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MNCPPC Lidar 2024

Lidar Mapping Report

June 2024

EXECUTIVE SUMMARY

The Sanborn Map Company, Inc. (Sanborn) was tasked to provide remote sensing services 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 ~ 1073 mi² was completed on December 20th, 2023.

The Leica TerrainMapper was used to collect data for the aerial survey campaign. The sensor is attached to an aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar Systems (ALS) are boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the system 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. 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 it relates survey assessments.

1.3 Project Location

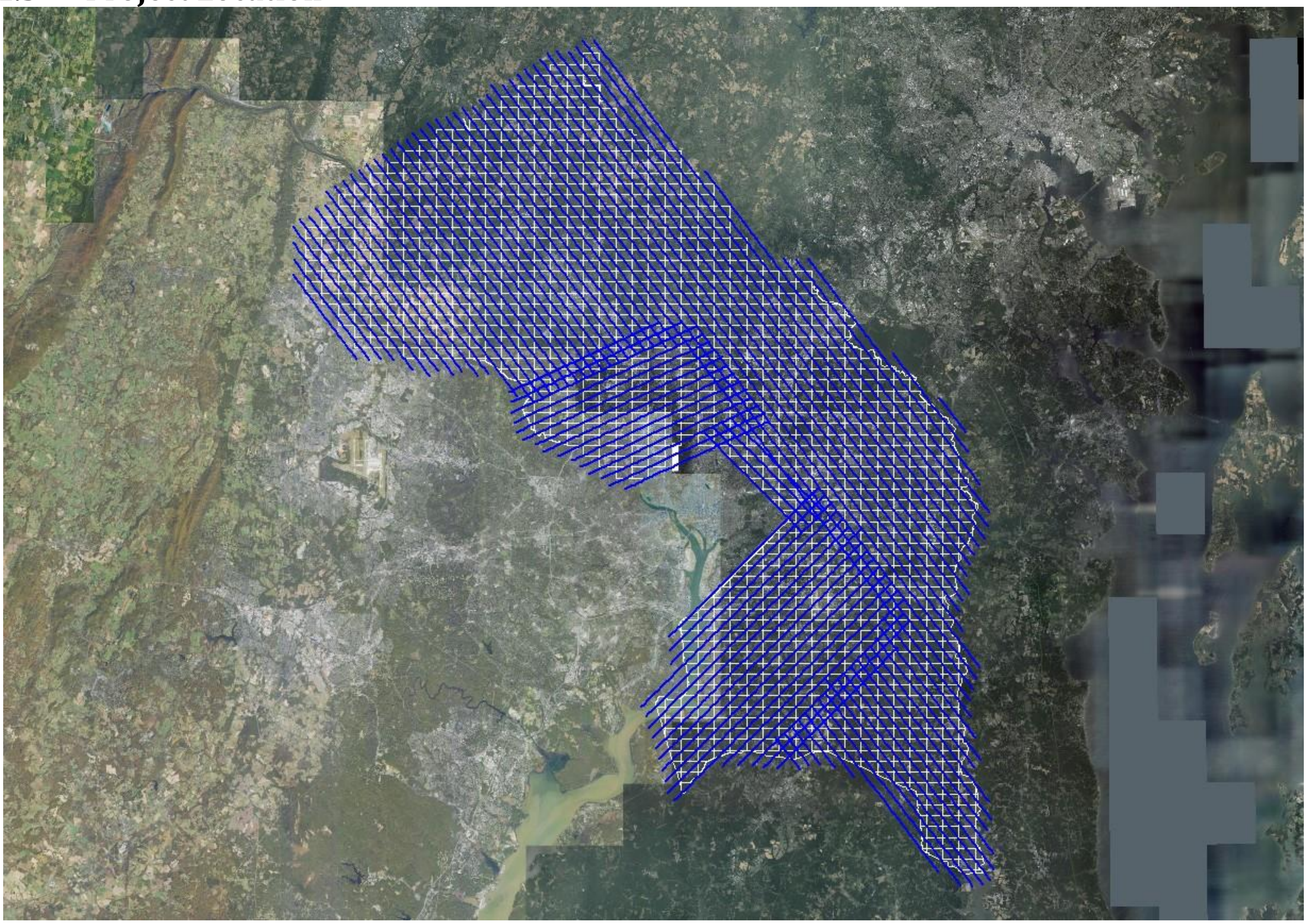


Figure 1: Tile Index and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting, and data acquisition methodology used during the collection of the lidar 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	
Aircraft	N117JP - PIPER PA-31-325
Sensor	Leica TerrainMapper
Max Number of Returns	15
Point Spacing (m)	0.34
Point Density (pls/m²)	8.81
Flying Height (AGL) (m)	2000
Air Speed (kts)	160
Field of View (degrees)	40
Scan Rate (Hz)	150
Pulse Rate (kHz)	1800
Laser Footprint (m)	0.47
Wavelength (nm)	1064
Multi-Pulse	Yes
Swath Width (m)	1456
Overlap (%)	20

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 three-minute static session was conducted on the ground with the engines running prior to take-off to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of six (6) missions. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP.

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.

Mission Characteristics							
Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
12/4/2023	Leica TerrainMapper	TM91512	N117JP	20231204A_N117JP_91512	1.4	14:54:38	16:22:03
12/5/2023	Leica TerrainMapper	TM91512	N117JP	20231205A_N117JP_91512	1.5	15:11:06	19:38:22
12/7/2023	Leica TerrainMapper	TM91512	N117JP	20231207A_N117JP_91512	1.5	14:22:02	18:34:34
12/9/2023	Leica TerrainMapper	TM91512	N117JP	20231209A_N117JP_91512	1.6	16:49:48	21:31:49
12/12/2023	Leica TerrainMapper	TM91512	N117JP	20231212A_N117JP_91512	1.5	14:25:55	17:54:49
12/20/2023	Leica TerrainMapper	TM91512	N117JP	20231220A_N117JP_91512	1.5	14:33:15	18:41:28

Table 2: Collection Date Time by Mission

GNSS Reference Station Coordinates					
Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
GODE	CORS	AF9646	39 01 18.21996	076 49 36.59163	14.559
HNPT	CORS	AI3494	38 35 19.74021	076 07 49.34788	-27.975
LOY8	CORS	DH7954	38 16 58.72119	077 27 09.48584	-6.214
LOYF	CORS	DK7414	38 58 28.10461	076 31 19.90184	-15.788
LOYQ	CORS	DL2039	39 38 02.62381	077 42 51.11629	127.220
UMBC	CORS	DF6305	39 15 24.38997	076 42 41.48499	64.665
ZDCI	CORS	DF9217	39 06 05.74479	077 32 33.88523	79.618

Table 3: GNSS Reference Station Coordinates

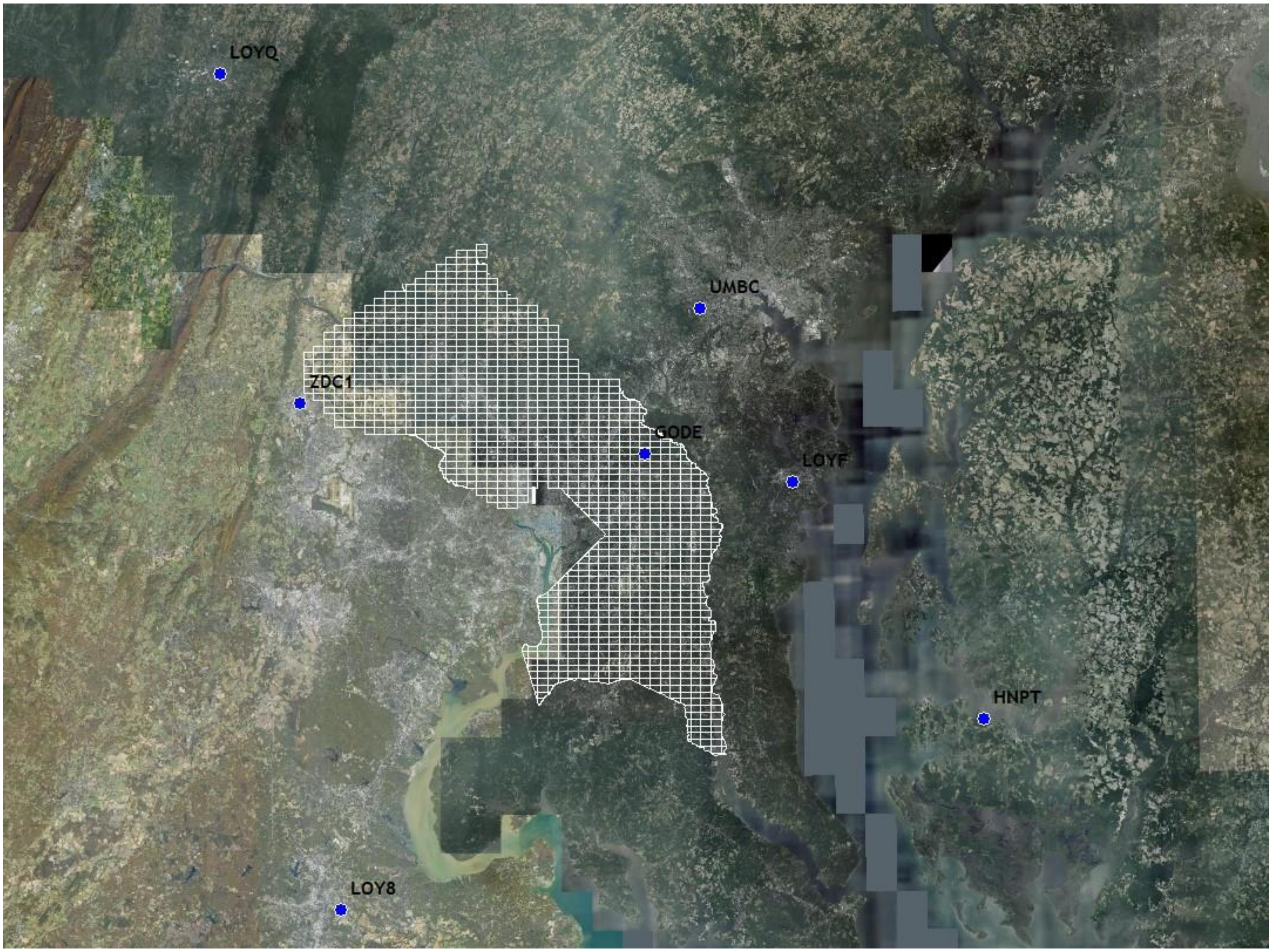


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The GNSS/IMU data was post-processed using Waypoint Inertial Explorer software to create Smoothed Best Estimate Trajectory (SBET) file(s). The SBET was then combined with the laser range measurements in Leica HexMap 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 lidar matching.

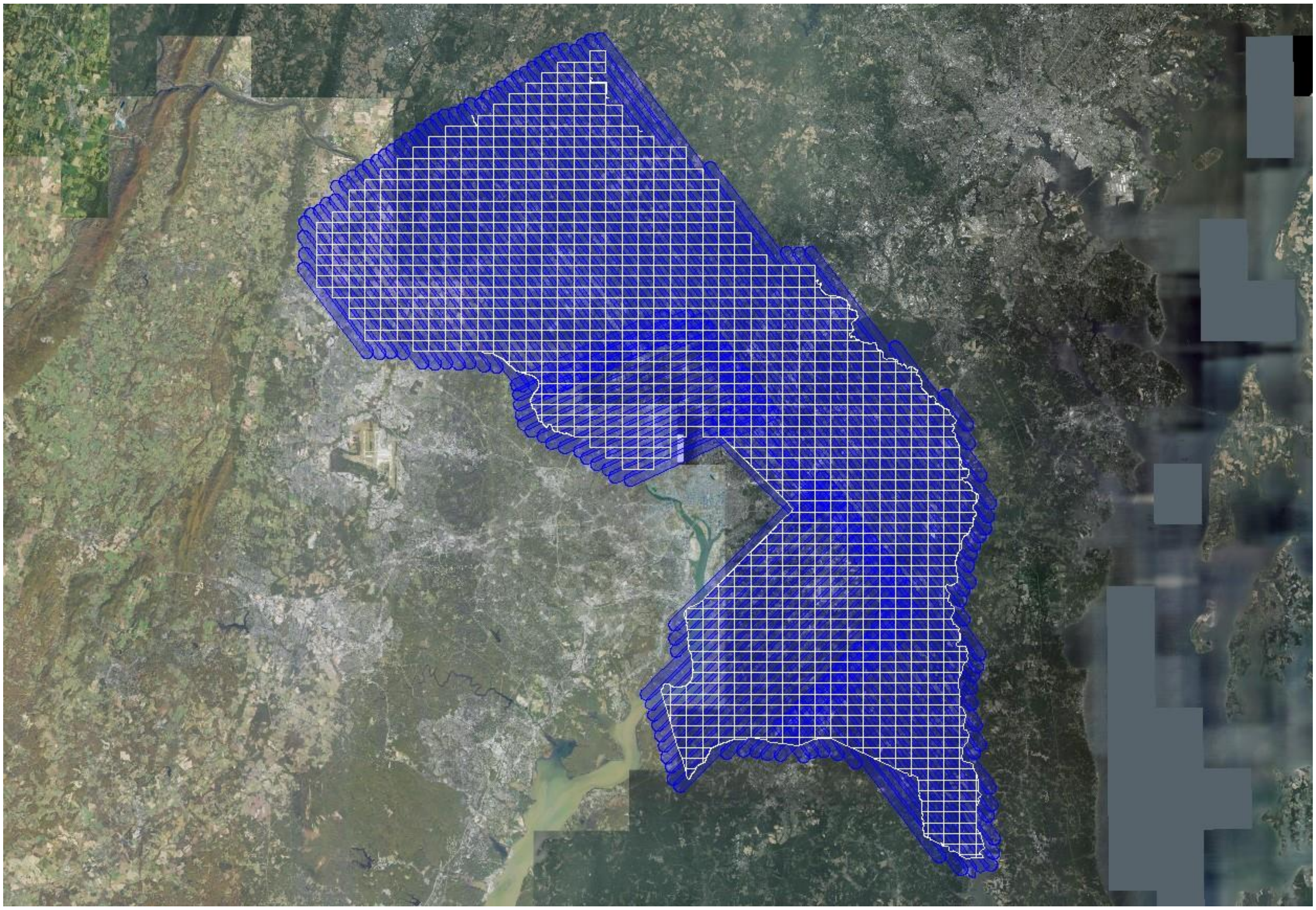


Figure 3: Raw Swath Coverage

The Leica HexMap 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
Aggregate Total Points	47,104,793,298
Aggregate Nominal Pulse Spacing (m)	0.28
Aggregate Nominal Pulse Density (pls/m²)	12.9
Aggregate Nominal Pulse Spacing (ft)	0.91
Aggregate Nominal Pulse Density (pls/ft²)	1.2

Table 4: Point Cloud Statistics

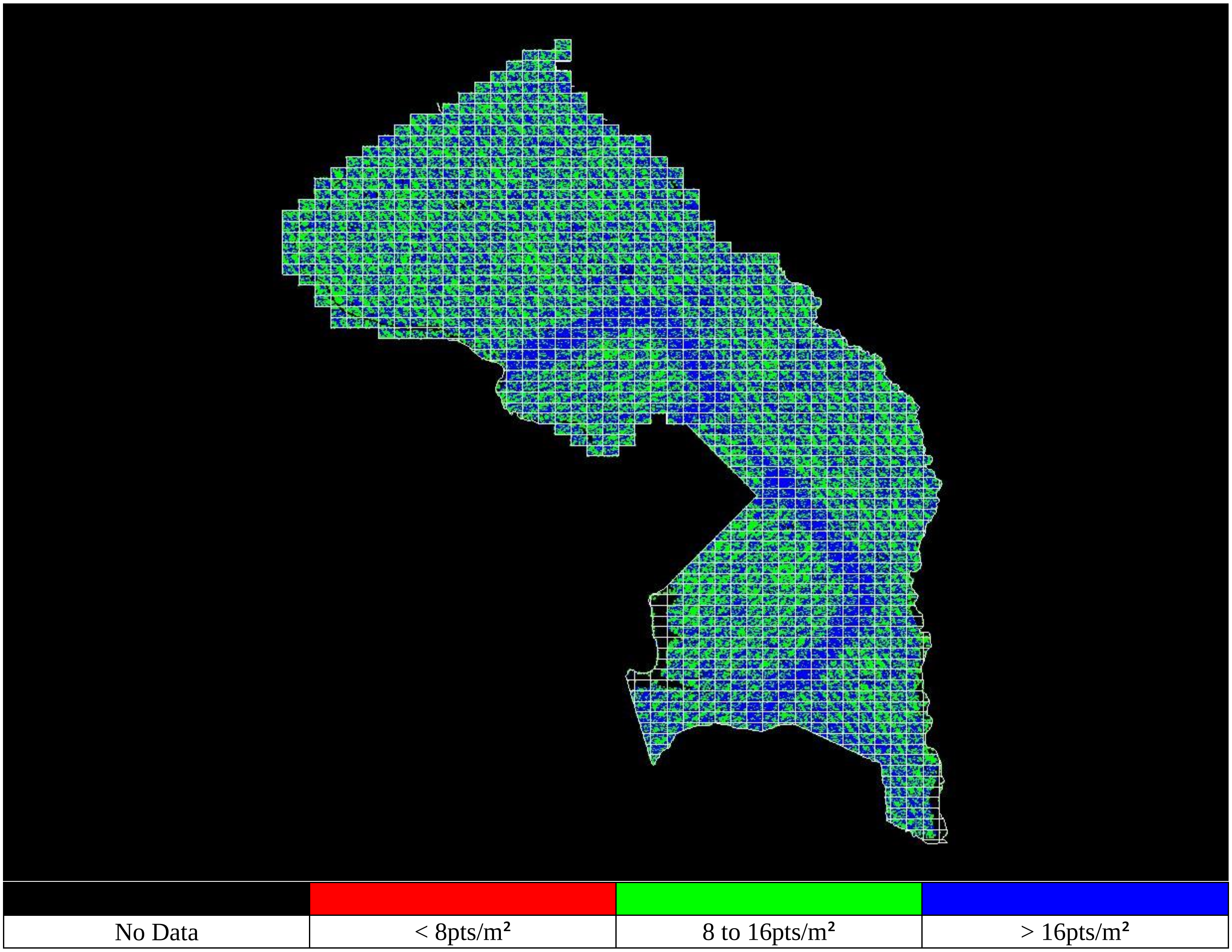


Figure 4: Point Cloud Density

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (HARN)
Projection: Maryland
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid12B
Units: Feet

3.3 Lidar Matching

Sanborn uses pre-processing software 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/or block 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.

