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U.S. Geological Survey

USGS Contract: G16PC00051

Lidar Report

September, 2018

EXECUTIVE SUMMARY

The U.S. Geological Survey (USGS) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services for OK_3_County in the form of Lidar. Utilizing a multi-return system, Light Detection and Ranging (Lidar) detects 3-dimensional positions and attributes to form a point cloud. The high accuracy airborne system is integrated with both Global Navigation Satellite System (GNSS) and an Inertial Measure Unit (IMU) for accurate position and orientation. Acquisition of the project area's ~2021mi² was completed on March 16th, 2018.

The Optech Orion H300 was used to collect data for the aerial survey campaign. The sensor is attached to the aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar System (ALS) is boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the calibration parameters are updated and used during post-processing of the lidar point cloud.

Differential GNSS unit in aircraft sampled positions at 2Hz or higher frequency. Lidar data was only acquired when GNSS PDOP is ≤4 and at least 6 satellites are in view. Collection conditions were for leaf-off vegetation. The atmosphere was free of clouds and fog between the aircraft and ground. The ground was free of snow and extensive flooding or any other type of inundation

The contents of this report summarize the methods used to establish the base station coordinates, perform the lidar data acquisition and processing as well as the results of these methods.

CONTENTS

1.0 INTRODUCTION

This document contains the technical write-up of the lidar campaign, including system calibration techniques, and the collection and processing of the lidar data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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1.2 Purpose of Lidar Acquisition

The objective of this project is to collect accurate measurements of the bare-earth surface as well as above ground features to be provided as geometric inputs for surface and/or change modeling as is relates survey assessments.

1.3 Project Location

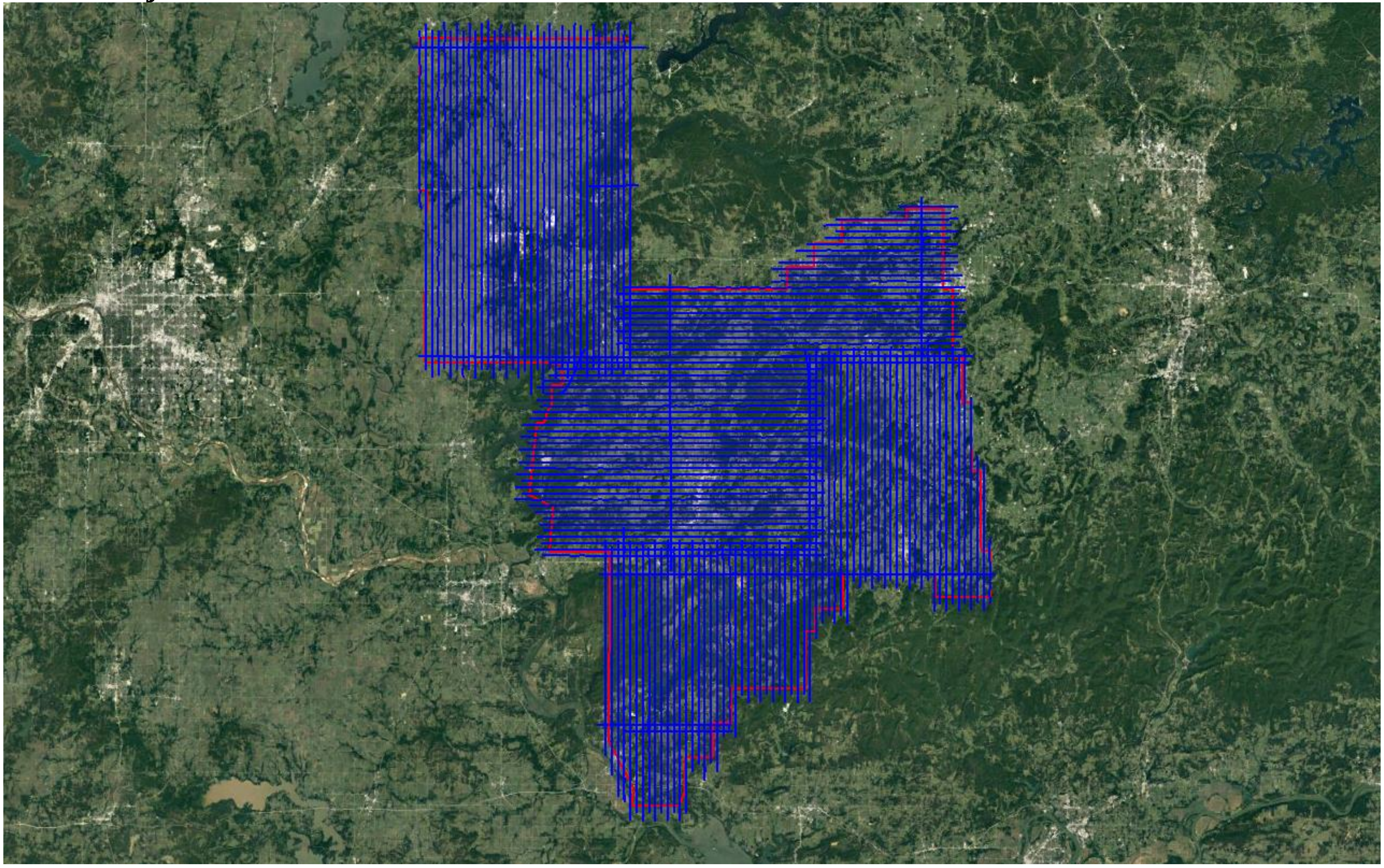


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the OK_3_County campaign. Although Sanborn conducts all lidar missions with the same rigorous and strict procedures and processes, all lidar collections are unique.

2.2 Acquisition Parameters

Sanborn specifically defined the collection parameters to accomplish the desired project specifications. **Table 1** shows the planned acquisition parameters utilized for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Sensor	Optech Orion H300
Aircraft	N206DV – CESSNA T206H
Flying Height (AGL)	2150m
Air Speed (kts)	110
Field of View (degrees)	34
Overlap (%)	20
Pulse Rate (kHz)	175
Scan Rate (Hz)	40.3
Laser Footprint (m)	0.54
Mode (PIA)	Multi-Pulse
Point Spacing (m)	0.7
Point Density (pls/m²)	2.03
Swath Width (m)	1315

Table 1: Lidar Acquisition Parameters

2.3 Field Work Procedures

Sanborn's standard procedure before every mission is to perform pre-flight checks to ensure correct operation of all systems. All cables were checked and the sensor head glass was cleaned. A five minute static session was conducted on the ground with the engines running prior to take-off in order to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of twelve (12) missions. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP. Near the end of each mission, GNSS ambiguities are again resolved by flying within ten kilometers of the base stations to aid in post-processing.

Preliminary data processing was performed in the field immediately following the missions for quality control of GNSS data and to ensure sufficient coverage of the project AOI. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs, CO office. **Table 2** below shows the flight acquisition metrics for the entire collection. **Table 3** contains the base station names and locations in operation during acquisition. Base station coordinates are provided in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
3/3/2018	Optech Orion H300	12SEN315	N206DV	20180303_1	1.6	15:31:06	21:00:46
3/7/2018	Optech Orion H300	12SEN315	N206DV	20180307_1	2.0	17:52:11	23:13:47
3/8/2018	Optech Orion H300	12SEN315	N206DV	20180308_1	2.1	18:25:02	22:56:12
3/9/2018	Optech Orion H300	12SEN315	N206DV	20180309_1	1.7	14:53:37	17:13:55
3/11/2018	Optech Orion H300	12SEN315	N206DV	20180311_1	1.8	14:55:10	16:44:16
3/12/2018	Optech Orion H300	12SEN315	N206DV	20180312_1	1.5	21:43:50	00:00:39
3/13/2018	Optech Orion H300	12SEN315	N206DV	20180313_1	2.9	14:05:44	18:42:34
3/13/2018	Optech Orion H300	12SEN315	N206DV	20180313_2	2.1	20:23:36	01:14:54
3/14/2018	Optech Orion H300	12SEN315	N206DV	20180314_1	2.9	13:56:46	18:44:56
3/14/2018	Optech Orion H300	12SEN315	N206DV	20180314_2	1.9	19:52:33	23:59:15
3/15/2018	Optech Orion H300	12SEN315	N206DV	20180315_1	1.5	13:22:49	16:31:17
3/16/2018	Optech Orion H300	12SEN315	N206DV	20180316_1	2.5	20:02:04	21:09:32

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
OKMU	CORS	DE7172	35 43 00.06244	95 24 05.82026	161.437
OKTU	CORS	DE8101	36 12 38.11392	95 51 15.78258	169.222
H60311o	AGI	N/A	35 55 34.17924	95 00 09.40410	232.583
H60312v	AGI	N/A	35 55 34.18993	95 00 09.41710	232.593
H60313n	AGI	N/A	35 55 34.18554	95 00 09.37076	232.648
H60313t	AGI	N/A	35 55 34.18547	95 00 09.37062	232.648
H60314n	AGI	N/A	35 55 34.19317	95 00 09.36457	232.652
H60314t	AGI	N/A	35 55 34.19317	95 00 09.36421	232.642
H60315m	AGI	N/A	35 55 34.20023	95 00 09.37382	232.621
SR40308r	AGI	N/A	35 55 34.17463	95 00 09.47264	233.025
SR40309o	AGI	N/A	35 55 34.18324	95 00 09.47732	233.009

Table 3: GNSS Reference Station Coordinates

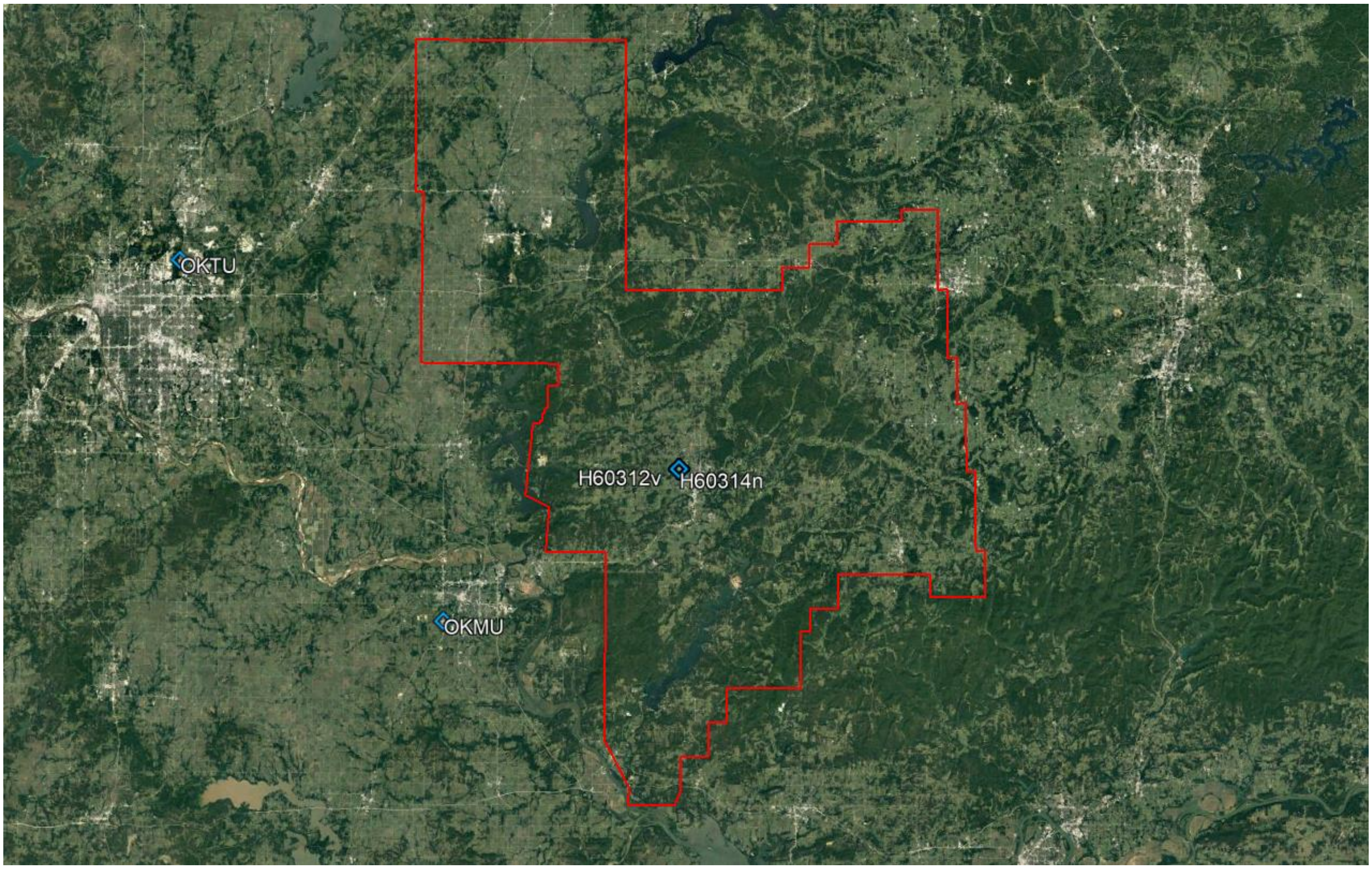


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The ABGNSS/IMU data was post-processed using Waypoint Inertial Explorer software to create Smoothed Best Estimate Trajectory (SBET) file(s). Please see **Appendix A** for an in depth assessment of the processed airborne trajectories. The SBET was then combined with the laser range measurements in Optech-LMS software to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath (*.las) files are output in WGS84, UTM, Ellipsoid, Meters and transformed to the project Coordinate Reference System (CRS) upon ingest into GeoCue before project wide calibration.

The Optech-LMS pre-processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the required feature for delivery. All lidar data is processed using the ASPRS binary LAS format version 1.4. **Table 4** illustrates the achieved point cloud statistics.

Category	Value
Total Points	20,672,237,269
Nominal Pulse Spacing (m)	0.66
Nominal Pulse Density (pls/m²)	2.3
Nominal Pulse Spacing (ft)	2.16
Nominal Pulse Density (pls/ft²)	0.2
Aggregate Total Points	19,761,683,618
Aggregate Nominal Pulse Spacing (m)	0.55
Aggregate Nominal Pulse Density (pls/m²)	3.3
Aggregate Nominal Pulse Spacing (ft)	1.80
Aggregate Nominal Pulse Density (pls/ft²)	0.3

Table 4: Point Cloud Statistics

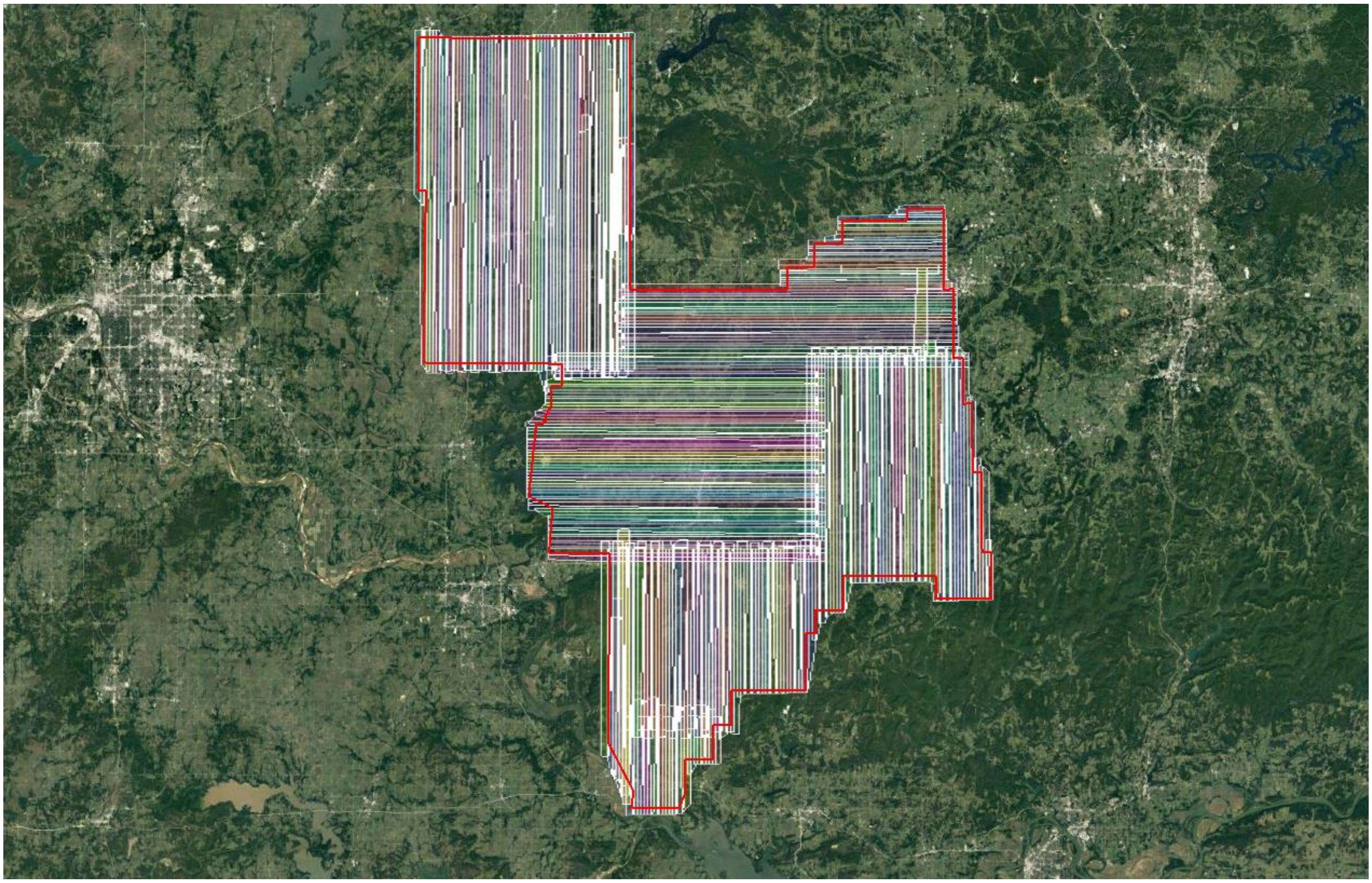


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Projection:	Universal Transverse Mercator Zone 15 North
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units:	Meters

3.3 Calibration

Sanborn uses Optech-LMS and the latest boresight values to combine the processed SBET with the laser scan files to produce the lidar point cloud. The data is processed by mission and is output in ASPRS LASv1.4 Point Data Record Format (PDRF) 6 with 16bit linearly scaled intensities to the nearest 0.001 3D position. Each mission is produced in WGS84, UTM, Ellipsoid, Meters and transformed to the project CRS upon import into GeoCue.

Each mission in imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the calibration process. The project area(s) are broken into logical blocks based on AOIs or predetermined delivery blocks and the individual flight lines are populated into calibration tile grids. These calibration tile grids are prepared for scanner, line, mission, block and eventual project wide calibration routines by first running point cloud filters to identify ground and building features to be used during TerraMatch processes.

After successful point cloud filters have been run on the calibration dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar points cloud intended to reduce the overwhelming data size to a more manageable amount. Each Tie Line is extracted using a series of parameters designed to identify features such a flat or sloping ground or roofline apexes that geospatially correlates to the same observation of an overlapping flight line. These collected 3D vectors are then utilized across multiple iterations to reduce the average offset from line to line, mission to mission, and block to block. TerraMatch Solutions are calculated to adjust Roll, Heading, Pitch, X, Y and Z in combination to reduce the Root Mean Square Deviation (RMSDr and RMSDz). These solutions are calculated, applied, and checked throughout the calibration process.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure overlap consistency of the lidar data meets and/or exceeds project specifications. Differential Elevation (dZ) rasters are color ramp (Dark Green, Green, Yellow, Orange, Red) based visual representations produced to identify vertical offsets between flight lines. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSDz. Furthermore, an additional set of TerraMatch Tie Lines are produced after corrections are applied and a Tie Line Report is produced to assess the X. Y. and Z offset averages for each line and the project. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project. **Tables 6 – 9** are the relative accuracies achieved.

Category	Value
Smooth Surface Repeatability (m)	≤0.06
Swath overlap difference, RMSDz (m)	≤0.08
Swath overlap difference, Maximum (m)	±0.16

Table 5: Relative Accuracy Requirements

No Data	0m to 0.04m	0.04m to 0.08m	0.08m to 0.12m	0.12m to 0.16m	> 0.16m

Figure 4: dZ Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
2	0.042	0.018	0.010	**74**	0.036	0.036	0.012	**142**	0.035	0.045	0.011
3	0.051	0.019	0.010	**75**	0.032	0.037	0.014	**144**	0.045	0.051	0.012
4	0.047	0.023	0.010	**76**	0.025	0.026	0.012	**145**	0.042	0.056	0.011
5	0.030	0.031	0.014	**77**	0.027	0.042	0.013	**146**	0.020	0.023	0.008
6	0.031	0.034	0.014	**78**	0.037	0.028	0.012	**147**	0.039	0.040	0.013
7	0.029	0.029	0.016	**79**	0.033	0.025	0.013	**148**	0.036	0.039	0.012
8	0.033	0.031	0.022	**80**	0.039	0.033	0.012	**149**	0.035	0.047	0.012
9	0.026	0.022	0.019	**81**	0.024	0.039	0.014	**150**	0.035	0.049	0.013
11	0.023	0.020	0.006	**82**	0.026	0.024	0.016	**151**	0.022	0.022	0.013
12	0.045	0.043	0.013	**83**	0.027	0.020	0.016	**152**	0.027	0.031	0.014
13	0.044	0.053	0.011	**84**	0.021	0.021	0.010	**153**	0.044	0.043	0.014
14	0.024	0.016	0.006	**85**	0.032	0.029	0.015	**155**	0.039	0.040	0.013
15	0.032	0.026	0.009	**86**	0.038	0.022	0.018	**156**	0.039	0.039	0.013
16	0.046	0.028	0.011	**88**	0.030	0.031	0.016	**157**	0.037	0.035	0.012
17	0.045	0.028	0.012	**89**	0.034	0.046	0.014	**158**	0.036	0.026	0.010
18	0.042	0.030	0.016	**90**	0.033	0.046	0.013	**159**	0.039	0.029	0.010
20	0.046	0.028	0.013	**91**	0.034	0.032	0.014	**160**	0.040	0.028	0.010
21	0.045	0.029	0.011	**92**	0.038	0.033	0.013	**161**	0.042	0.026	0.010
22	0.035	0.029	0.009	**93**	0.031	0.037	0.014	**162**	0.037	0.033	0.010
23	0.033	0.032	0.010	**94**	0.041	0.027	0.014	**163**	0.034	0.032	0.010
24	0.038	0.049	0.010	**95**	0.039	0.026	0.015	**164**	0.043	0.026	0.010
25	0.036	0.053	0.010	**96**	0.045	0.030	0.012	**165**	0.041	0.025	0.009
26	0.047	0.038	0.010	**97**	0.045	0.032	0.012	**166**	0.045	0.029	0.011
27	0.049	0.038	0.011	**98**	0.037	0.037	0.012	**167**	0.048	0.029	0.011
28	0.048	0.039	0.010	**99**	0.037	0.032	0.012	**168**	0.024	0.035	0.018
29	0.045	0.036	0.010	**100**	0.034	0.032	0.014	**169**	0.029	0.036	0.011
30	0.046	0.028	0.011	**101**	0.039	0.033	0.012	**170**	0.033	0.041	0.011
31	0.040	0.029	0.010	**102**	0.042	0.029	0.011	**171**	0.034	0.042	0.011
32	0.037	0.030	0.009	**103**	0.042	0.026	0.012	**173**	0.031	0.035	0.011
33	0.042	0.038	0.011	**106**	0.038	0.033	0.012	**176**	0.032	0.051	0.012
34	0.042	0.041	0.011	**107**	0.045	0.033	0.011	**177**	0.041	0.040	0.012
37	0.027	0.030	0.016	**108**	0.049	0.040	0.011	**178**	0.035	0.036	0.011
38	0.024	0.035	0.019	**109**	0.035	0.038	0.010	**179**	0.033	0.035	0.012
39	0.020	0.024	0.021	**110**	0.038	0.031	0.010	**180**	0.039	0.038	0.013
40	0.032	0.028	0.021	**111**	0.046	0.036	0.011	**181**	0.032	0.044	0.011
41	0.030	0.027	0.022	**112**	0.041	0.047	0.010	**182**	0.035	0.042	0.010
43	0.049	0.028	0.014	**113**	0.036	0.041	0.013	**183**	0.025	0.043	0.011
44	0.044	0.023	0.010	**114**	0.034	0.033	0.011	**184**	0.024	0.042	0.010
45	0.027	0.031	0.013	**115**	0.030	0.036	0.011	**185**	0.034	0.042	0.011
46	0.041	0.025	0.012	**116**	0.036	0.033	0.012	**186**	0.043	0.050	0.011
47	0.037	0.029	0.013	**117**	0.034	0.022	0.012	**187**	0.030	0.046	0.010
48	0.025	0.023	0.015	**118**	0.038	0.038	0.011	**188**	0.025	0.045	0.010
51	0.016	0.029	0.010	**119**	0.032	0.037	0.011	**189**	0.031	0.045	0.010
52	0.019	0.038	0.009	**121**	0.034	0.030	0.016	**190**	0.032	0.040	0.011
53	0.013	0.032	0.009	**122**	0.027	0.028	0.012	**191**	0.028	0.037	0.010
54	0.013	0.038	0.010	**123**	0.037	0.032	0.011	**193**	0.031	0.038	0.011
55	0.017	0.063	0.010	**124**	0.045	0.030	0.011	**194**	0.032	0.047	0.010

56	0.020	0.060	0.010	**125**	0.049	0.033	0.010	**195**	0.033	0.049	0.010
57	0.019	0.042	0.009	**126**	0.044	0.034	0.011	**196**	0.023	0.041	0.010
58	0.023	0.043	0.011	**127**	0.039	0.033	0.011	**197**	0.025	0.038	0.009
59	0.040	0.037	0.014	**128**	0.026	0.032	0.011	**198**	0.033	0.039	0.009
61	0.035	0.030	0.010	**129**	0.016	0.035	0.010	**199**	0.027	0.044	0.009
62	0.037	0.036	0.011	**132**	0.035	0.019	0.010	**200**	0.027	0.043	0.011
63	0.026	0.026	0.012	**133**	0.041	0.023	0.010	**201**	0.035	0.039	0.011
64	0.024	0.023	0.015	**134**	0.031	0.036	0.010	**202**	0.034	0.035	0.012
66	0.019	0.025	0.007	**135**	0.029	0.044	0.013	**203**	0.030	0.035	0.012
67	0.027	0.039	0.014	**136**	0.038	0.022	0.011	**204**	0.025	0.031	0.012
68	0.020	0.026	0.009	**137**	0.033	0.027	0.010	**205**	0.029	0.030	0.015
69	0.018	0.028	0.009	**138**	0.019	0.029	0.007	**206**	0.034	0.033	0.022
70	0.021	0.028	0.010	**139**	0.025	0.045	0.011	**207**	0.032	0.037	0.023
72	0.028	0.026	0.017	**140**	0.026	0.049	0.011	**208**	0.026	0.028	0.013
73	0.033	0.039	0.015	**141**	0.031	0.050	0.011	**209**	0.026	0.033	0.012

Table 6: Average Magnitudes by Line (Meters)

Category	X	Y	Z
Average Magnitude	0.032	0.033	0.012
RMS Values	0.049	0.050	0.016
Maximum Values	0.162	0.160	0.160
Observation Weight	64706.0	64706.0	888234.0

Table 7: Internal Observation Statistics (Meters)

Category	Mismatch
Average 3D Mismatch	0.01562
Average XY Mismatch	0.05690
Average Z Mismatch	0.01209

Table 8: Overall Relative Accuracy (Meters)

Category	Observations
Section Lines	376,659
Roof Lines	28,630

Table 9: Vector Observations

3.4 Lidar Classification

Lidar filtering was accomplished using GeoCue with TerraSolid processing and modeling software. The filtering process reclassifies all the data into classes with in the point cloud file based scheme. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract requirements. This can include, but is not limited to, removing bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 10** outlines the point classes leveraged in the lidar dataset.

