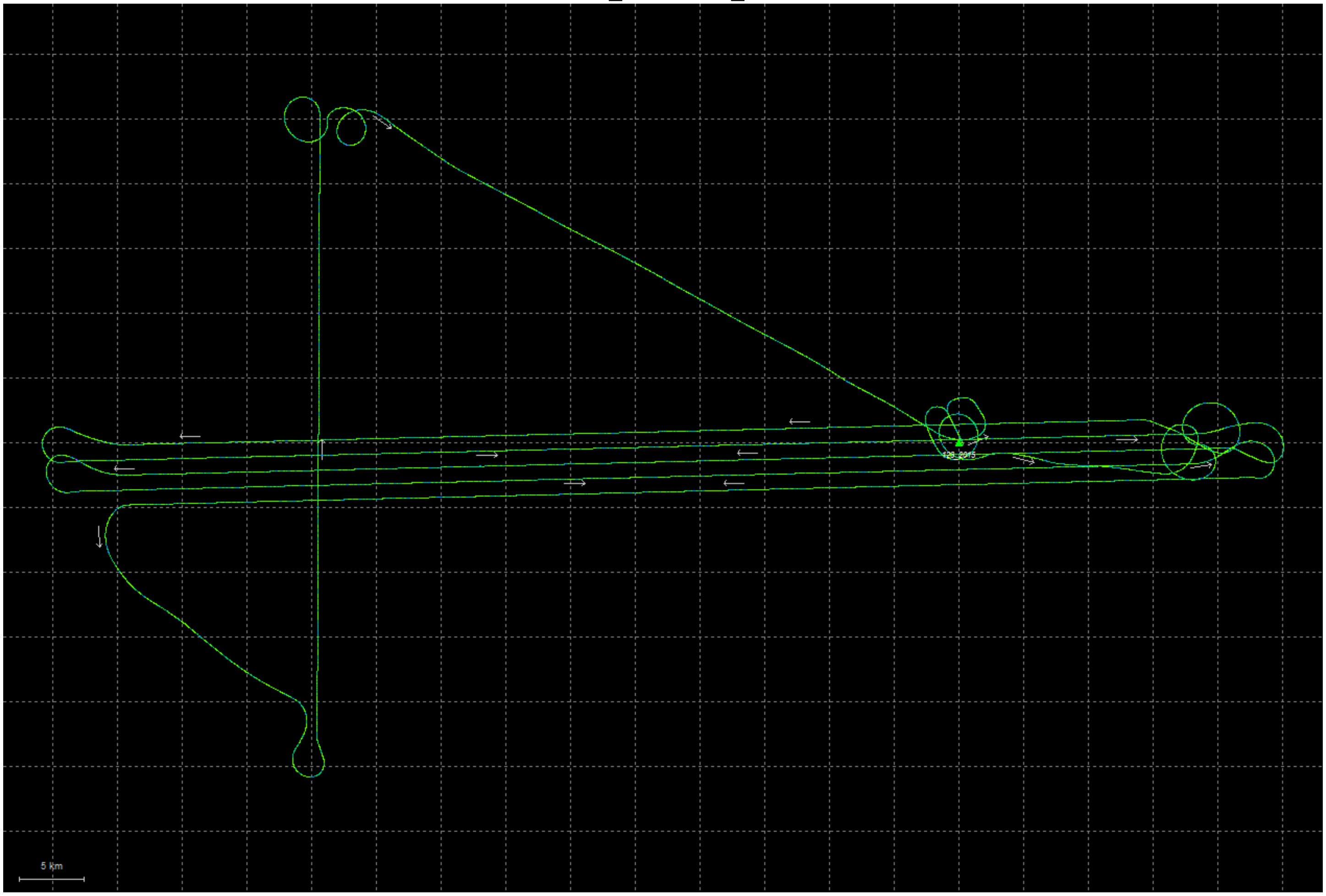

0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
Estimated Std Dev (m)
400000
Week 1834
402000
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

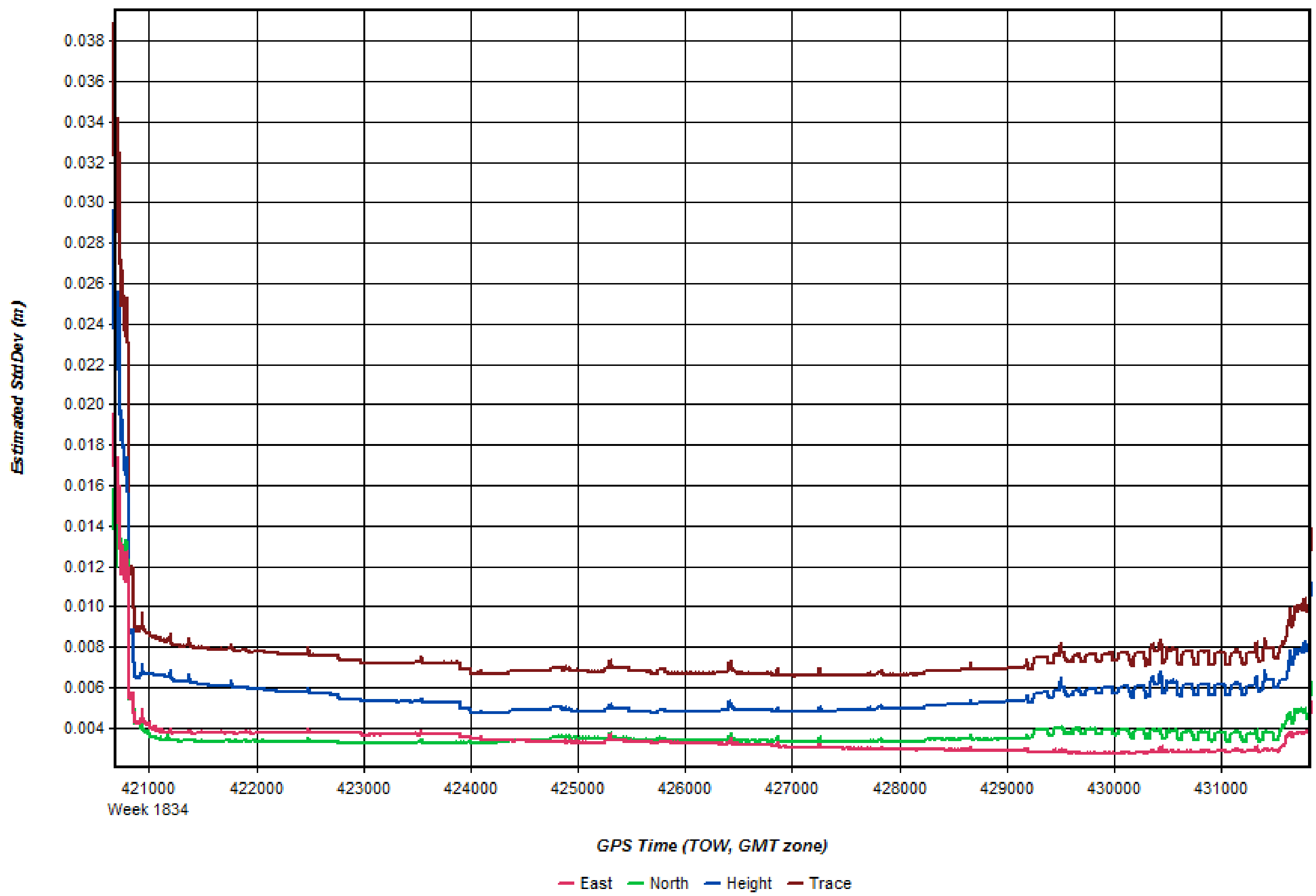

Num Sats
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
400000
Week 1834
402000
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