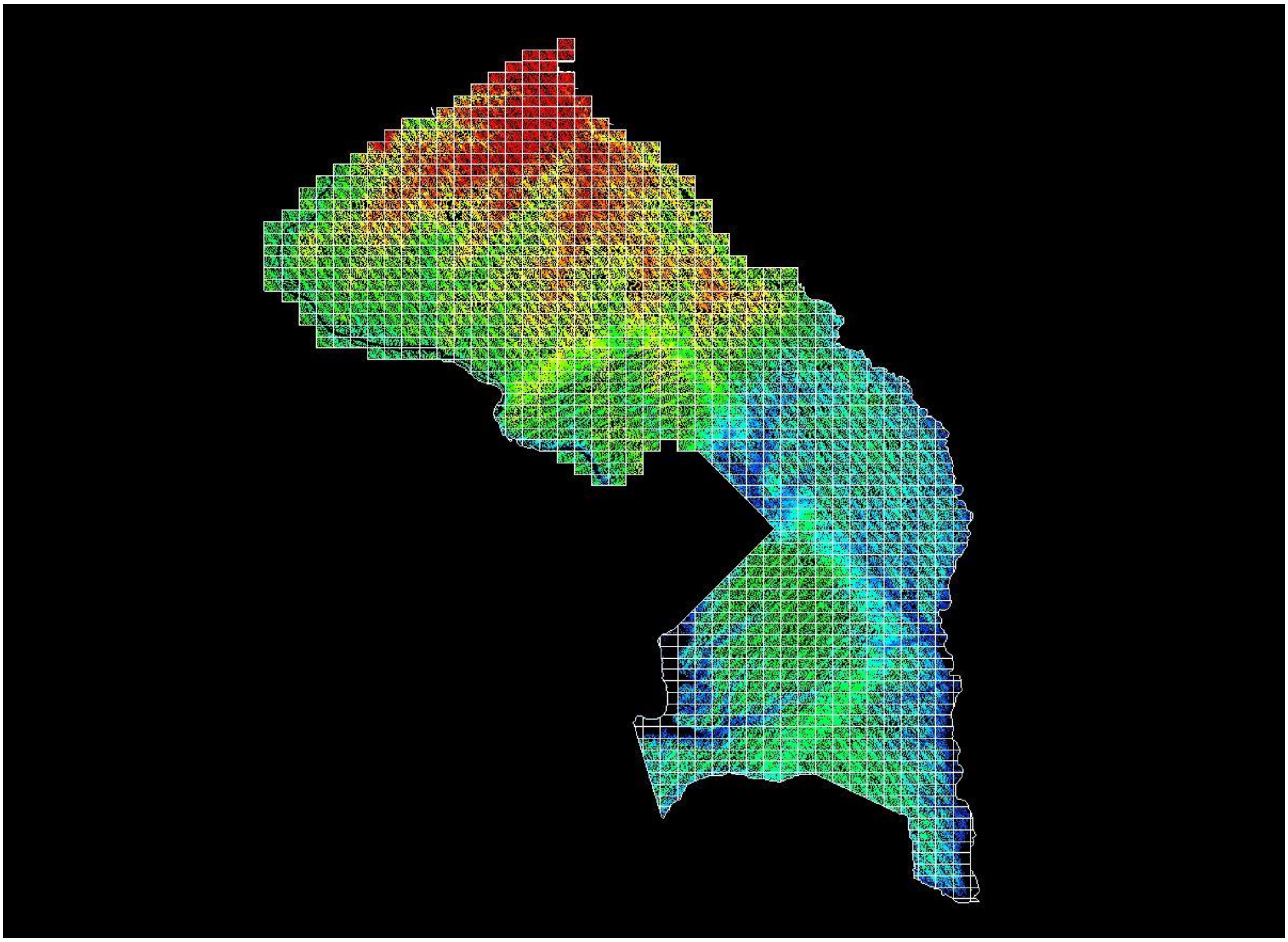


Figure 5: Point Cloud Elevation

Each mission is imported into GeoCue where each individual flight line is assigned a unique Source ID number. The SBET is cut per swath into TerraScan Trajectory files based on Source ID number and timestamp; these are utilized during the lidar matching 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 lidar matching tile grids. These lidar matching tile grids are prepared for scanner, line, mission, block and eventual project wide lidar matching routines by first running point cloud filters to identify ground and building features to be used during any TerraMatch processes.

Swath Separation Images modulated by Intensity are representative of the interswath alignment and provide a holistic qualitative look at the positional quality of the point cloud. The images are reviewed in their entirety. This visual review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project.

Category	Value (m)	Value (ft)
Smooth Surface Repeatability	≤0.060	≤0.197
Swath overlap difference, RMSDz	≤0.080	≤0.262

Table 5: Relative Accuracy Requirements

No Data	< 0.262ft	0.262ft to 0.524ft	0.524ft to 0.786ft	> 0.786ft

Figure 6: Swath Separation

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 within the point cloud classification 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, classifying bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 6** outlines a statistical summary of the point classes leveraged in the lidar dataset.

Point Classification Statistics		
Code	**Class**	**Points**
1	Unclassified	29,093,129,881
2	Ground	17,808,501,949
7	Low Noise	66,166,422
9	Water	4,814,723
17	Bridge Decks	12,050,428
18	High Noise	119,192,237
20	Ignored Ground	937,658
Flag	Withheld	185,358,659

Table 6: Lidar Classification Statistics

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of 24 control points. The result provided a vertical accuracy that fell within project specifications. Please see the full Vertical Accuracy Report and the project Metadata for an in-depth accuracy assessment. **Table 7** outlines the absolute accuracy requirements of the project. **Table 8** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value (m)	Value (ft)
RMSEz	≤0.100	≤0.328
@ 95-Percent Confidence Level	≤0.196	≤0.643
@ 95th Percentile	≤0.300	≤0.984

Table 7: Absolute Accuracy Requirements

Control Point Error Statistics								
Category	**# of Points**	**Min**	**Max**	**Mean**	**Median**	**Skew**	**Std Dev**	**RMSEz**
Control Points	24	-0.338	0.242	-0.078	-0.062	0.393	0.150	0.166

Table 8: Vertical Accuracy Assessment of Check Points (Feet)

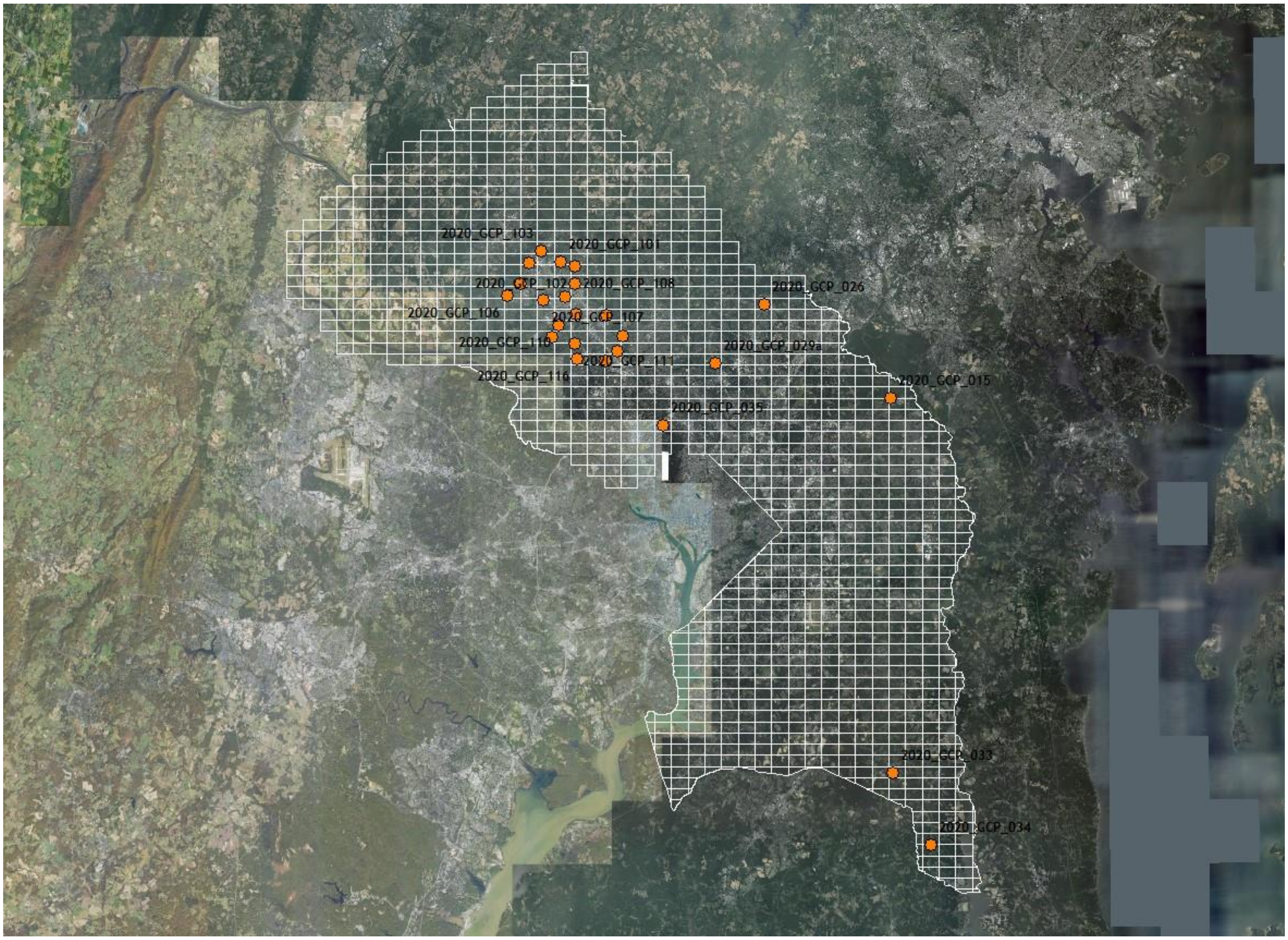


Figure 7: Control Point Distribution

4.0 PRODUCT GENERATION

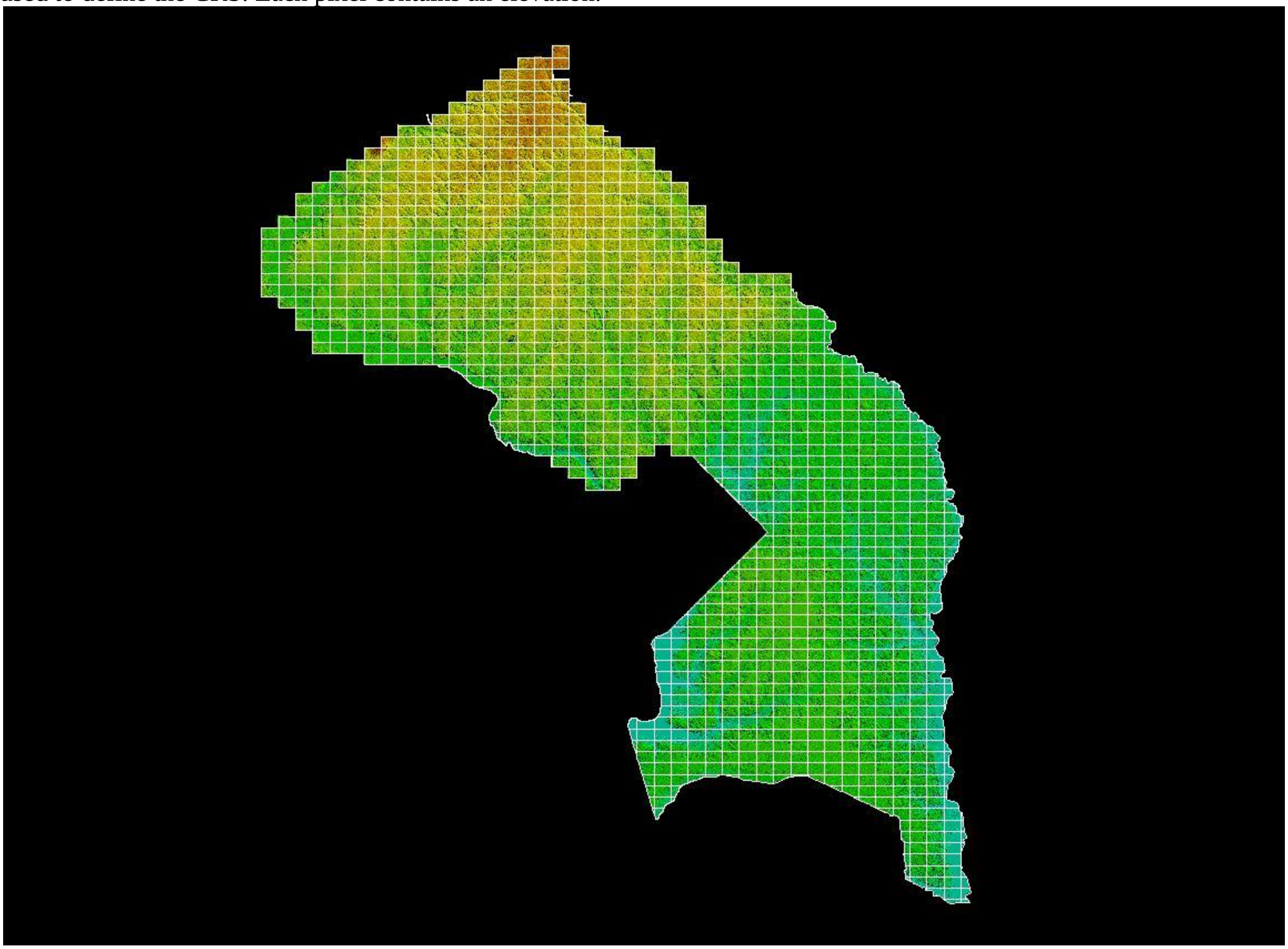
The following products were generated using the final coordinate system as defined in the contract:

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.