Code	Description	Definition
1	Unclassified	Processed, but unclassified
2	Ground	Bare-earth surface
7	Low Noise	Erroneous returns below bare-earth surface
9	Water	Hydrologically identified water surface points
10	Ignored Ground	Bare-earth points near breaklines excluded from
17	Bridge Decks	Structure carrying a means of transit of higher
18	High Noise	Erroneous atmospheric returns above bare-earth
Flag	Overlap	Overage points lying within overlapping areas of two or more swaths
Flag	Withheld	Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath

Table 10: Lidar Classification Scheme

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of one hundred and forty-six (146) check points (80 NVA + 66 VVA). The end result provided an RMSEz that fell within project specifications. Please see the **Attachment A** for the full Vertical Accuracy Report and the project **Metadata** for an in-depth accuracy assessment. **Table 11** outlines the absolute accuracy requirements of the project. **Table 12** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value
RMSEz (m)	≤0.10
@ 95-percent confidence level (m)	≤0.294

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	80	0.076	0.149	
NVA of Bare Earth	80	0.074	0.145	
NVA of DEM	80	0.073	0.143	
VVA of Bare Earth	66	0.099		0.231
VVA of DEM	66	0.096		0.232

Table 12: Vertical Accuracy Assessment of Check Points (Meters)

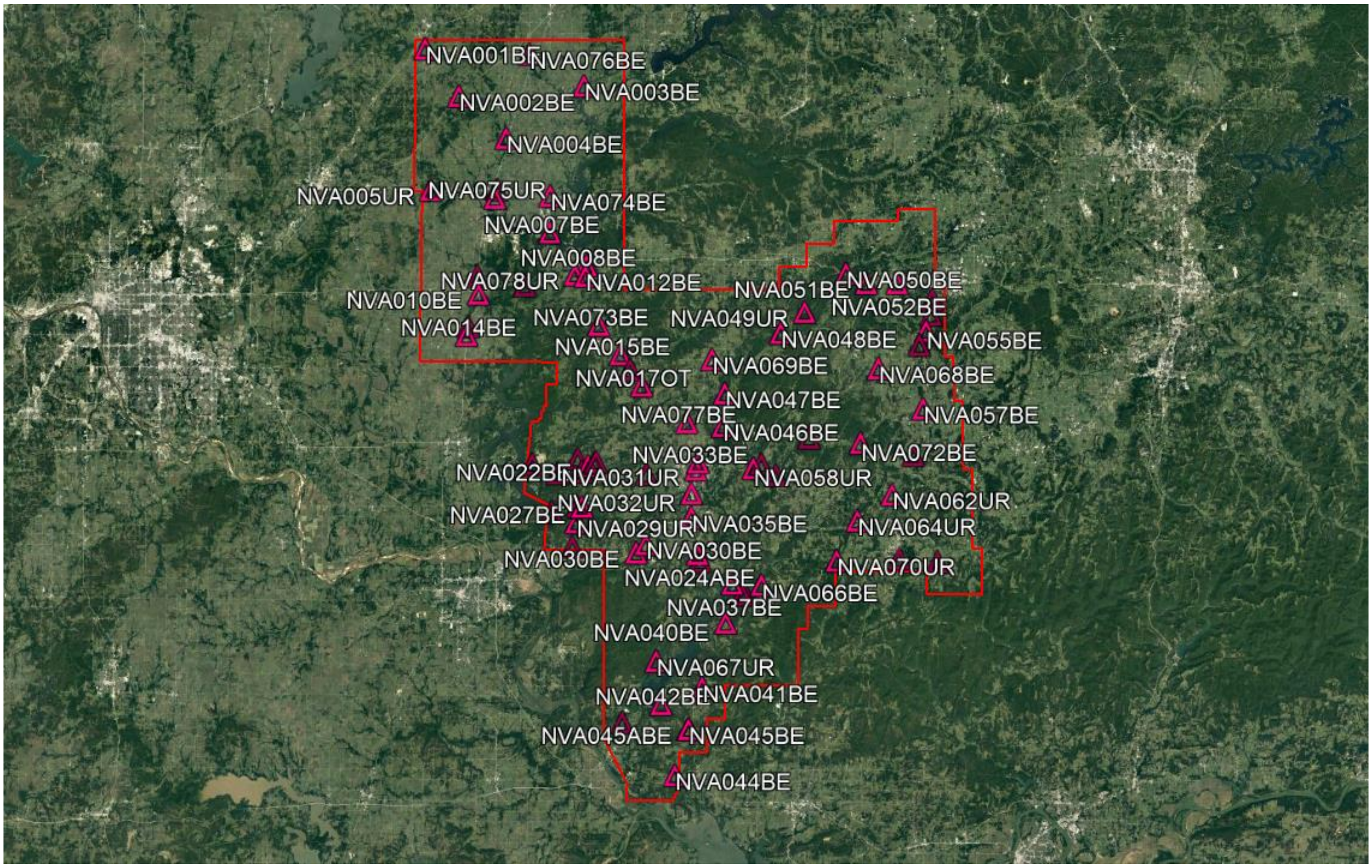


Figure 5: Non-vegetated Check Point Distribution

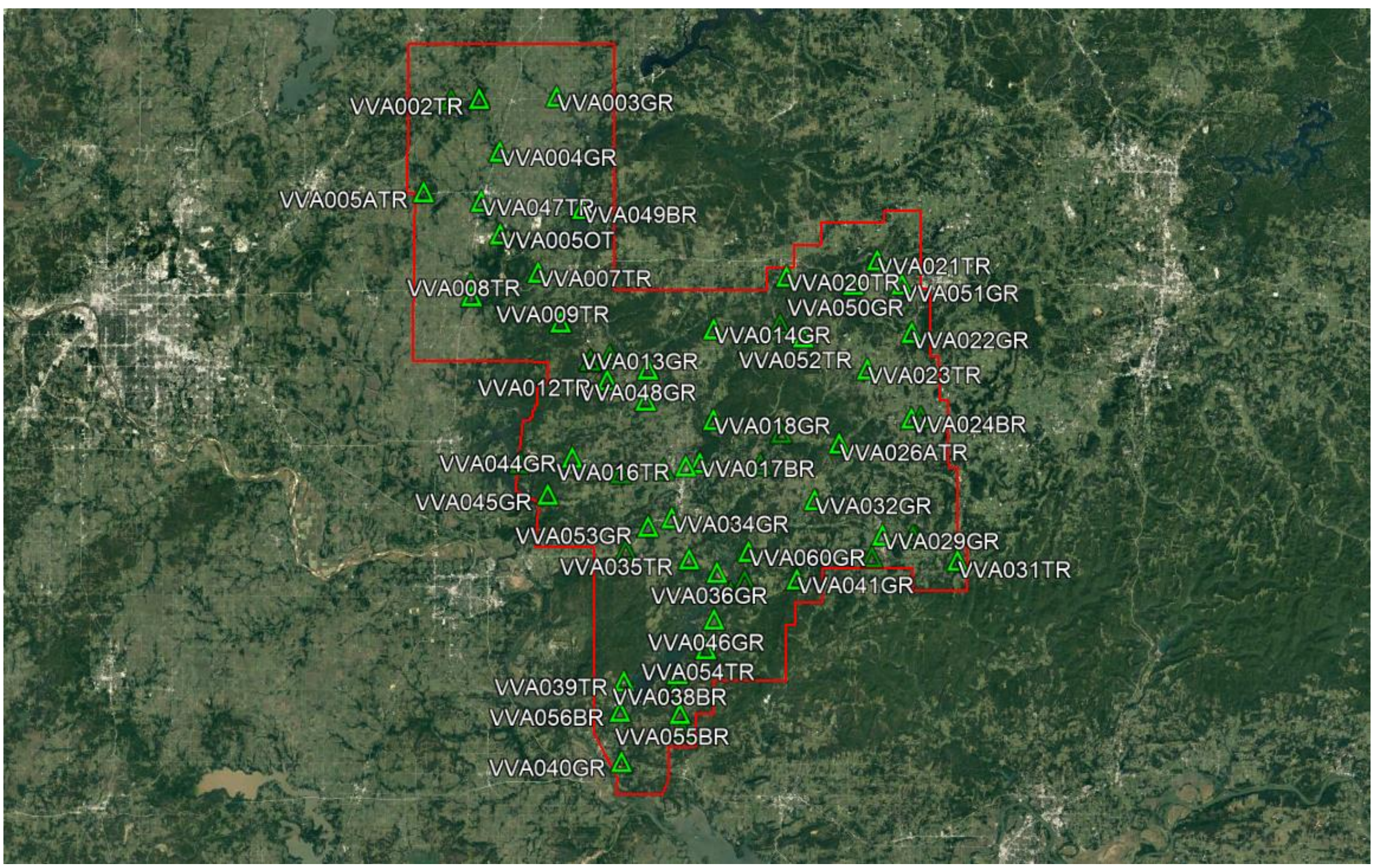


Figure 6: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

Once the lidar surface was finalized and manually QC'd for anomalies, the required deliverables were then generated and/or organized. The following products were generated using the final coordinate system as defined in the contract, and provided in section 4.0 of this report.

Classified Point Cloud
The Classified Point Cloud, containing all returns, is delivered in LASv1.4 (*.las) format and meets project specifications. The Classified Point Cloud contains file names referencing the tile index.

Bare-Earth Digital Terrain Model
32-bit ERDAS Imagine (*.img) 1m elevation rasters were created from the bare-earth points in the processed lidar dataset. Each pixel contains an elevation value interpolated from the lidar.

Intensity Rasters
8-bit GeoTIFF (*.tiff) 1m intensity rasters were created from the first-return points in the processed lidar dataset.

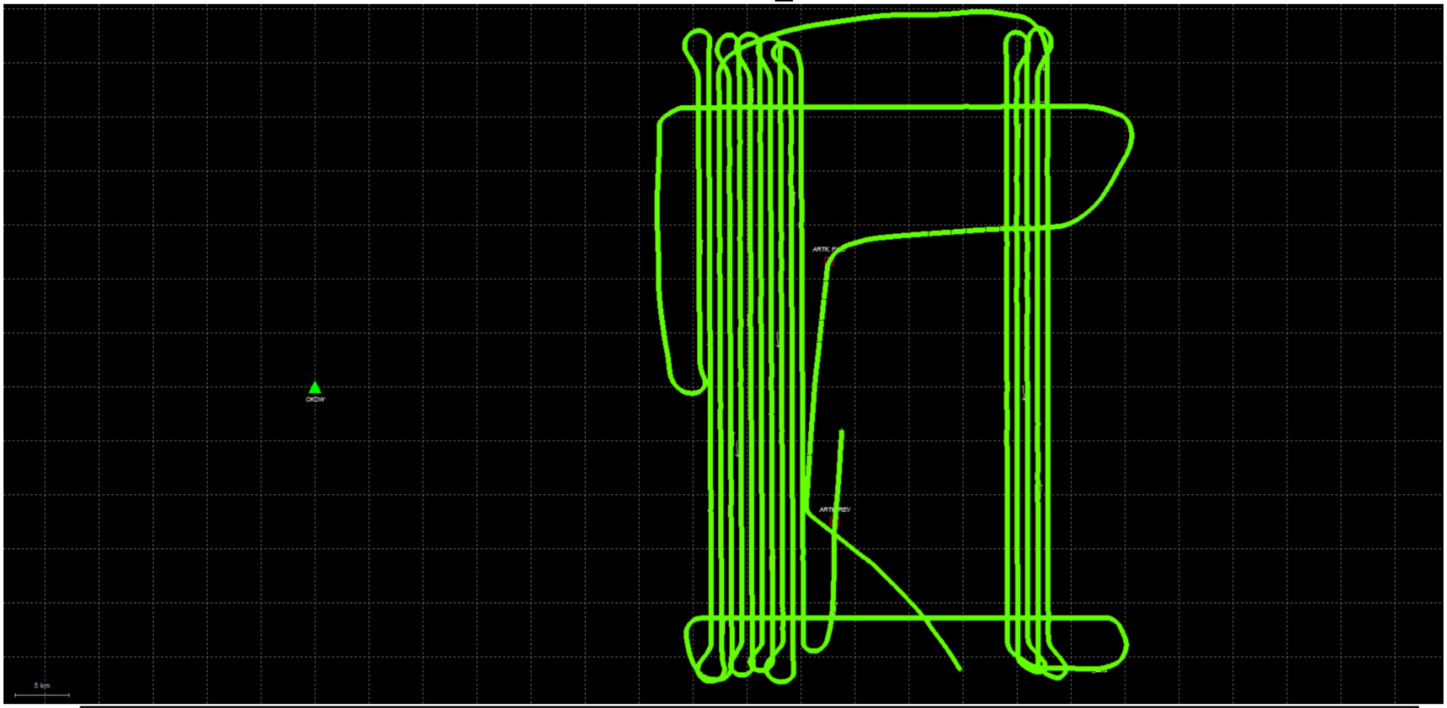
Other Deliverables
Vertical Accuracy Report
Metadata

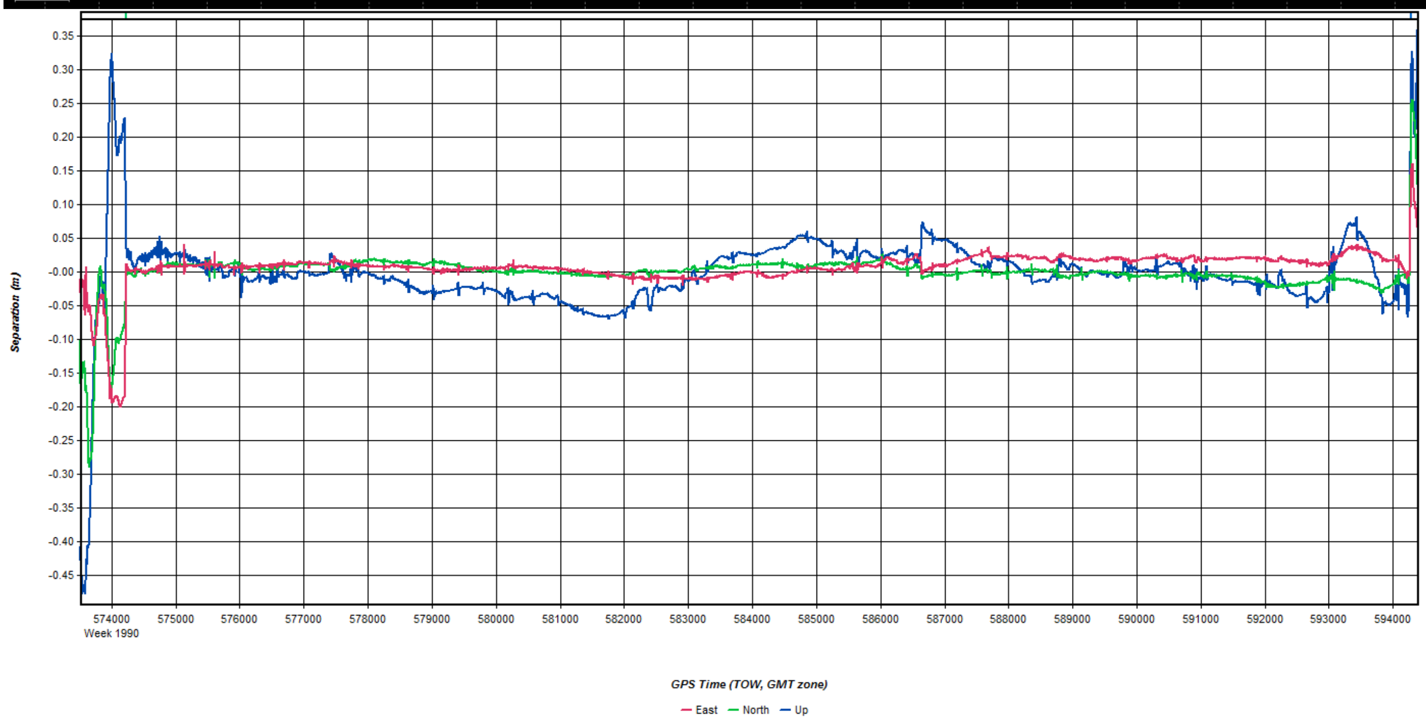
A final QC process was undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/quality assurance department reviews the data and then releases it for delivery.

APPENDIX A – ABGNSS/IMU PLOTS

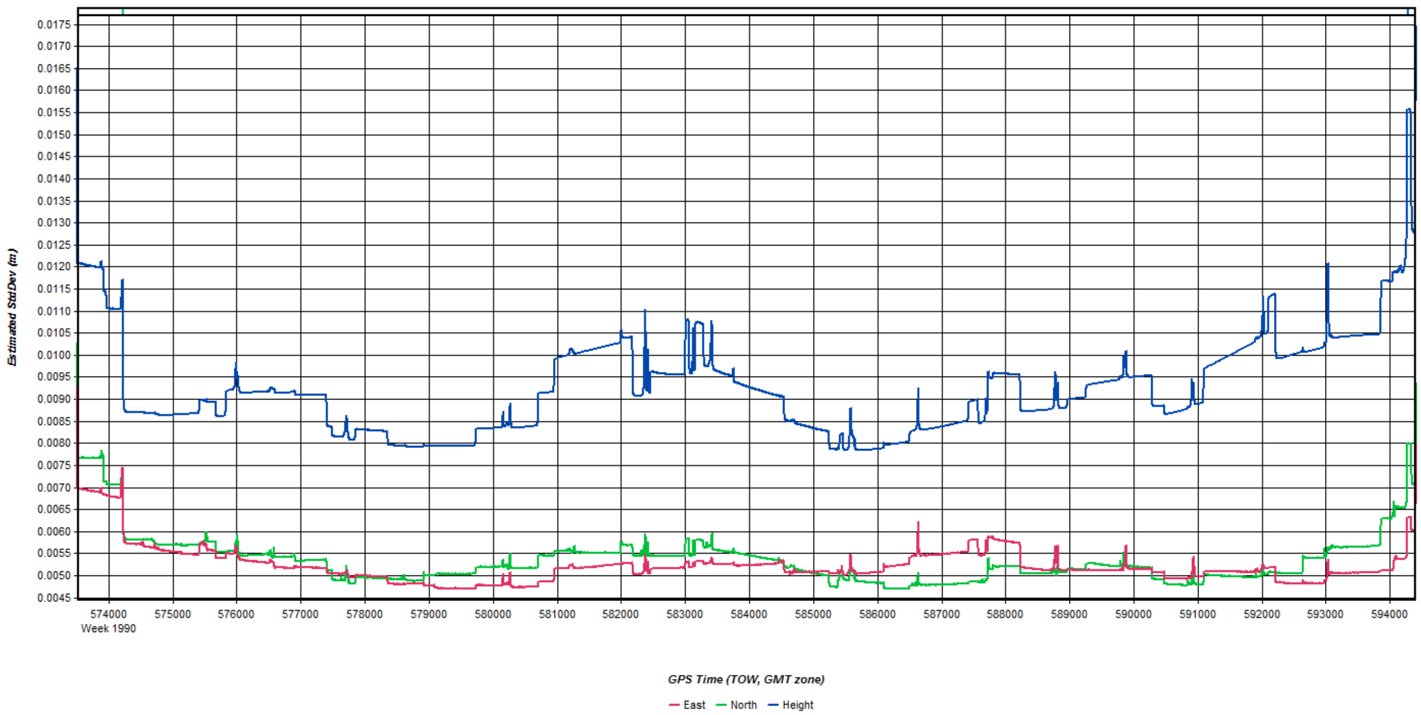
Coverage Map	The Coverage Map plot shows the Aircraft GNSS-IMU Trajectory in reference to localized GNSS Reference Stations.
Estimated Position Accuracy	The Estimated Position Accuracy plot shows the standard deviations of the east, north, and up directions versus time for the solution. The total standard 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.

20180303_1

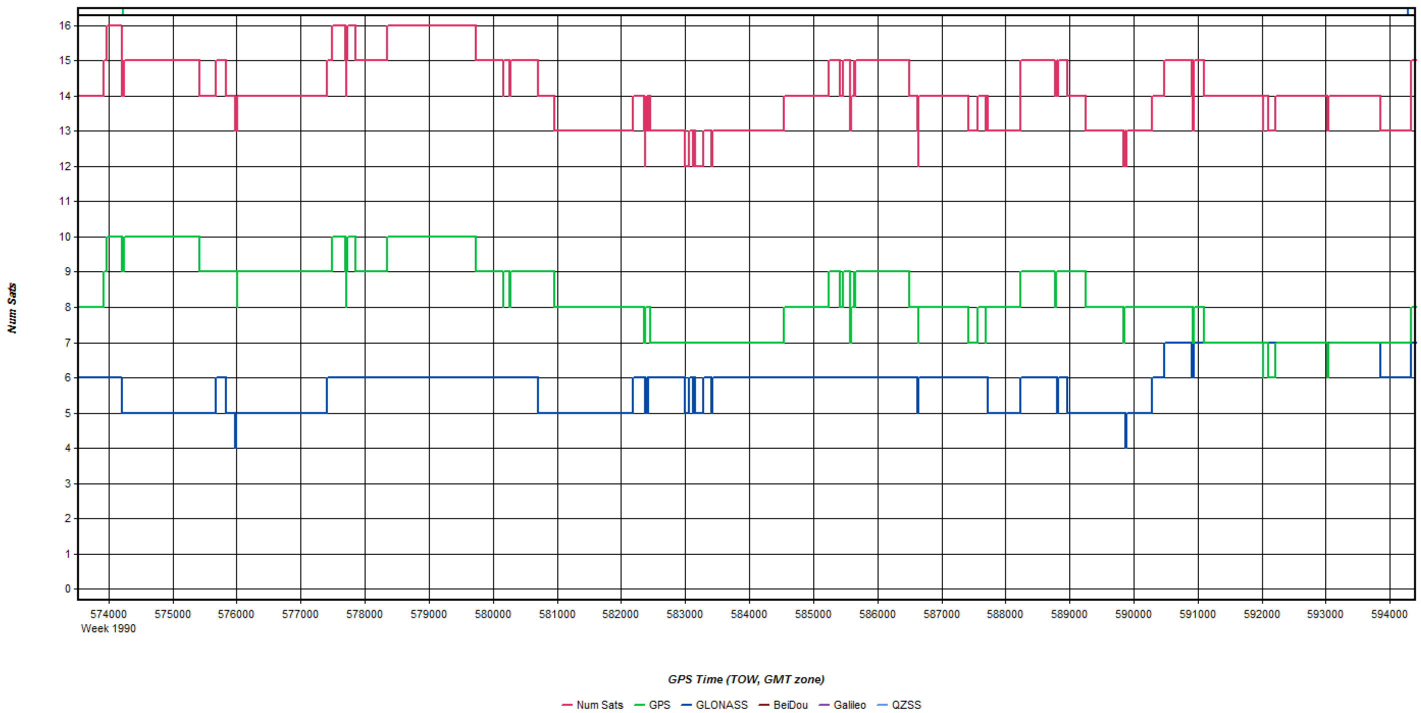




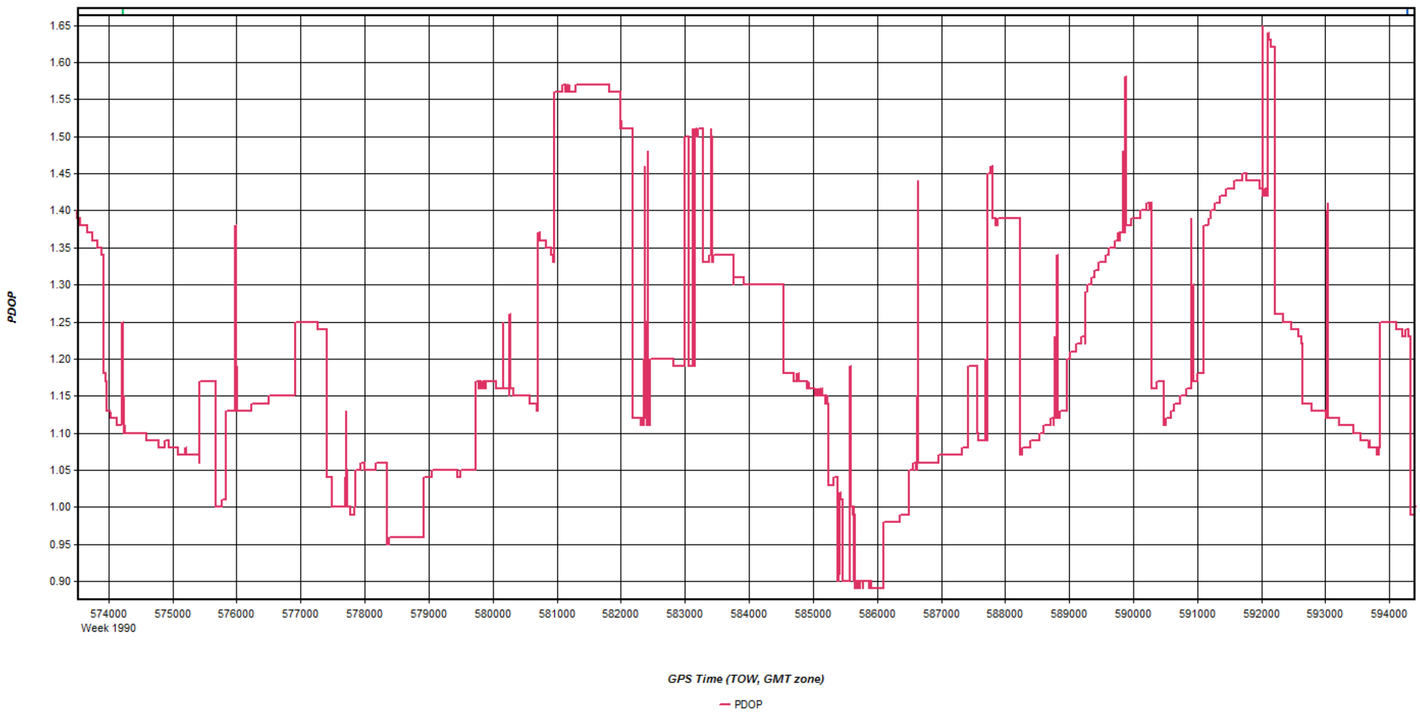
Separation (m)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
574000 575000 576000 577000 578000 579000 580000 581000 582000 583000 584000 585000 586000 587000 588000 589000 590000 591000 592000 593000 594000
Week 1990
GPS Time (TOW, GMT zone)
East North Up



Estimated Std/Dev (m)
GPS Time (TOW, GMT zone)
Week 1990
East
North
Height

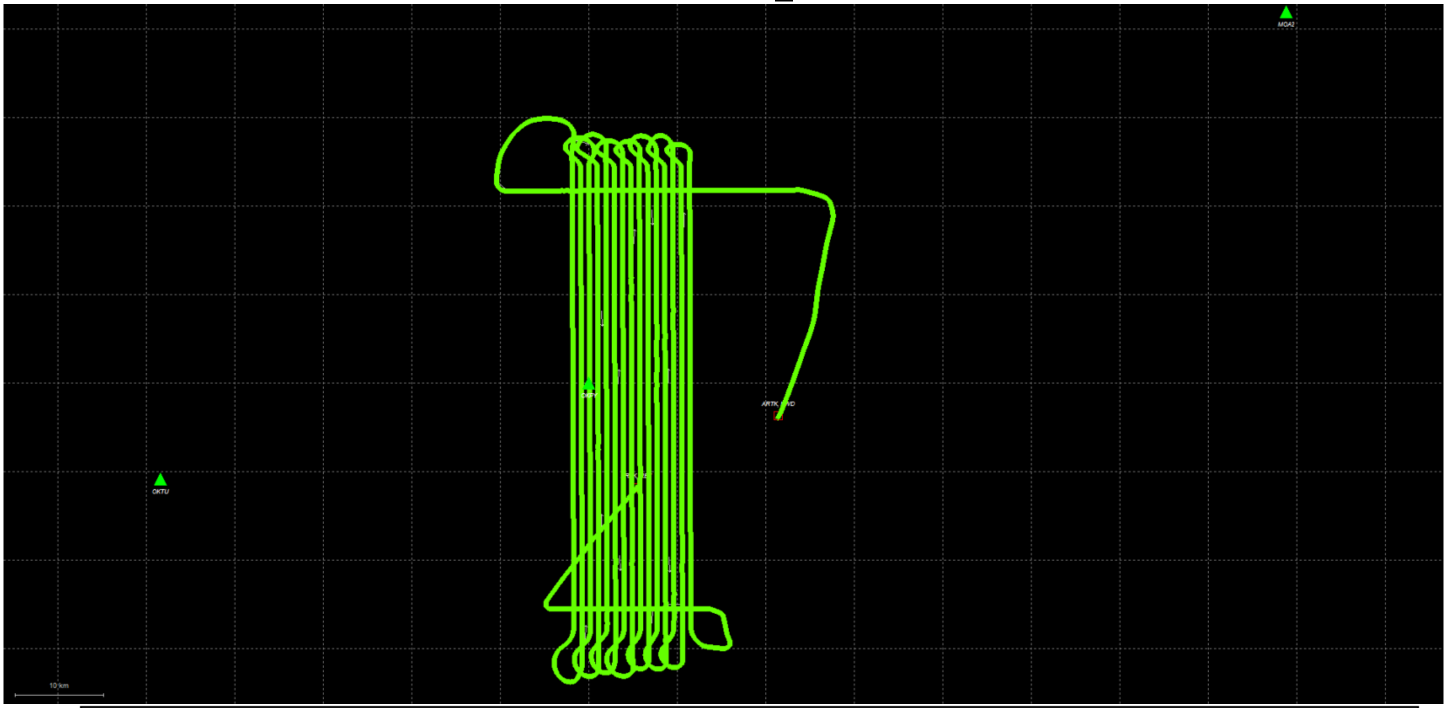


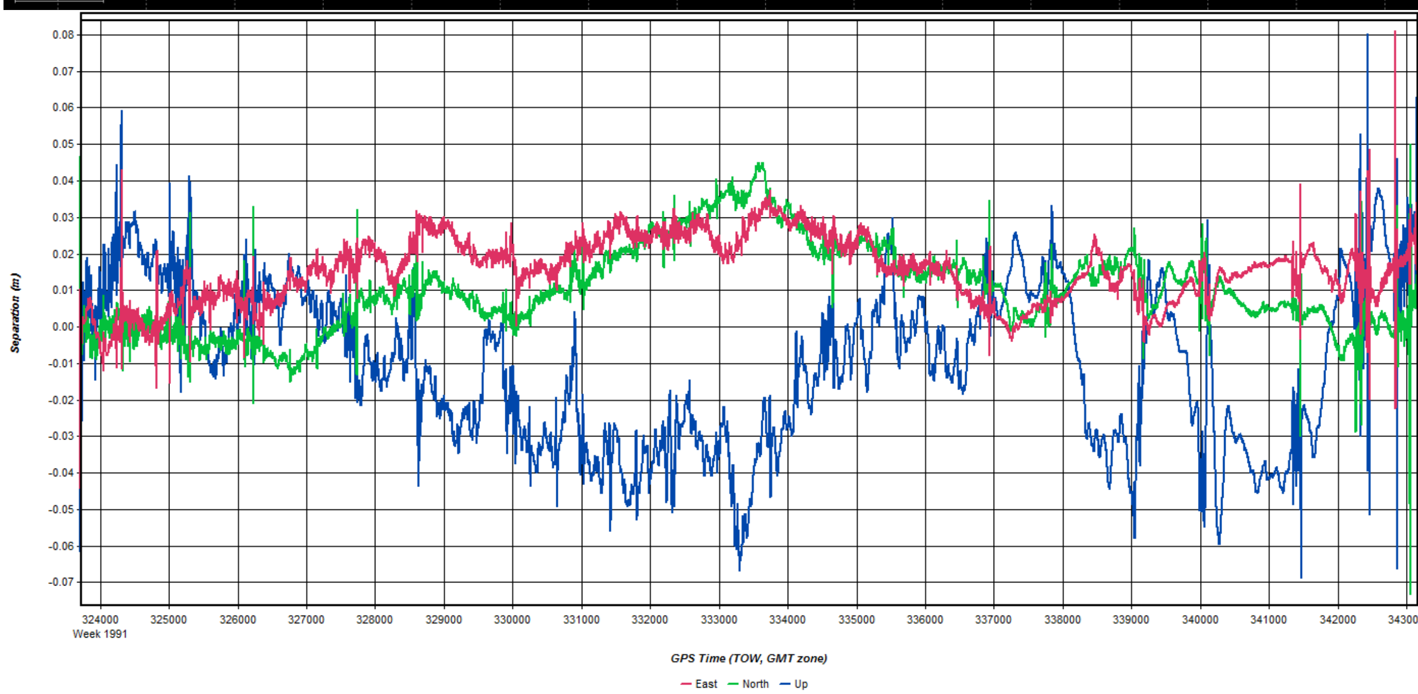
Num Sats
GPS Time (TOW, GMT zone)
Week 1990
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS