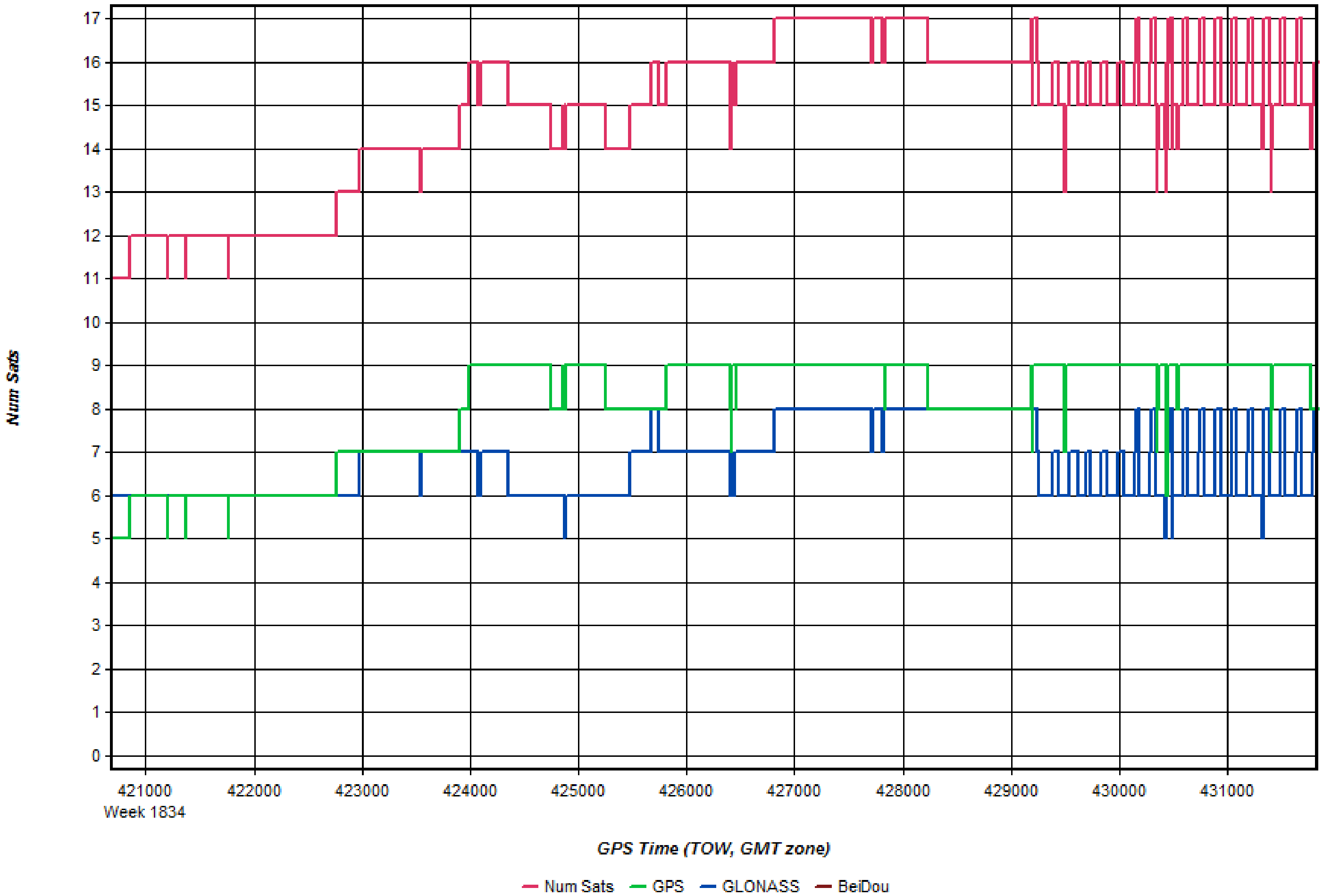

Separation (m)
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
400000
Week 1834
402000
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
East
North
Up

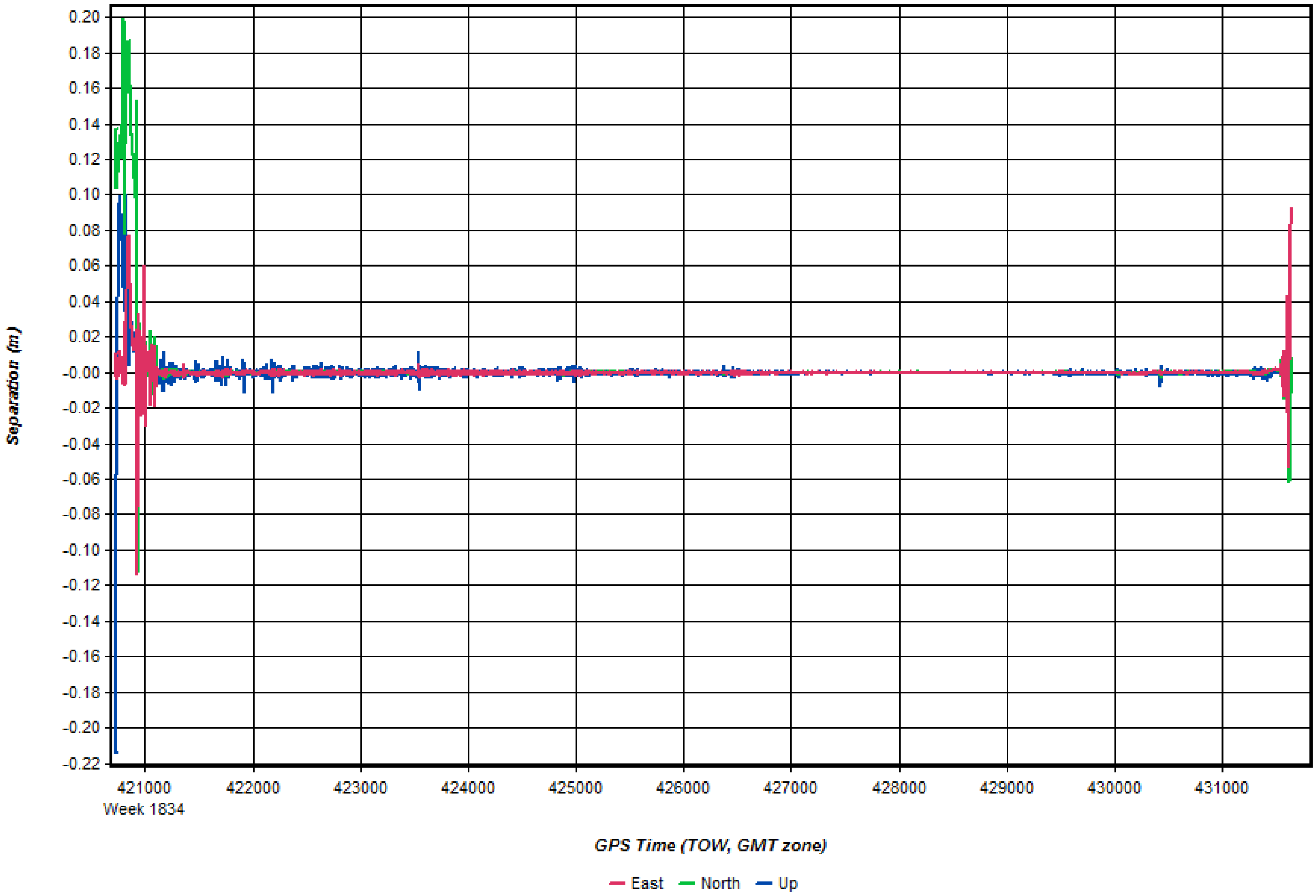

PDOP
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
400000
Week 1834
402000
404000
406000
408000
410000
412000
414000
416000
GPS Time (TOW, GMT zone)
PDOP