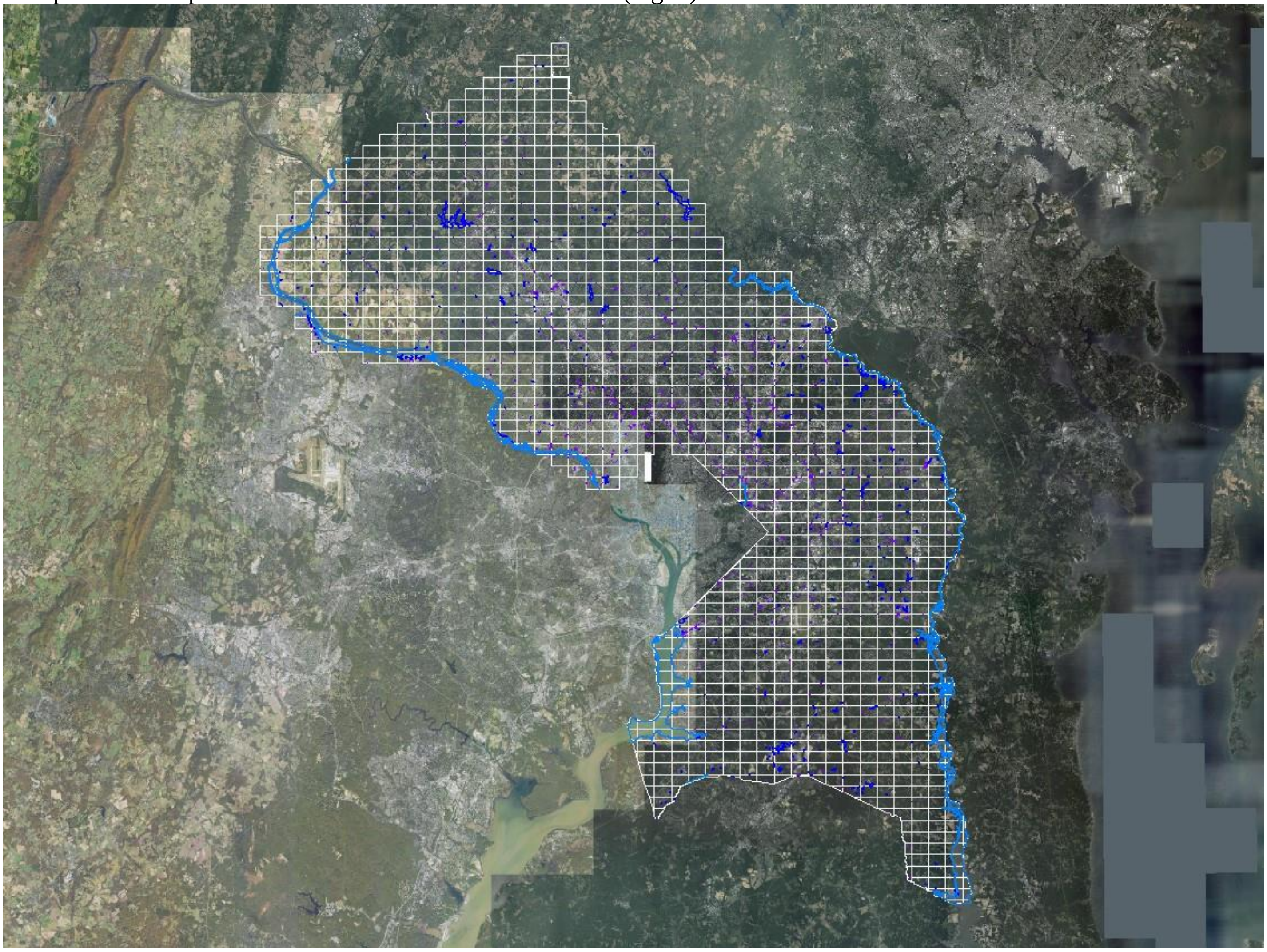
Bare-earth Digital Elevation Model (DEM)

32-bit GeoTIFF (*.tif) elevation rasters were created from the bare-earth points in the processed lidar dataset and hydro-flattened breaklines. Bare-earth rasters were produced with the bilinear interpolation methodology and GDAL v2.4.0 was used to define the CRS. Each pixel contains an elevation.



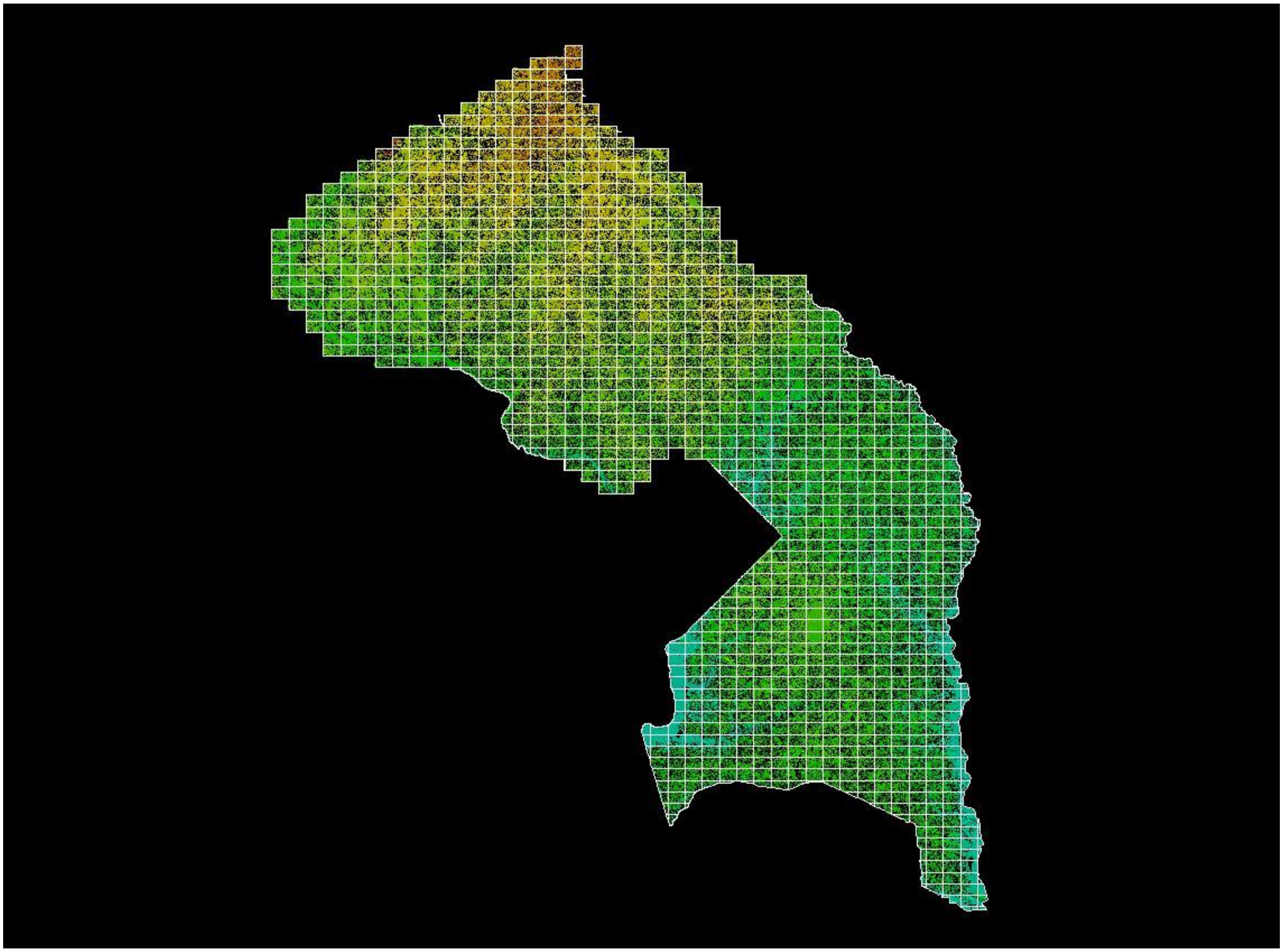
Breaklines

Hydro-flattened breaklines were generated from digitized water features conflated to the elevations derived from the bare-earth points in the processed lidar dataset. Delivered in Esri (*.gdb) format.



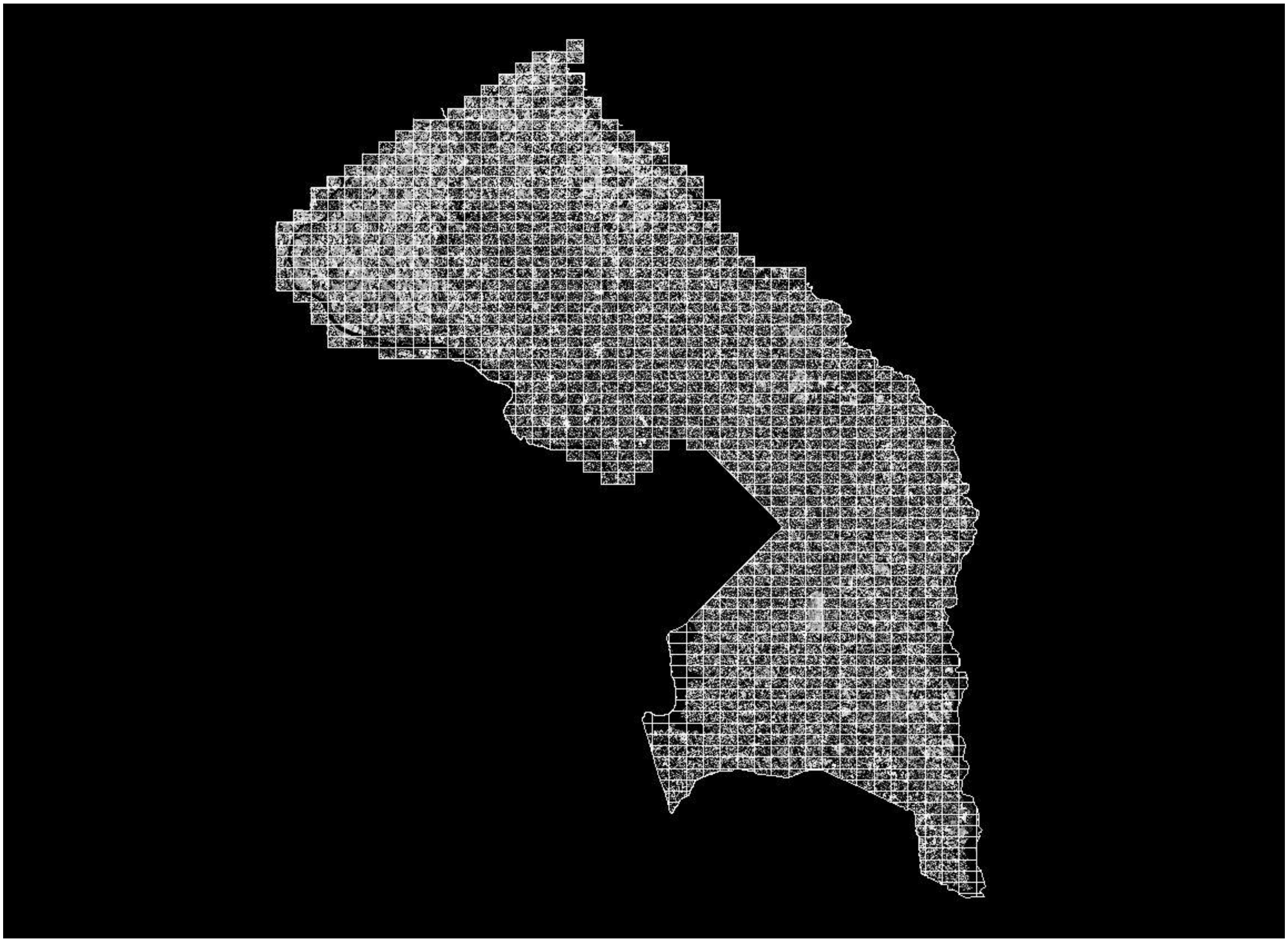
Maximum Surface Height Rasters (MSHR)

32-bit GeoTIFF (*.tif) elevation rasters were created from all return points in the processed lidar dataset. The rasters were produced with the bilinear interpolation methodology and GDAL v2.4.0 was used to define the CRS. Each pixel contains an elevation.



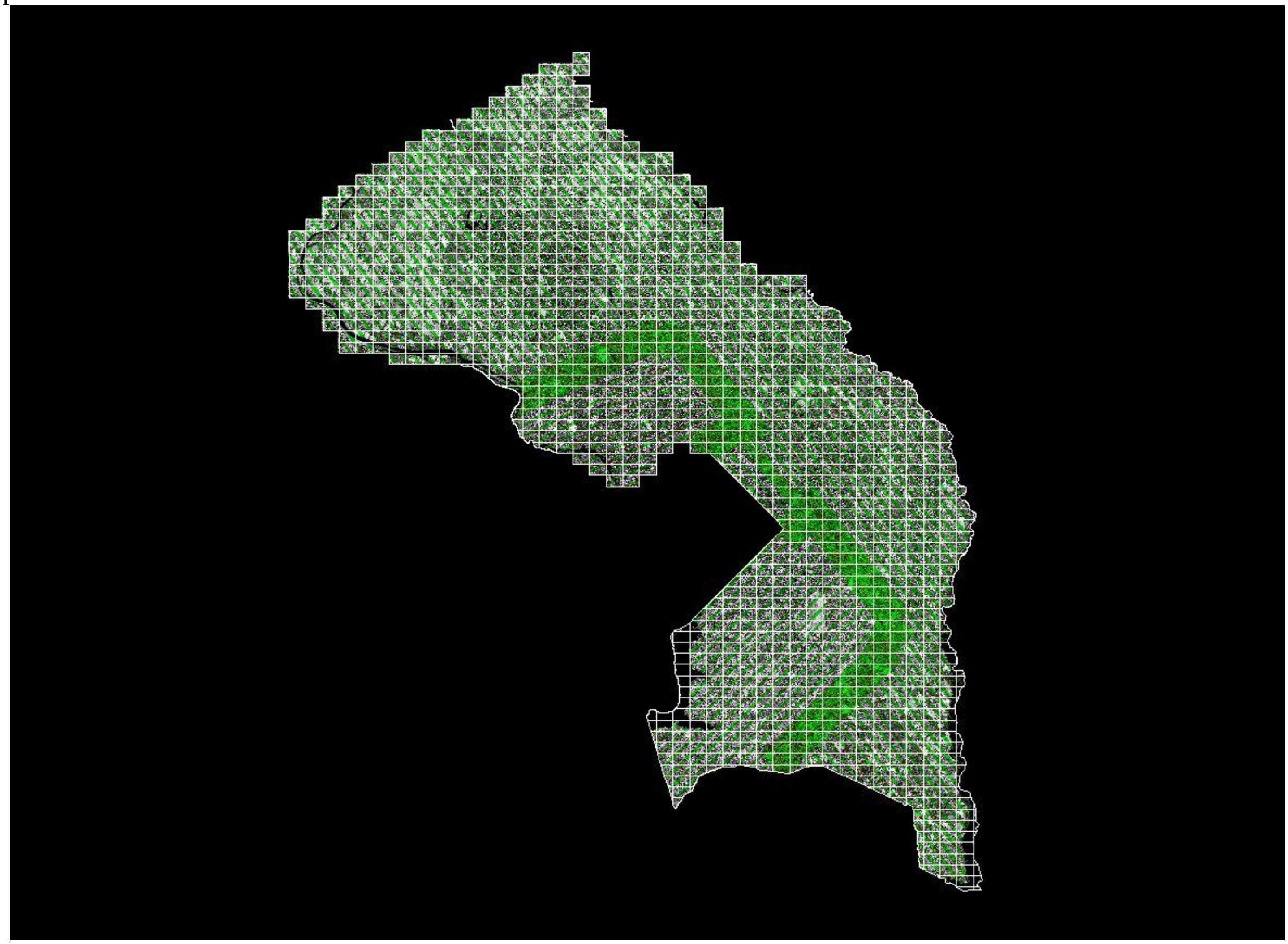
Intensity Images

8-bit GeoTIFF (*.tif) intensity rasters were created from the first-return points in the processed lidar dataset. GDAL v2.4.0 was used to define the CRS.



Swath Separation Images

24-bit GeoTIFF (*.tif) swath separation images modulated by intensity were created from the last-return points in the processed lidar dataset. GDAL v2.4.0 was used to define the CRS.



Other Deliverables

Metadata
Vertical Accuracy Report

A final quality assurance 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	Plots the Aircraft GNSS-IMU Trajectory in reference to localized GNSS Reference Stations.
Estimated Position Accuracy	Plots 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, GLONASS, and the total number of satellites are distinguished with separate color-coded lines.
Combined Separation	Plots the north, east, and height position difference between any two solutions loaded into the project. These are 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 unitless 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 where the antenna angle is unfavorable; these spikes while aesthetically unfavorable do not generally reduce the accuracy of the acquired data.