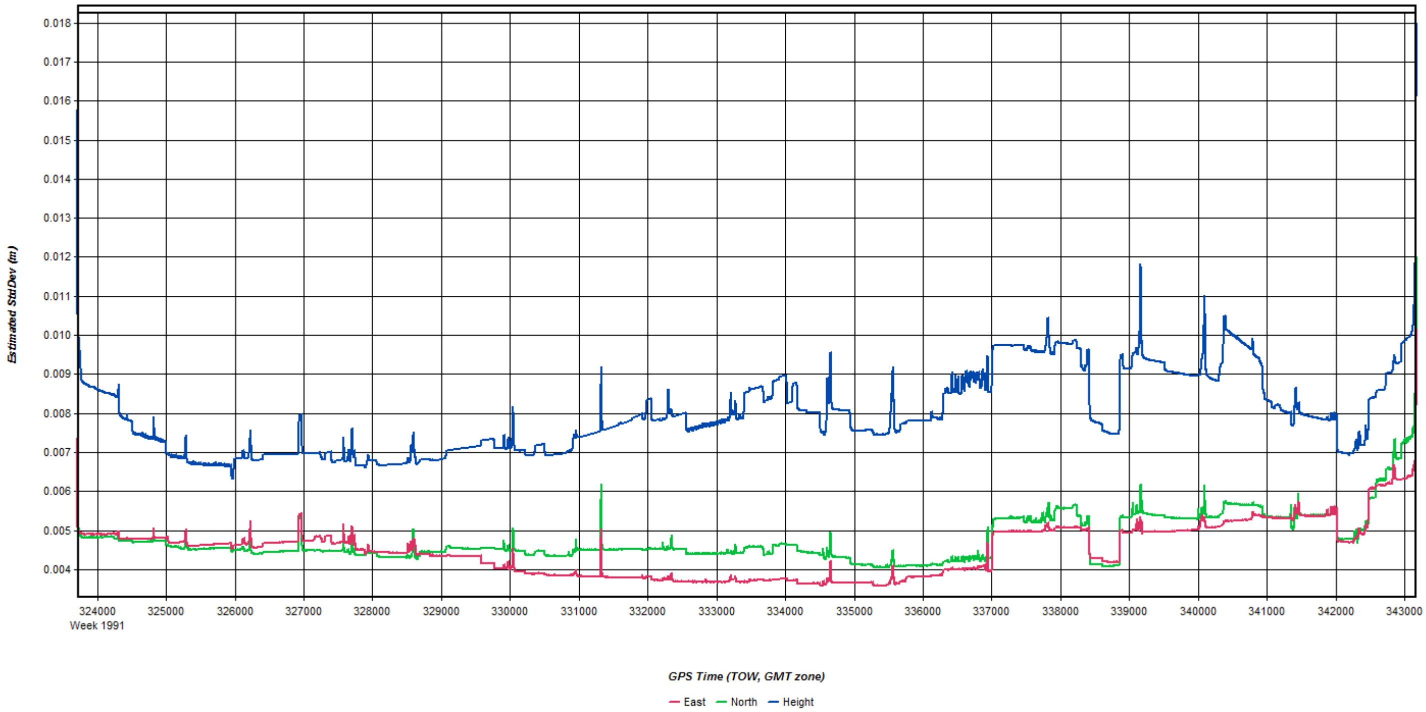


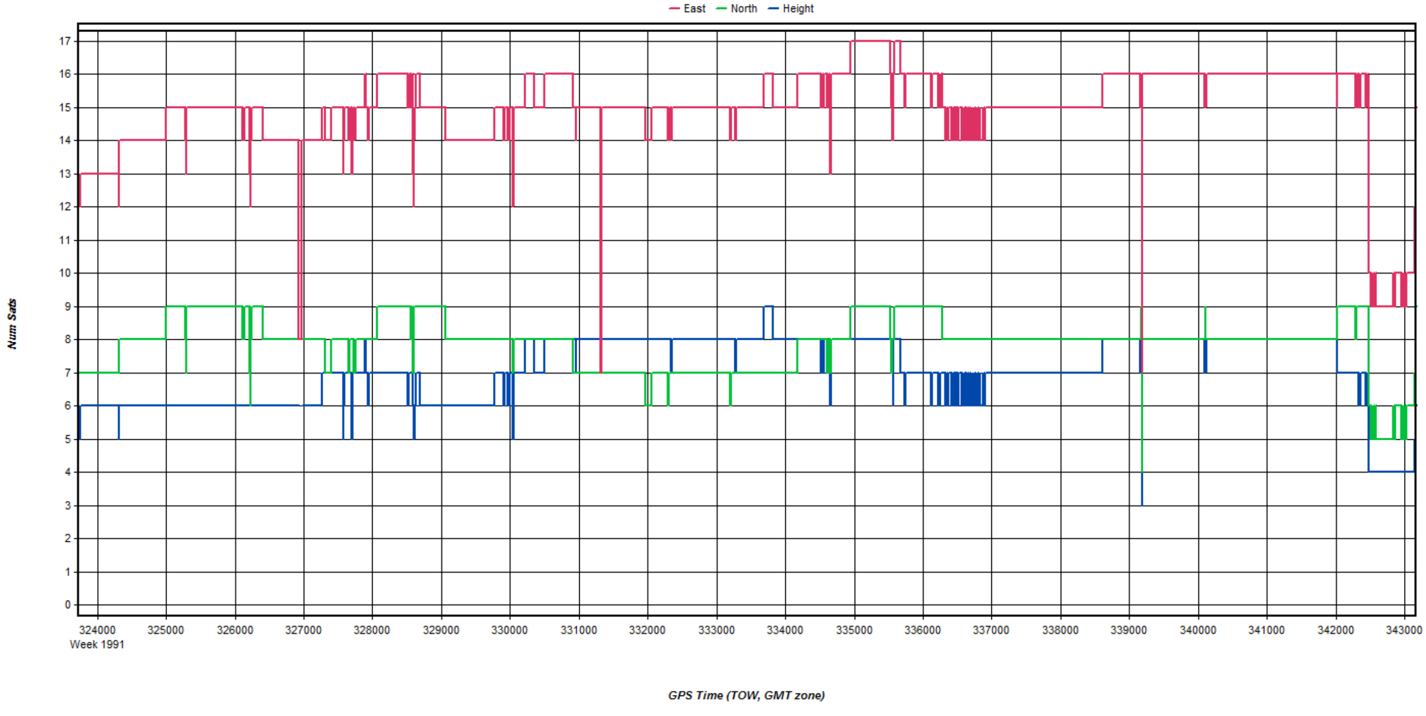
PDOP
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
574000
Week 1990
575000
576000
577000
578000
579000
580000
581000
582000
583000
584000
585000
586000
587000
588000
589000
590000
591000
592000
593000
594000
GPS Time (TOW, GMT zone)
PDOP

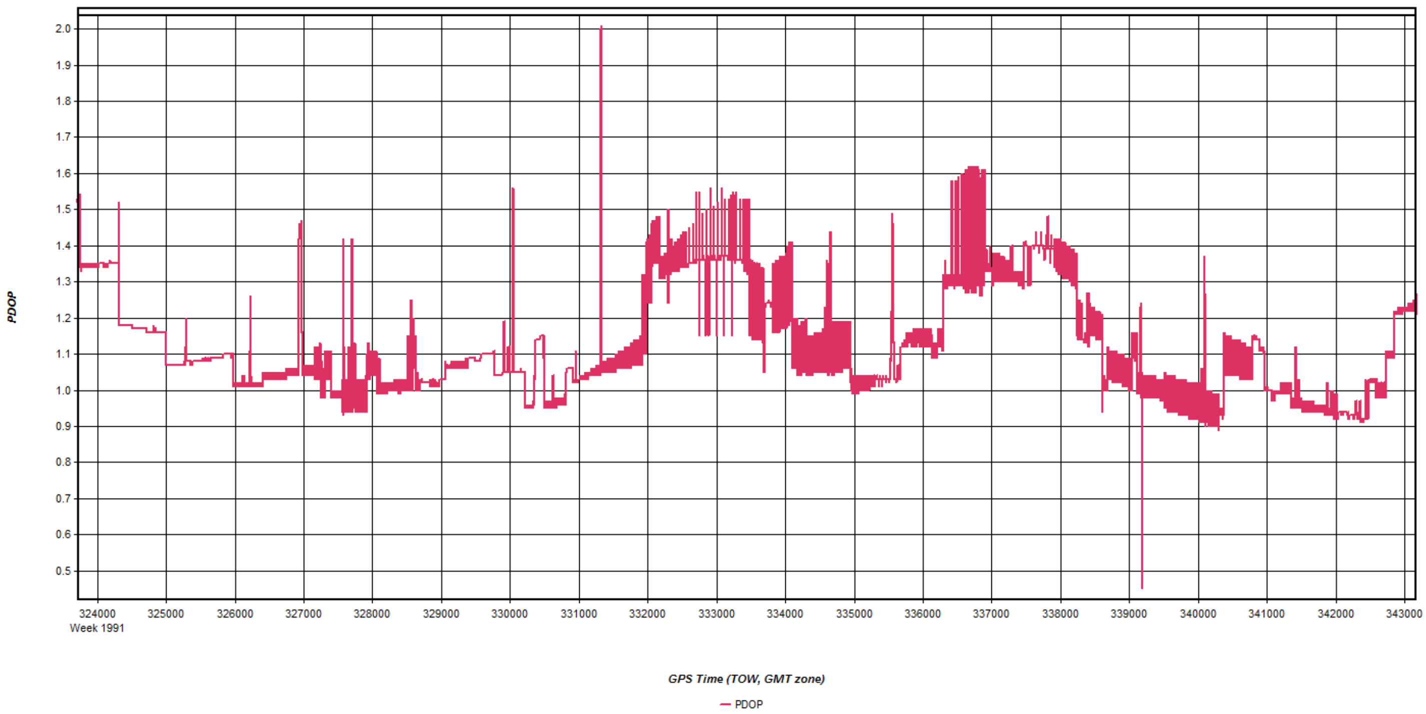
20180307_1



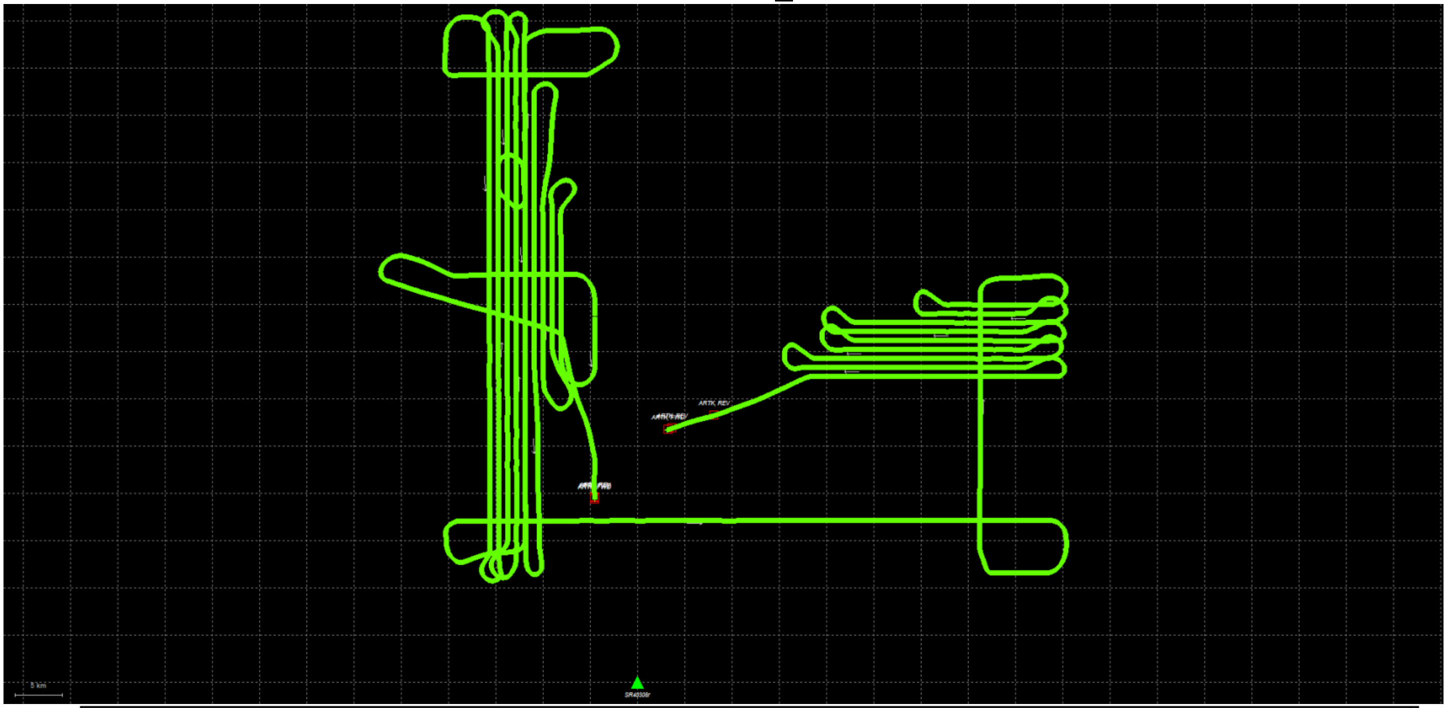

0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
Separation (m)
324000
325000
326000
327000
328000
329000
330000
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
Week 1991
GPS Time (TOW, GMT zone)
East
North
Up

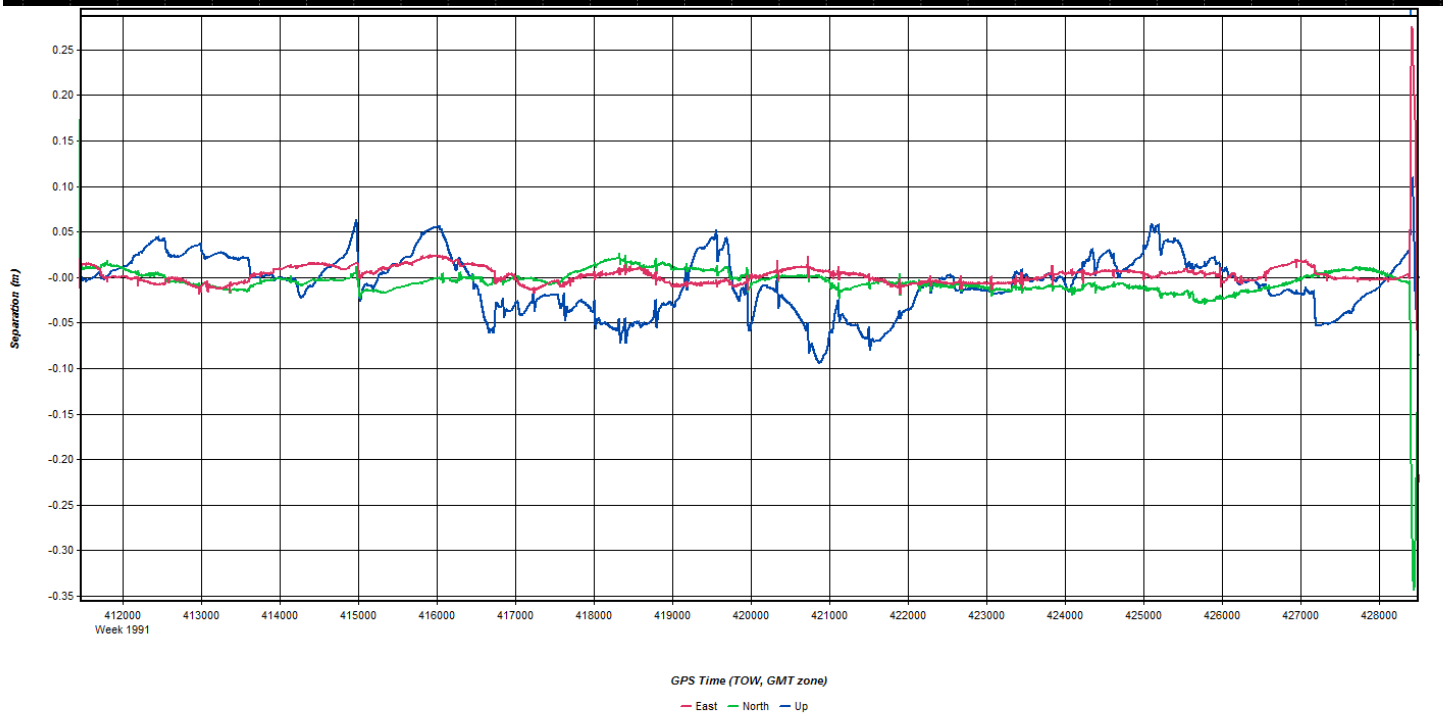

0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
Estimated StdDev (m)
324000
Week 1991
325000
326000
327000
328000
329000
330000
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
GPS Time (TOW, GMT zone)
East
North
Height


17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
324000
Week 1991
325000
326000
327000
328000
329000
330000
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS

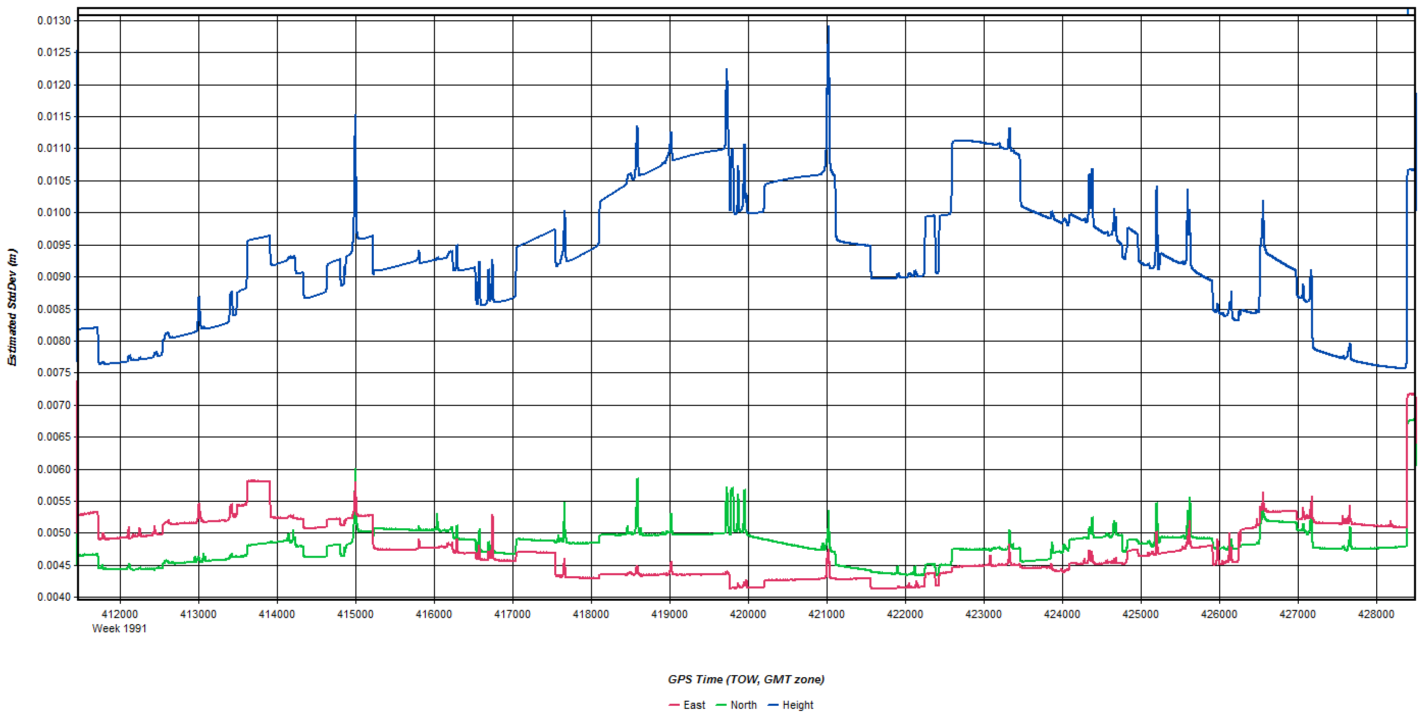

PDOP
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
324000
Week 1991
325000
326000
327000
328000
329000
330000
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
GPS Time (TOW, GMT zone)
PDOP

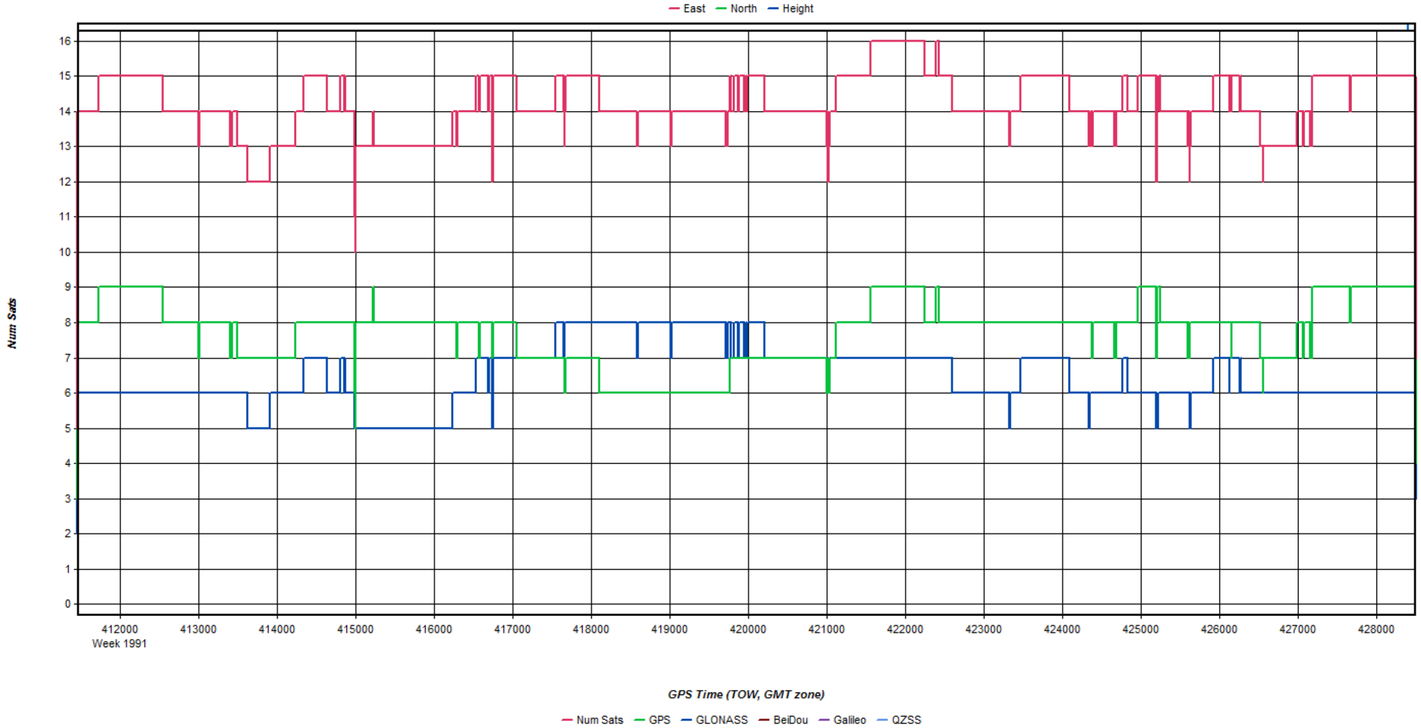
20180308_1

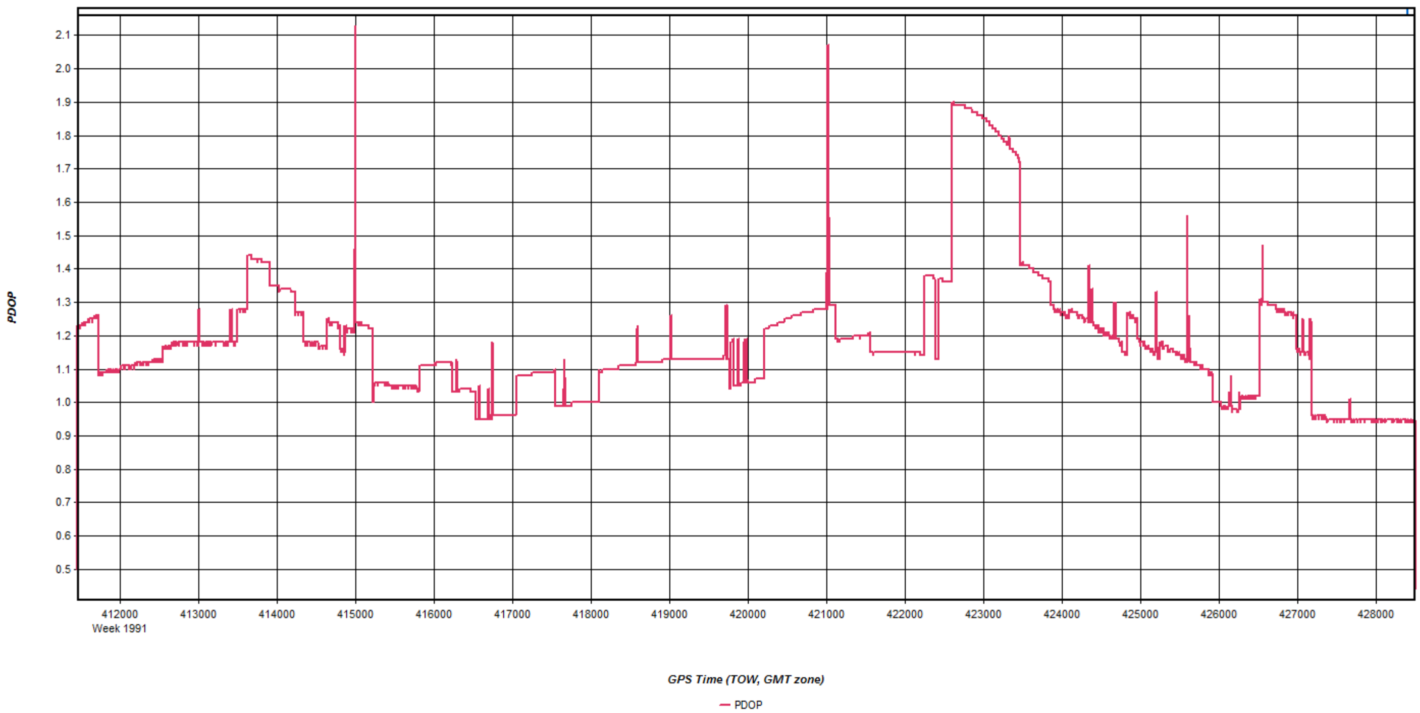




Separation (m)
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
412000
Week 1991
413000
414000
415000
416000
417000
418000
419000
420000
421000
422000
423000
424000
425000
426000
427000
428000
GPS Time (TOW, GMT zone)
East
North
Up