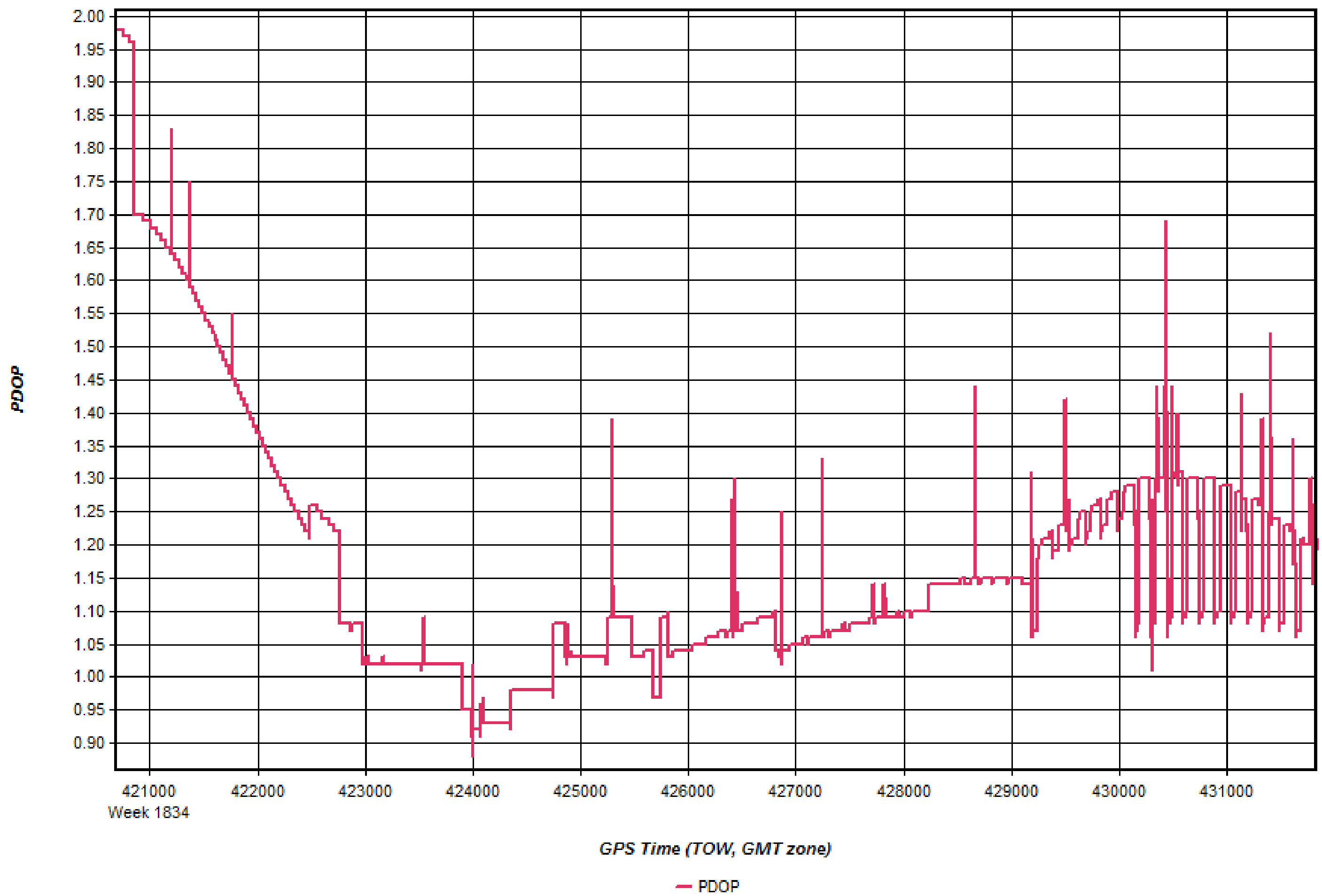
123_20150305_2



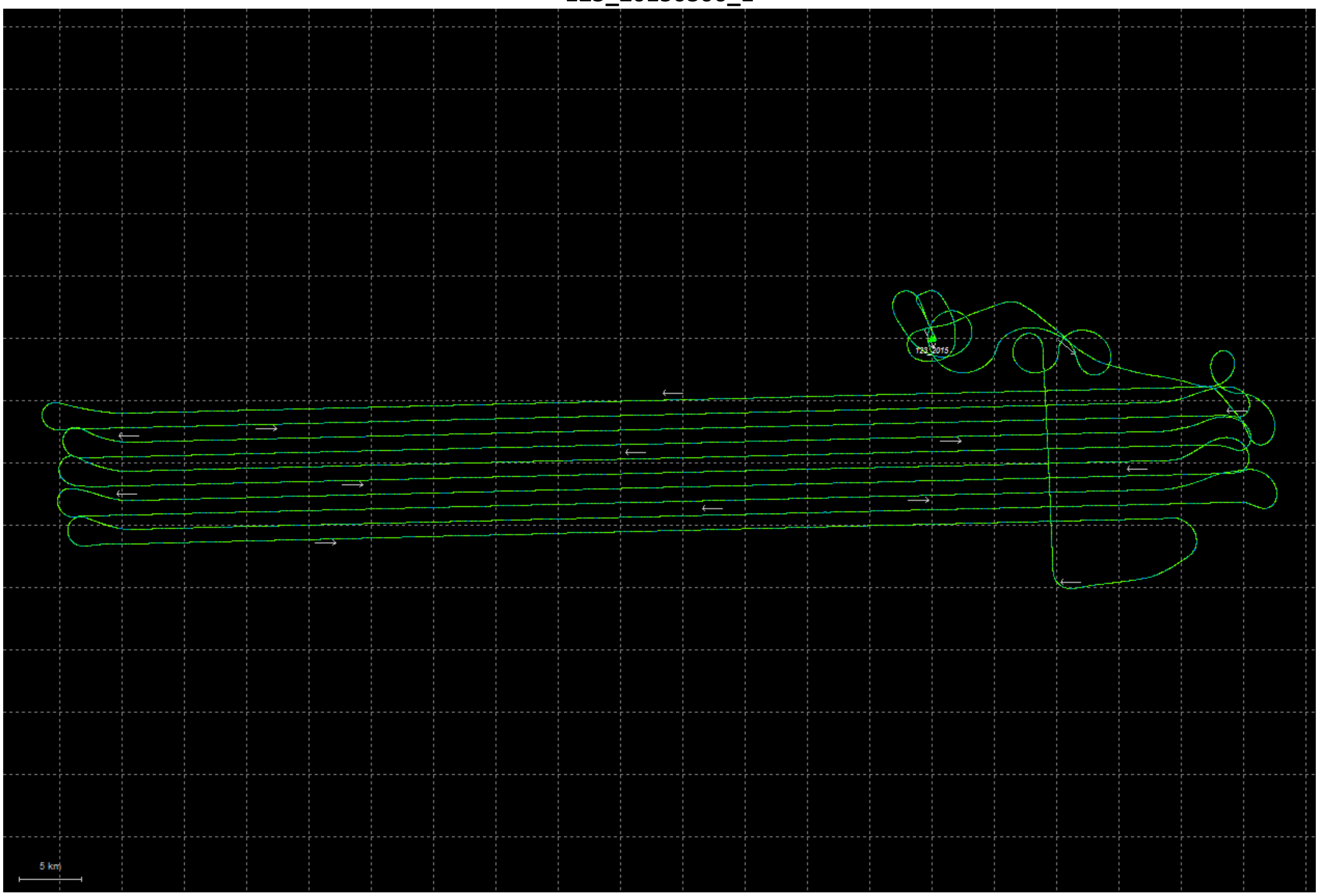

Estimated Std Dev (m)
0.038
0.036
0.034
0.032
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
421000
Week 1834
422000
423000
424000
425000
426000
427000
428000
429000
430000