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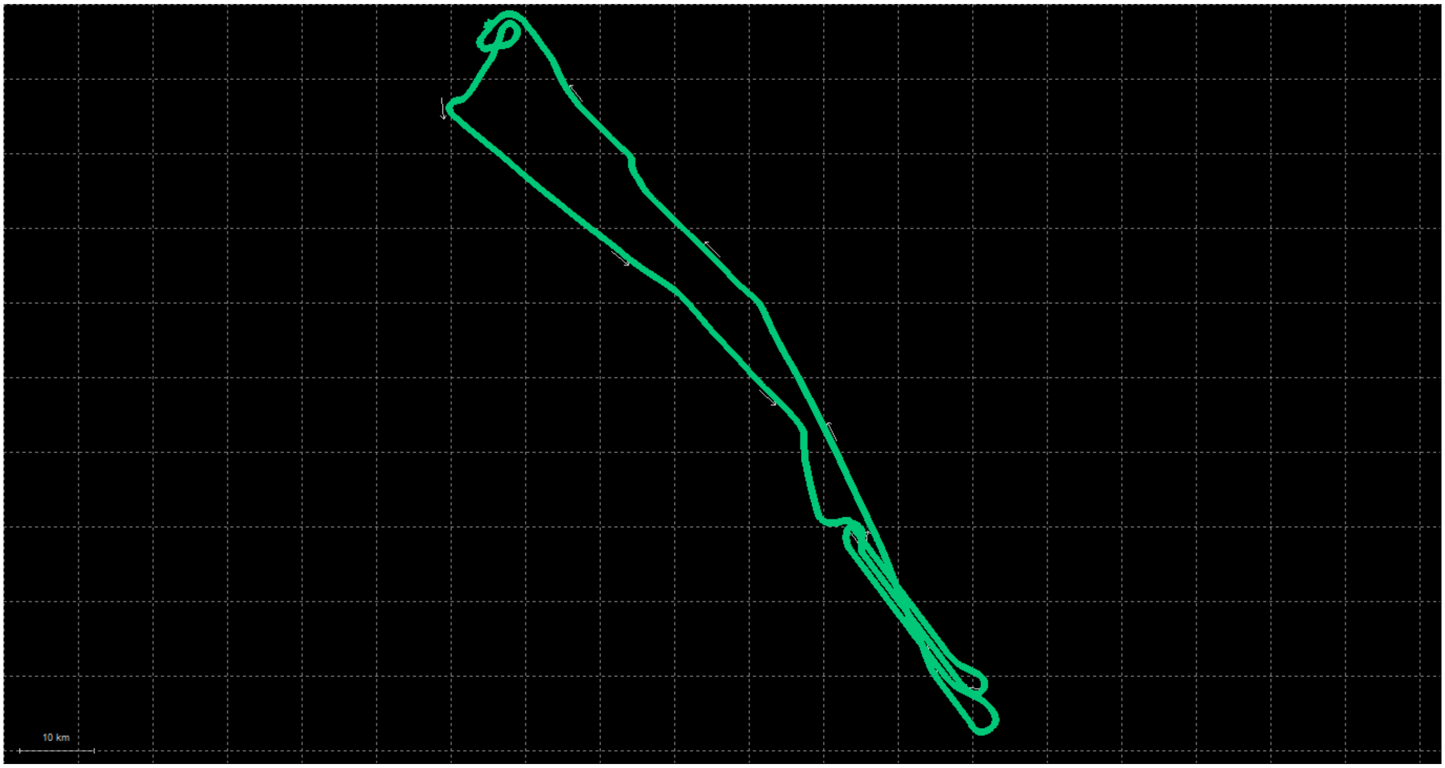

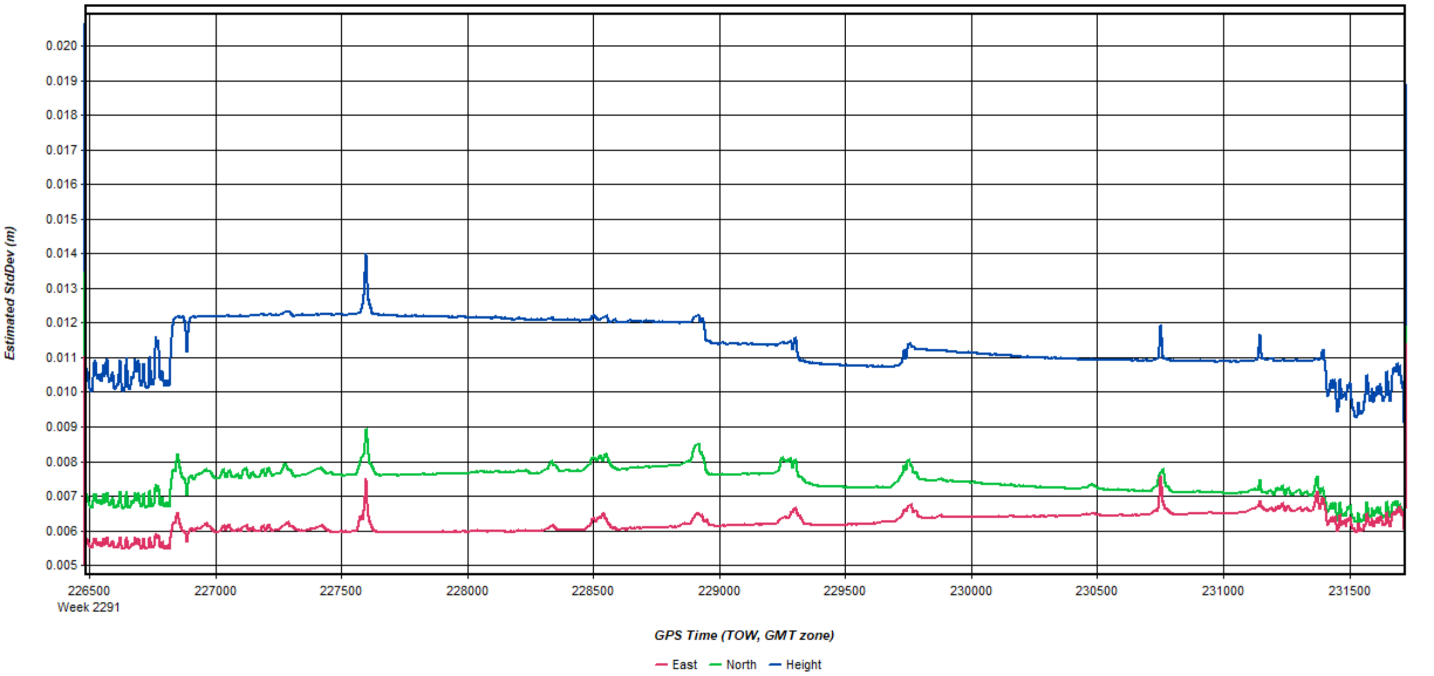

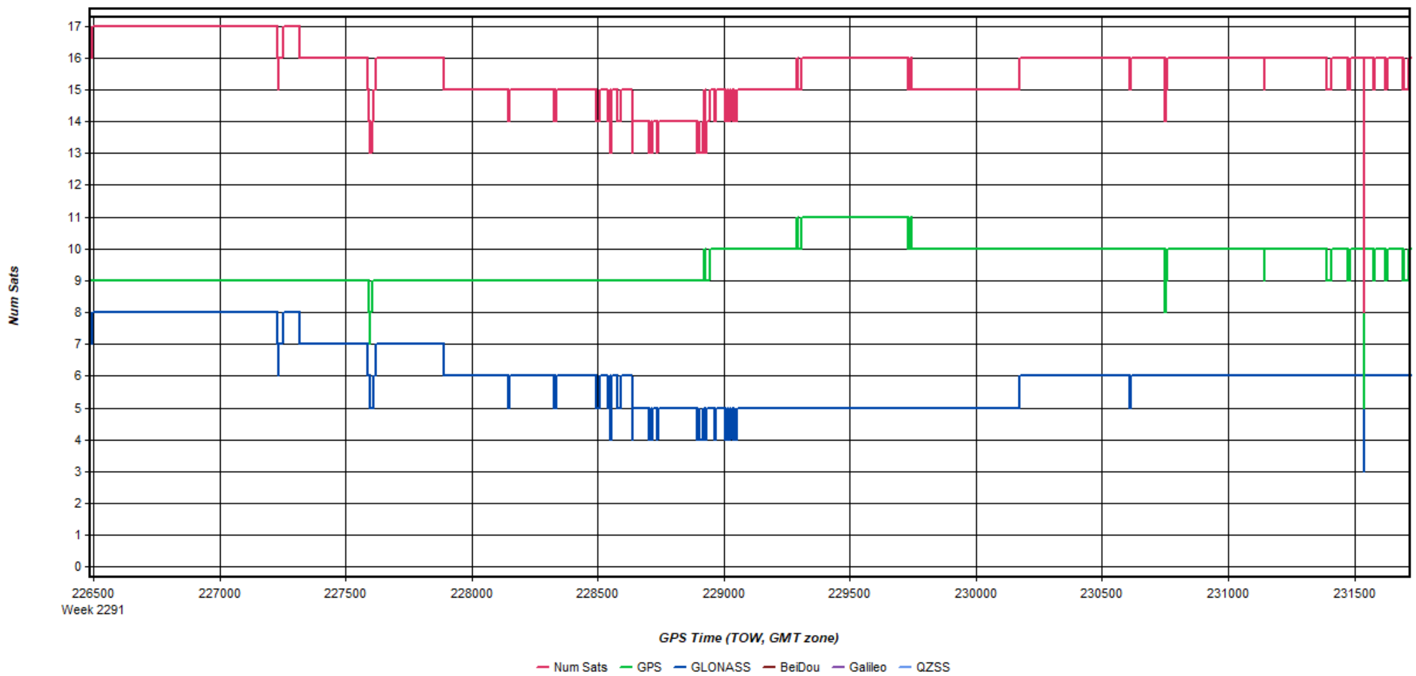
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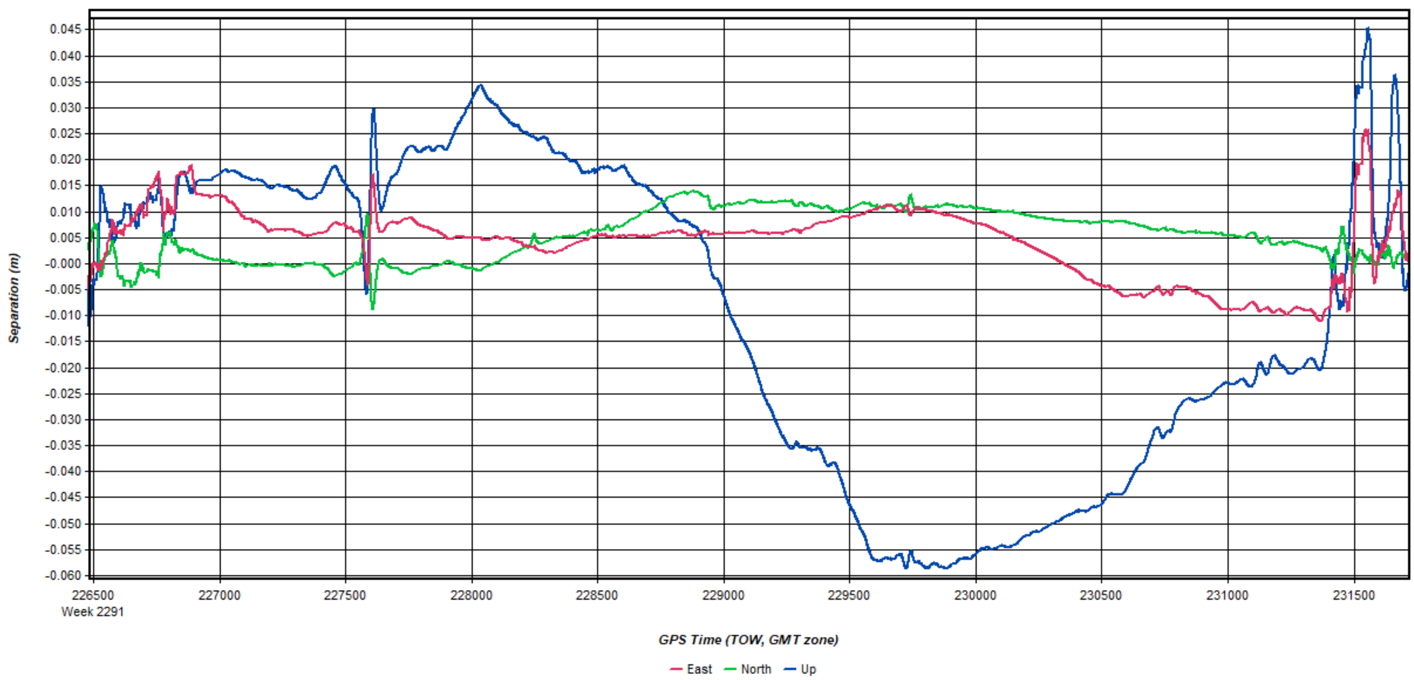
GLONASS
BeiDou
Galileo
QZSS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Week 2291
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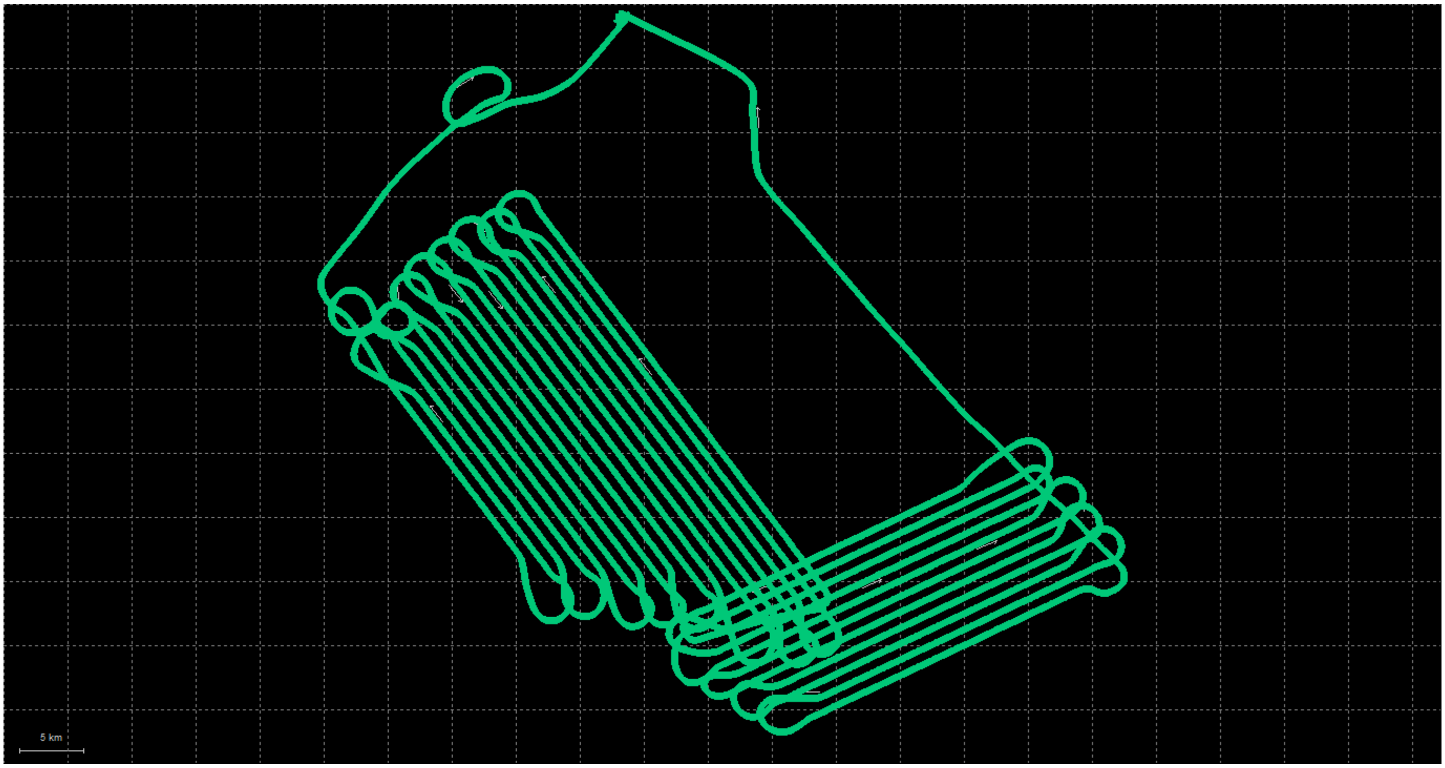