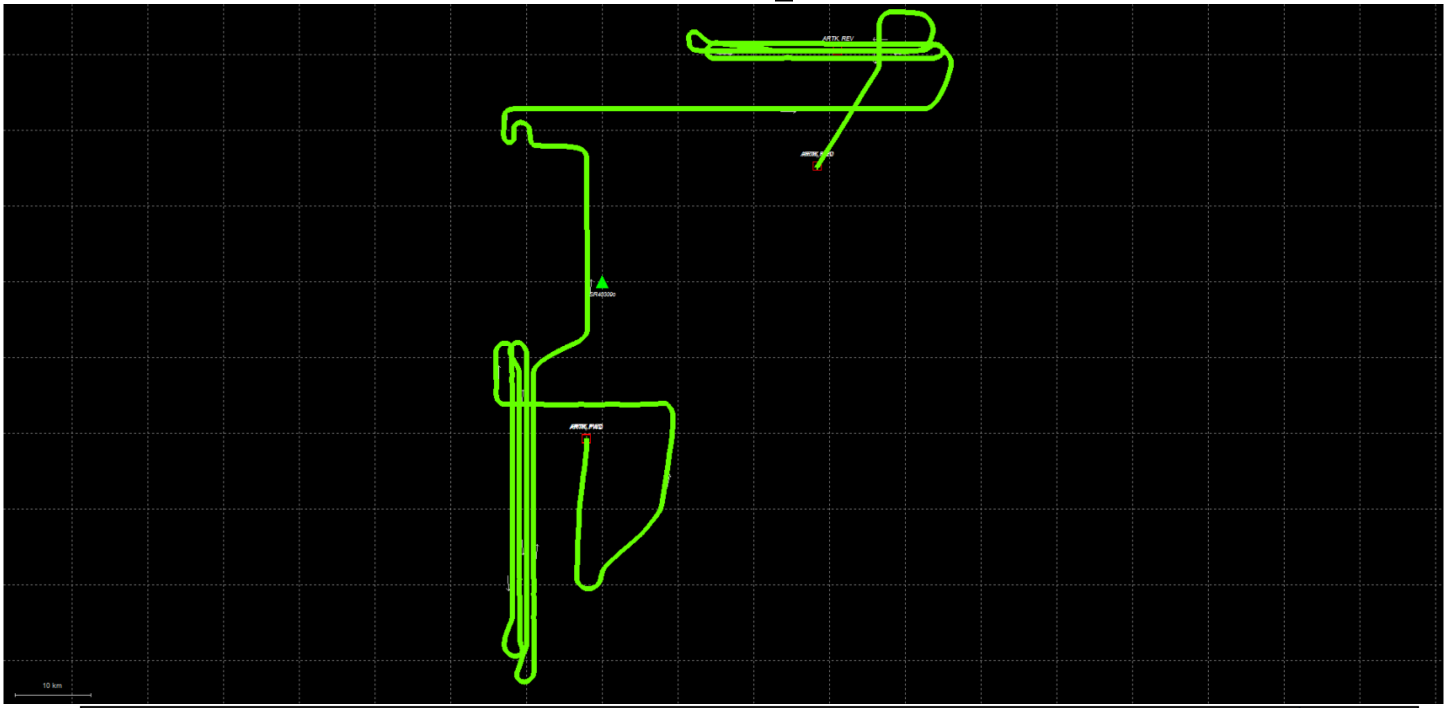

Estimated StdDev (m)
0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
412000 413000 414000 415000 416000 417000 418000 419000 420000 421000 422000 423000 424000 425000 426000 427000 428000
Week 1991
GPS Time (TOW, GMT zone)
East North Height

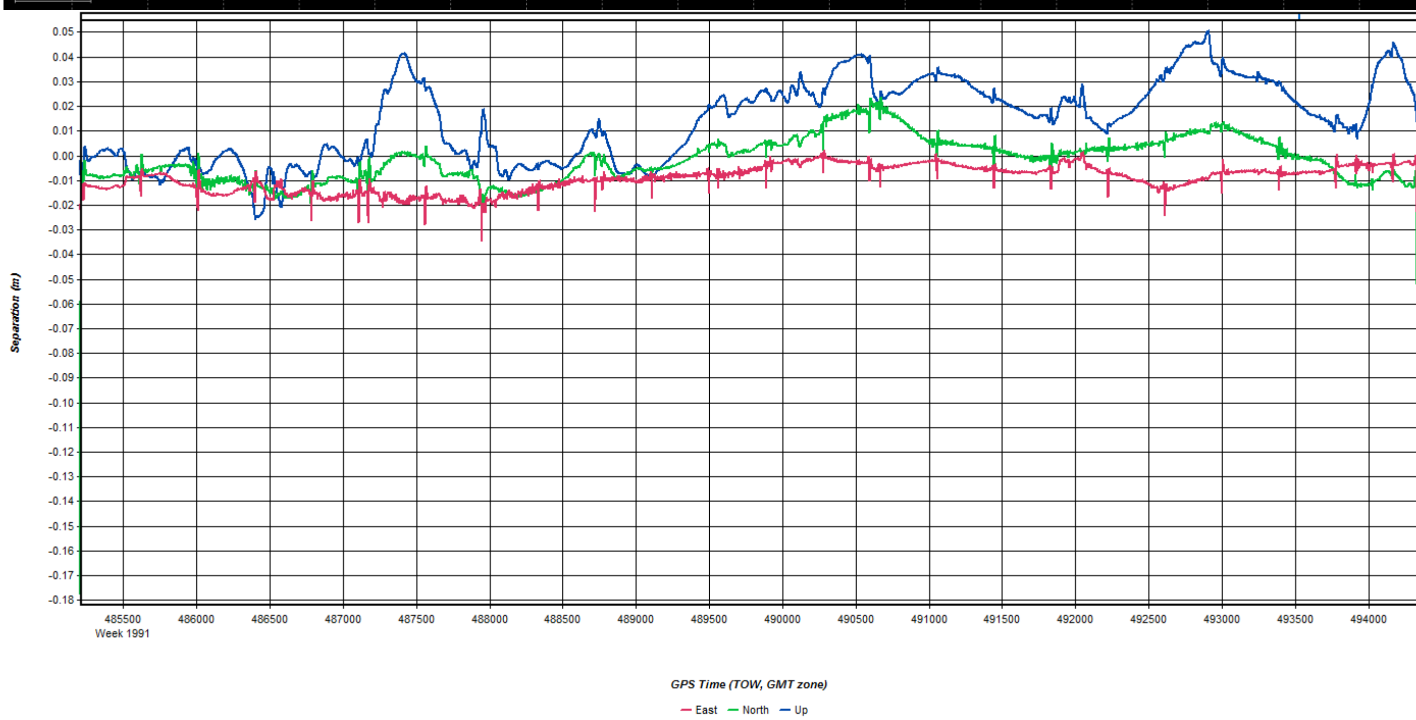

Num Sats
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
412000 413000 414000 415000 416000 417000 418000 419000 420000 421000 422000 423000 424000 425000 426000 427000 428000
Week 1991
GPS Time (TOW, GMT zone)
Num Sats GPS GLONASS BeiDou Galileo QZSS

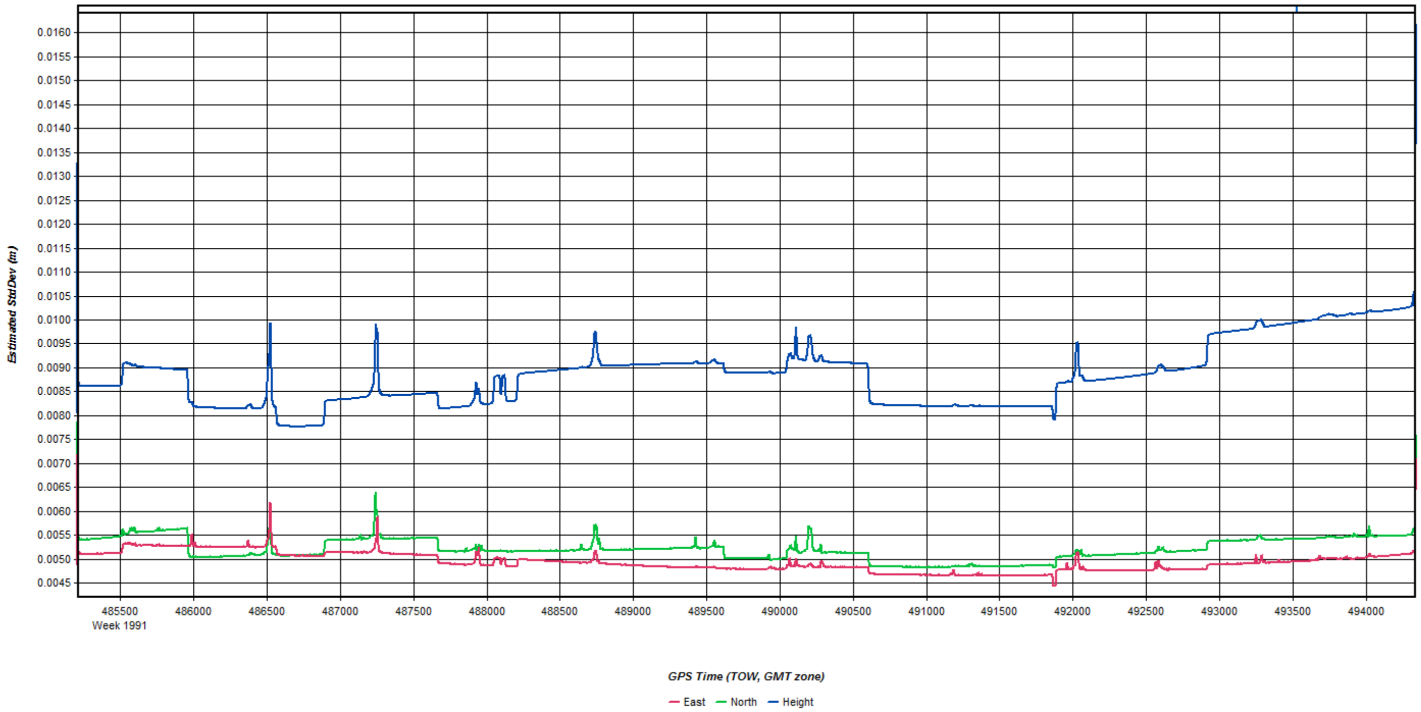


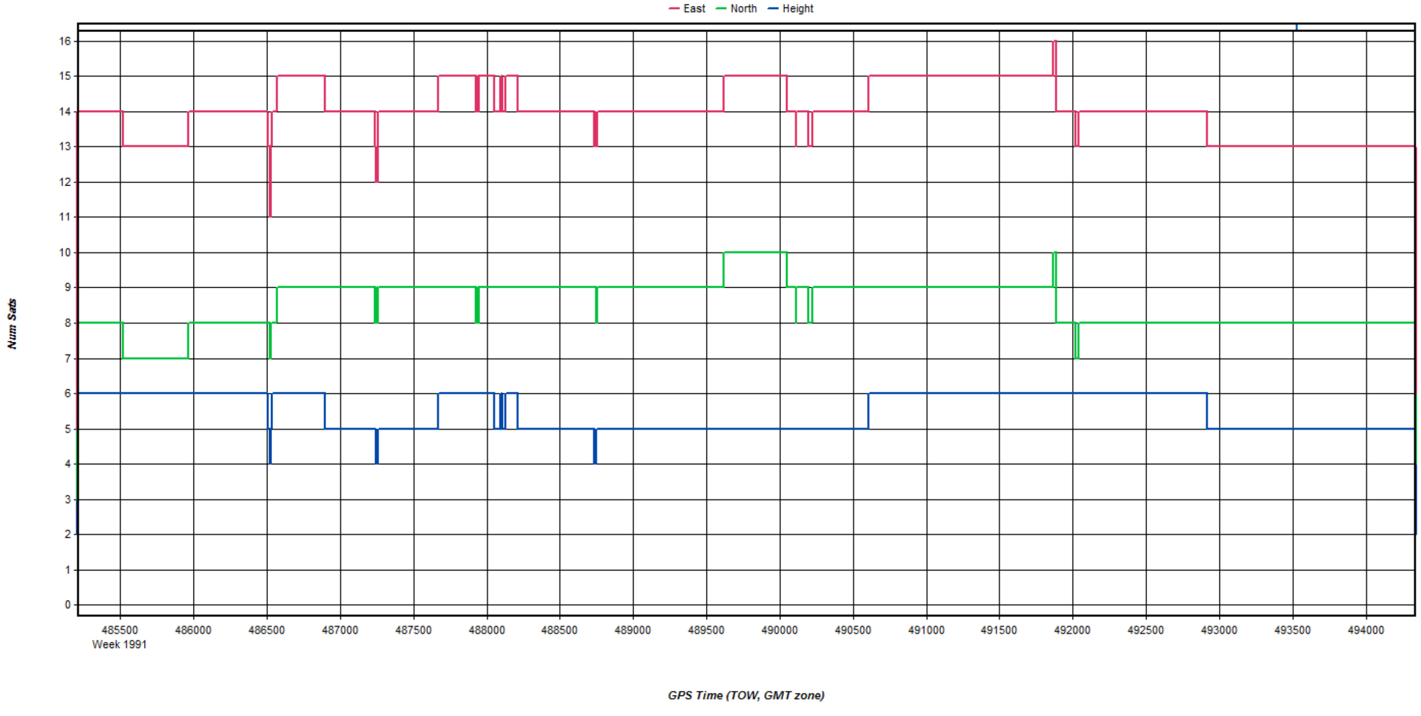
PDOP
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
412000
Week 1991
413000
414000
415000
416000
417000
418000
419000
420000
421000
422000
423000
424000
425000
426000
427000
428000
GPS Time (TOW, GMT zone)
PDOP

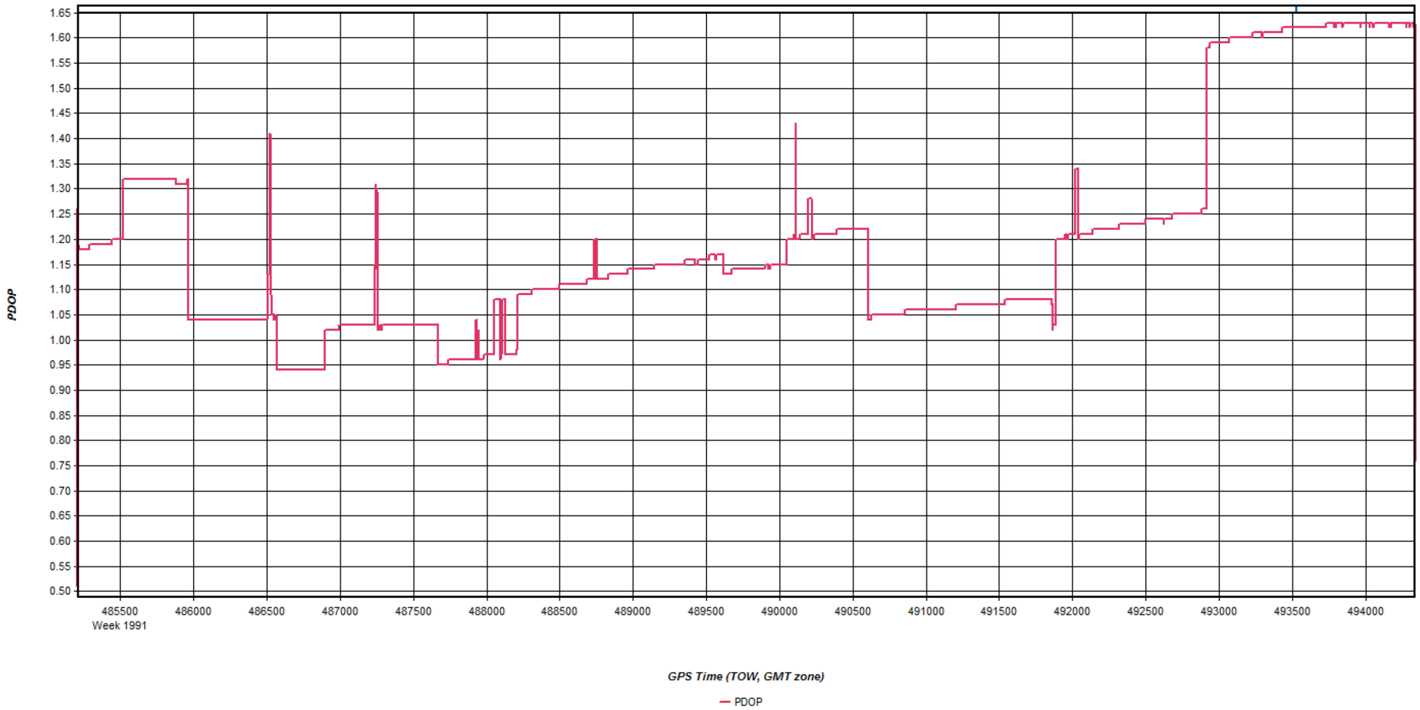
20180309_1





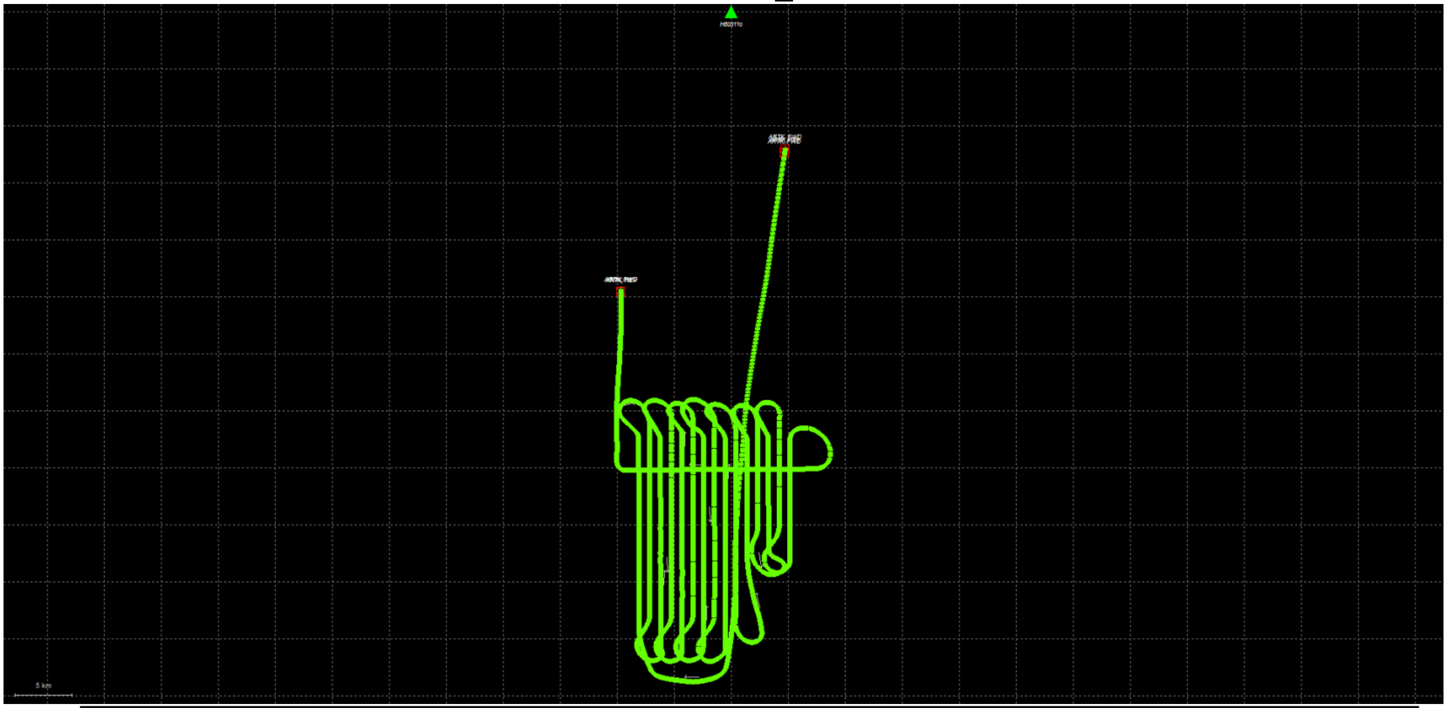

Estimated StdDev (m)
GPS Time (TOW, GMT zone)
Week 1991
East
North
Height

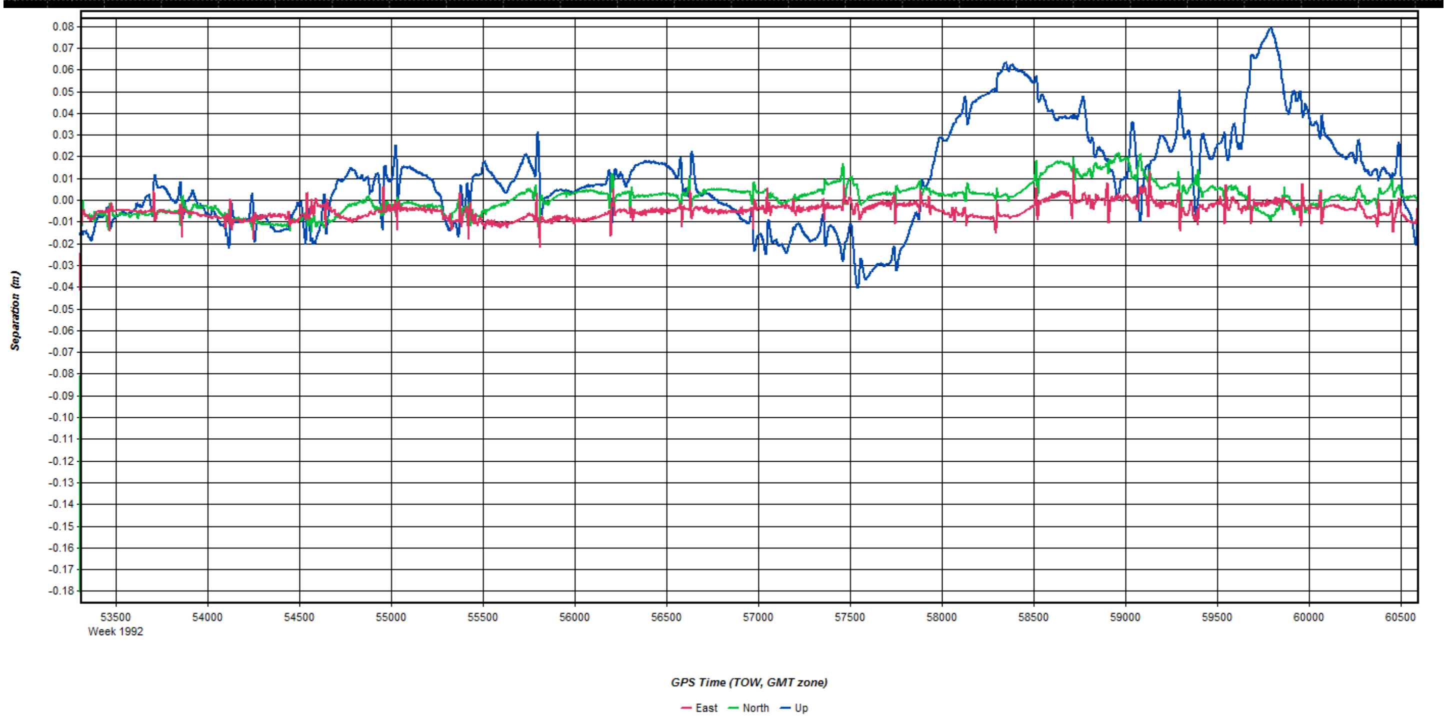

Num Sats
GPS Time (TOW, GMT zone)
Week 1991
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS

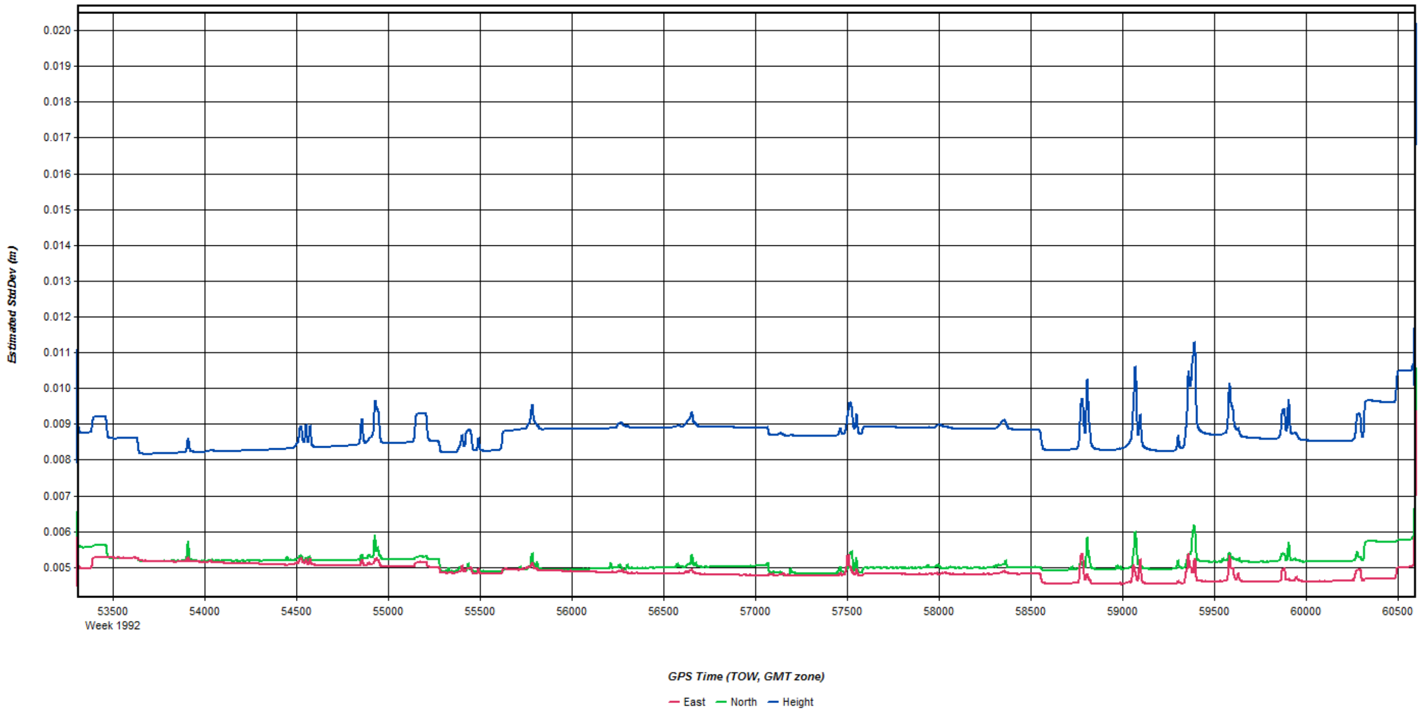


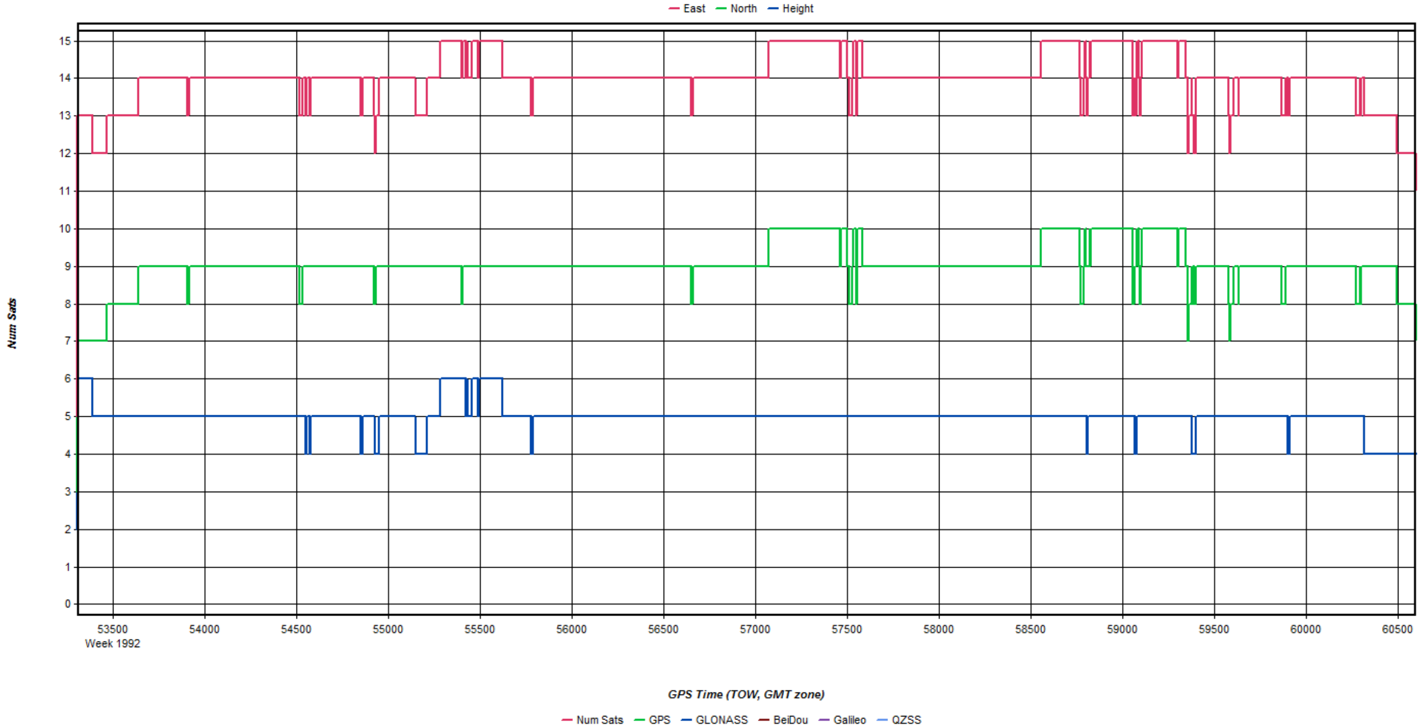
PDOP
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
485500
Week 1991
486000
486500
487000
487500
488000
488500
489000
489500
490000
490500
491000
491500
492000
492500
493000
493500
494000
GPS Time (TOW, GMT zone)
PDOP