431000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

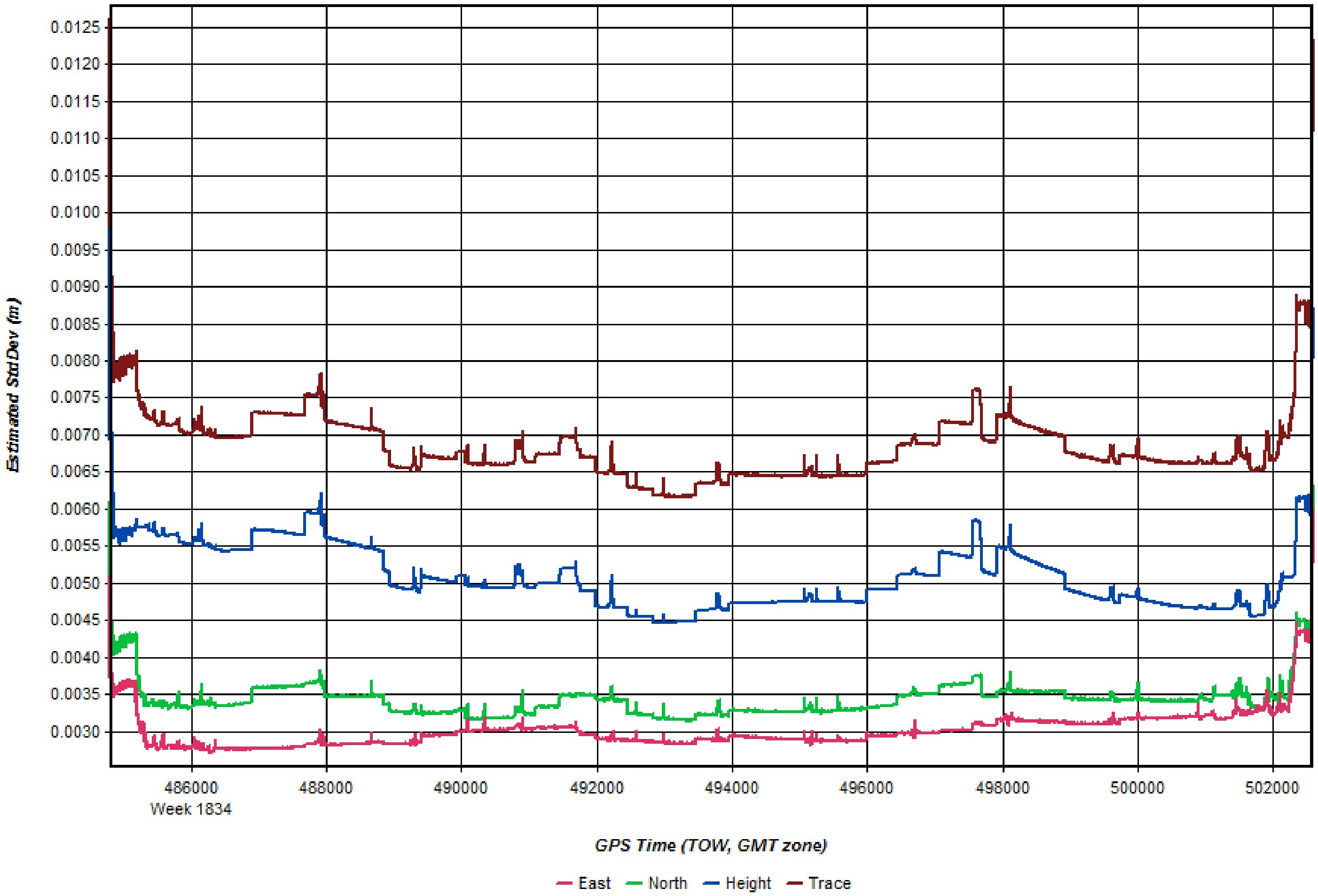

Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
421000
Week 1834
422000
423000
424000
425000
426000
427000
428000
429000
430000
431000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