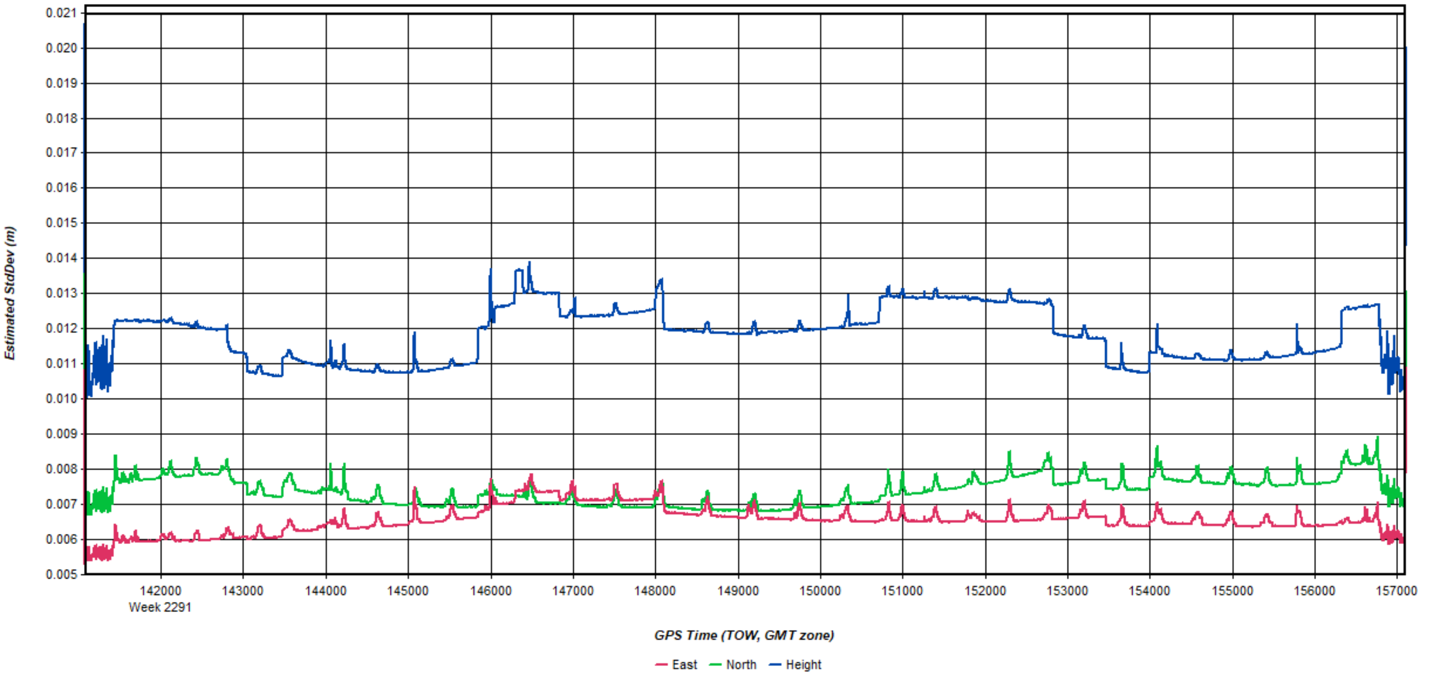

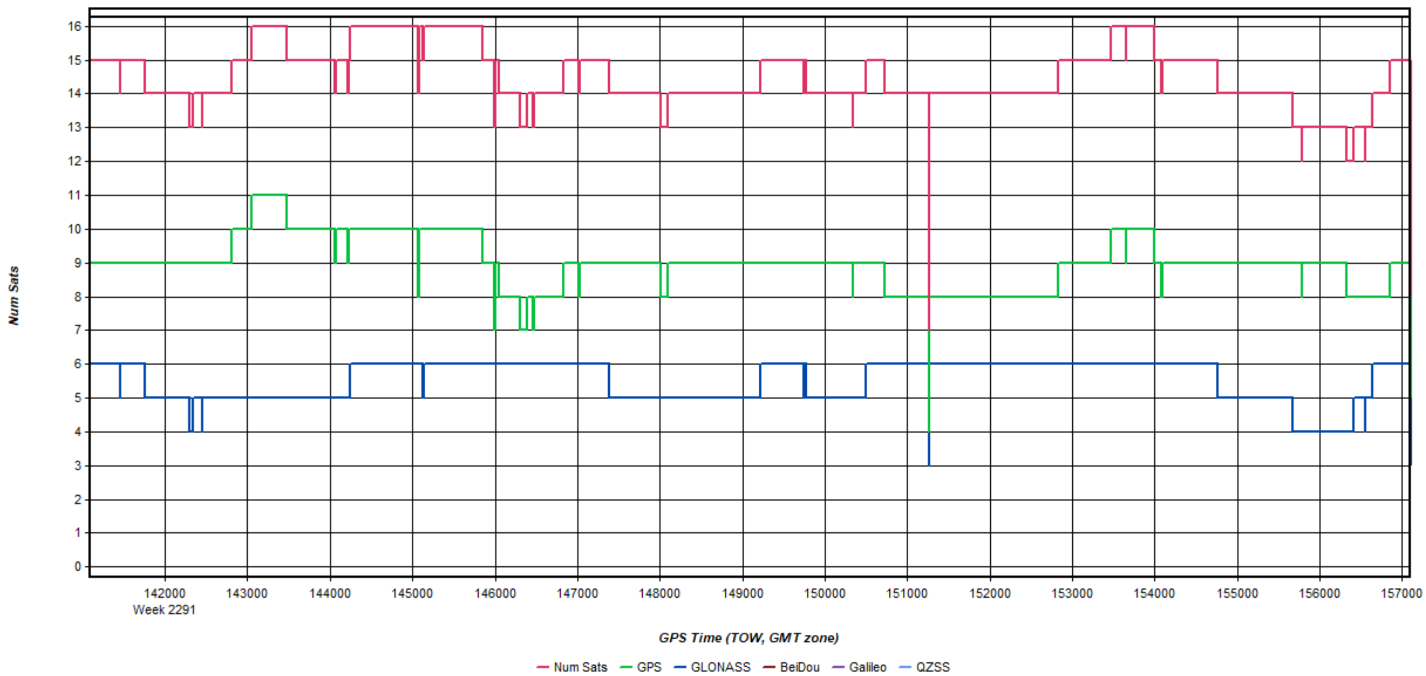

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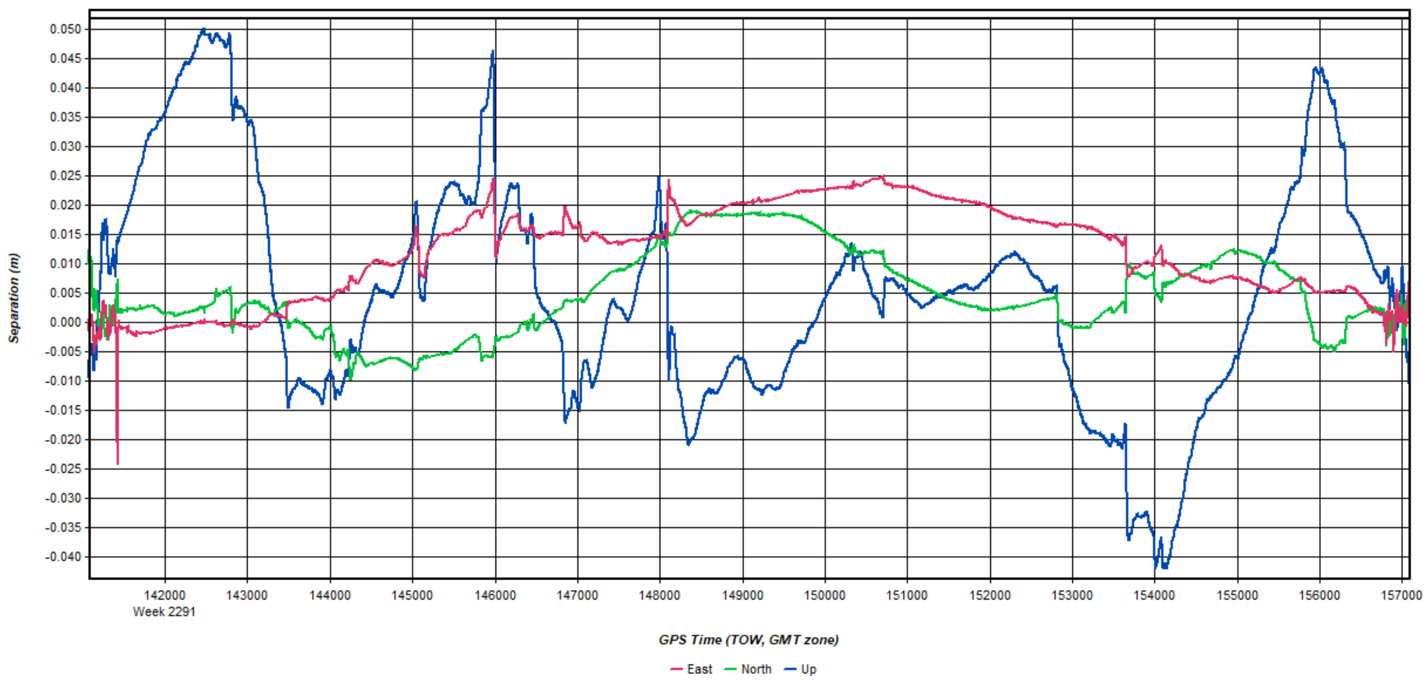

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Week 2291
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North
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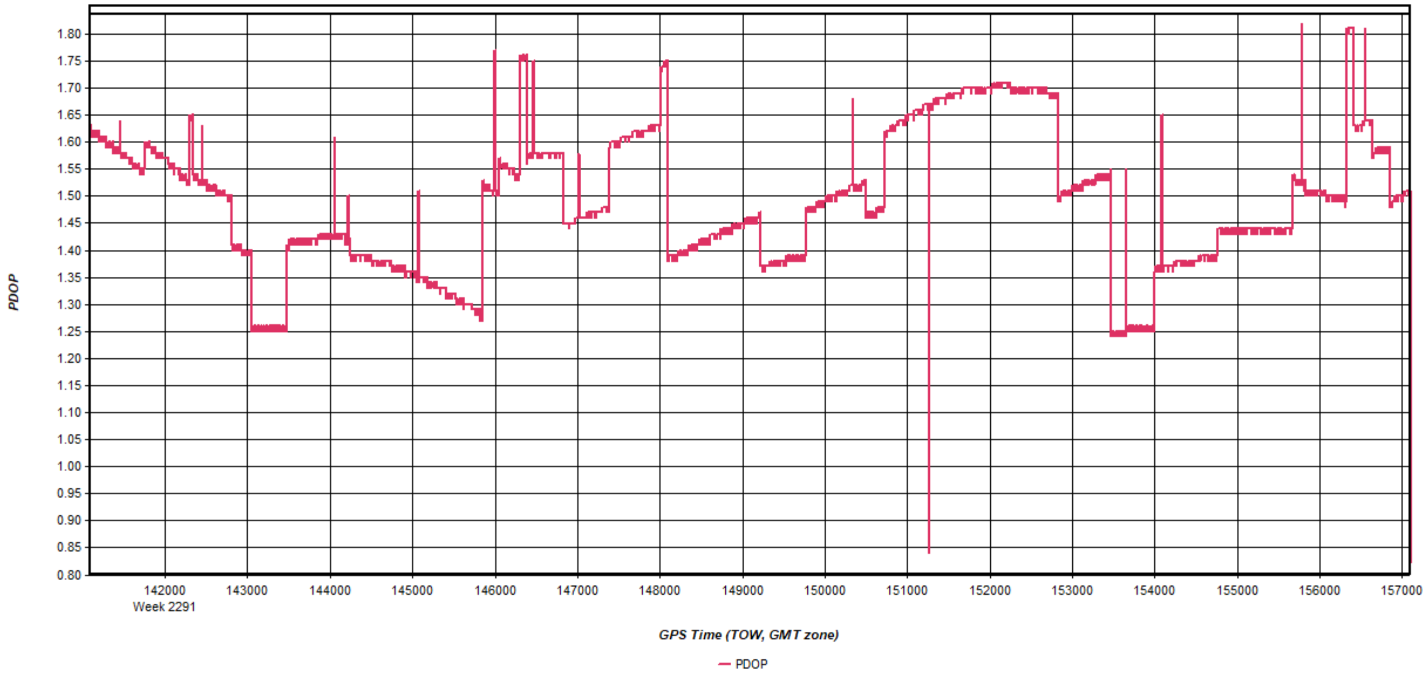

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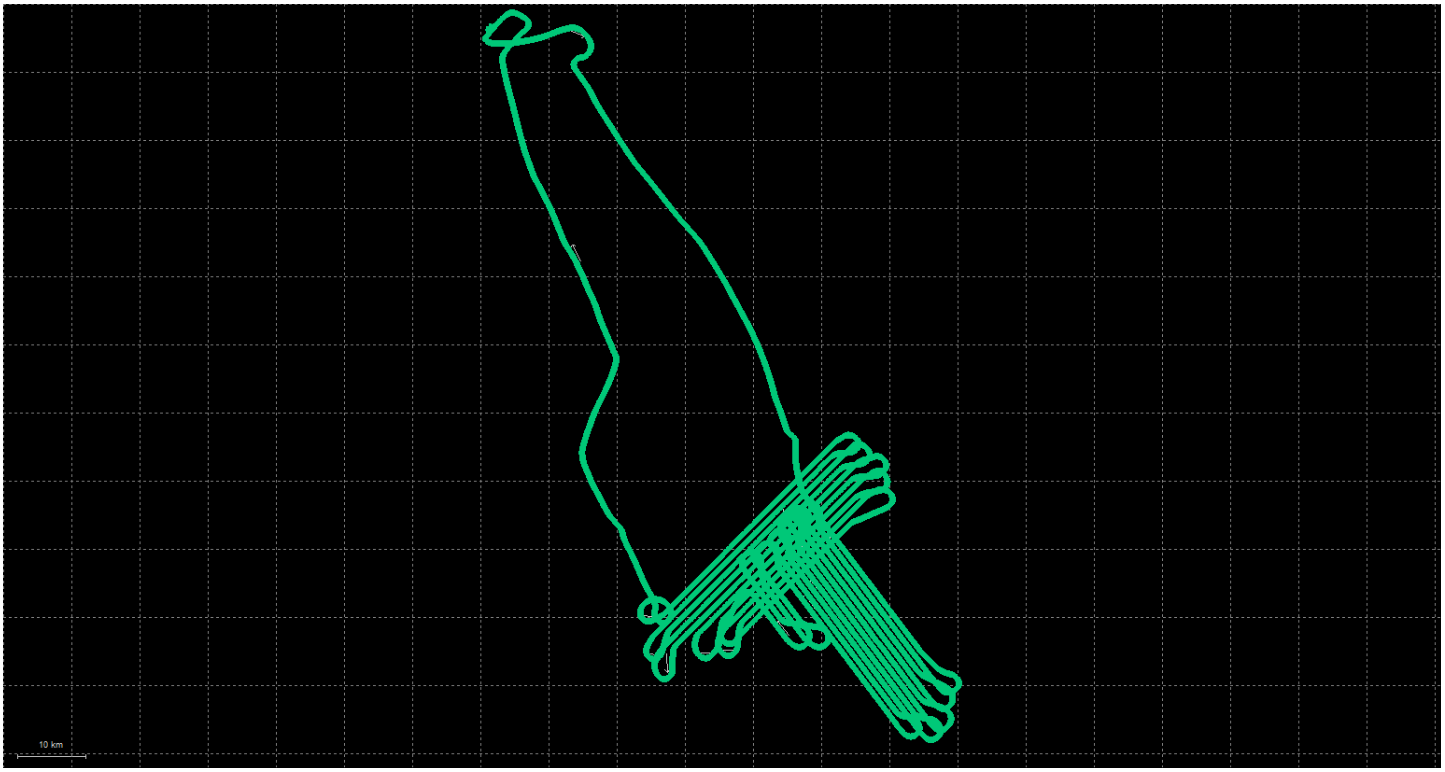