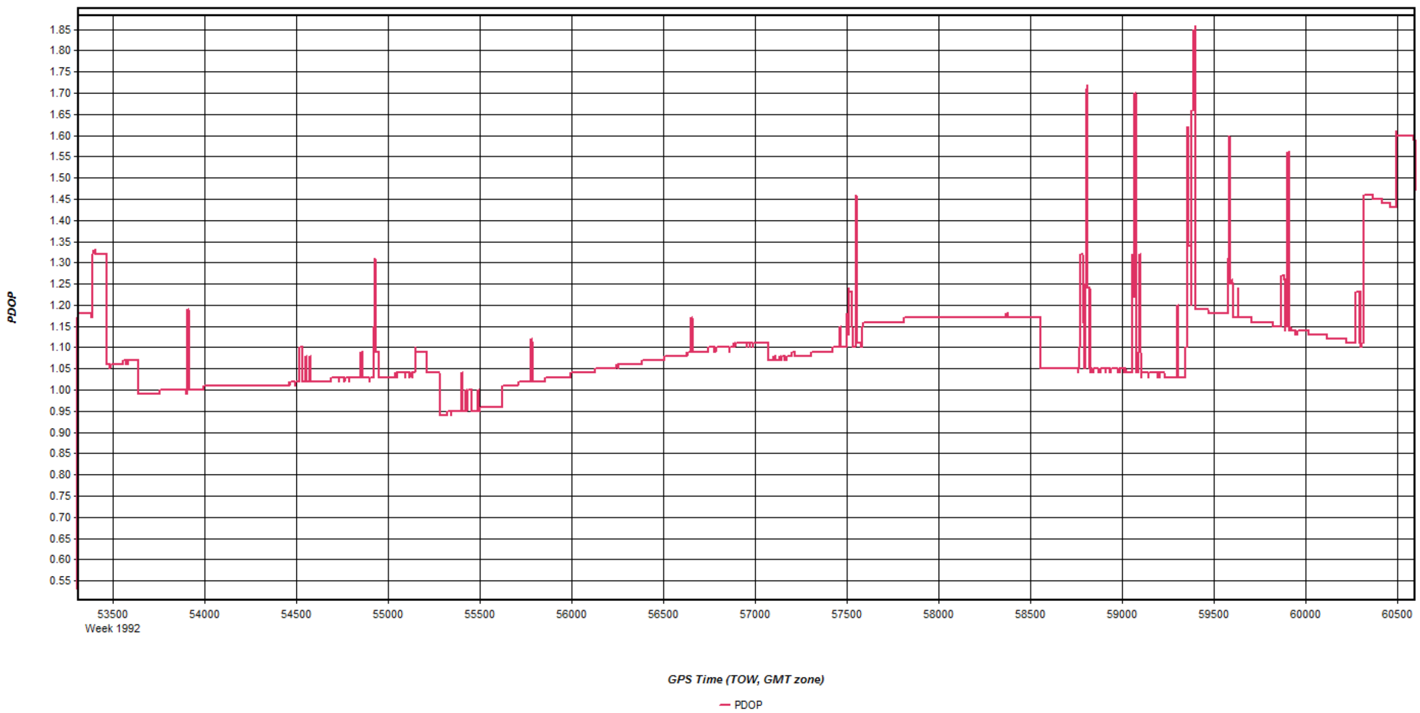
20180311_1



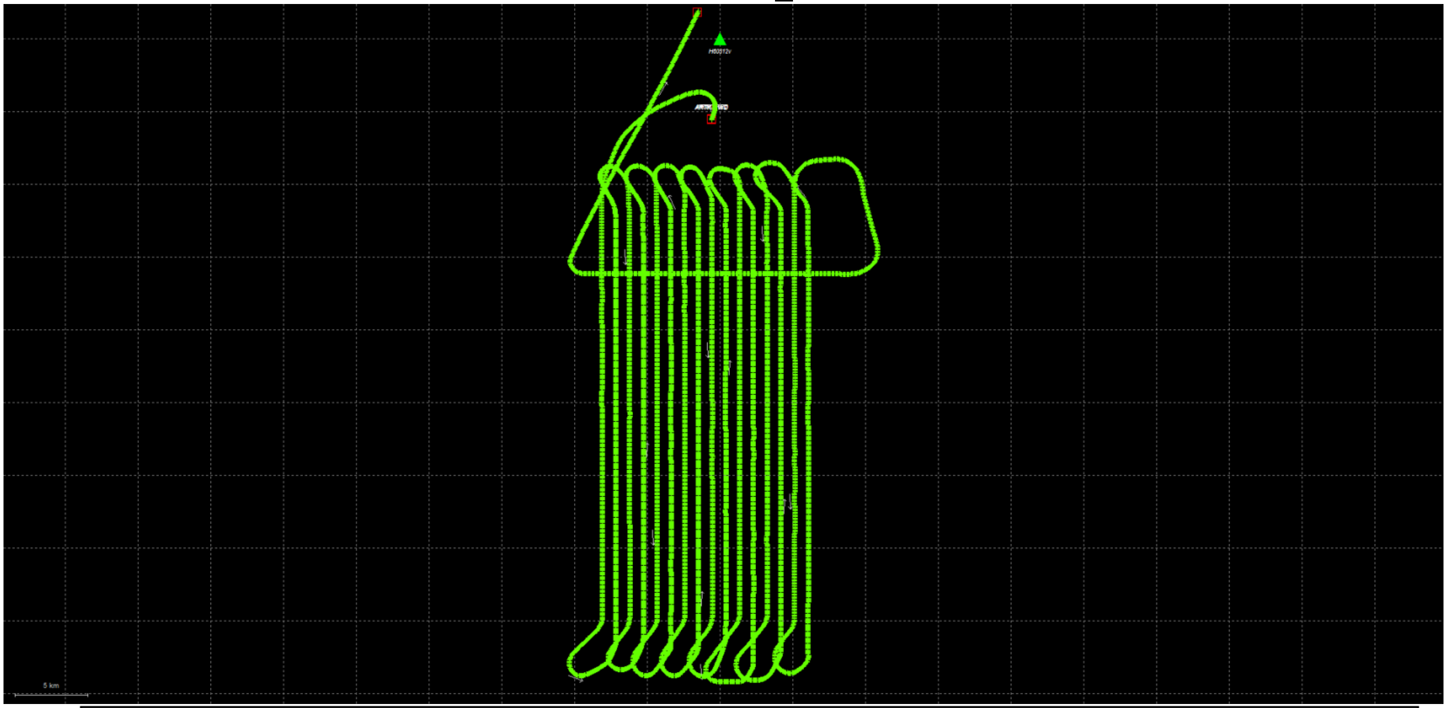

Separation (m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
-0.18
53500
Week 1992
54000
54500
55000
55500
56000
56500
57000
57500
58000
58500
59000
59500
60000
60500
GPS Time (TOW, GMT zone)
East
North
Up

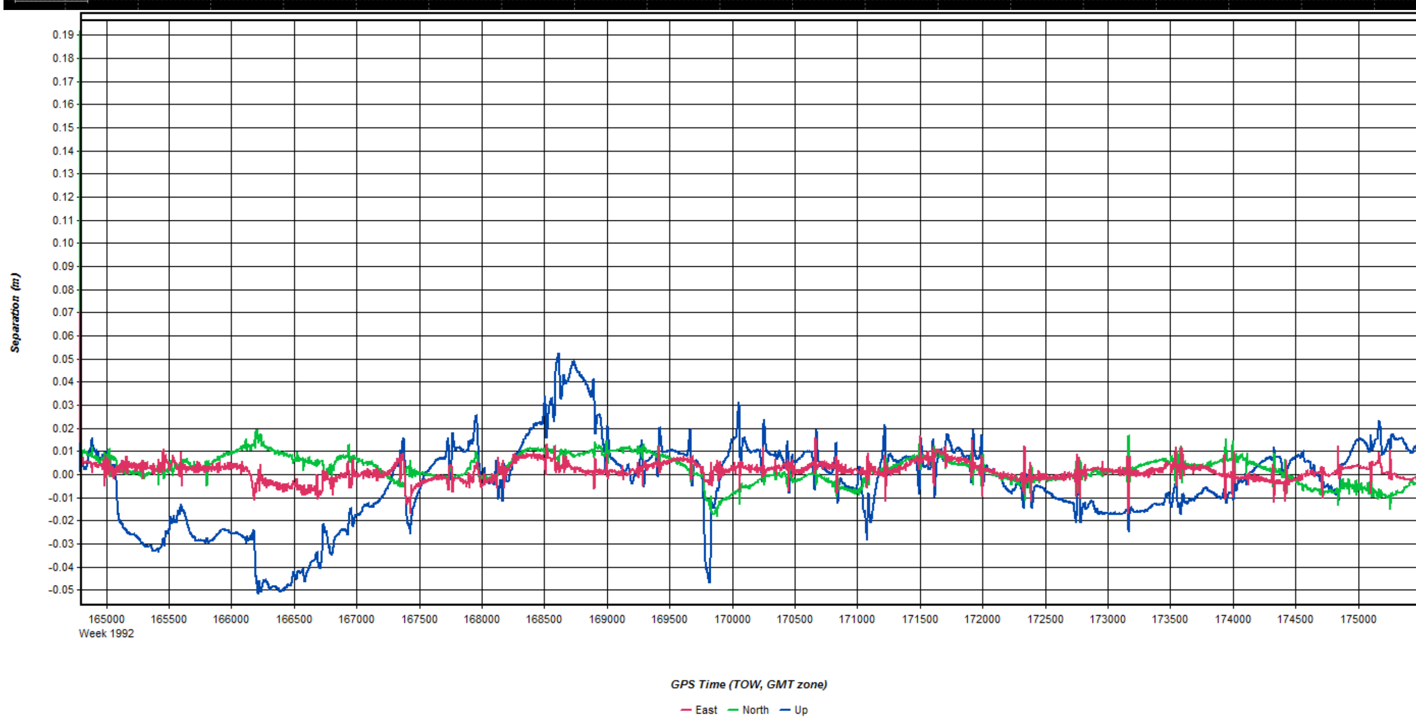

Estimated StdDev (m)
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
53500
Week 1992
54000
54500
55000
55500
56000
56500
57000
57500
58000
58500
59000
59500
60000
60500
GPS Time (TOW, GMT zone)
East
North
Height


Num Sats
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
53500
Week 1992
54000
54500
55000
55500
56000
56500
57000
57500
58000
58500
59000
59500
60000
60500
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS

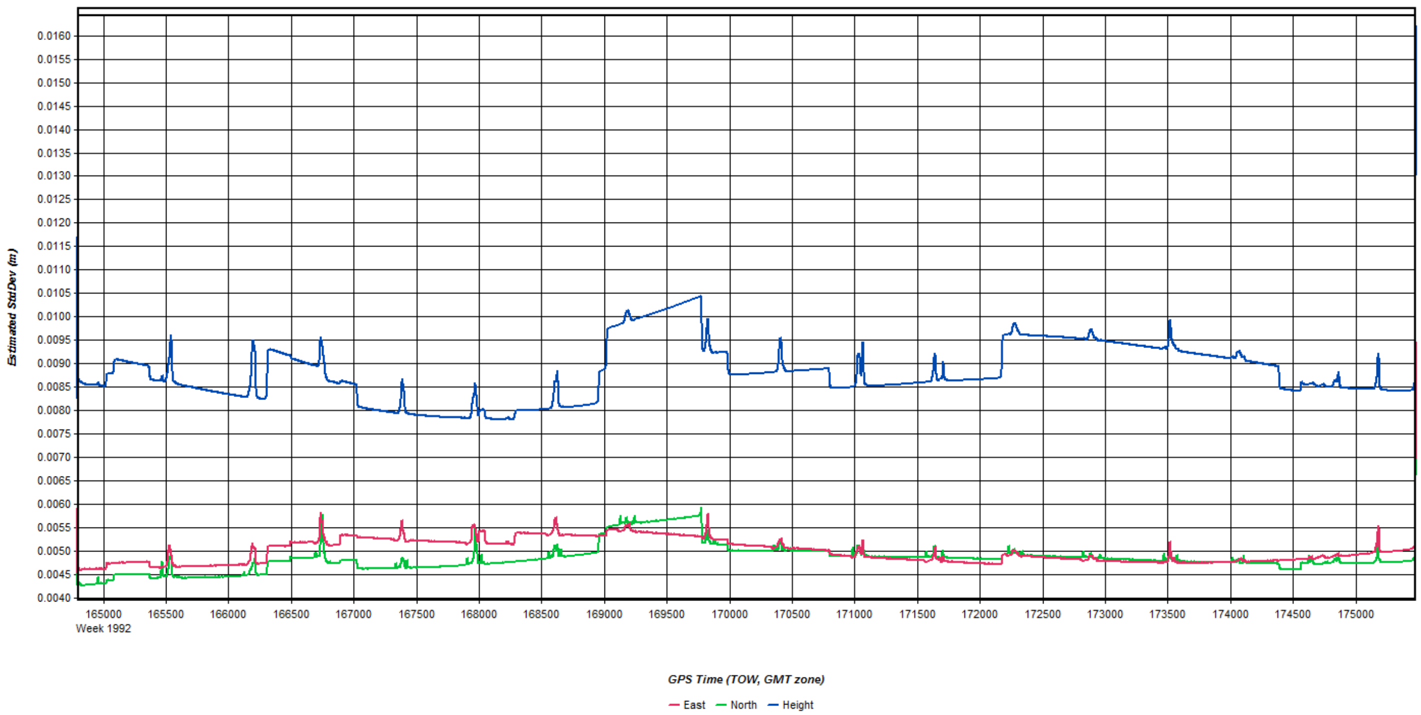

PDOP
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
53500
Week 1992
54000
54500
55000
55500
56000
56500
57000
57500
58000
58500
59000
59500
60000
60500
GPS Time (TOW, GMT zone)
PDOP

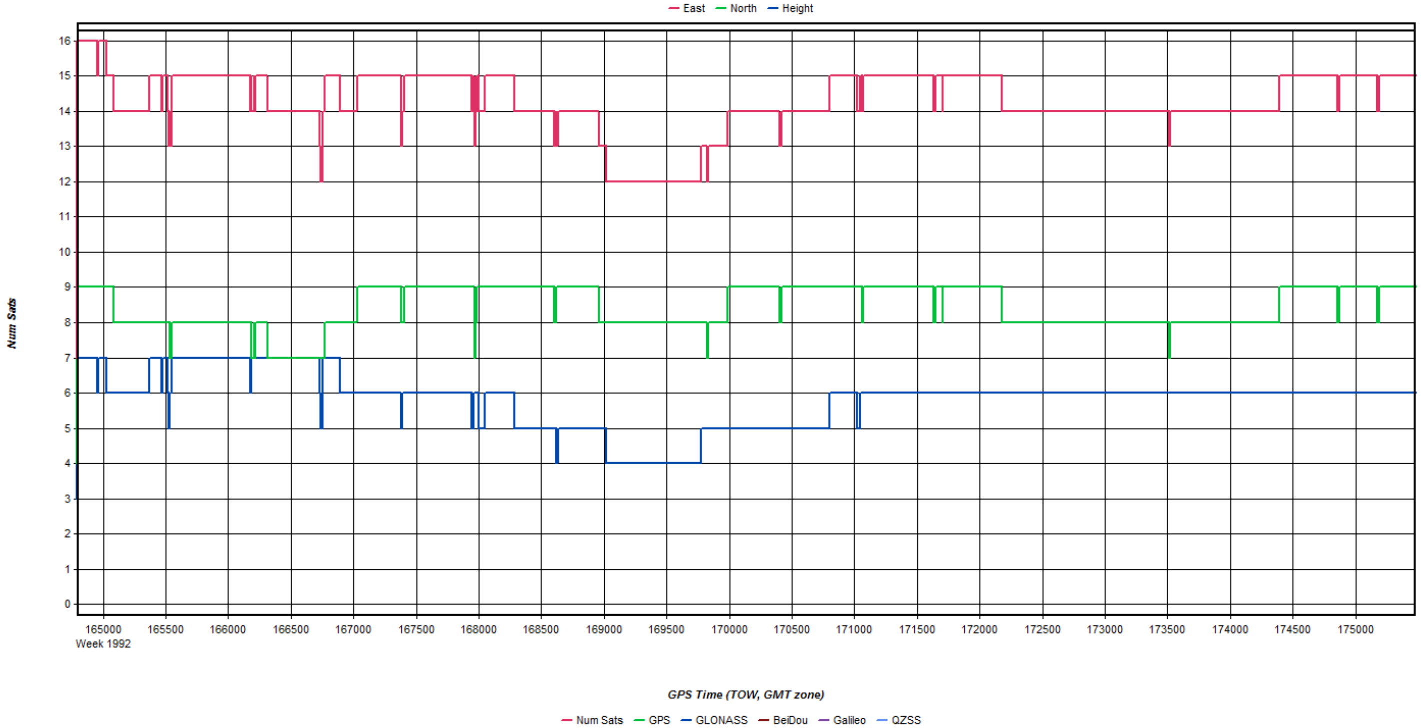
20180312_1

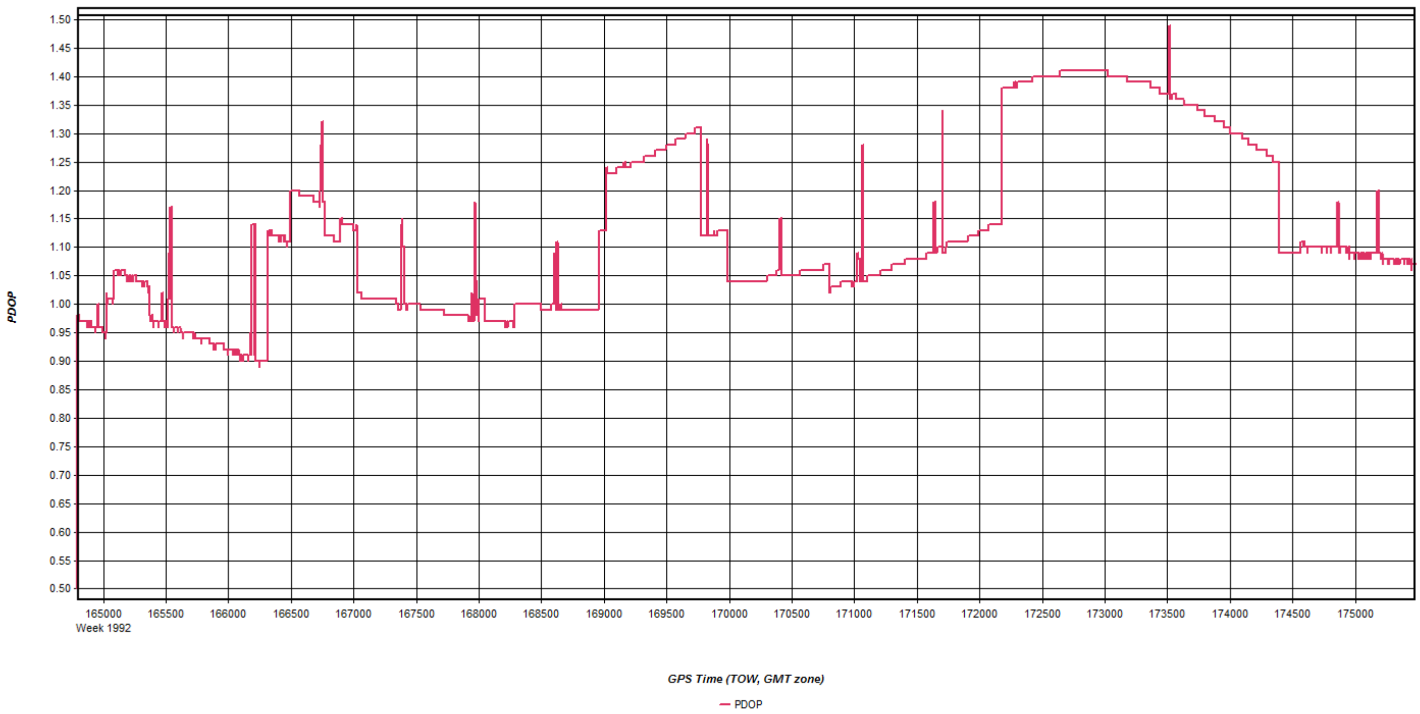




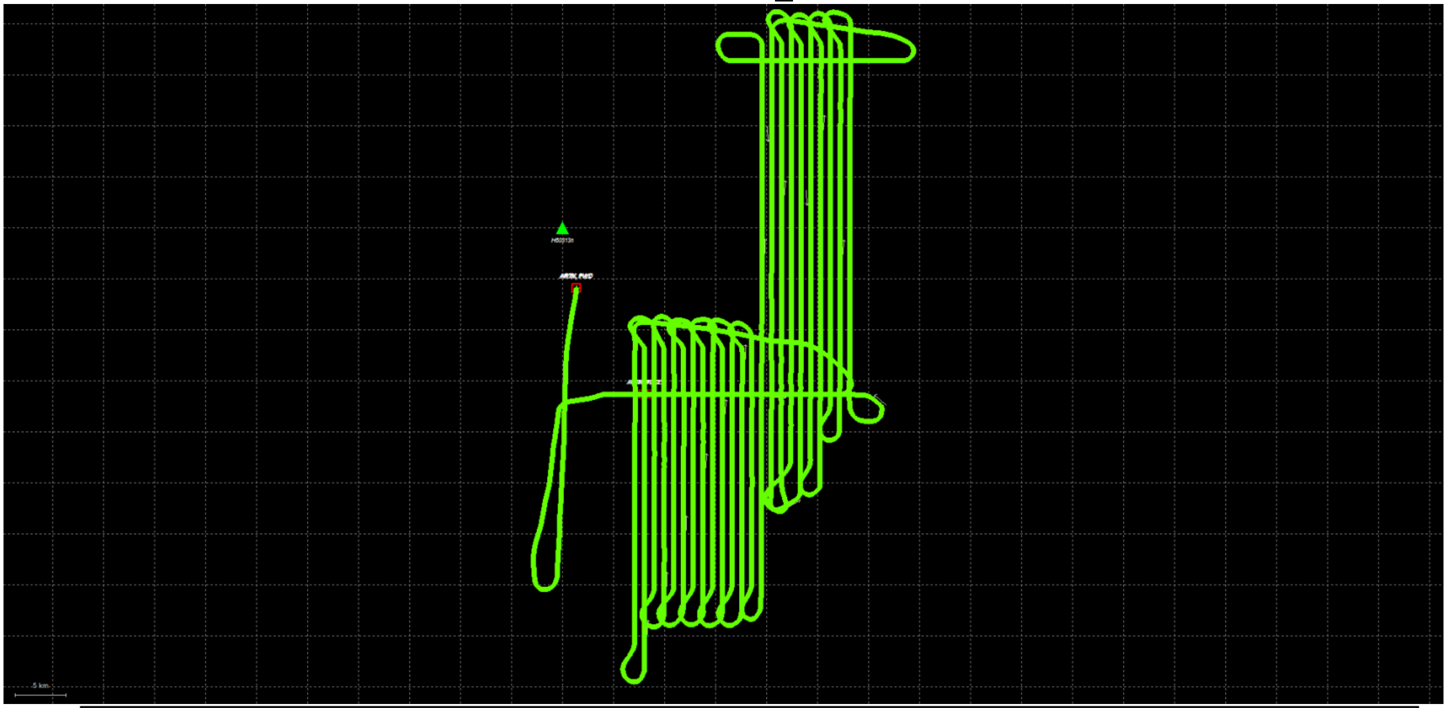
Separation (m)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
165000
165500
166000
166500
167000
167500
168000
168500
169000
169500
170000
170500
171000
171500
172000
172500
173000
173500
174000
174500
175000
Week 1992
GPS Time (TOW, GMT zone)
East
North
Up

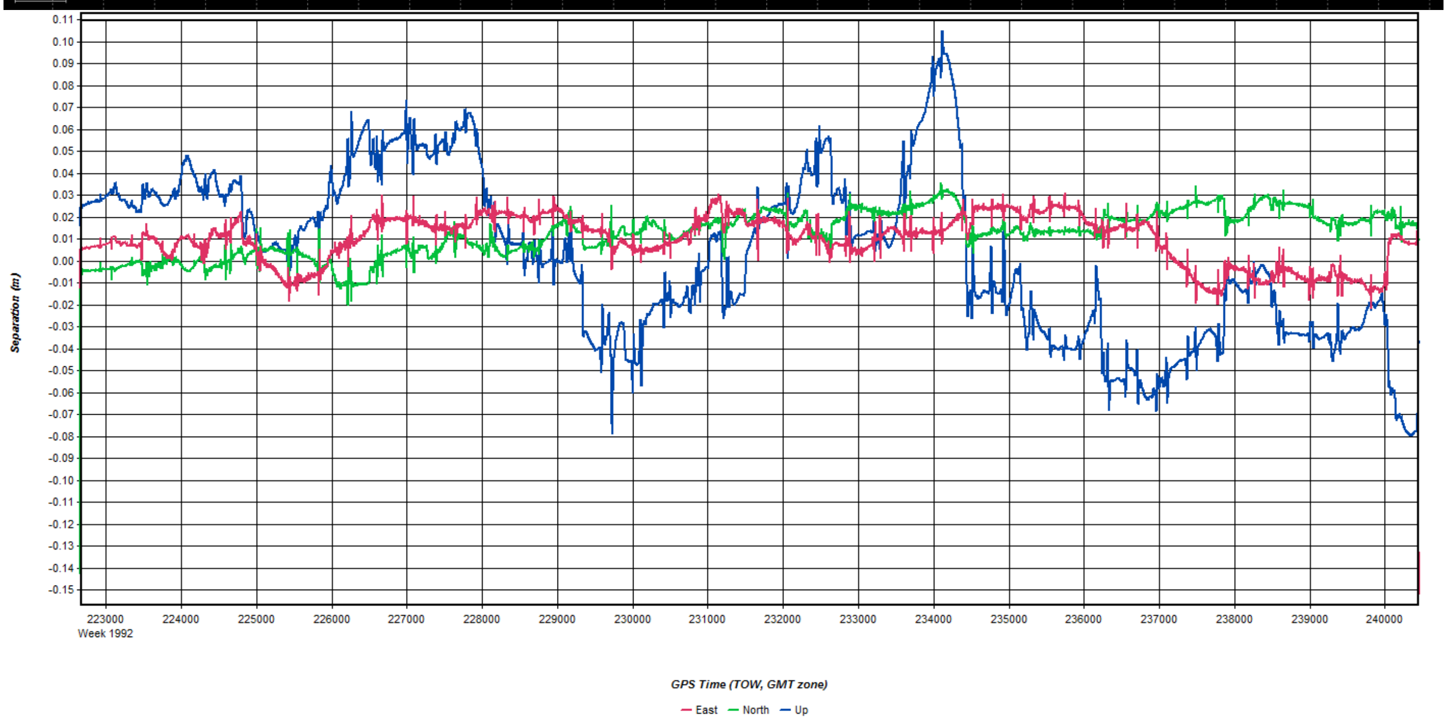

Estimated Std Dev (m)
GPS Time (TOW, GMT zone)
Week 1992
East
North
Height

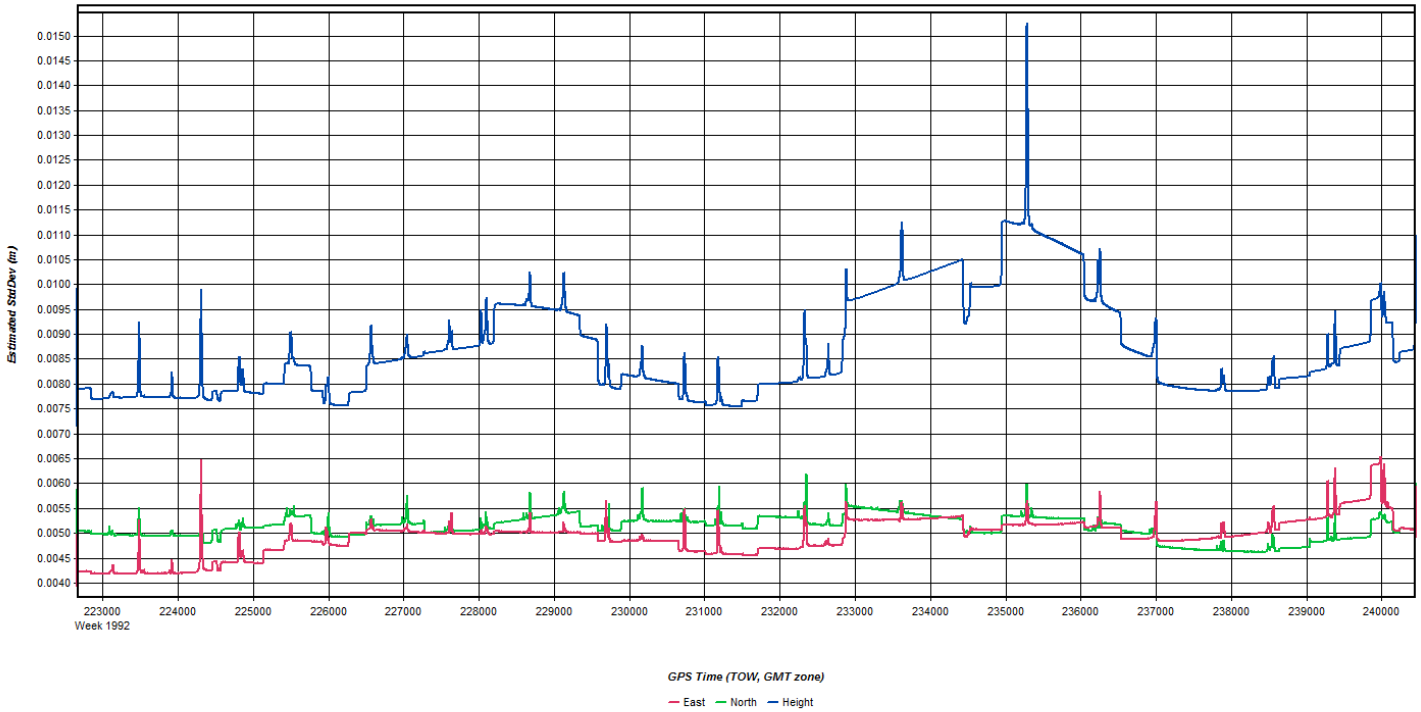

Num Sats
GPS Time (TOW, GMT zone)
Week 1992
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