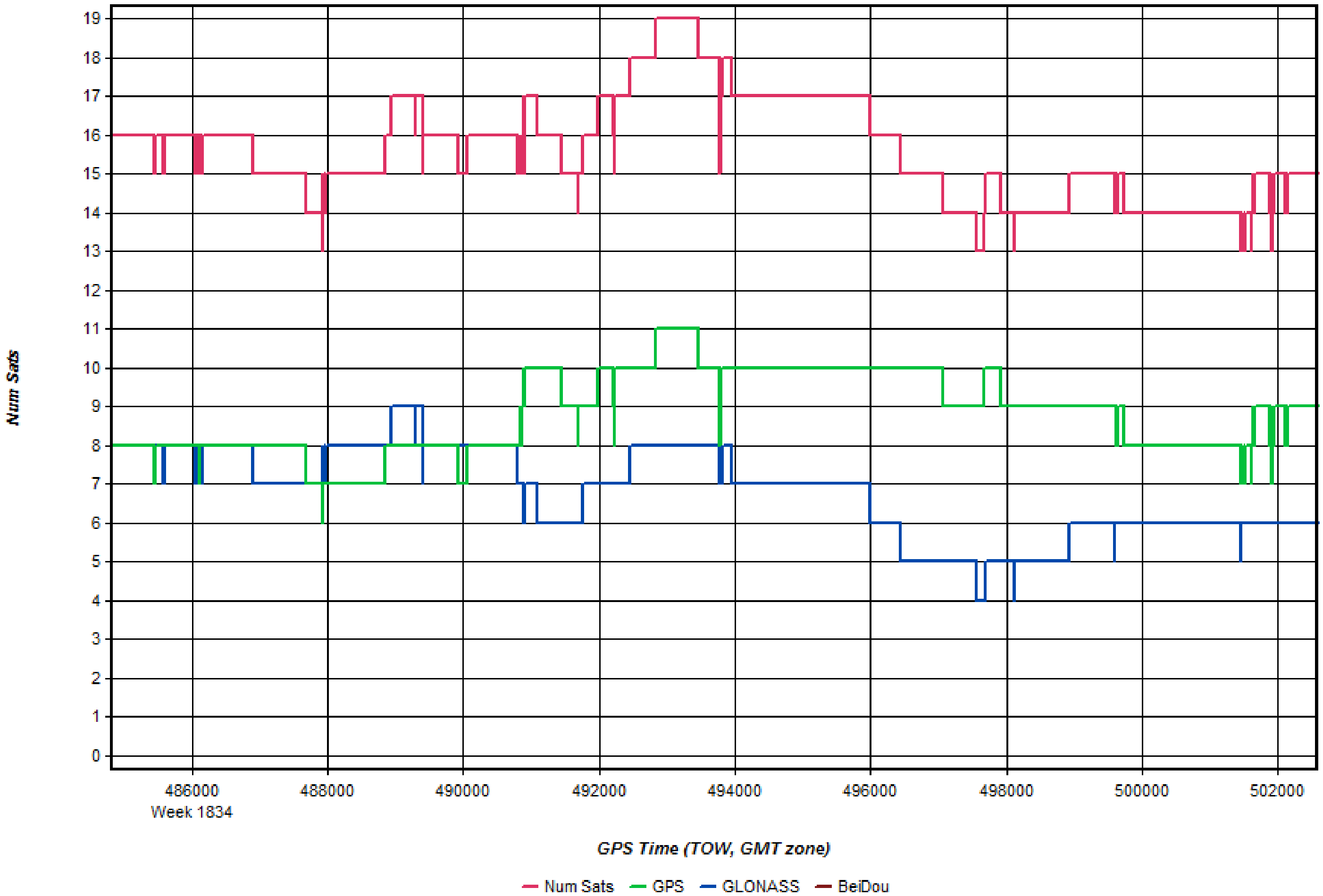

0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
-0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
-0.22
Separation (m)
421000
Week 1834
422000
423000
424000
425000
426000
427000
428000
429000
430000
431000
GPS Time (TOW, GMT zone)
East
North
Up

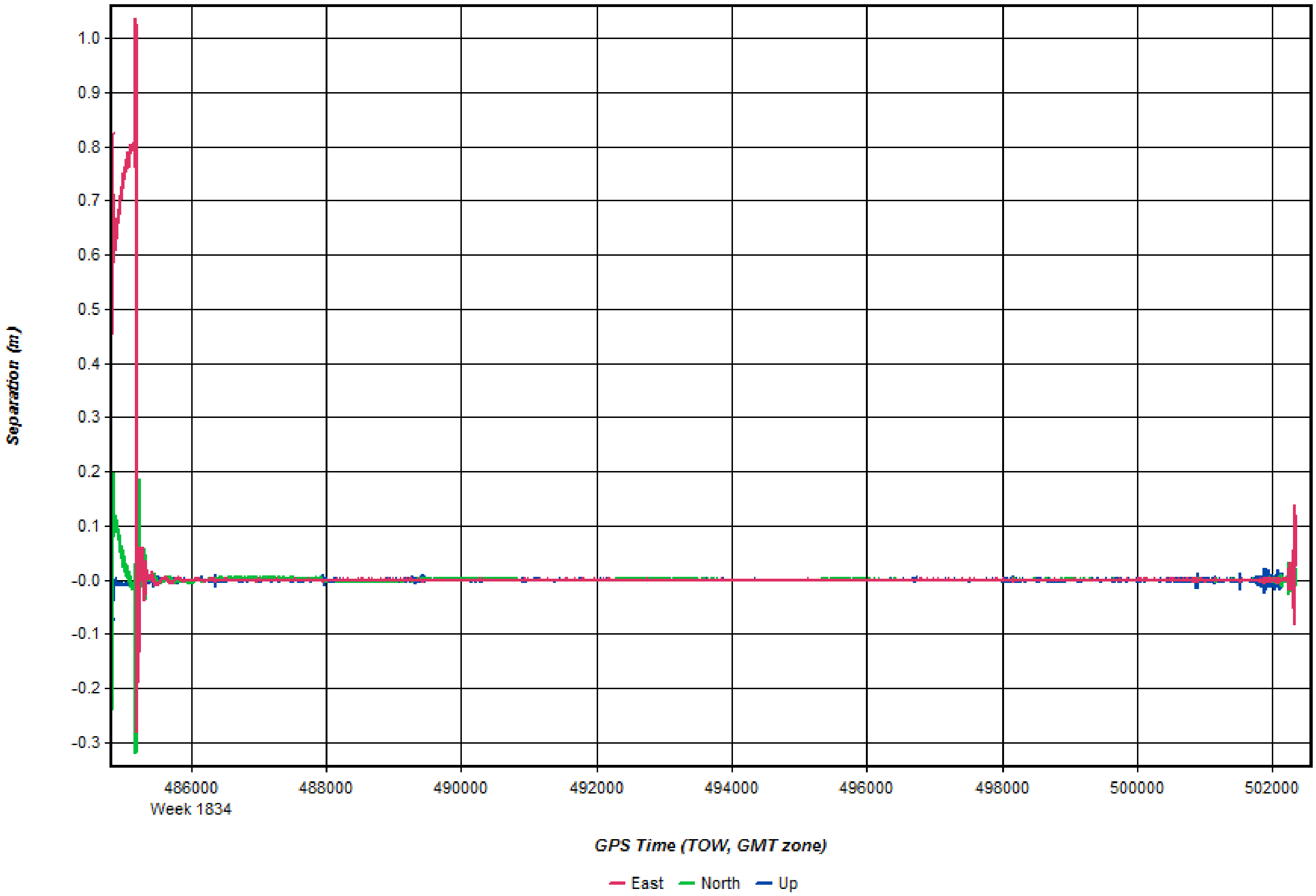

PDOP
2.00
1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
421000
Week 1834
422000
423000
424000
425000
426000
427000
428000
429000
430000
431000
GPS Time (TOW, GMT zone)
PDOP