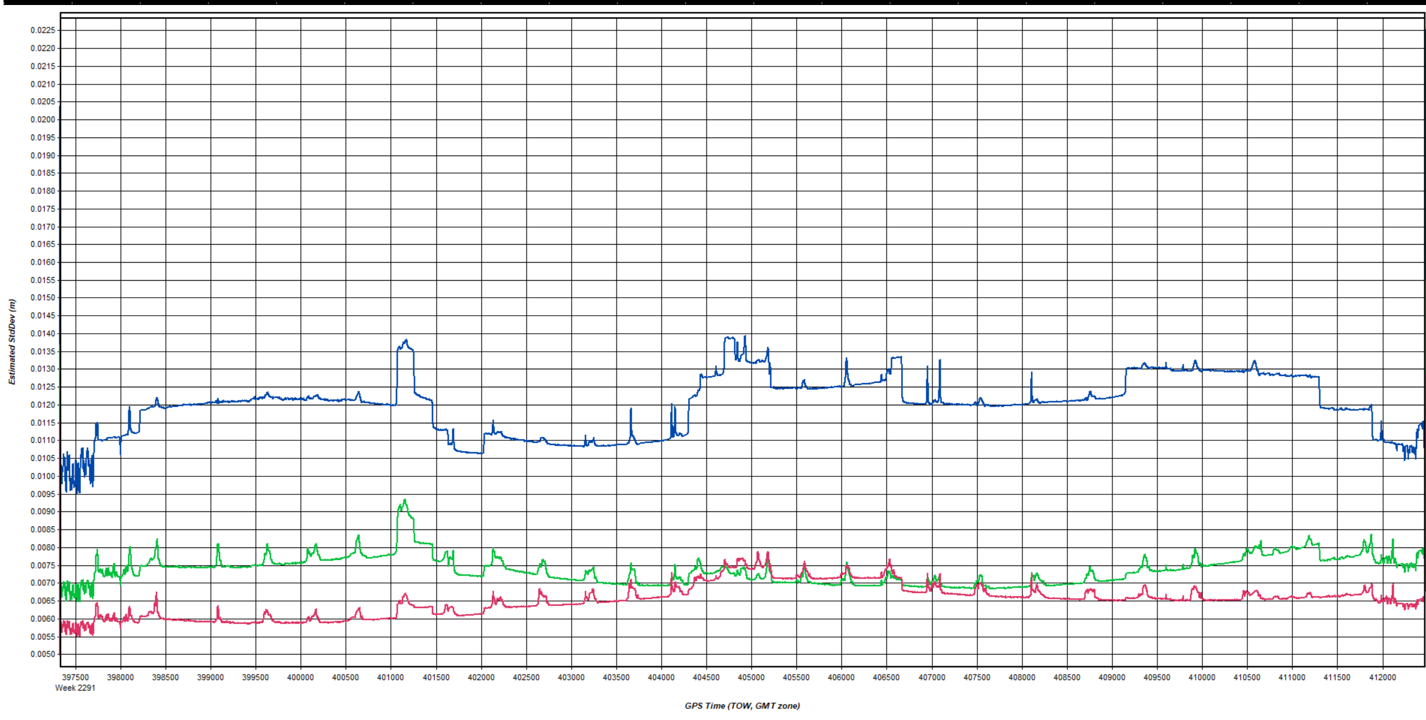

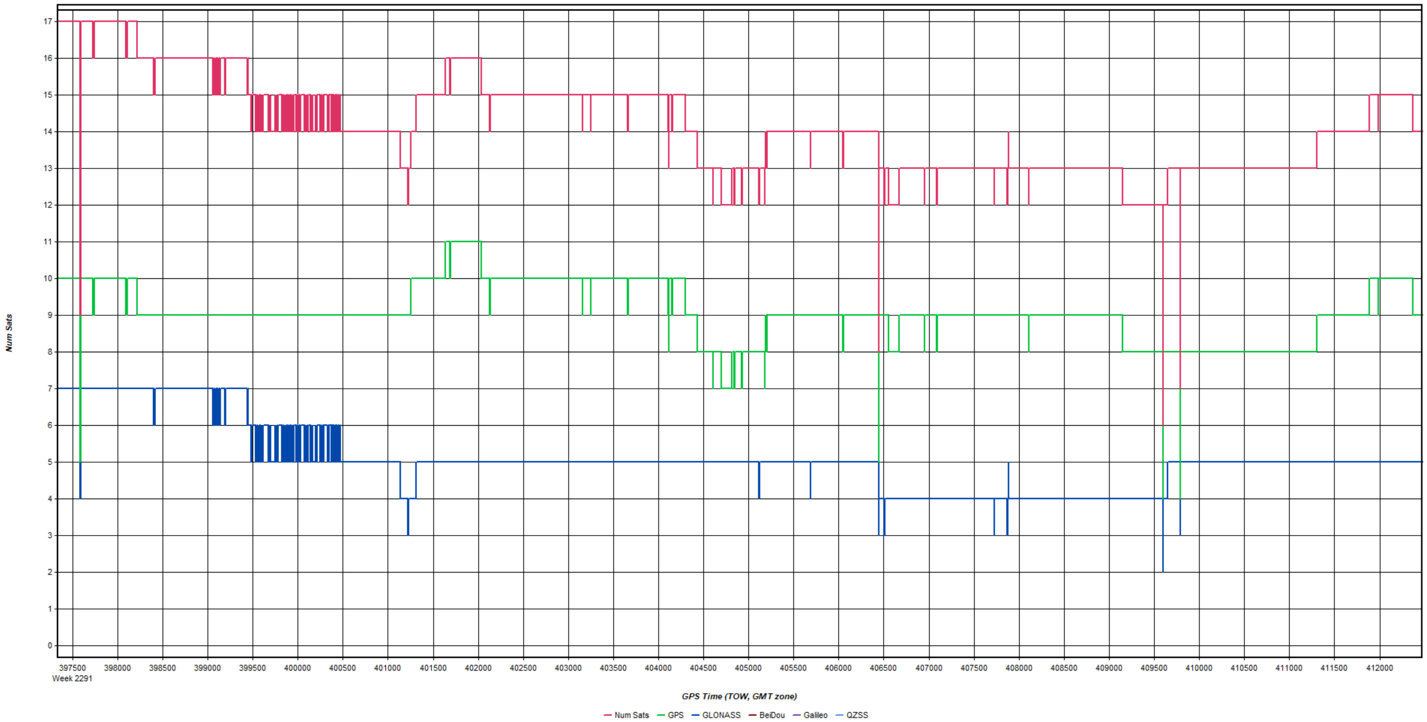

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GLONASS
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Galileo
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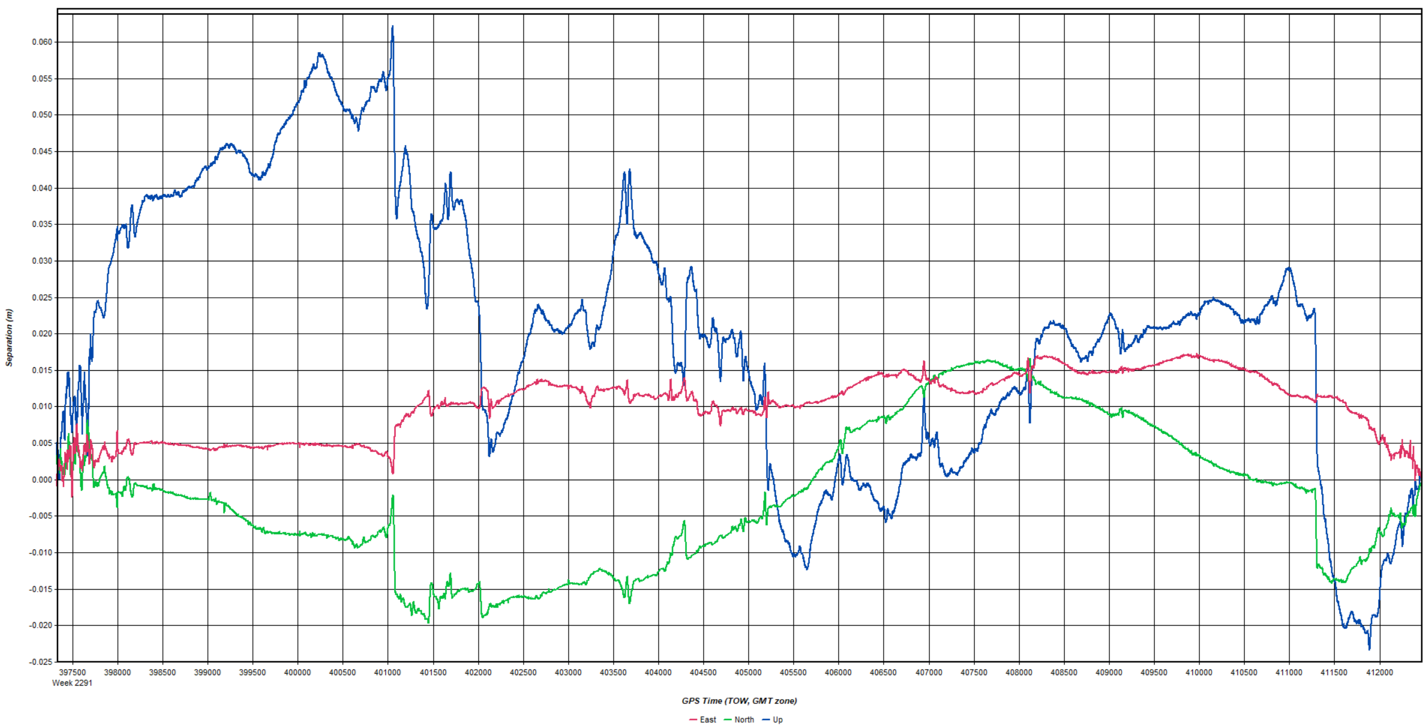

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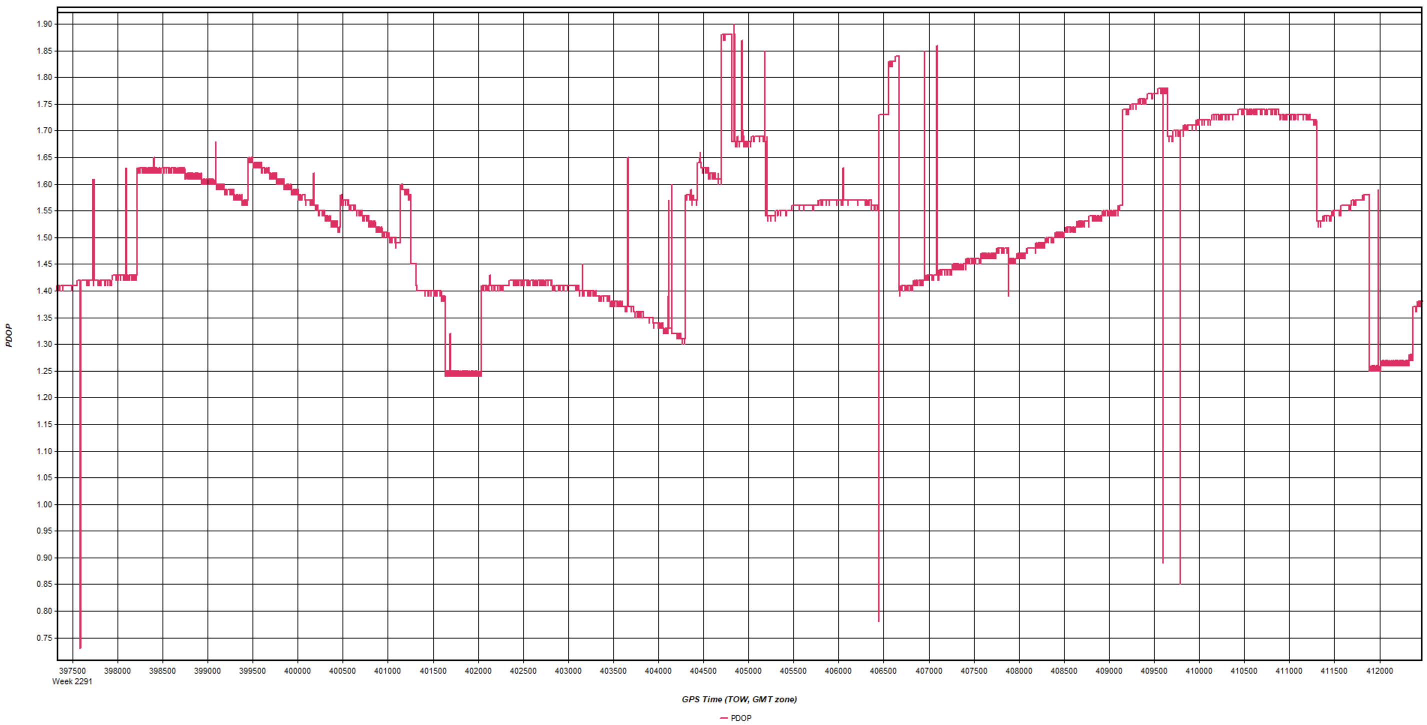
East
North
Up



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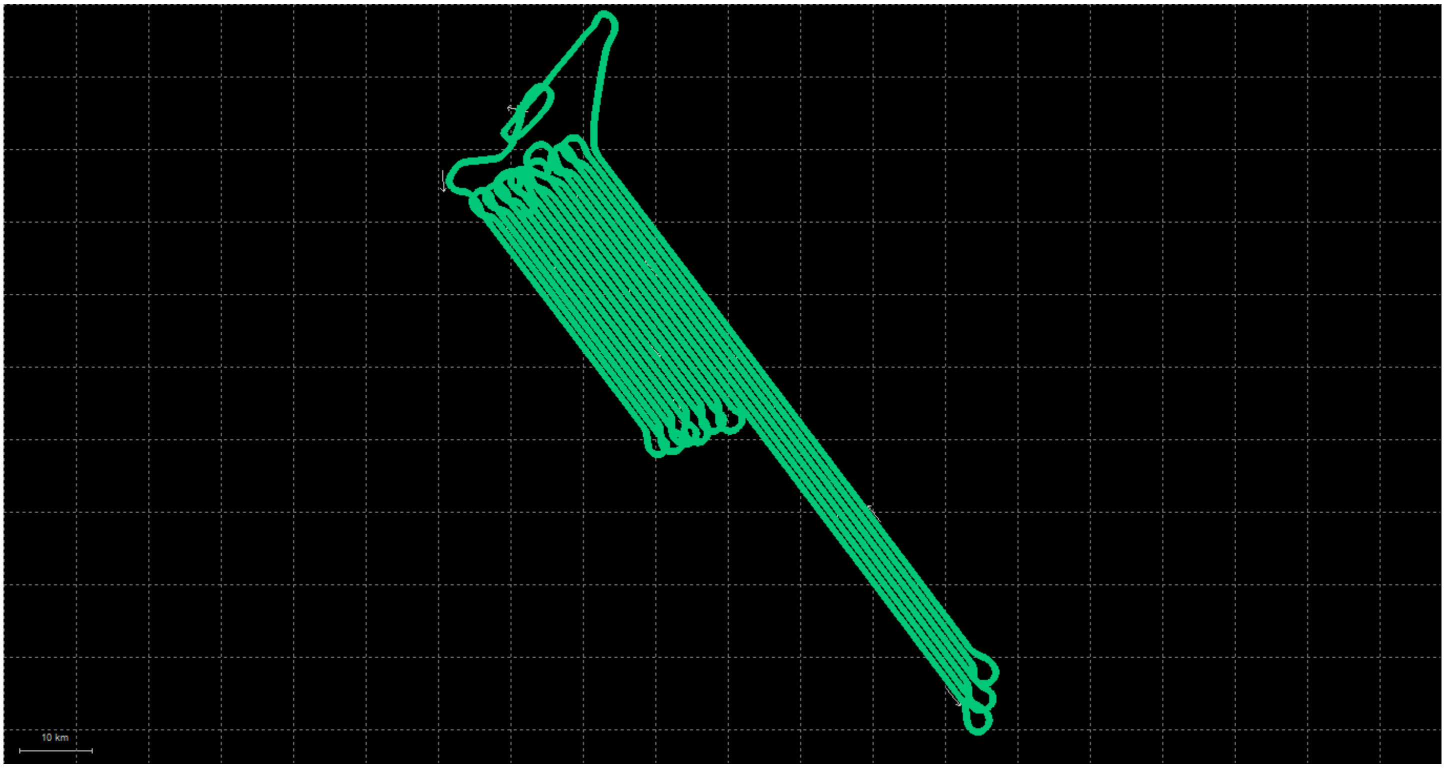