PDOP
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
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
165000
165500
166000
166500
167000
167500
168000
168500
169000
169500
170000
170500
171000
171500
172000
172500
173000
173500
174000
174500
175000
Week 1992
GPS Time (TOW, GMT zone)
PDOP

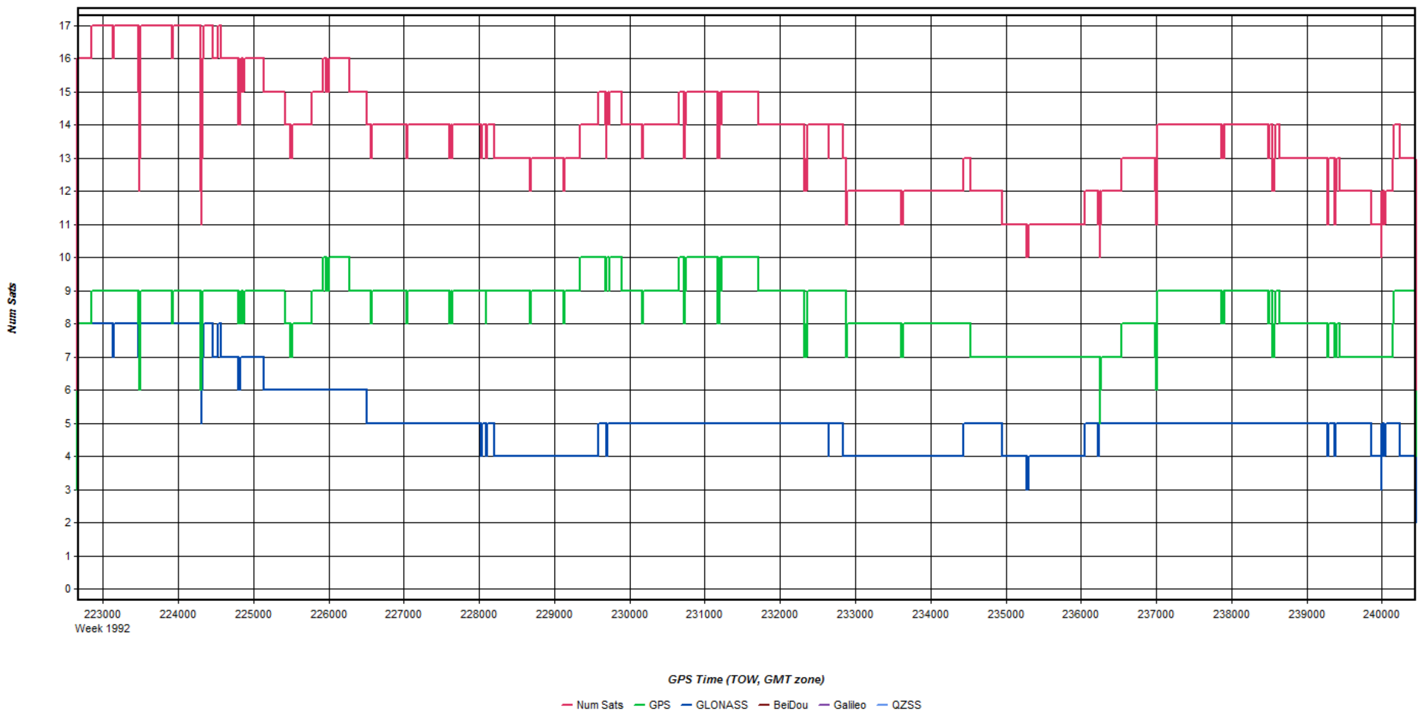
20180313_1



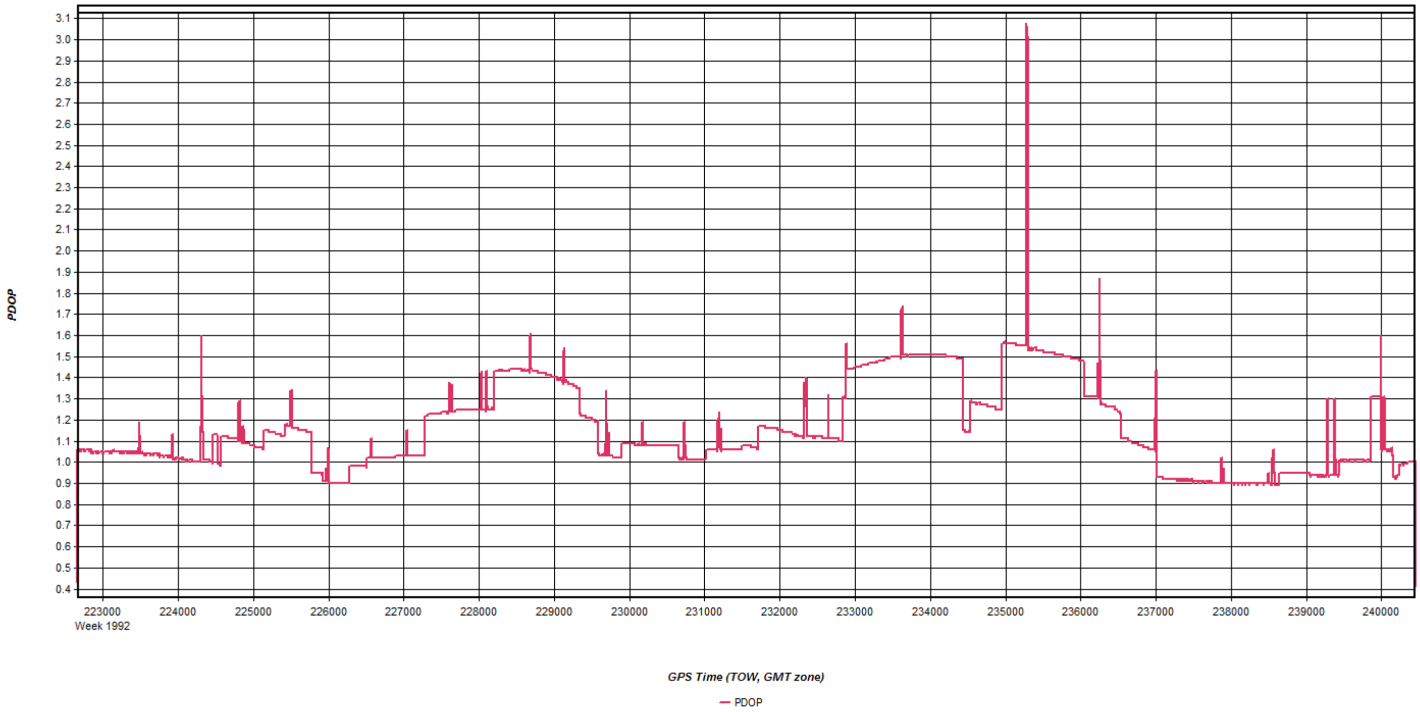

0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
-0.11
-0.12
-0.13
-0.14
-0.15
Separation (m)
223000
Week 1992
224000
225000
226000
227000
228000
229000
230000
231000
232000
233000
234000
235000
236000
237000
238000
239000
240000
GPS Time (TOW, GMT zone)
East
North
Up



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
223000 224000 225000 226000 227000 228000 229000 230000 231000 232000 233000 234000 235000 236000 237000 238000 239000 240000
Week 1992
GPS Time (TOW, GMT zone)
East North Height



Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
223000 224000 225000 226000 227000 228000 229000 230000 231000 232000 233000 234000 235000 236000 237000 238000 239000 240000
Week 1992
GPS Time (TOW, GMT zone)
Num Sats GPS GLONASS BeiDou Galileo QZSS



PDOP
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
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
0.8
0.7
0.6
0.5
0.4
223000
Week 1992
224000
225000
226000
227000
228000
229000
230000
231000
232000
233000
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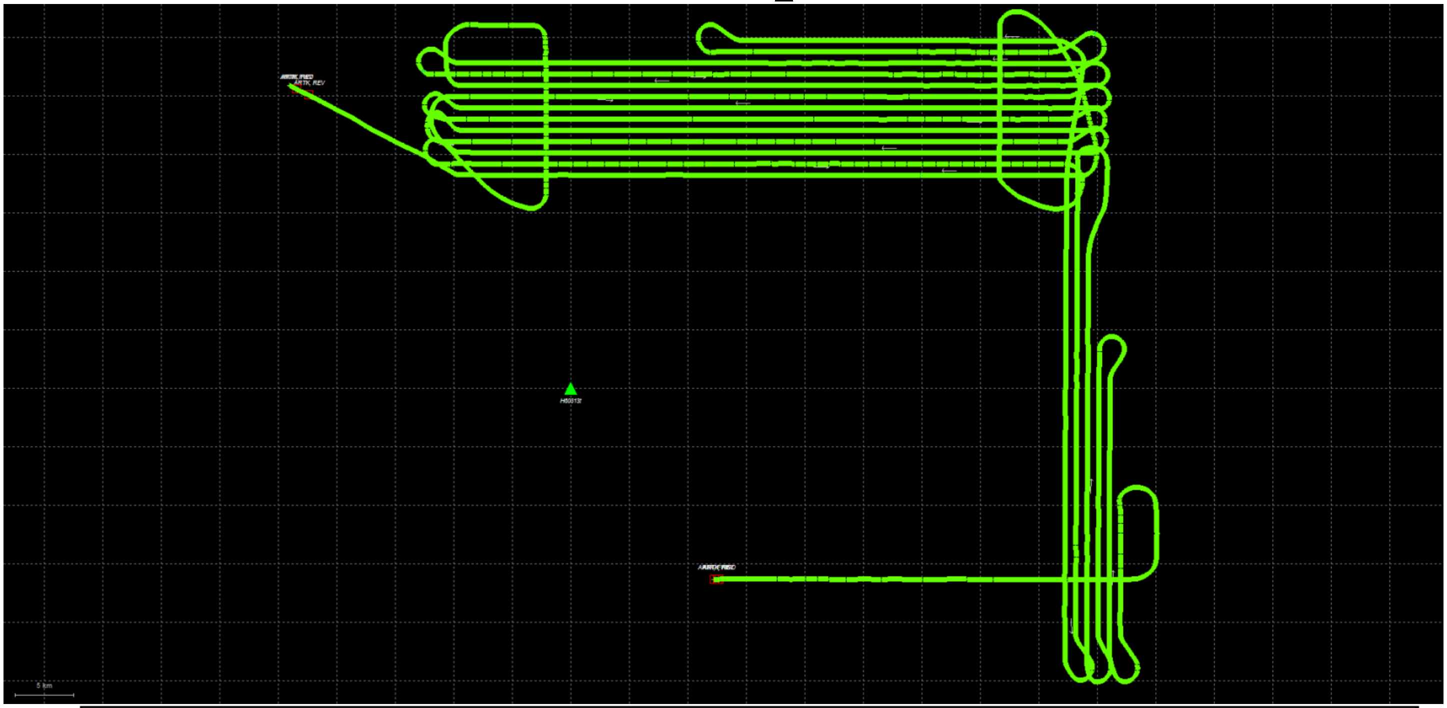
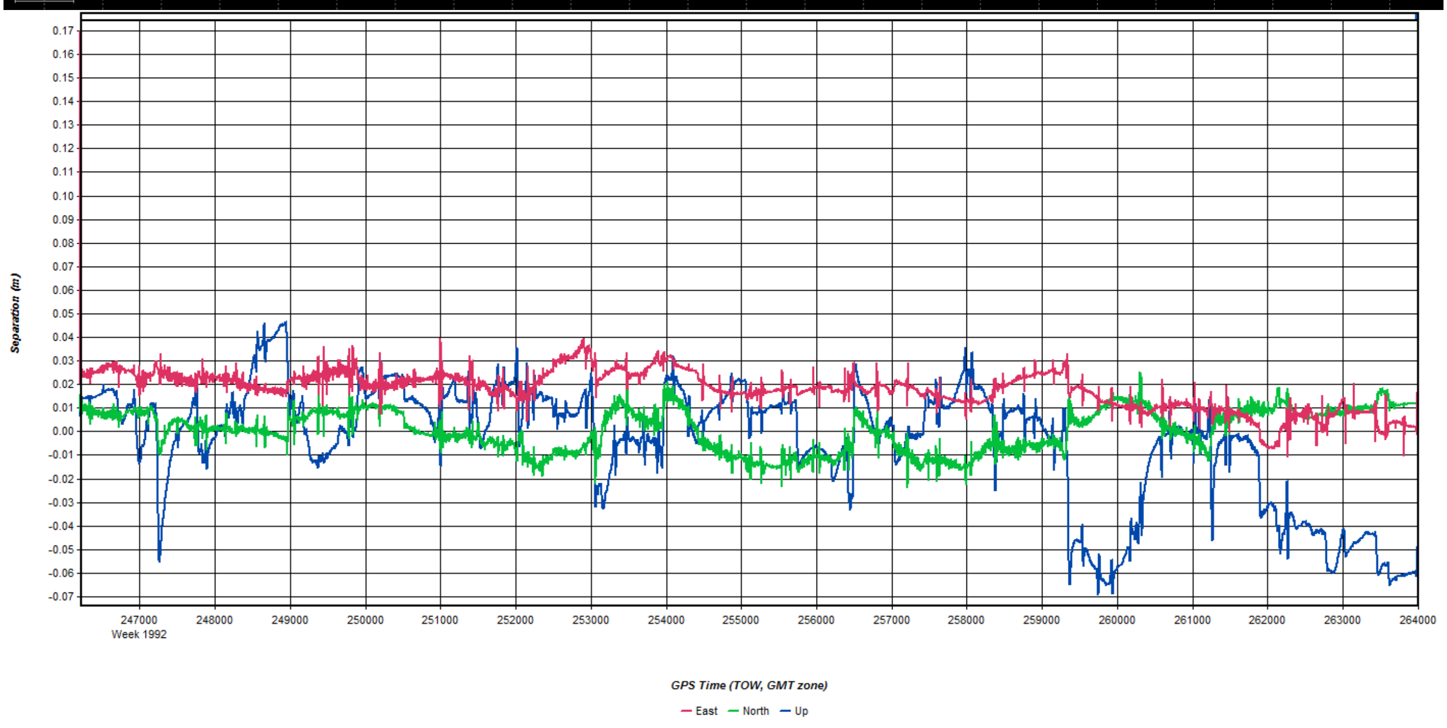
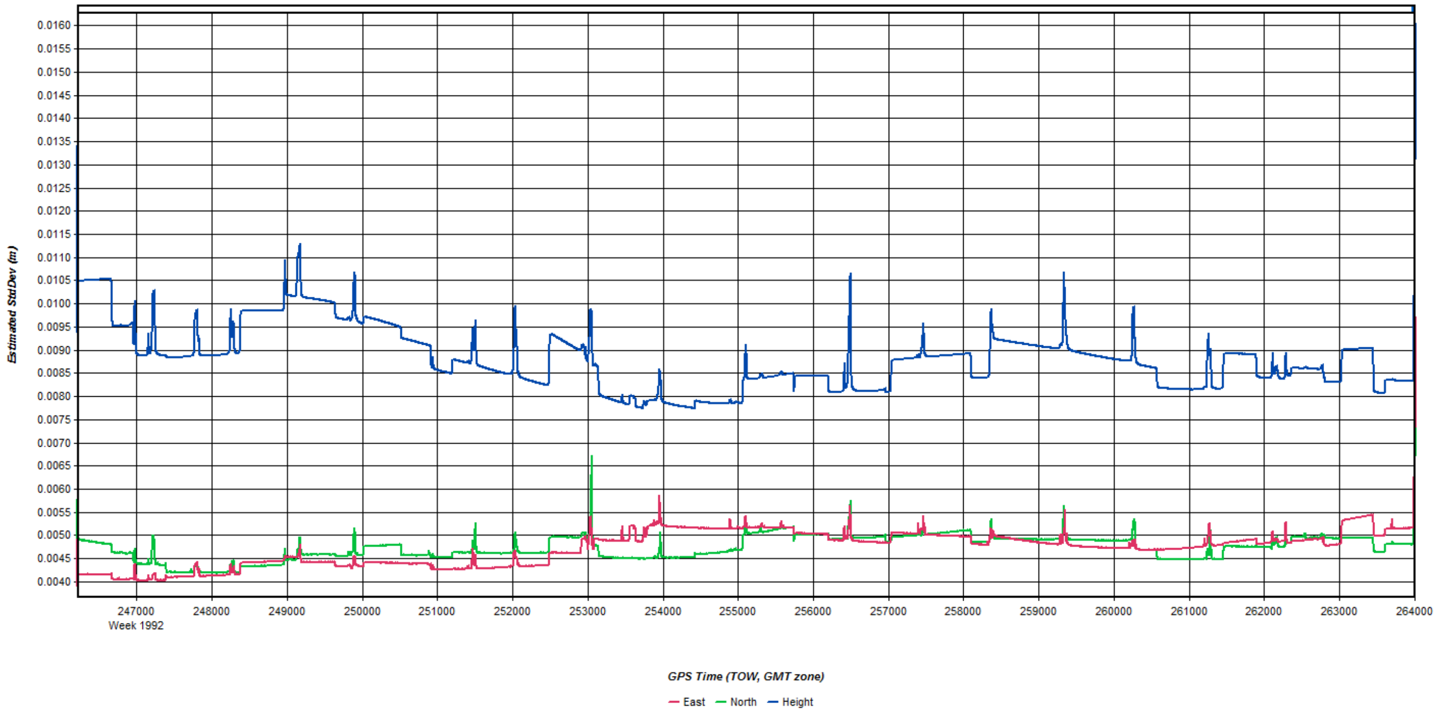
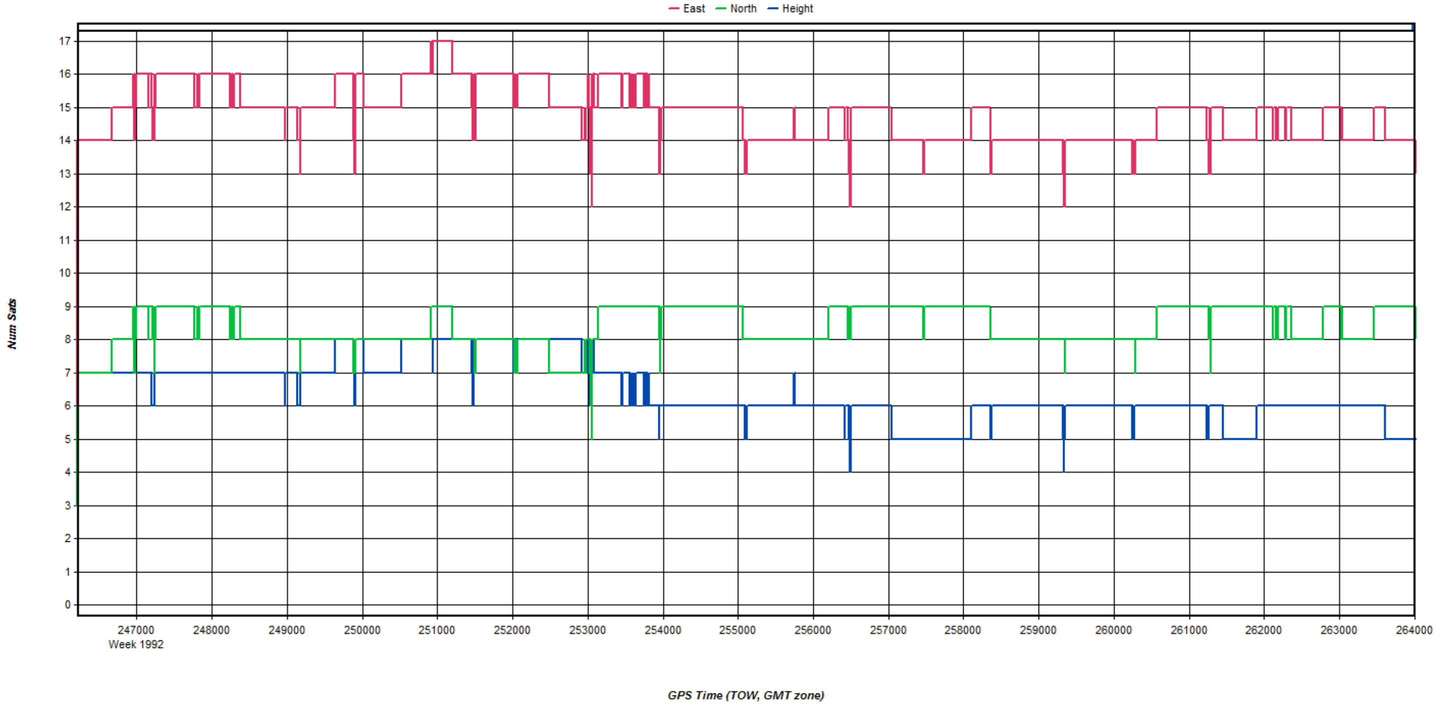
236000
237000
238000
239000
240000
GPS Time (TOW, GMT zone)
PDOP

20180313_2



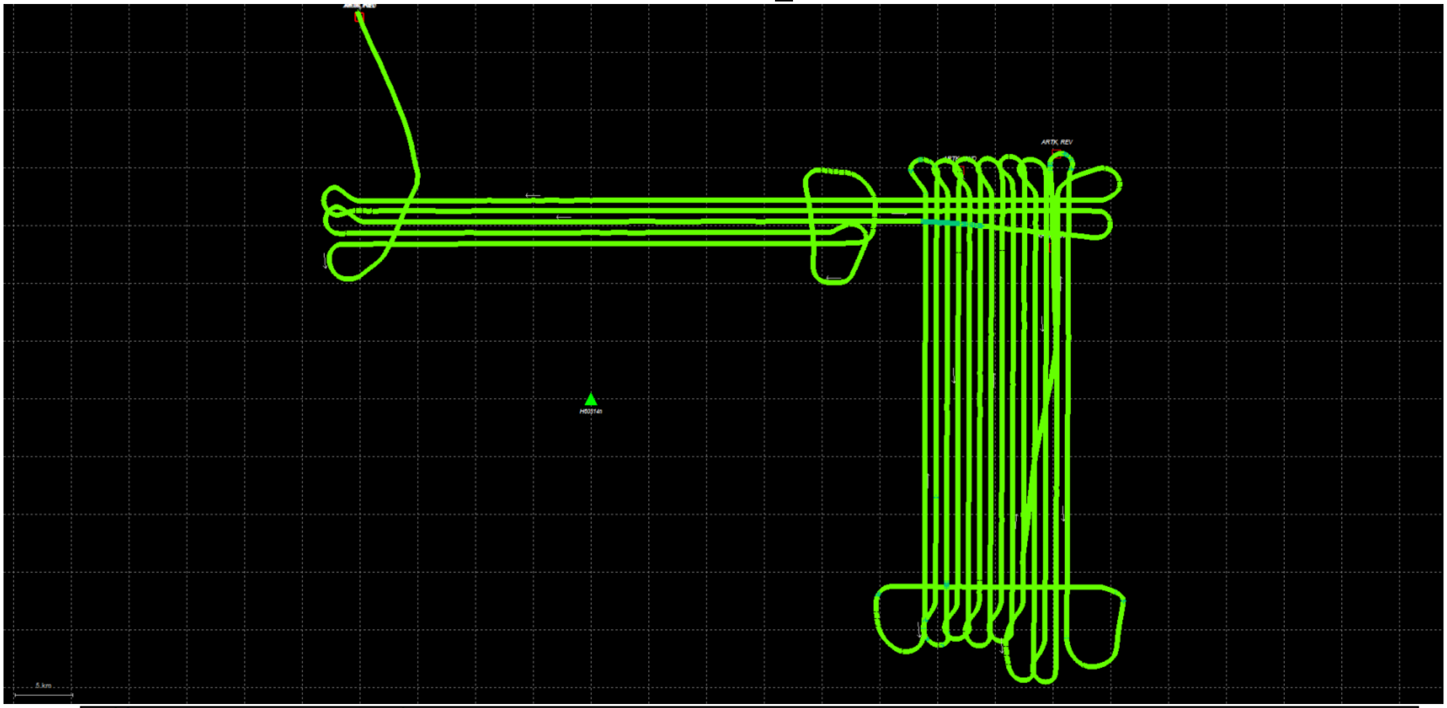

Separation (m)
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
247000
Week 1992
248000
249000
250000
251000
252000
253000
254000
255000
256000
257000
258000
259000
260000
261000
262000
263000
264000
GPS Time (TOW, GMT zone)
East
North
Up

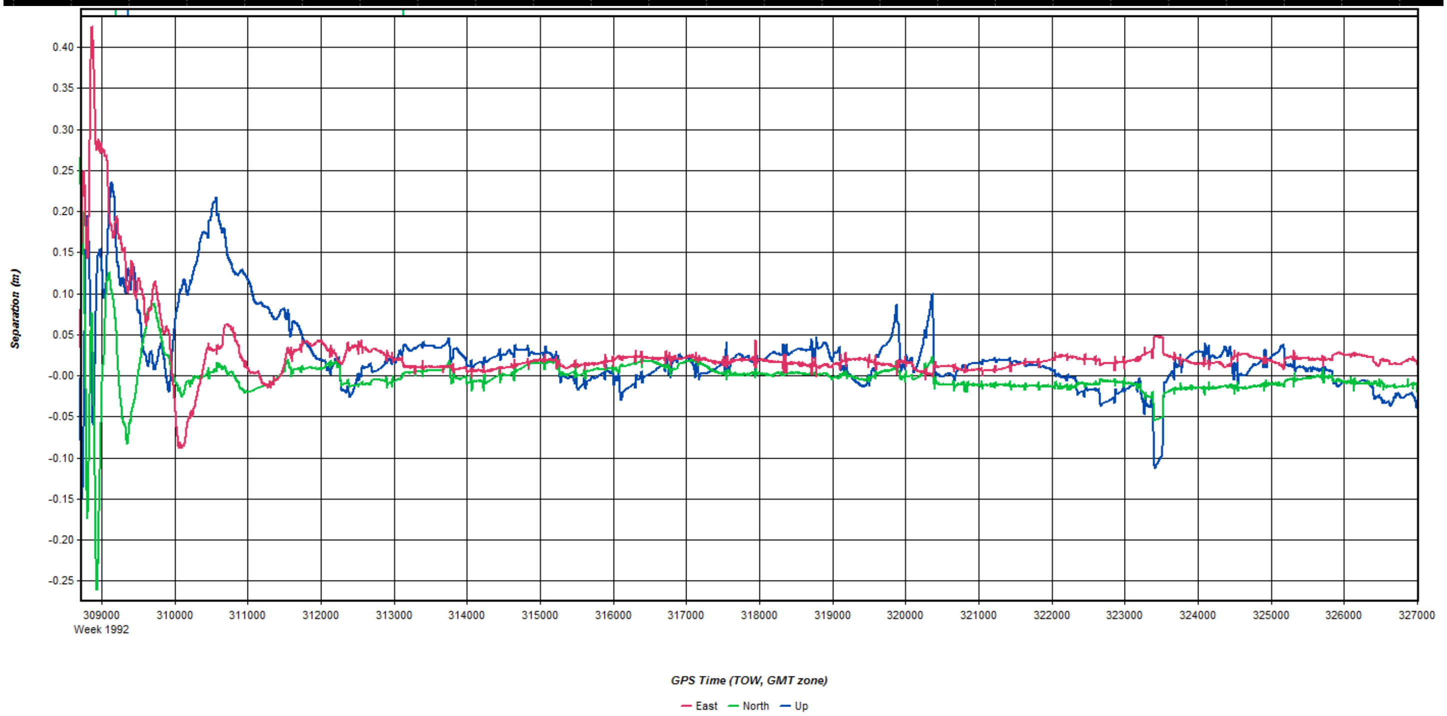

Estimated StdDev (m)
0.0160
0.0155
0.0150
0.0145
0.0140
0.0135
0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
247000 248000 249000 250000 251000 252000 253000 254000 255000 256000 257000 258000 259000 260000 261000 262000 263000 264000
Week 1992
GPS Time (TOW, GMT zone)
East North Height

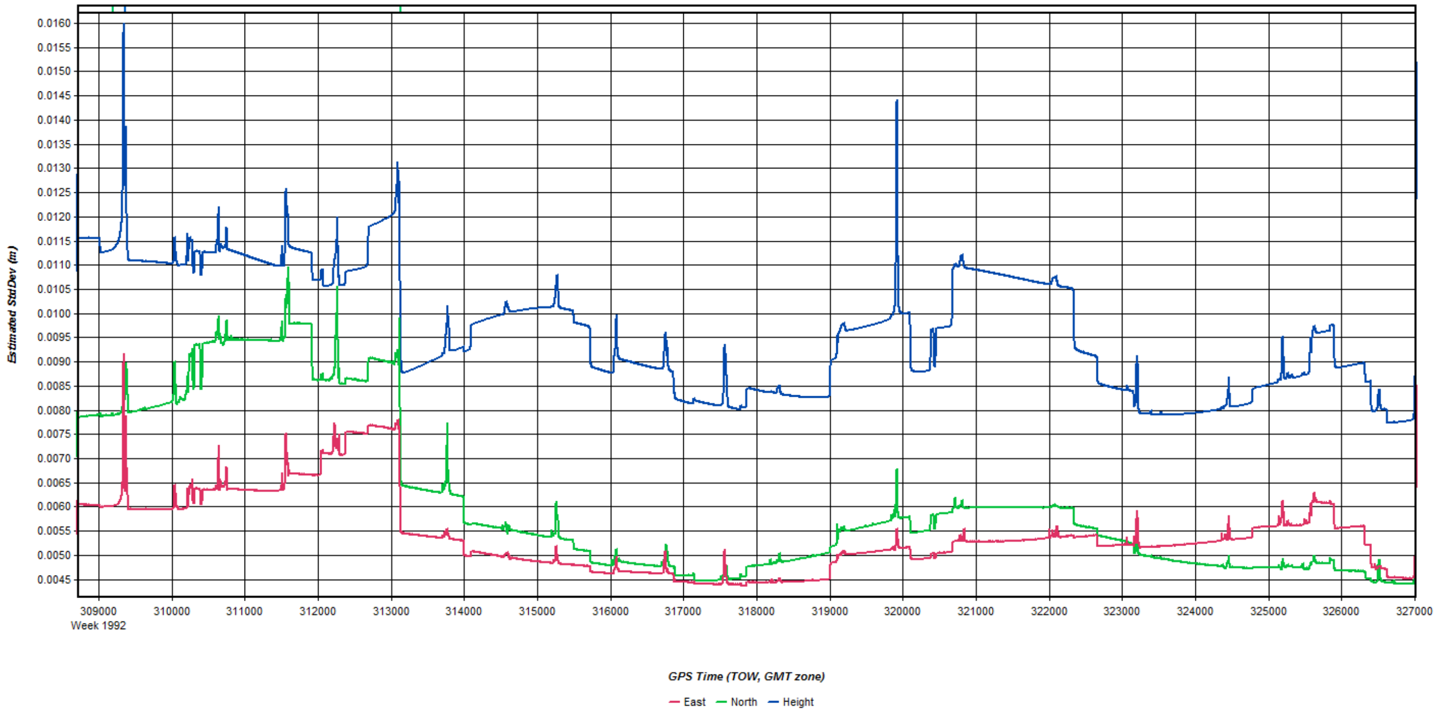

Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
247000 248000 249000 250000 251000 252000 253000 254000 255000 256000 257000 258000 259000 260000 261000 262000 263000 264000
Week 1992
GPS Time (TOW, GMT zone)
Num Sats GPS GLONASS BeiDou Galileo QZSS