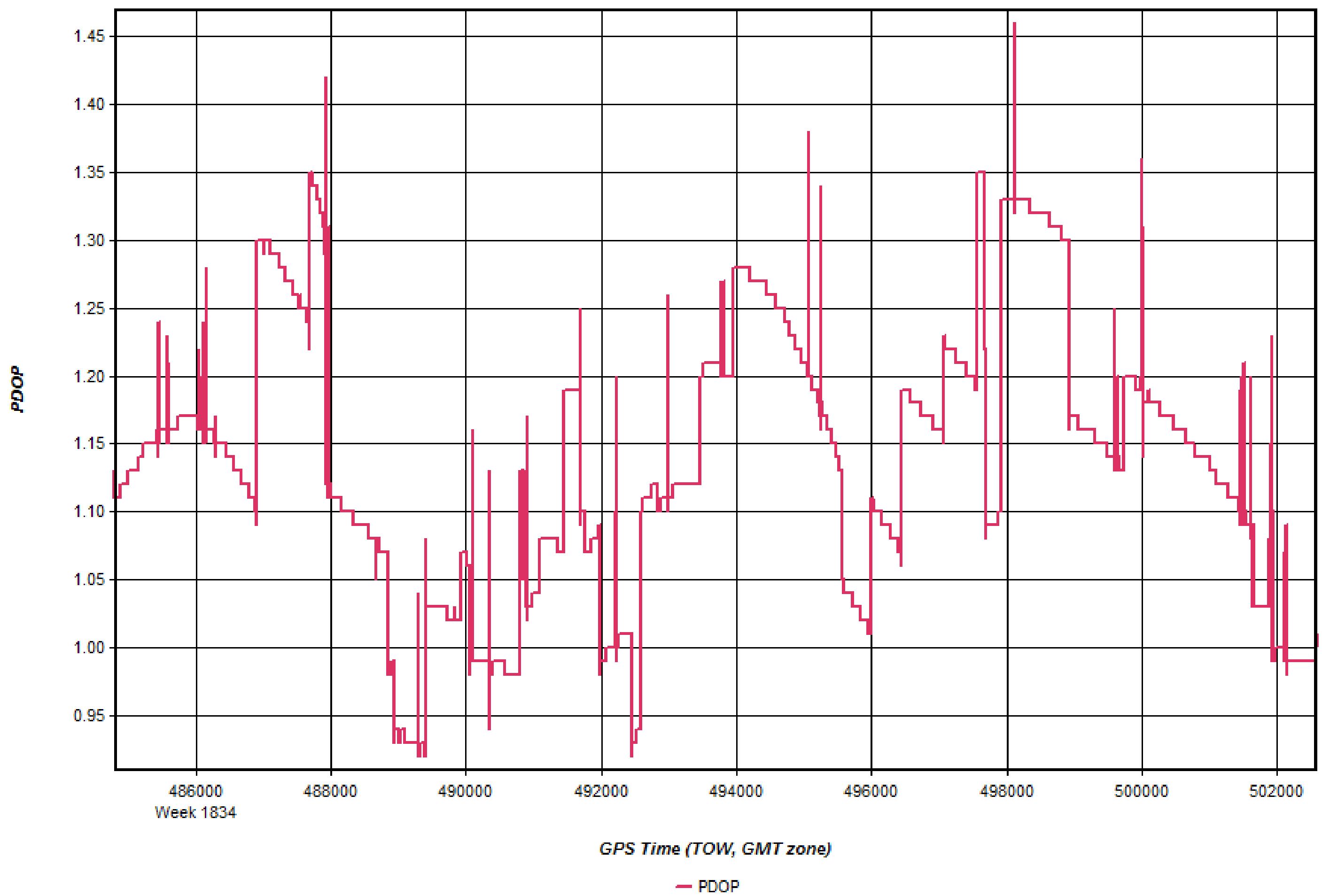
123_20150306_1



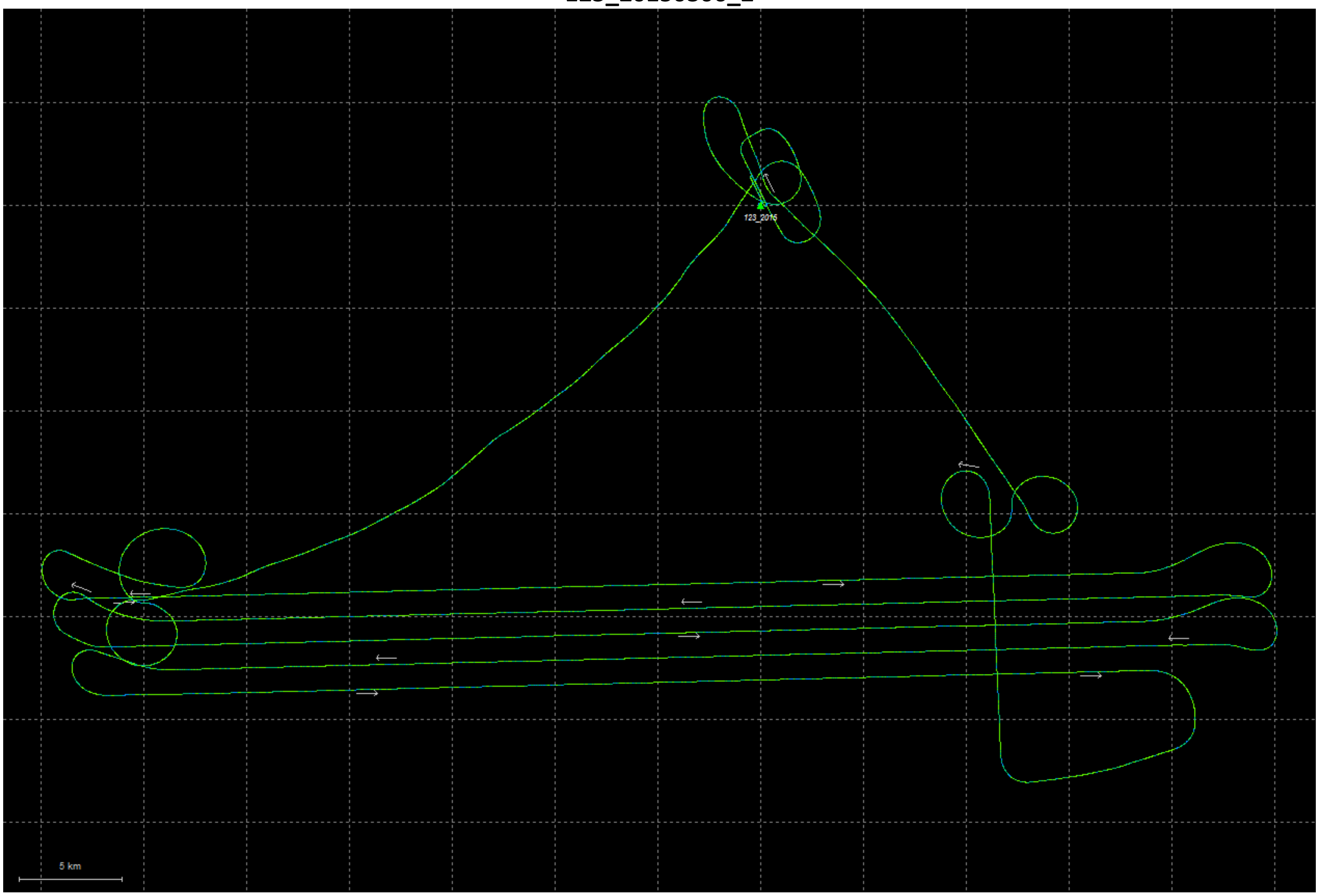

0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
Estimated Std Dev (m)
486000
Week 1834
488000
490000
492000
494000
496000
498000
500000
502000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