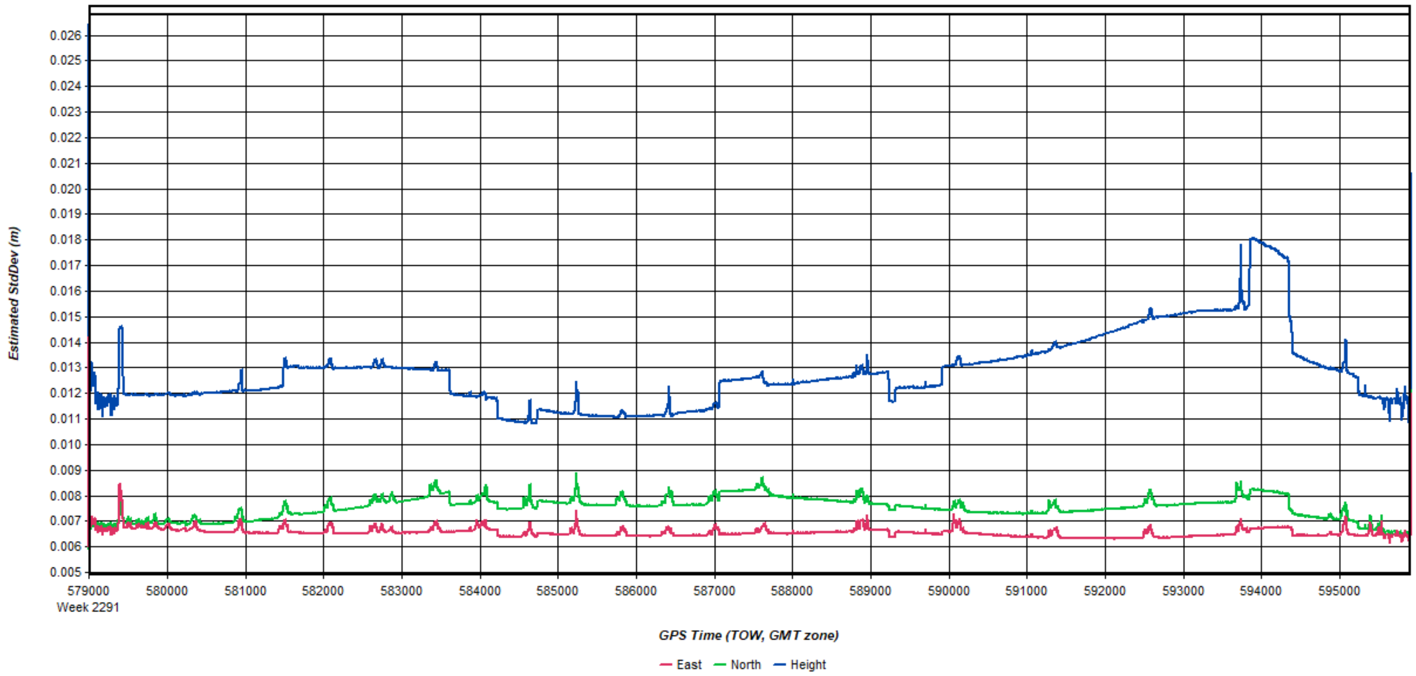

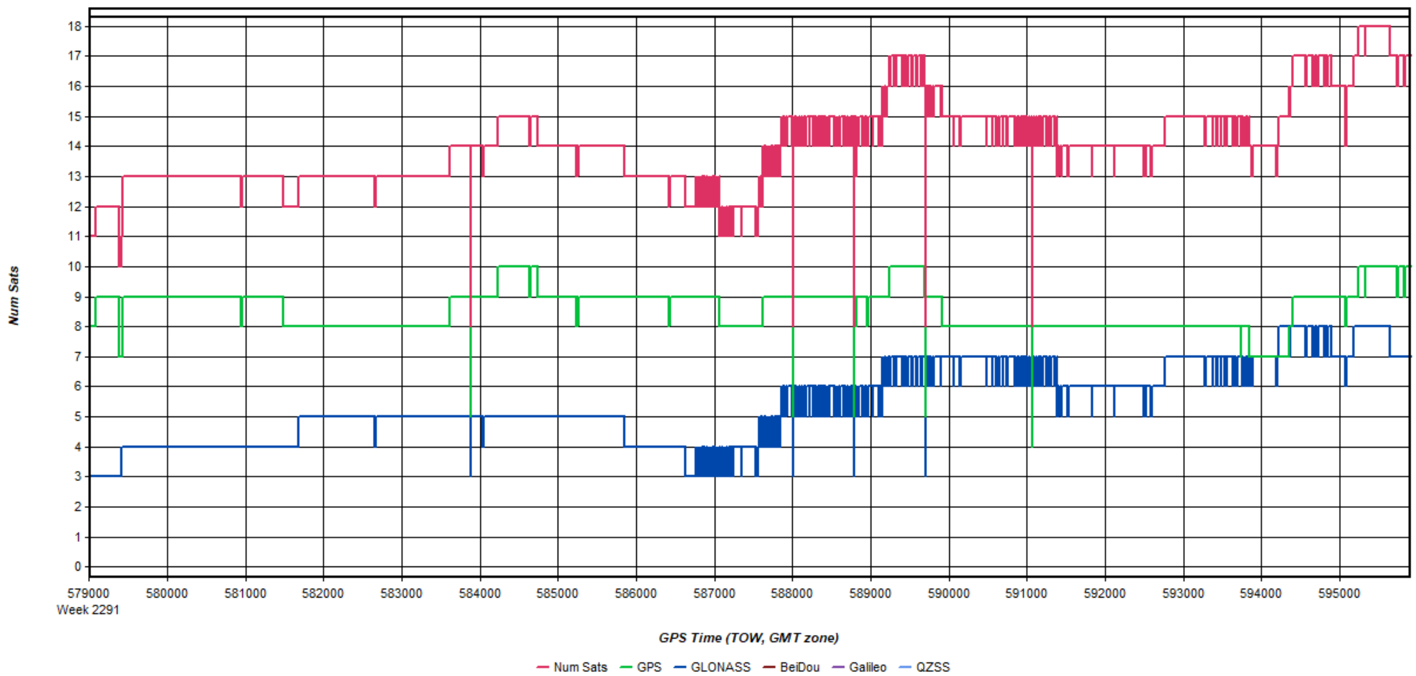

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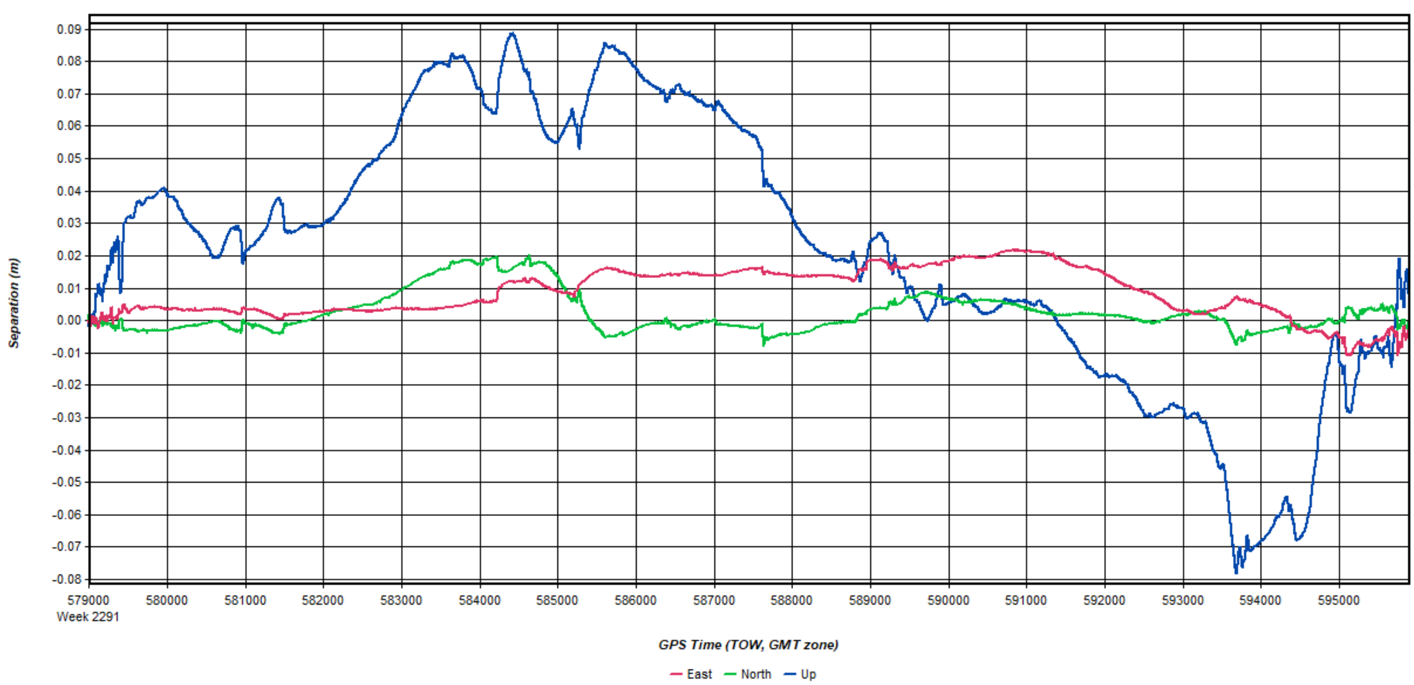
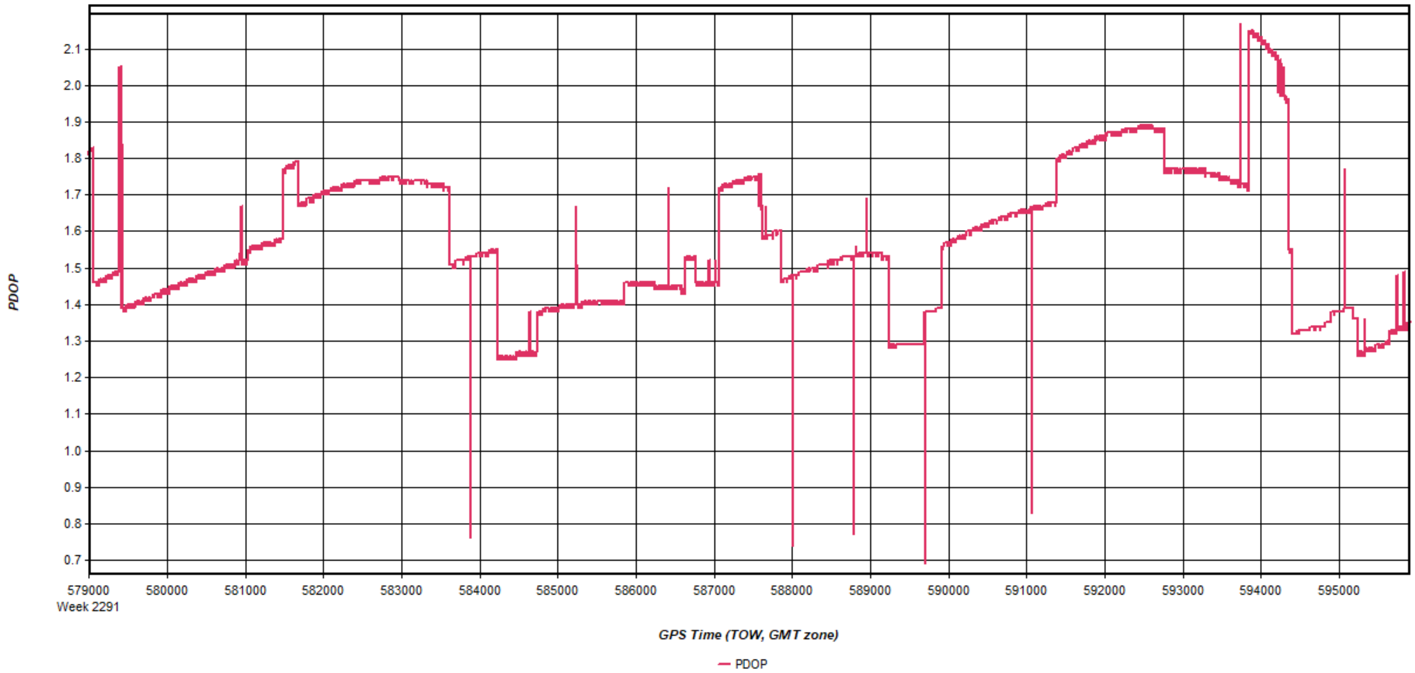
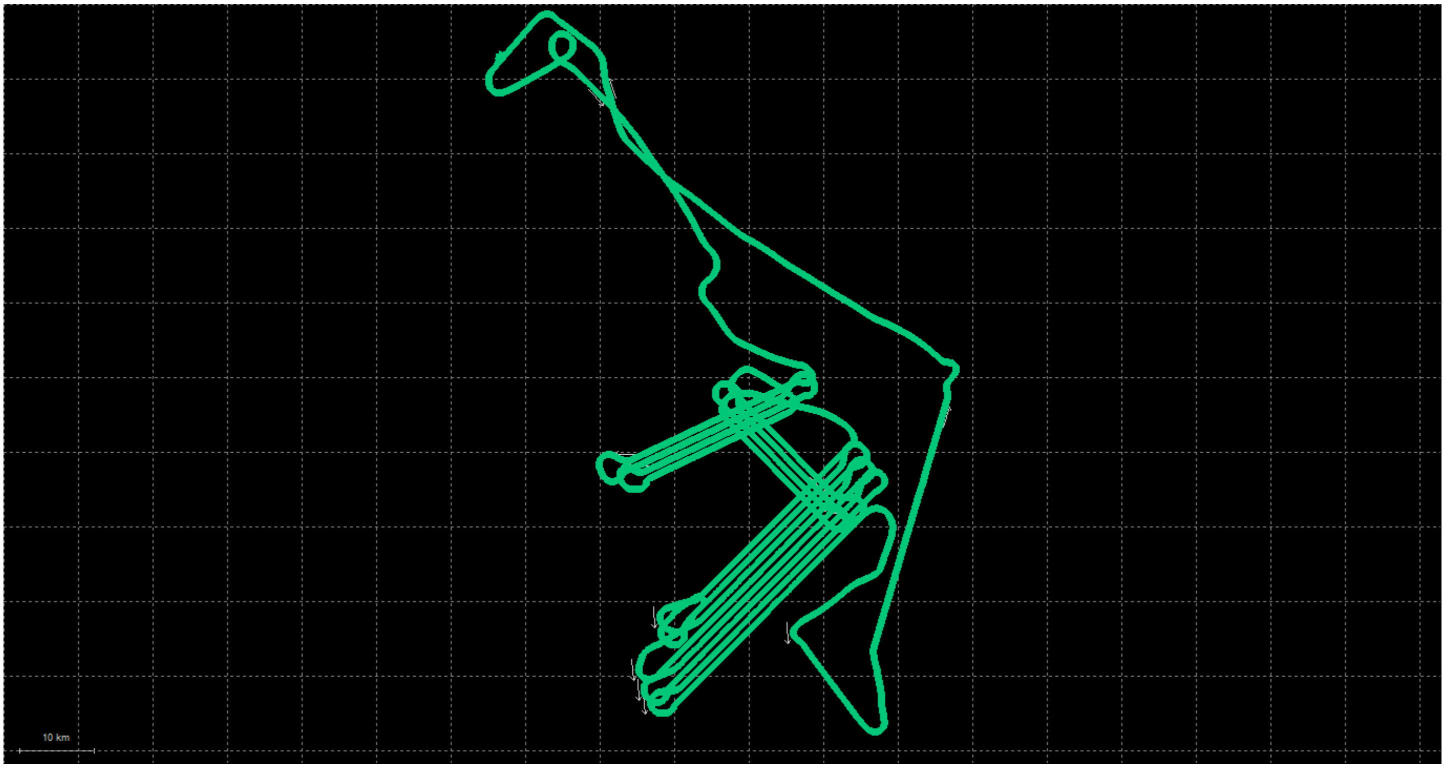
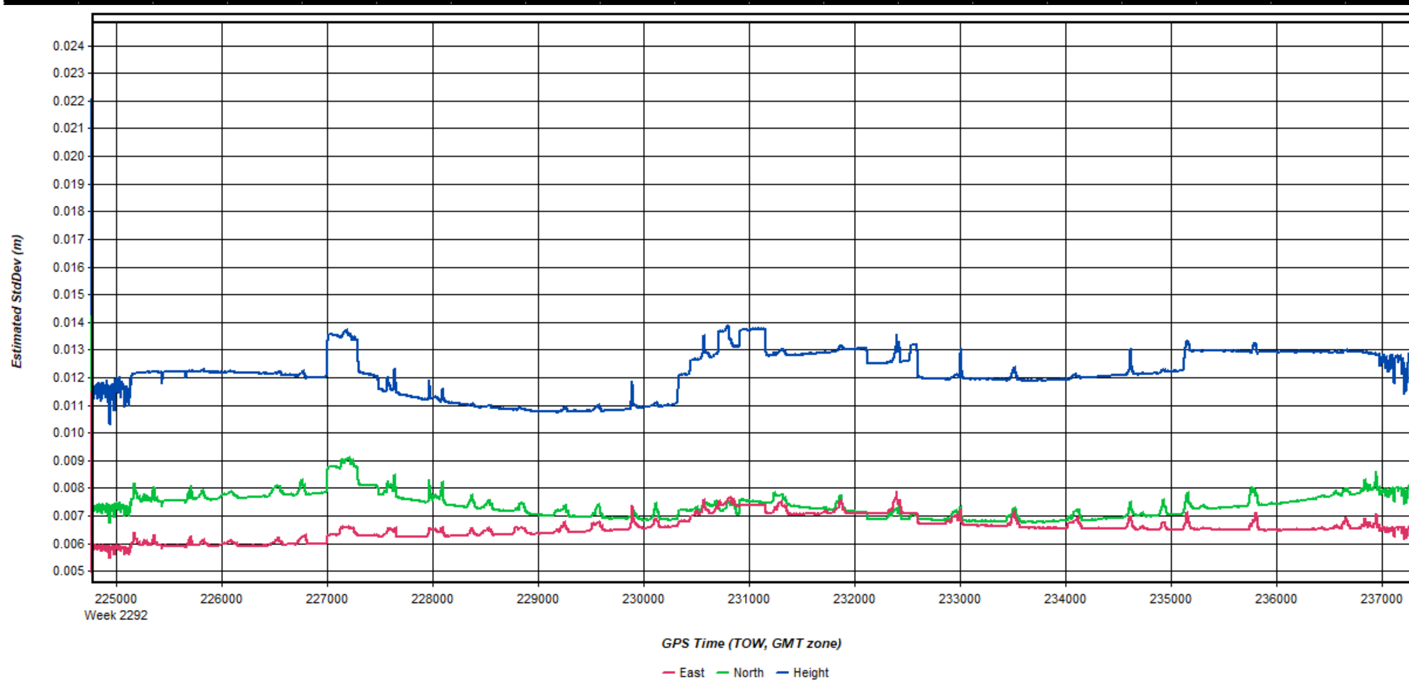