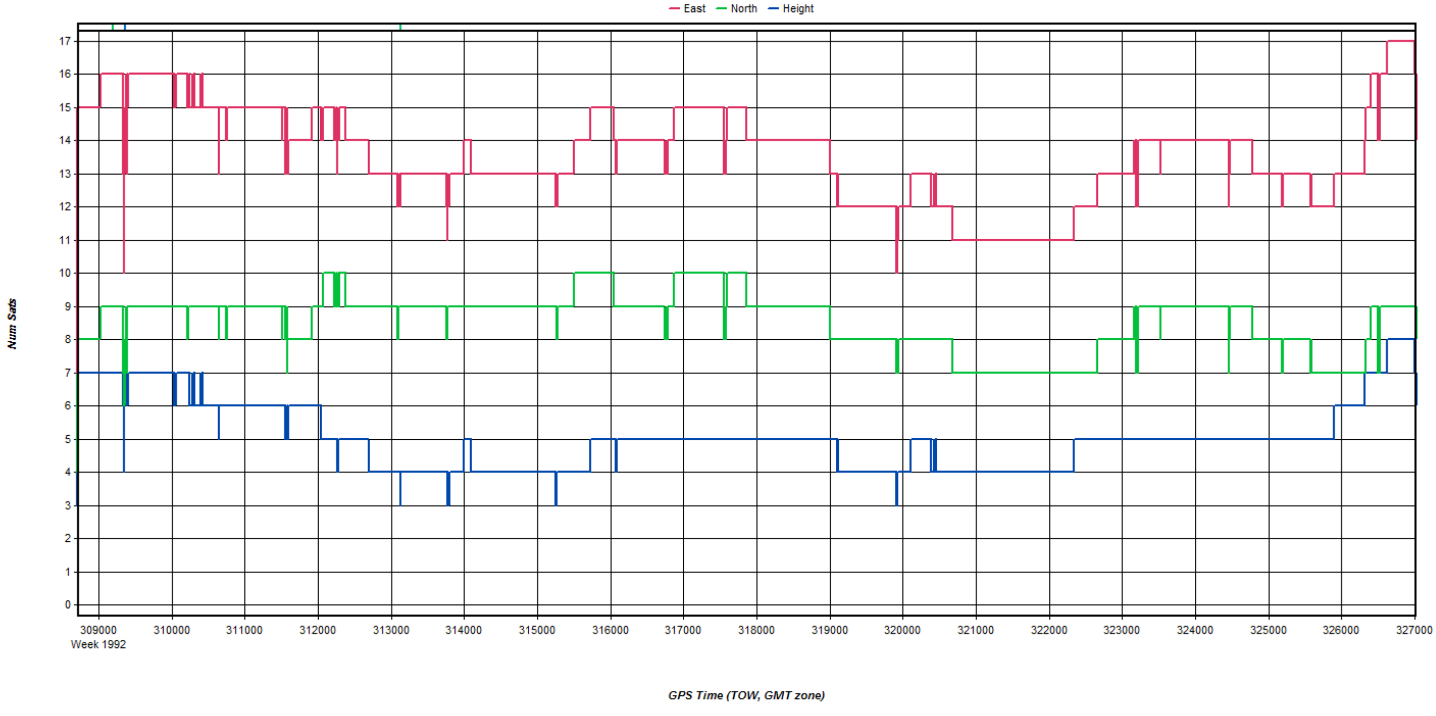

PDOP
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
247000
Week 1992
248000
249000
250000
251000
252000
253000
254000
255000
256000
257000
258000
259000
260000
261000
262000
263000
264000
GPS Time (TOW, GMT zone)
PDOP

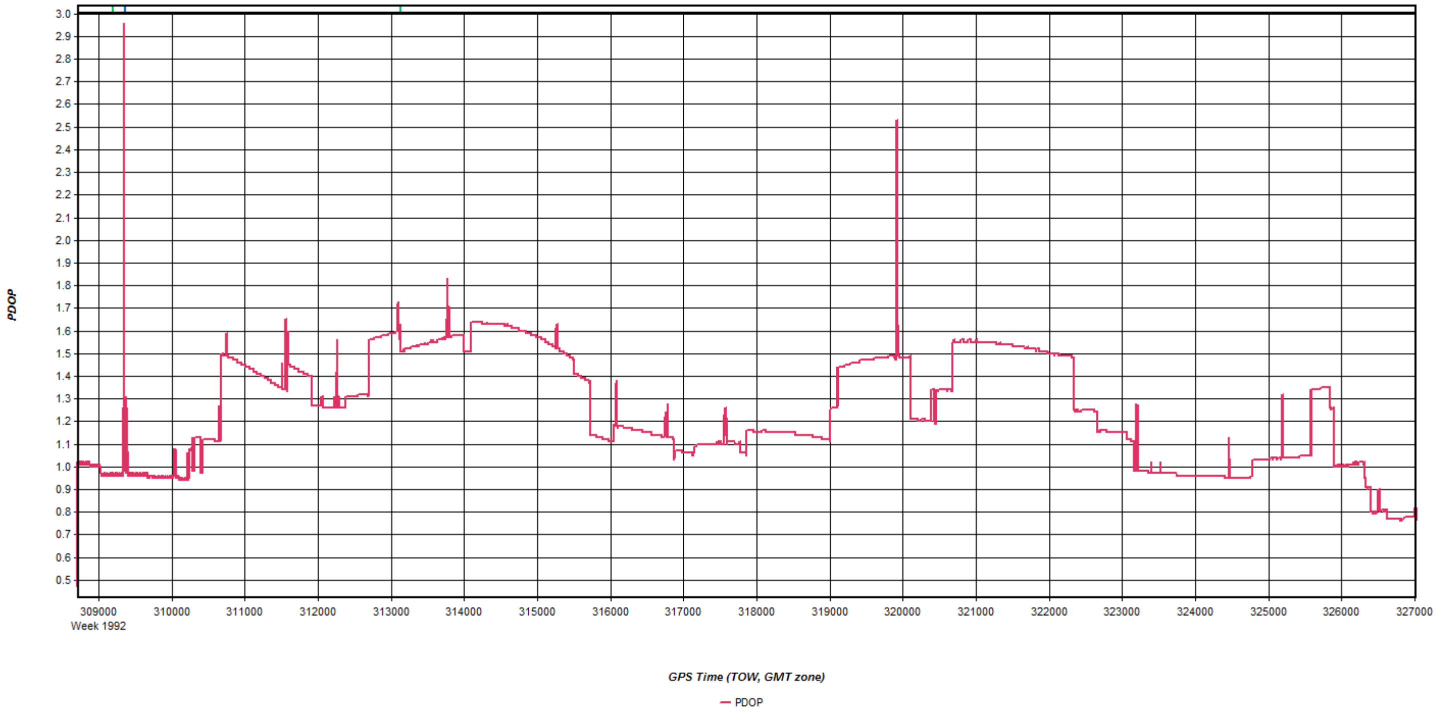
20180314_1




Separation (m)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
-0.20
-0.25
309000
Week 1992
310000
311000
312000
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
327000
GPS Time (TOW, GMT zone)
East
North
Up


Estimated StdDev (m)
0.0160
0.0155
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
309000
Week 1992
310000
311000
312000
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
327000
GPS Time (TOW, GMT zone)
East
North
Height


Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
309000
Week 1992
310000
311000
312000
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
327000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


PDOP
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
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
0.8
0.7
0.6
0.5
309000
Week 1992
310000
311000
312000
313000
314000
315000
316000
317000
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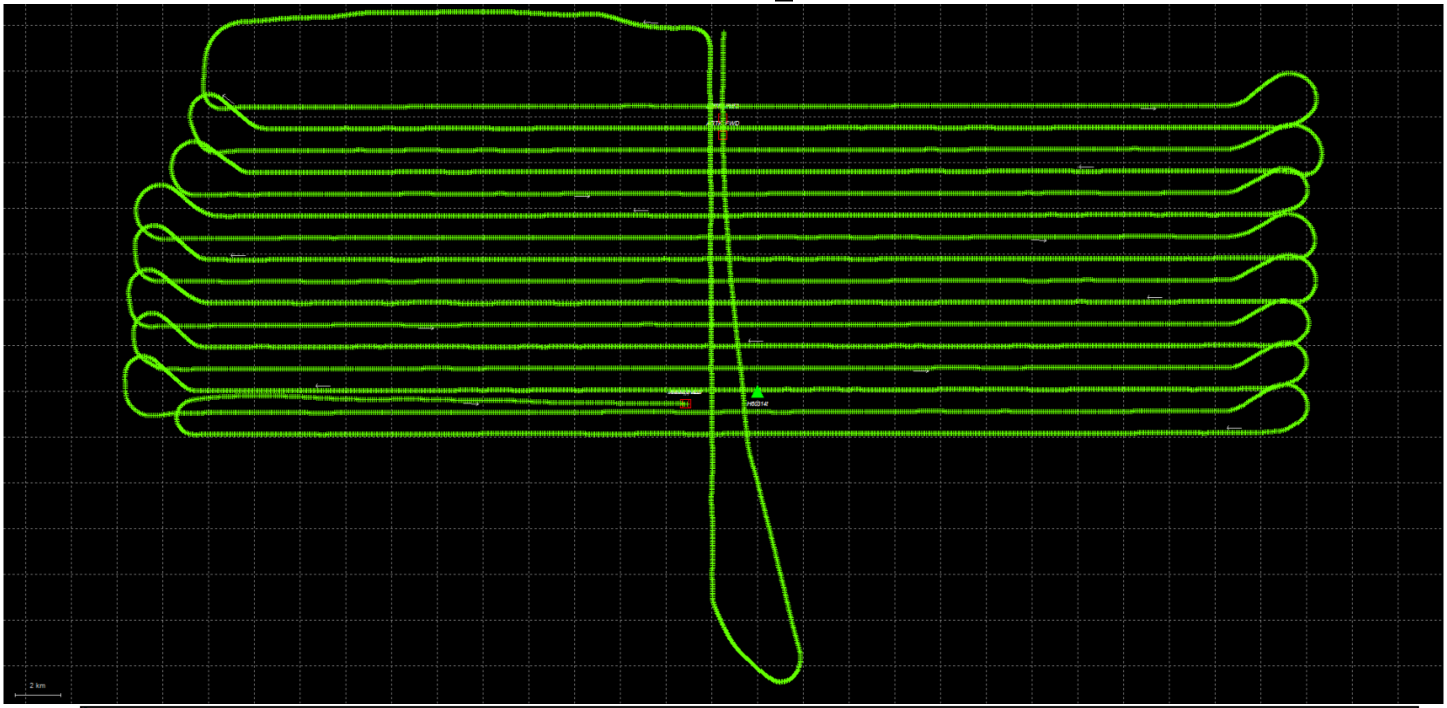
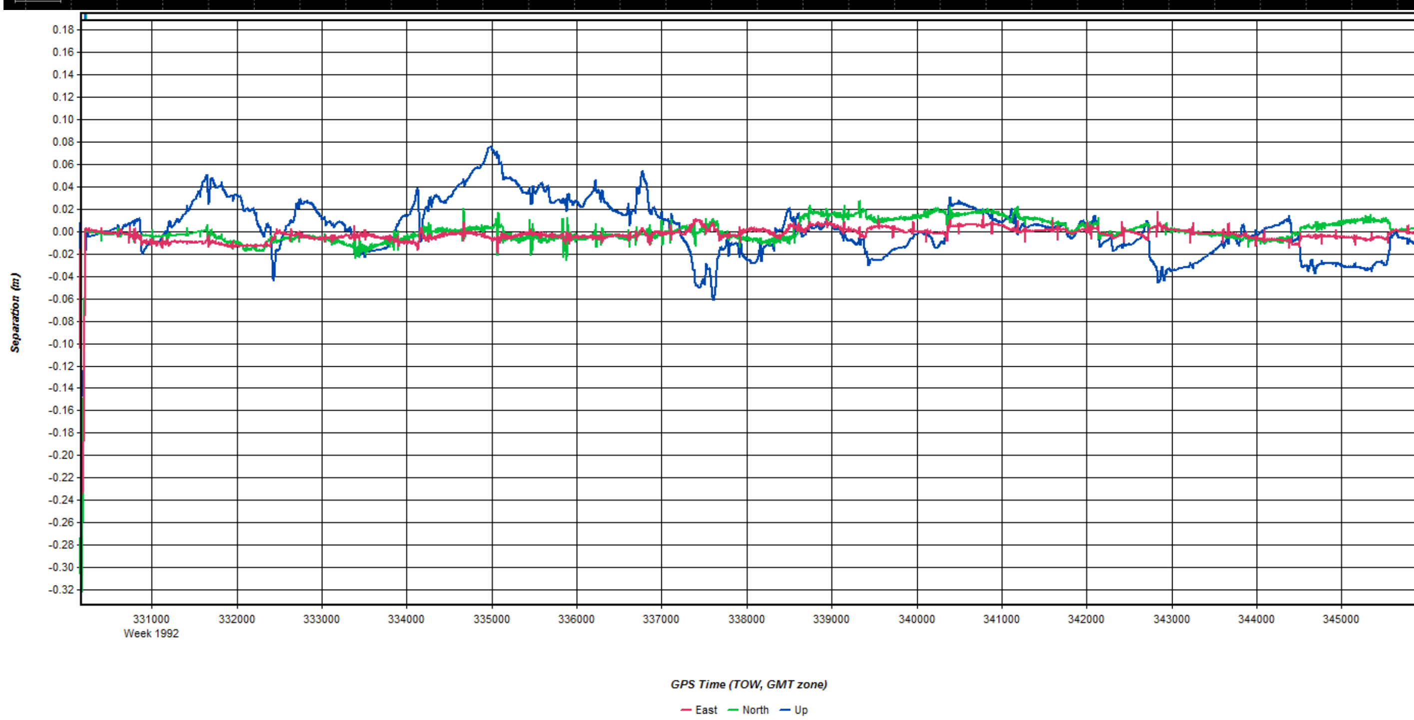
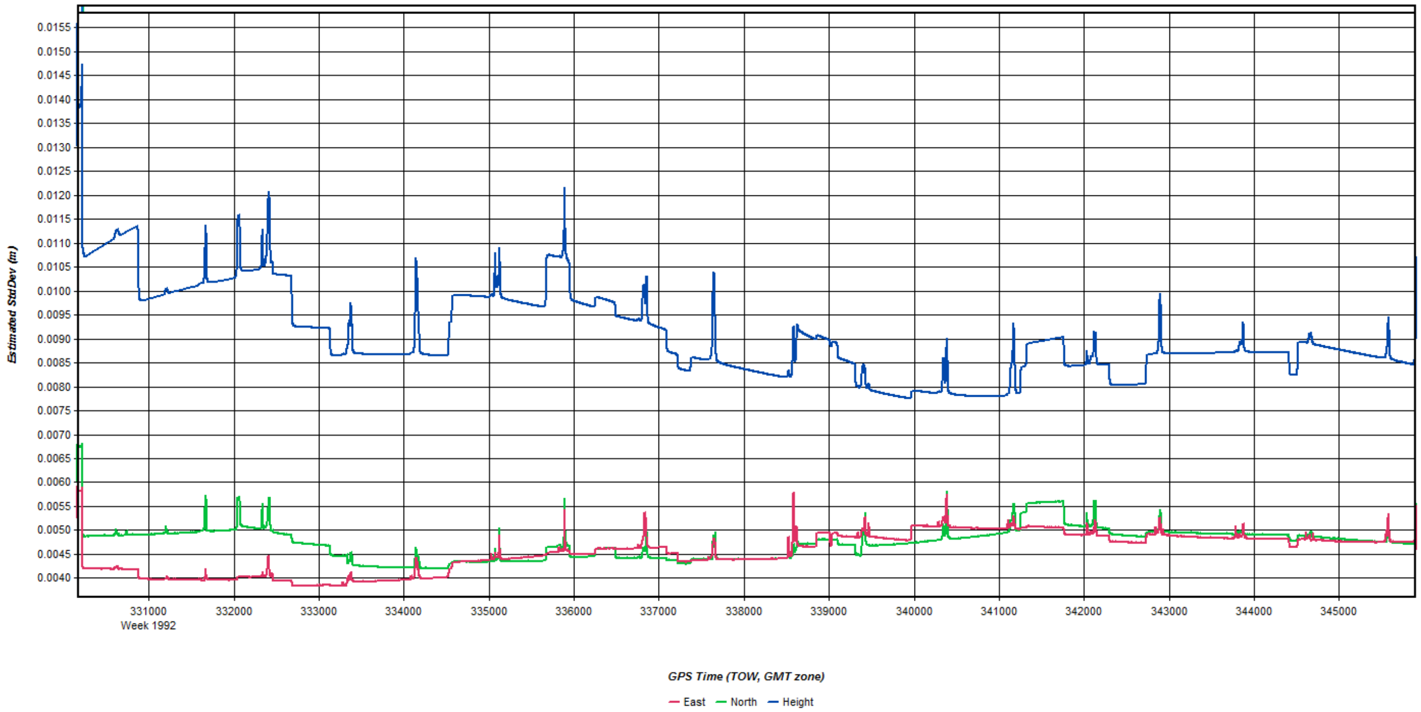
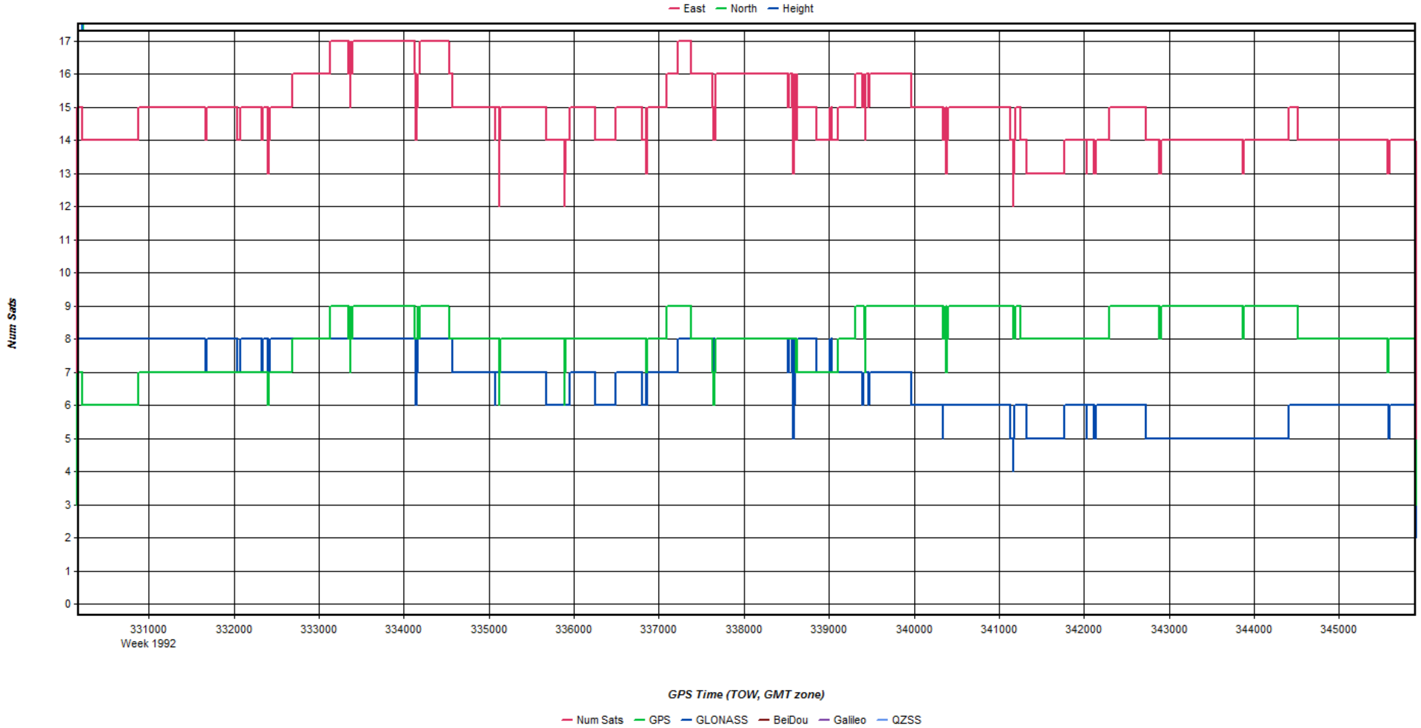
322000
323000
324000
325000
326000
327000
GPS Time (TOW, GMT zone)
PDOP

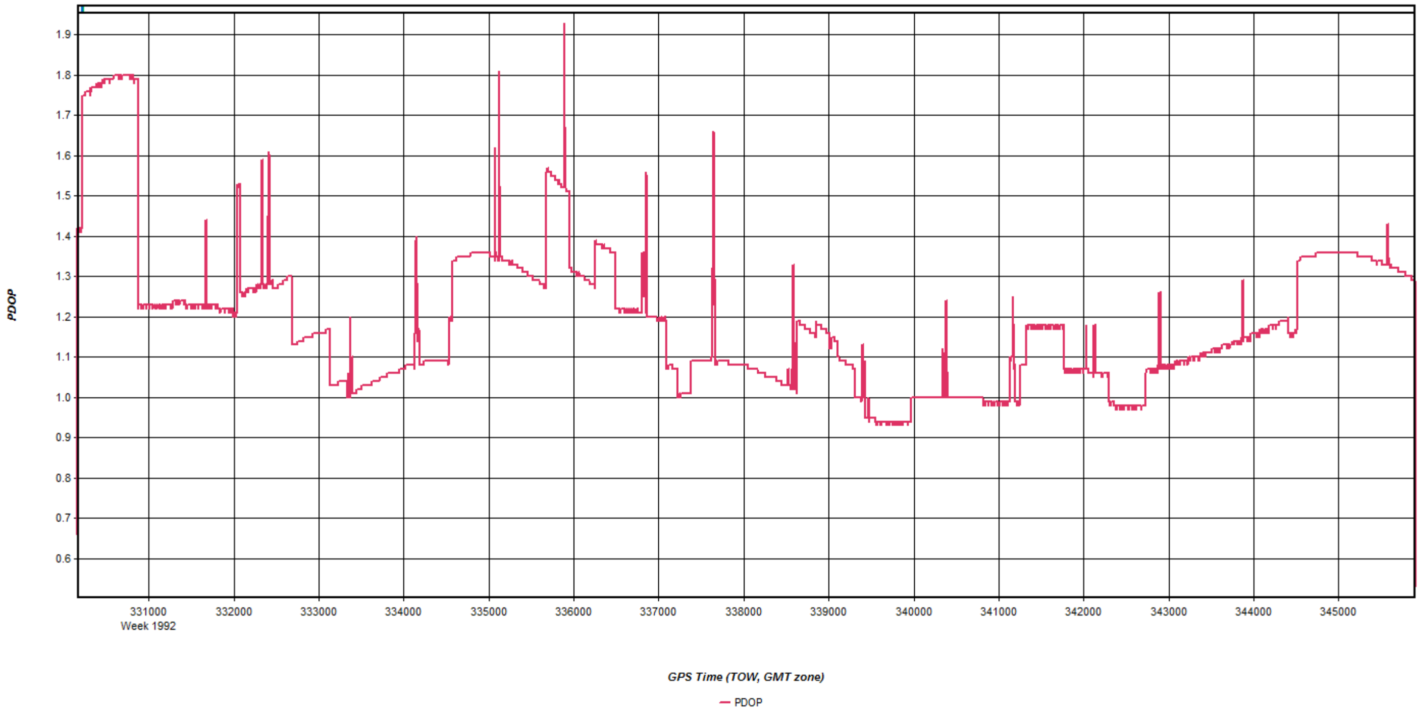
20180314_2


2 km


Separation (m)
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
-0.24
-0.26
-0.28
-0.30
-0.32
331000
Week 1992
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
345000
GPS Time (TOW, GMT zone)
East
North
Up

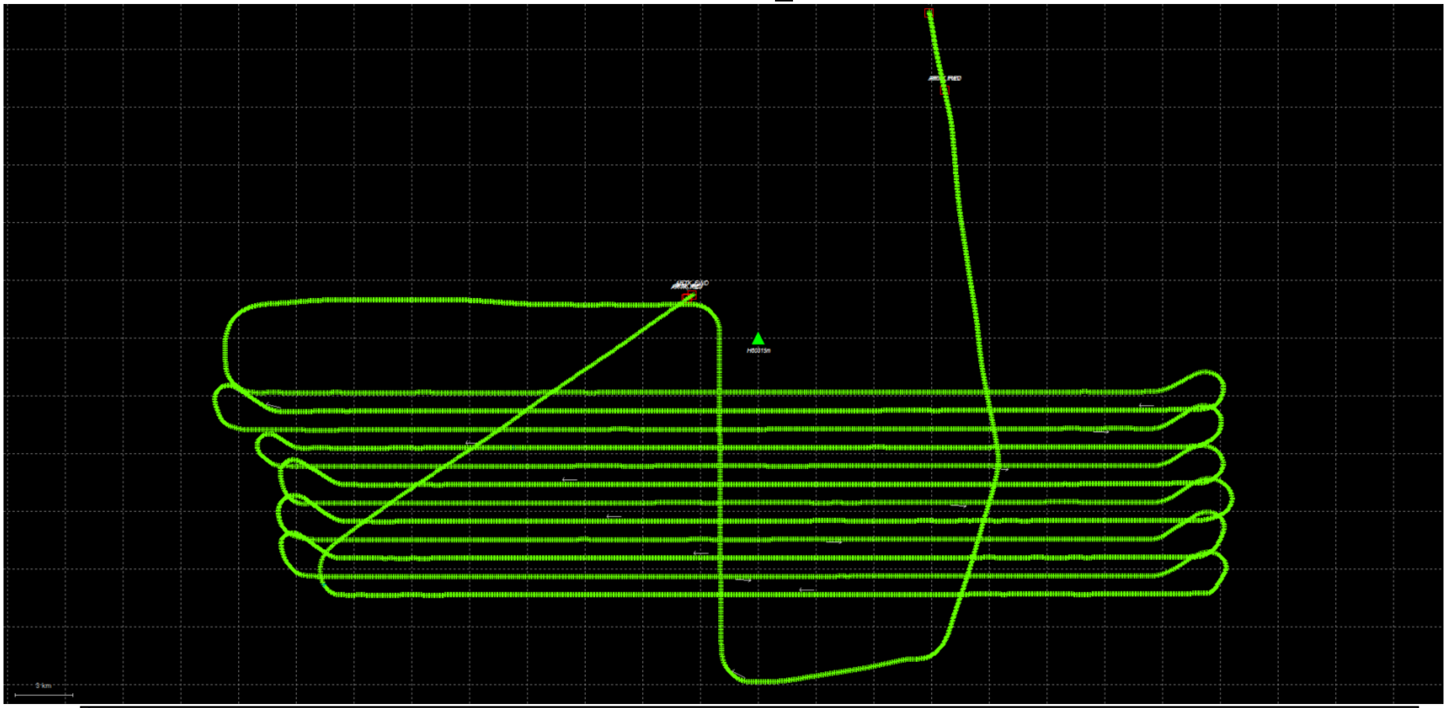

Estimated StdDev (m)
0.0155
0.0150
0.0145
0.0140
0.0135
0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
331000 332000 333000 334000 335000 336000 337000 338000 339000 340000 341000 342000 343000 344000 345000
Week 1992
GPS Time (TOW, GMT zone)
East North Height