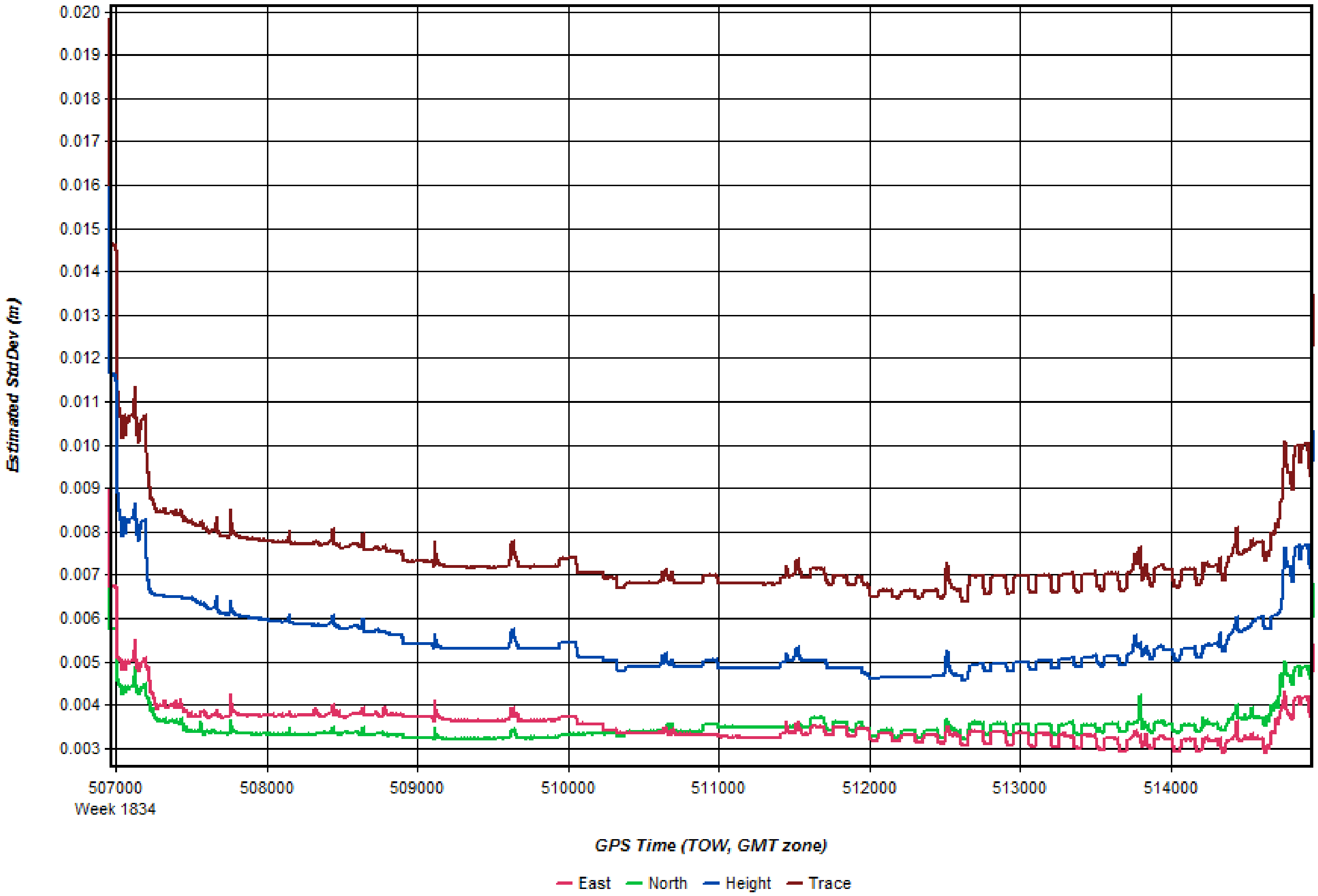

Num Sats
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
486000
Week 1834
488000
490000
492000
494000
496000
498000
500000
502000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

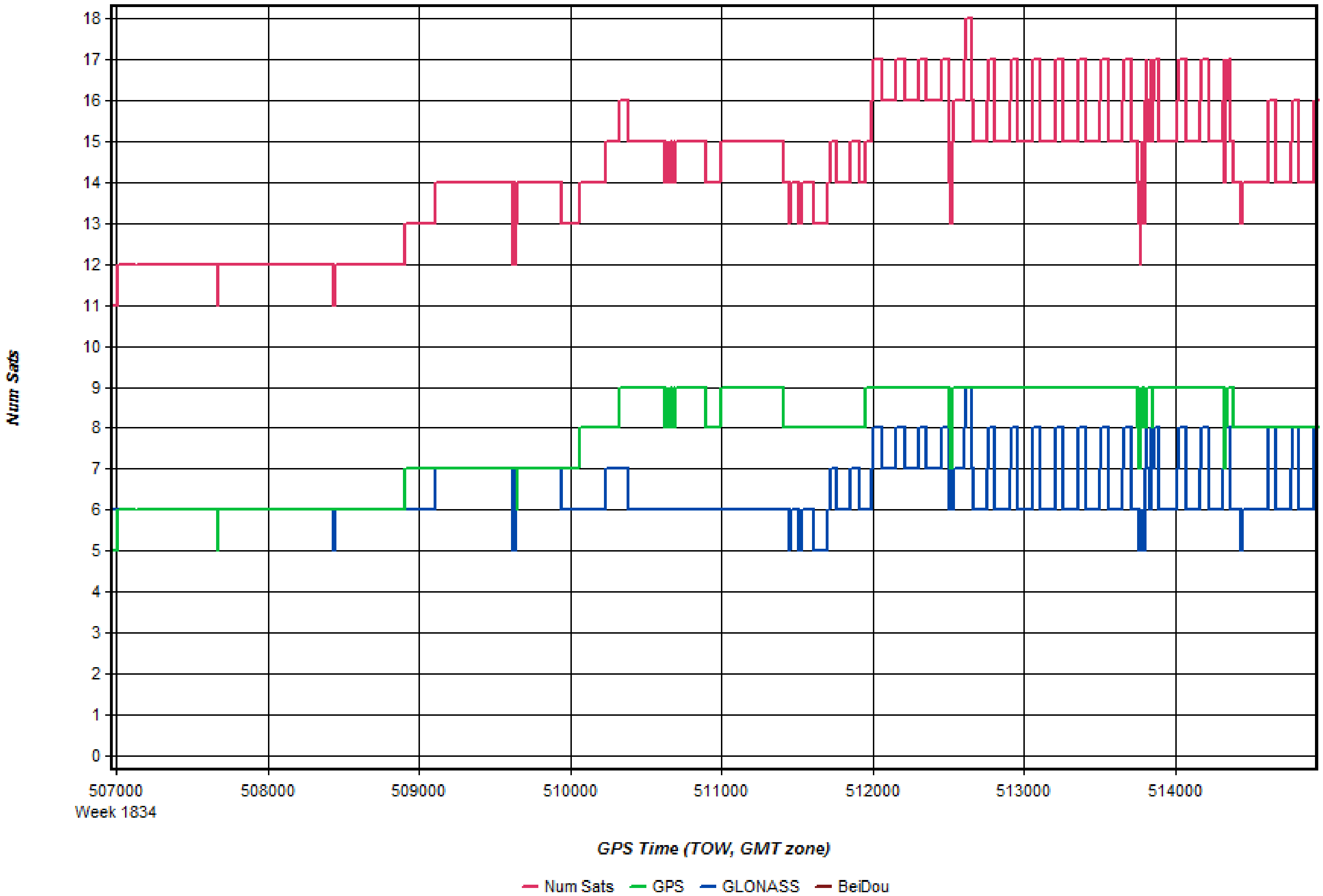

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
Separation (m)
486000
Week 1834
488000
490000
492000
494000
496000
498000
500000
502000
GPS Time (TOW, GMT zone)
East
North
Up

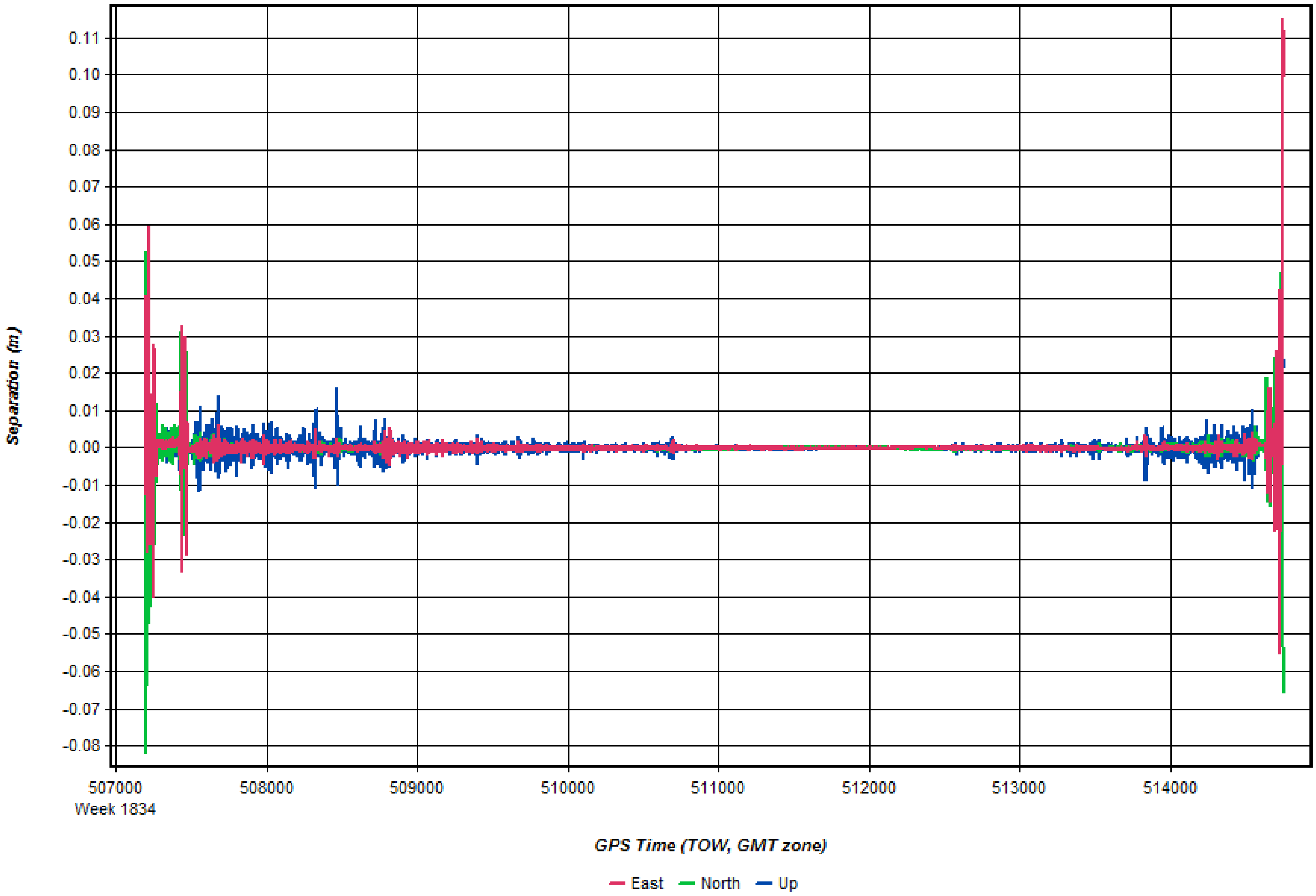

PDOP
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
486000
Week 1834
488000
490000
492000
494000
496000
498000
500000
502000
GPS Time (TOW, GMT zone)
PDOP

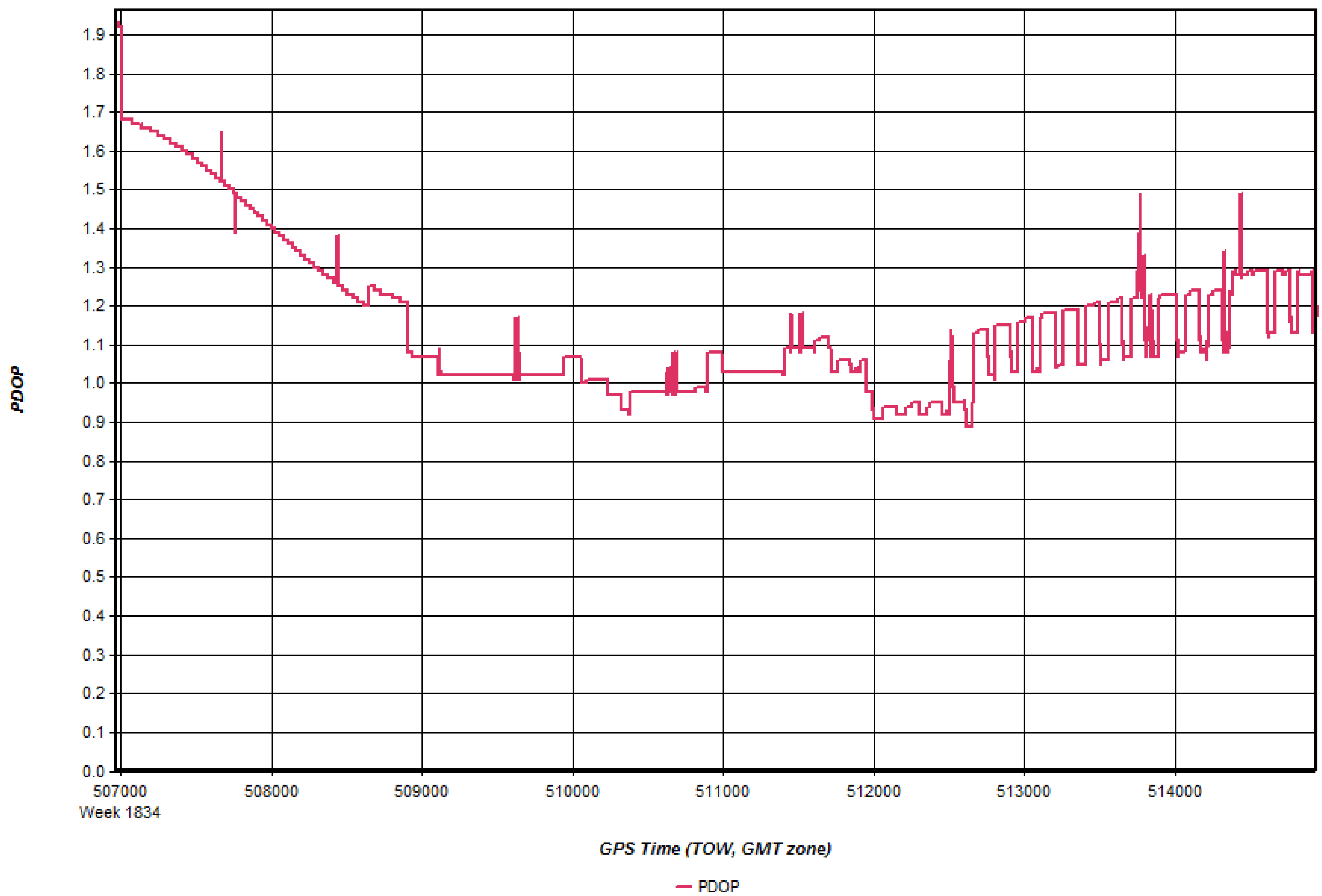
123_20150306_2




0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
Estimated Std Dev (m)
507000
Week 1834
508000
509000
510000
511000
512000
513000
514000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
507000
Week 1834
508000
509000
510000
511000
512000
513000
514000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


0.11
0.10
0.09
0.08
0.07
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)
507000
Week 1834
508000
509000
510000
511000
512000
513000
514000
GPS Time (TOW, GMT zone)
East
North
Up


PDOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
507000
Week 1834
508000
509000
510000
511000
512000
513000
514000
GPS Time (TOW, GMT zone)
PDOP