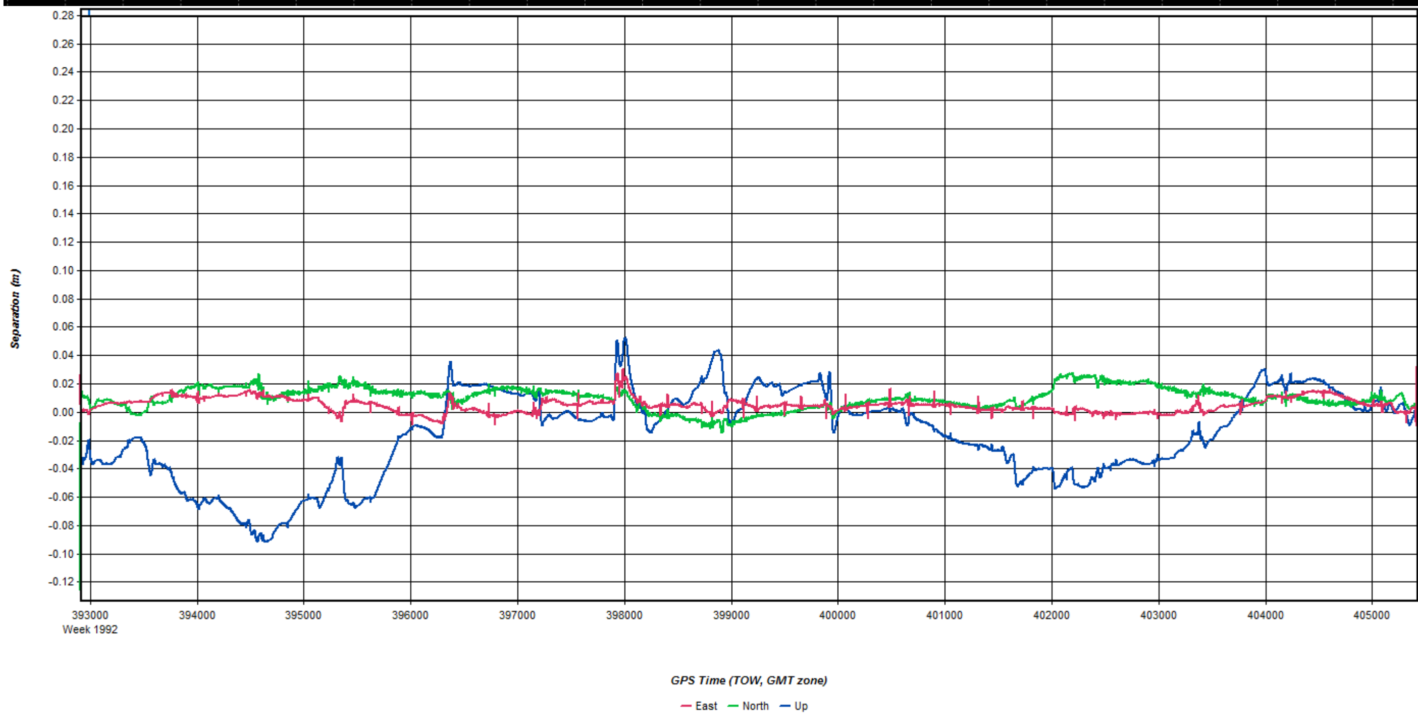

Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
331000 332000 333000 334000 335000 336000 337000 338000 339000 340000 341000 342000 343000 344000 345000
Week 1992
GPS Time (TOW, GMT zone)
Num Sats GPS GLONASS BeiDou Galileo QZSS

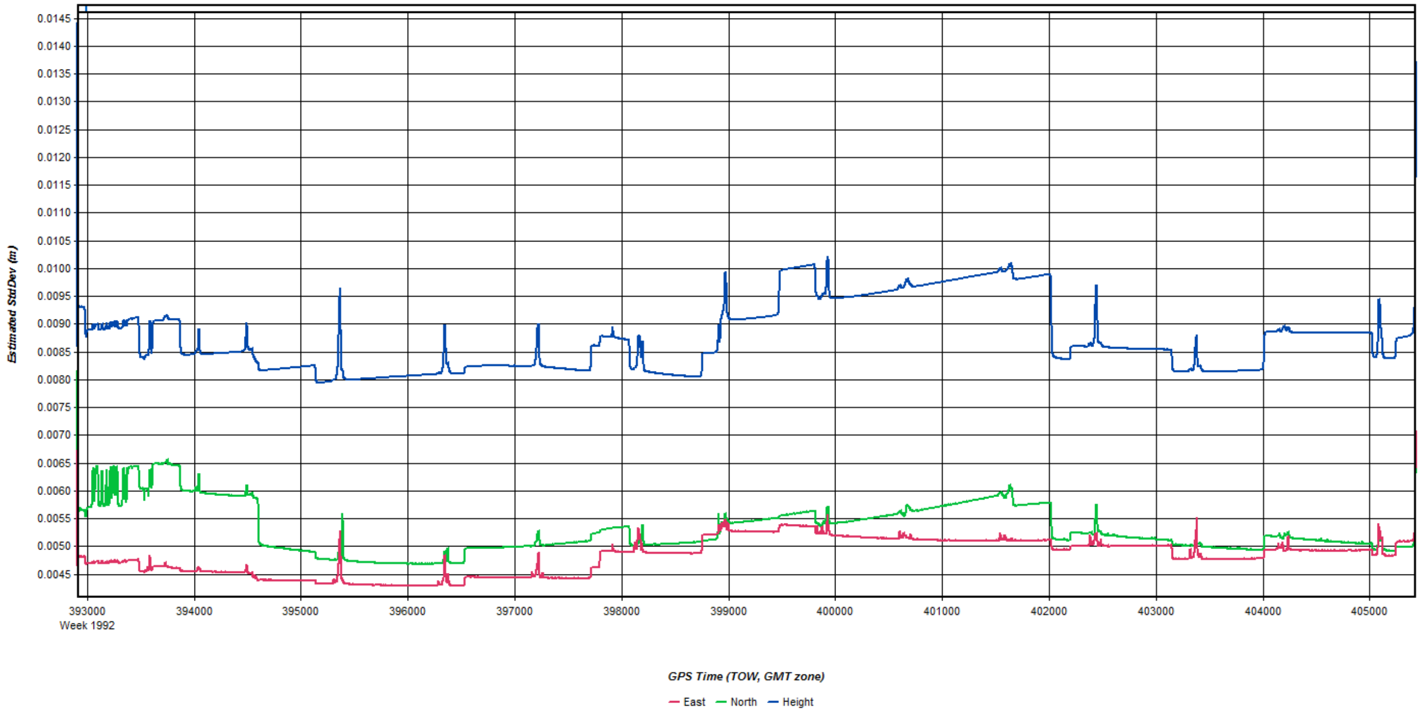


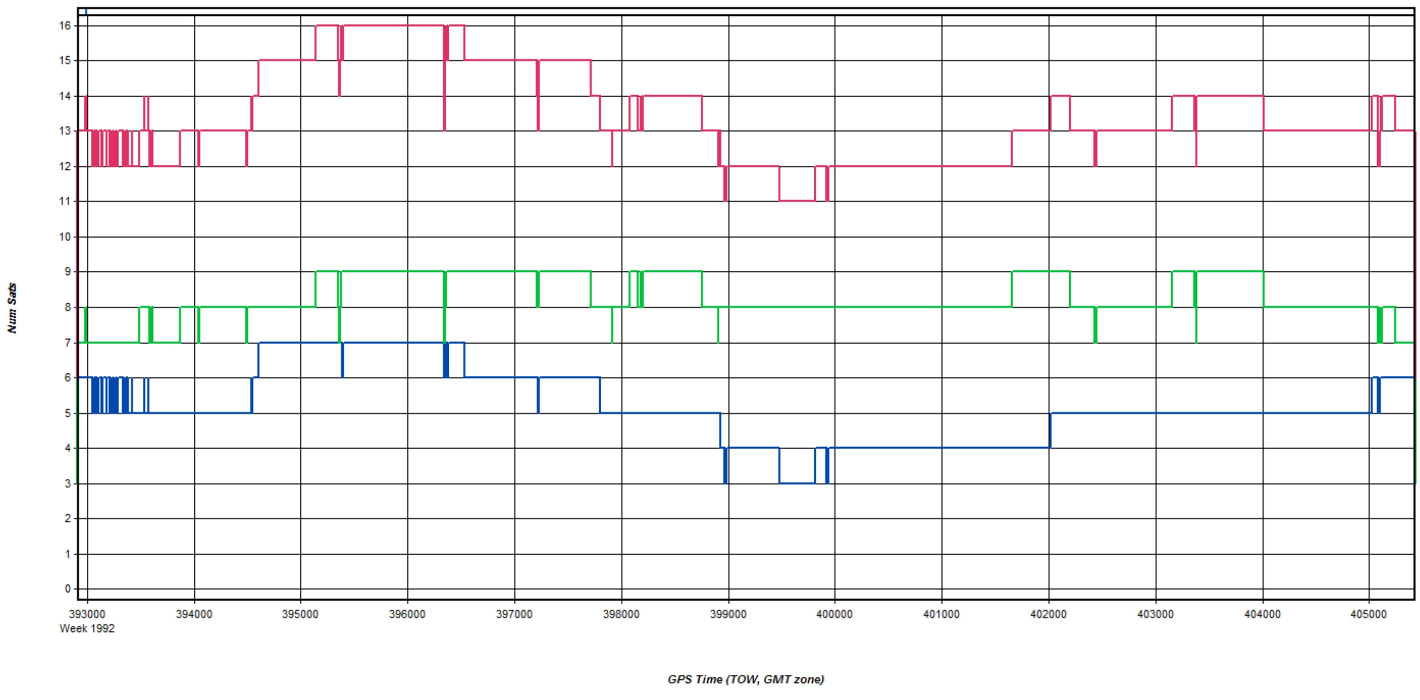
PDOP
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
331000
Week 1992
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
345000
GPS Time (TOW, GMT zone)
PDOP

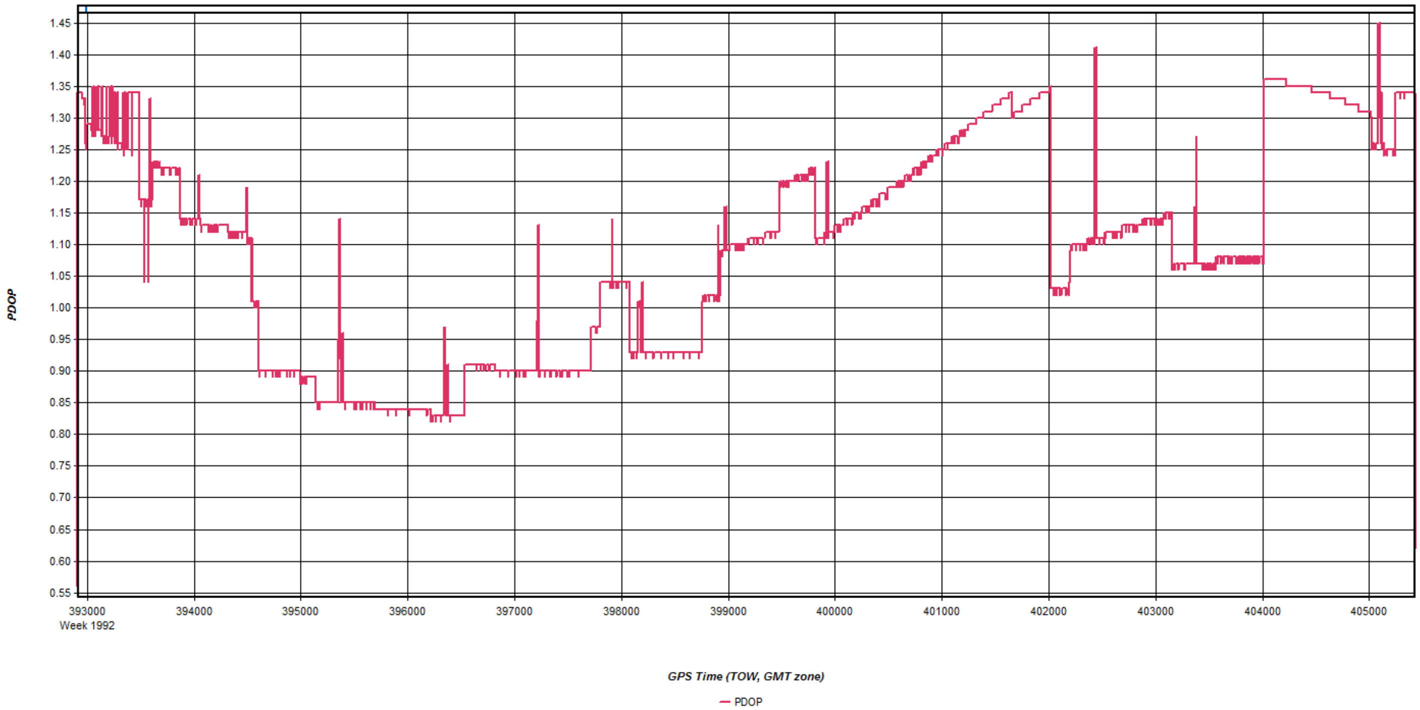
20180315_1






Estimated StdDev (m)
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
393000
Week 1992
394000
395000
396000
397000
398000
399000
400000
401000
402000
403000
404000
405000
GPS Time (TOW, GMT zone)
East
North
Height


Num Sats
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
393000
Week 1992
394000
395000
396000
397000
398000
399000
400000
401000
402000
403000
404000
405000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


PDOP
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
393000
Week 1992
394000
395000
396000
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400000
401000
402000
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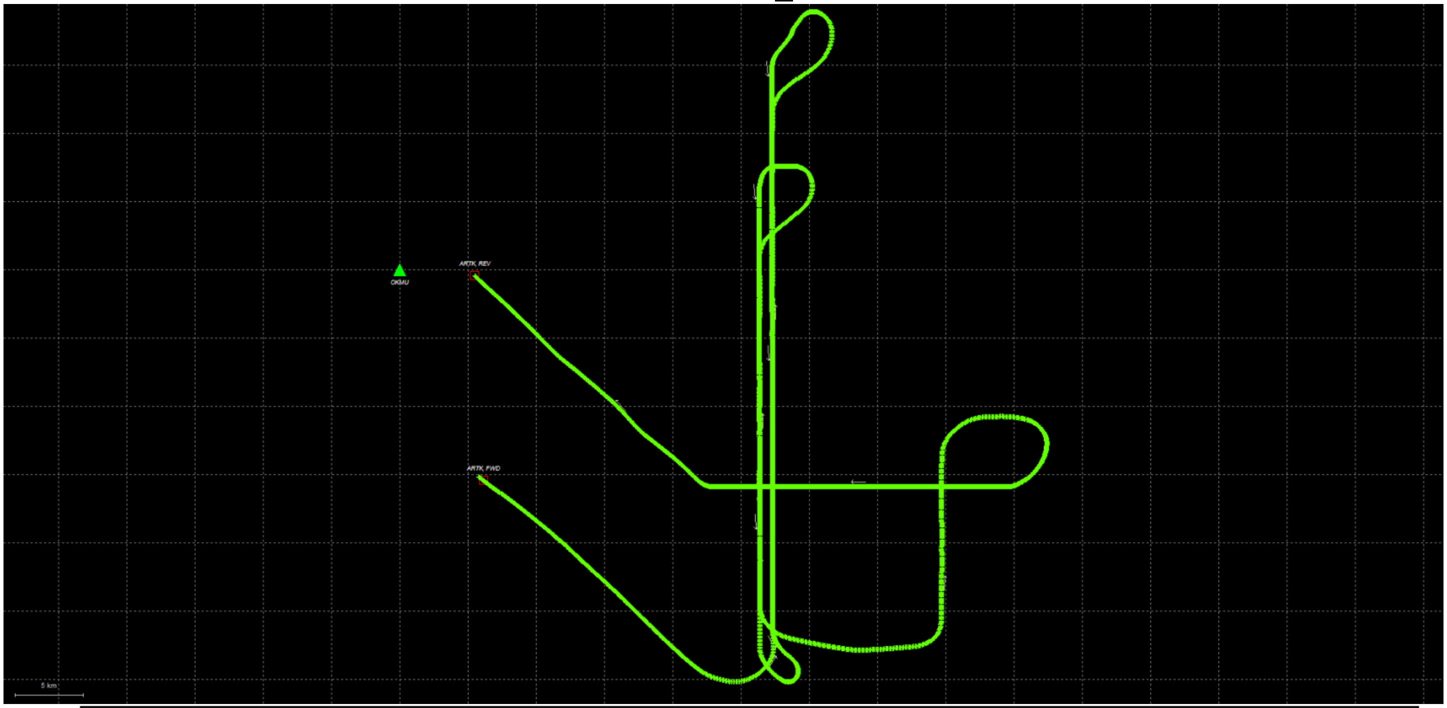
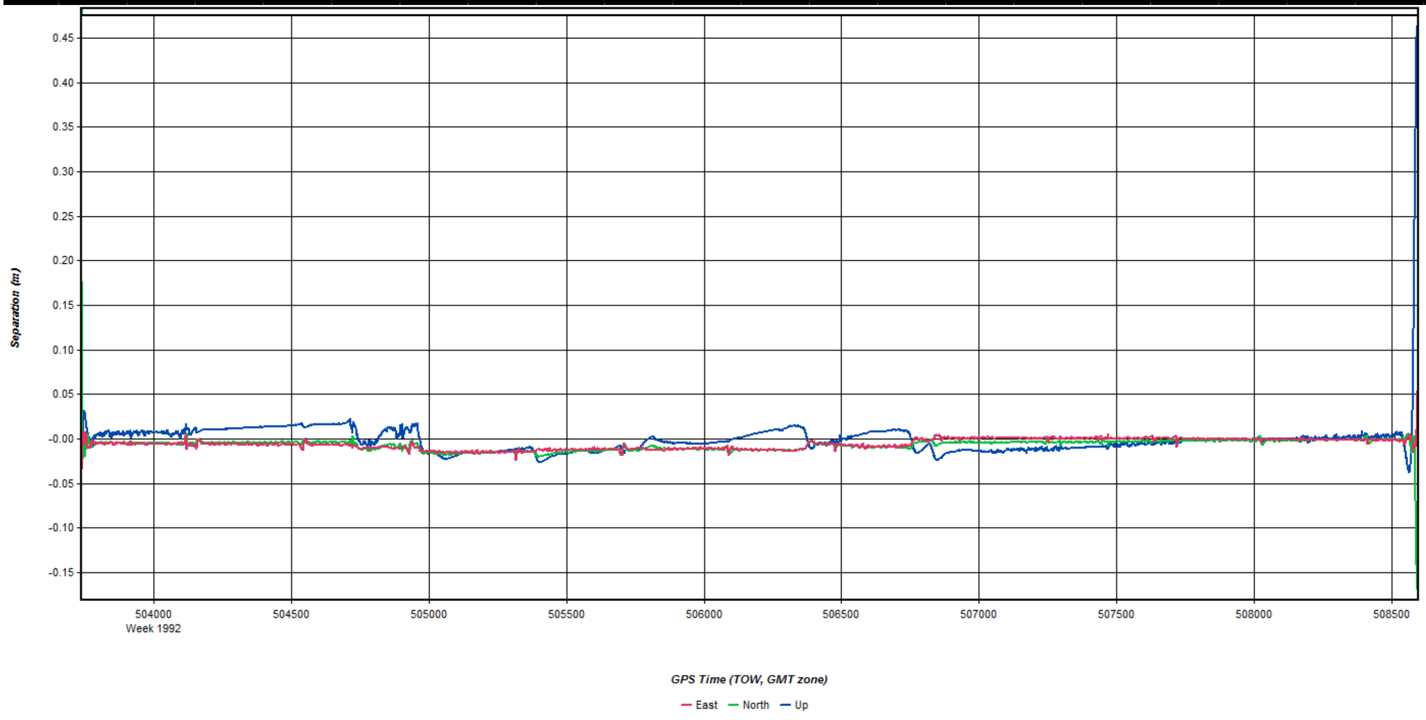
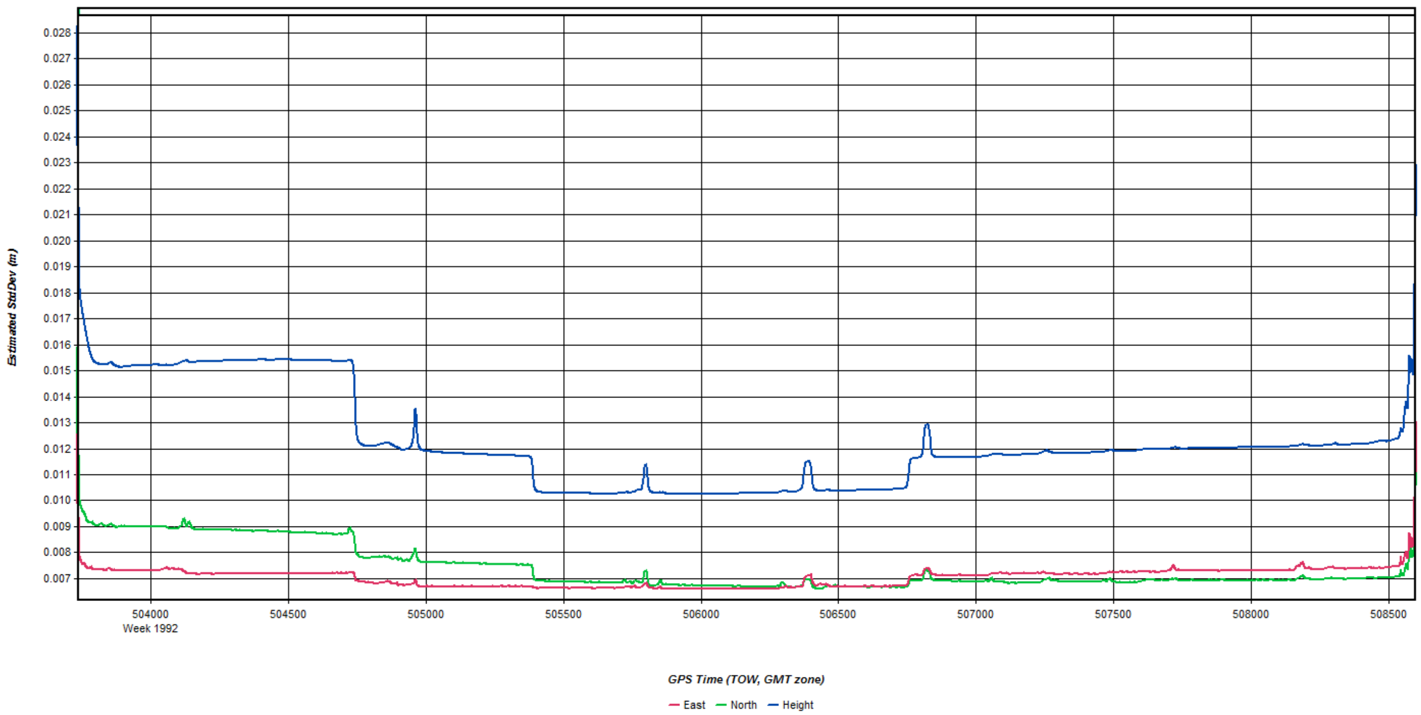
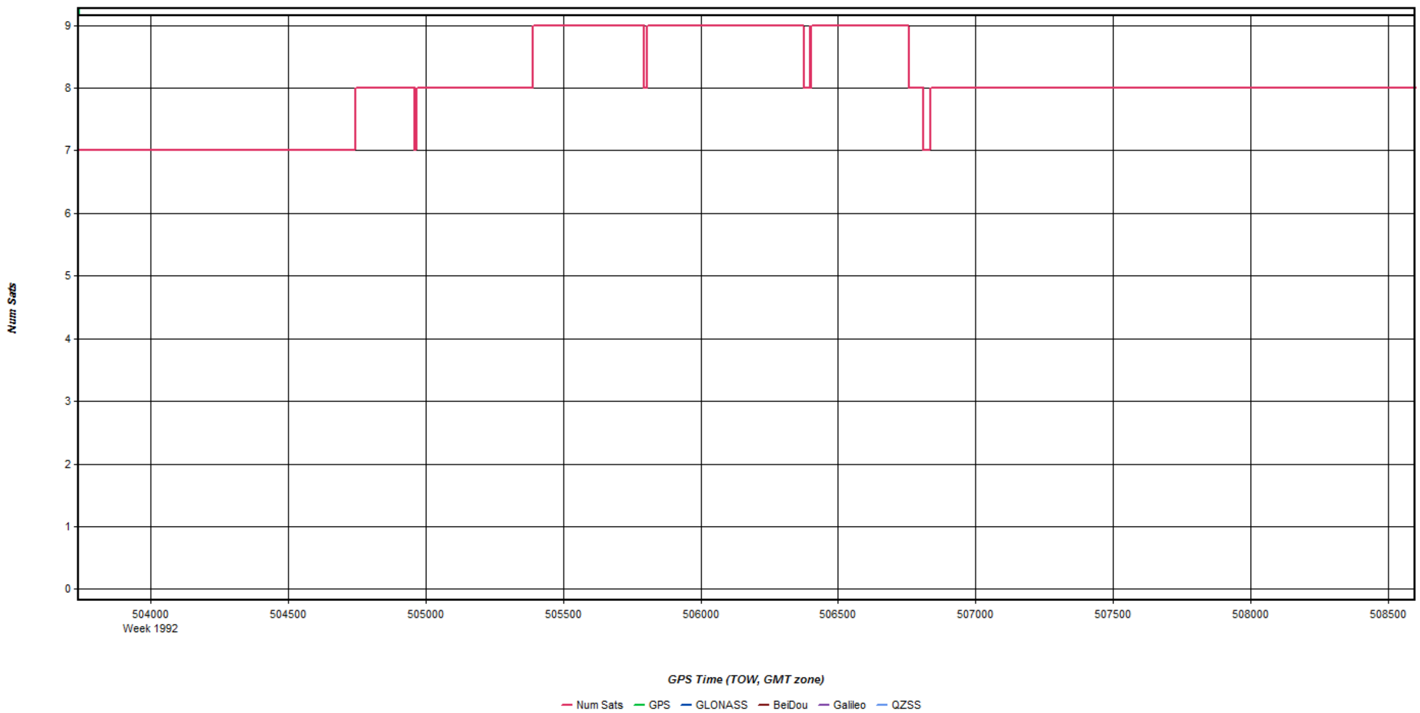
405000
GPS Time (TOW, GMT zone)
PDOP

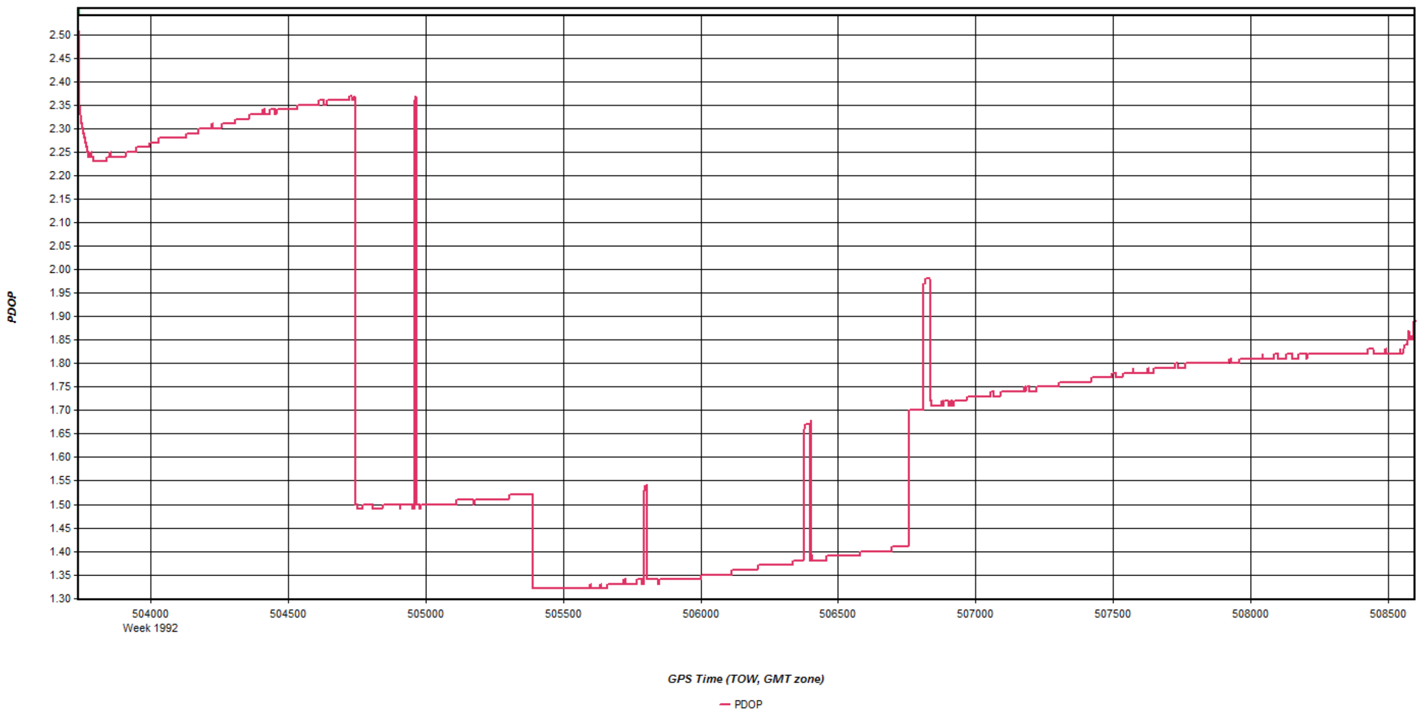
20180316_1


ARTK_REV
ARTK_FWD


Separation (m)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
504000
Week 1992
504500
505000
505500
506000
506500
507000
507500
508000
508500
GPS Time (TOW, GMT zone)
East
North
Up


Estimated StdDev (m)
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
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
504000
Week 1992
504500
505000
505500
506000
506500
507000
507500
508000
508500
GPS Time (TOW, GMT zone)
East
North
Height


Num Sats
9
8
7
6
5
4
3
2
1
0
504000
Week 1992
504500
505000
505500
506000
506500
507000
507500
508000
508500
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


PDOP
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
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
504000
Week 1992
504500
505000
505500
506000
506500
507000
507500
508000
508500
GPS Time (TOW, GMT zone)
PDOP