Separation (m)
GPS Time (TOW, GMT zone)
Week 2291
East — North — Up


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
579000
Week 2291
580000
581000
582000
583000
584000
585000
586000
587000
588000
589000
590000
591000
592000
593000
594000
595000
GPS Time (TOW, GMT zone)
PDOP

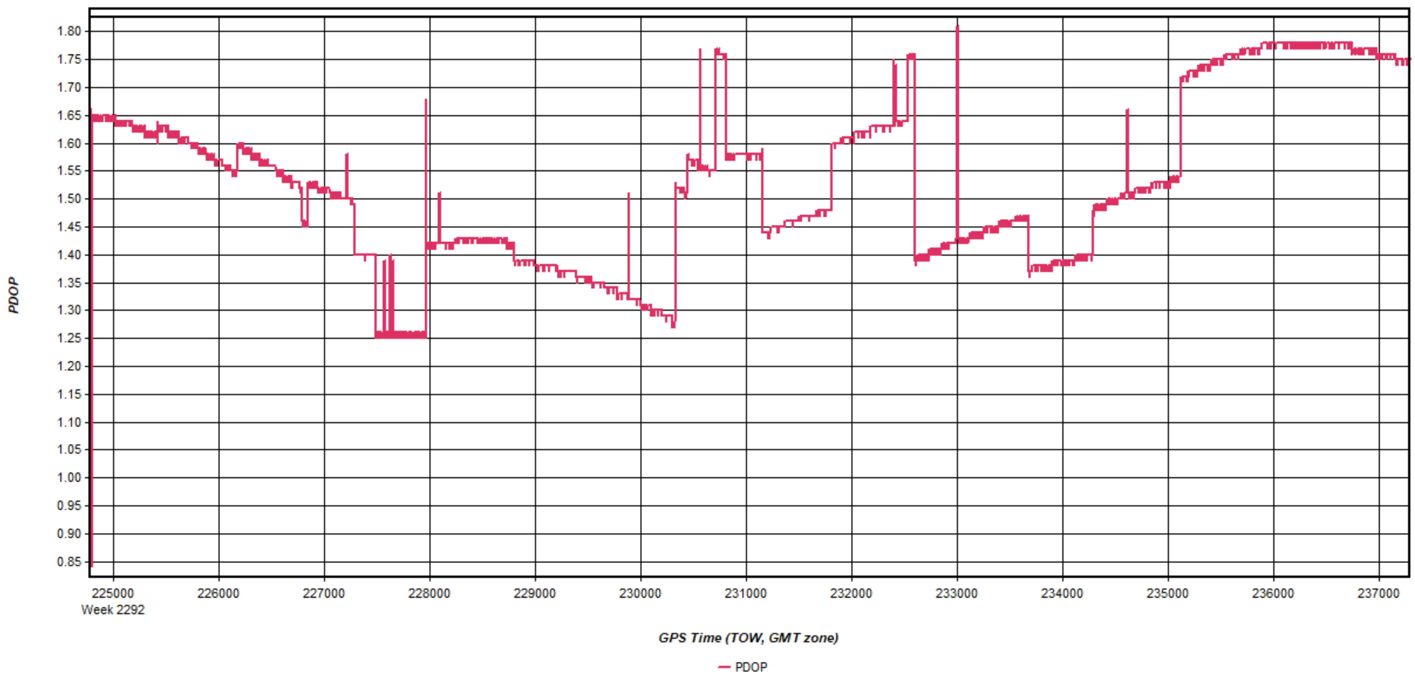
20231212_A_N117JP_91512





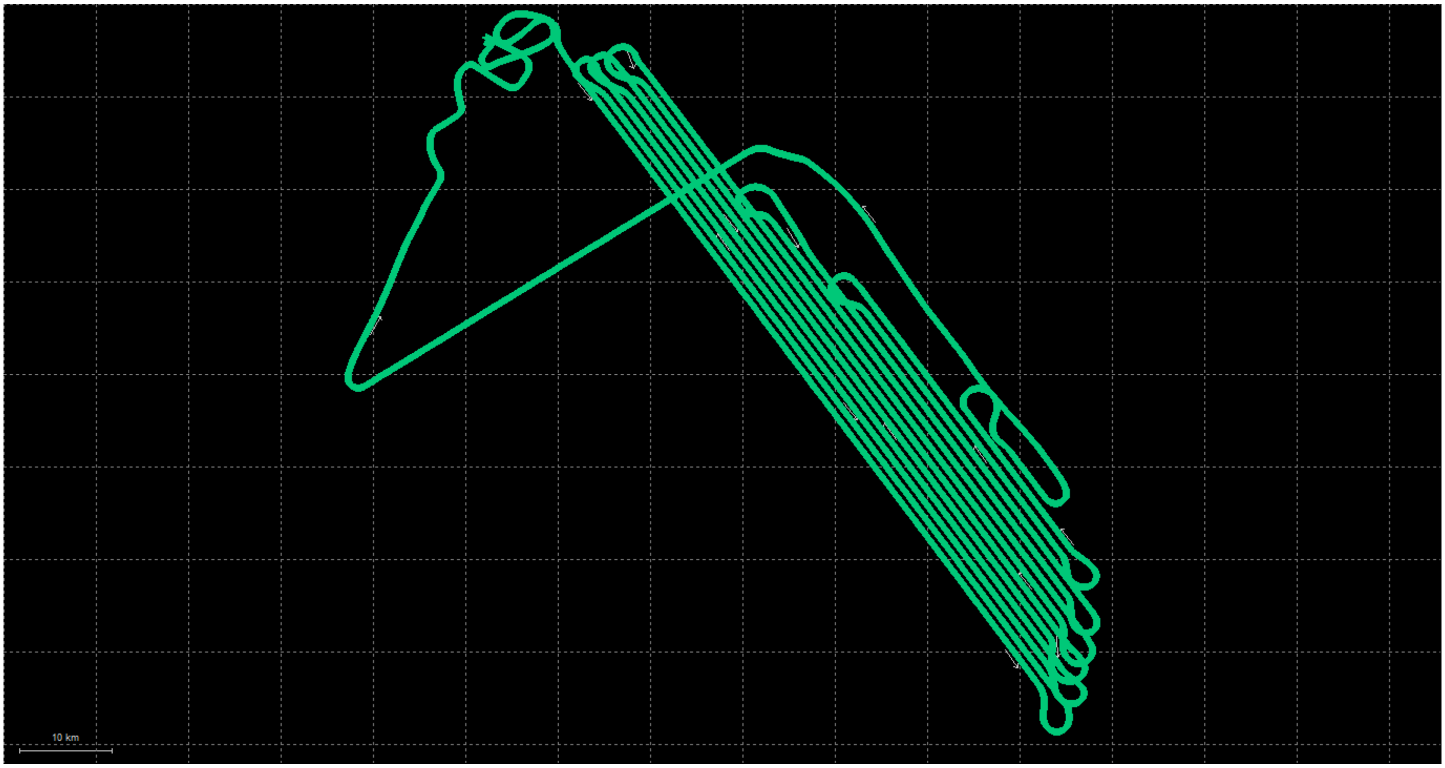

16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
225000
Week 2292
226000
227000
228000
229000
230000
231000
232000
233000
234000
235000
236000
237000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS

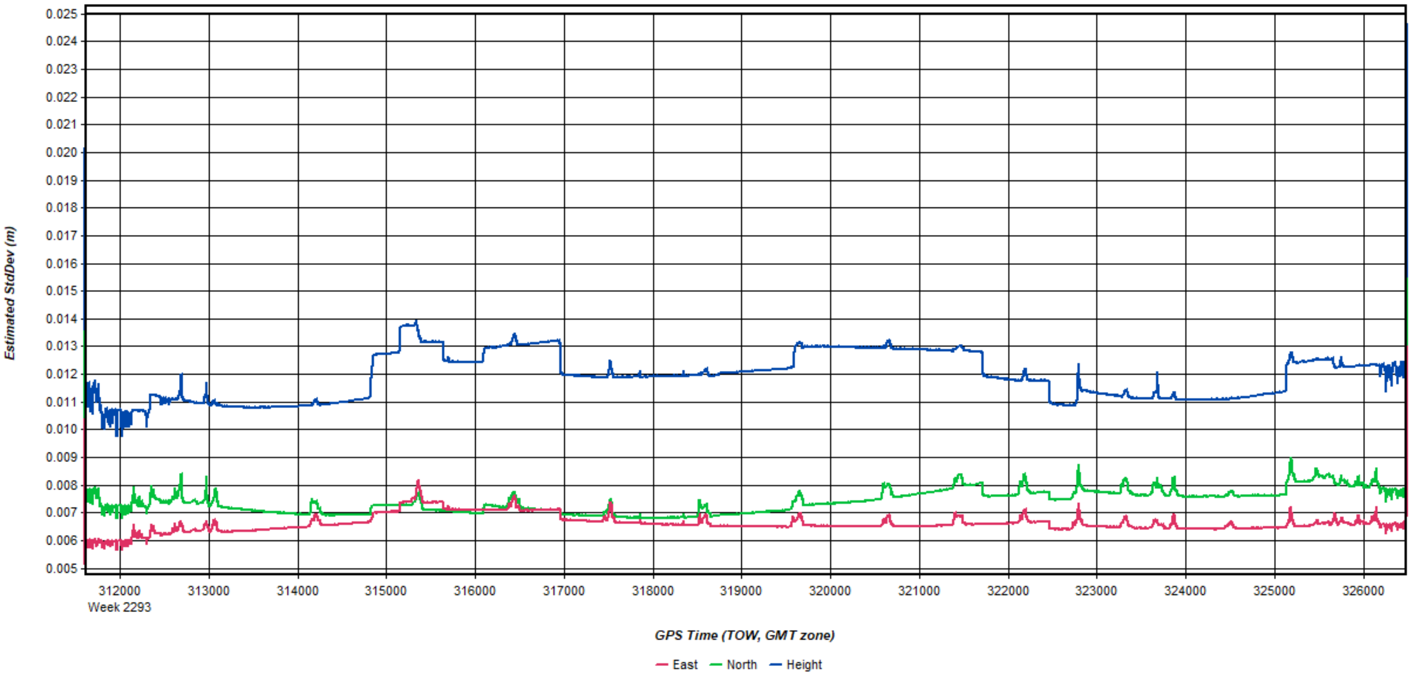

0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
-0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
-0.055
-0.060
Separation (m)
225000
Week 2292
226000
227000
228000
229000
230000
231000
232000
233000
234000
235000
236000
237000
GPS Time (TOW, GMT zone)
East
North
Up

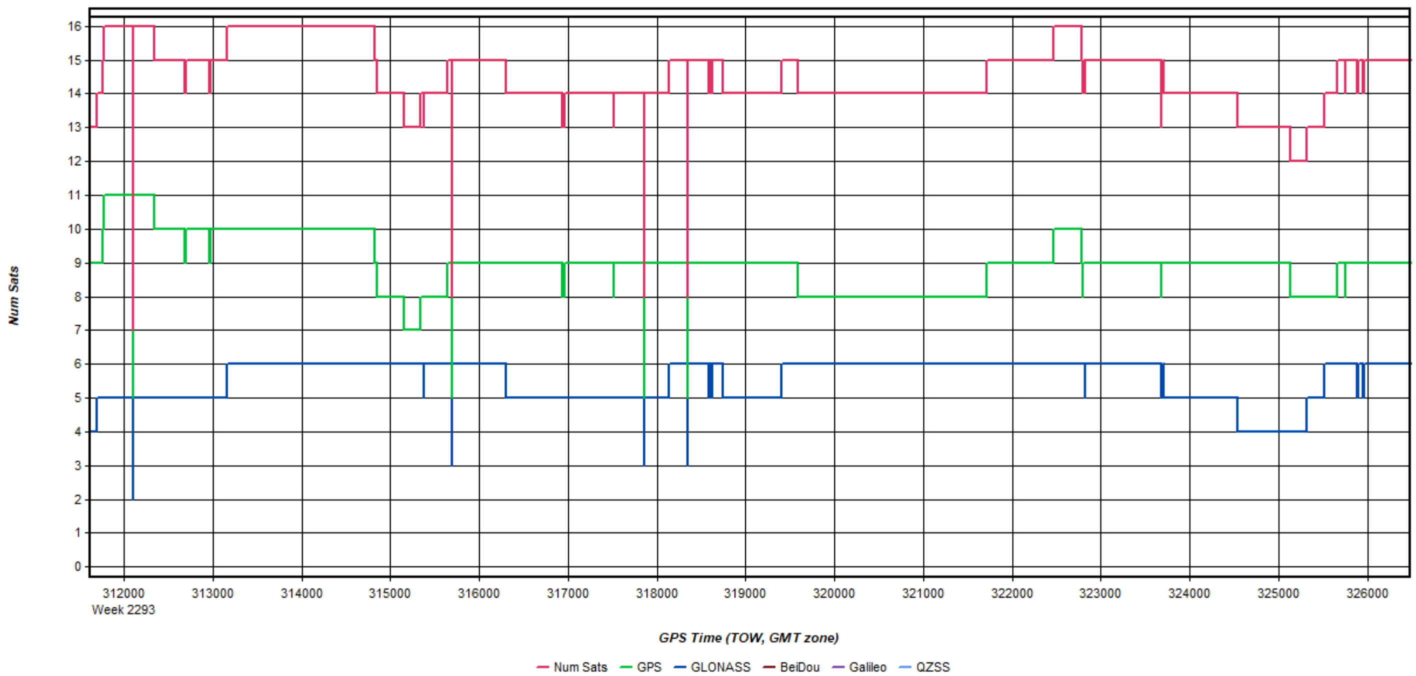


PDOP
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
225000
Week 2292
226000
227000
228000
229000
230000
231000
232000
233000
234000
235000
236000
237000
GPS Time (TOW, GMT zone)
PDOP

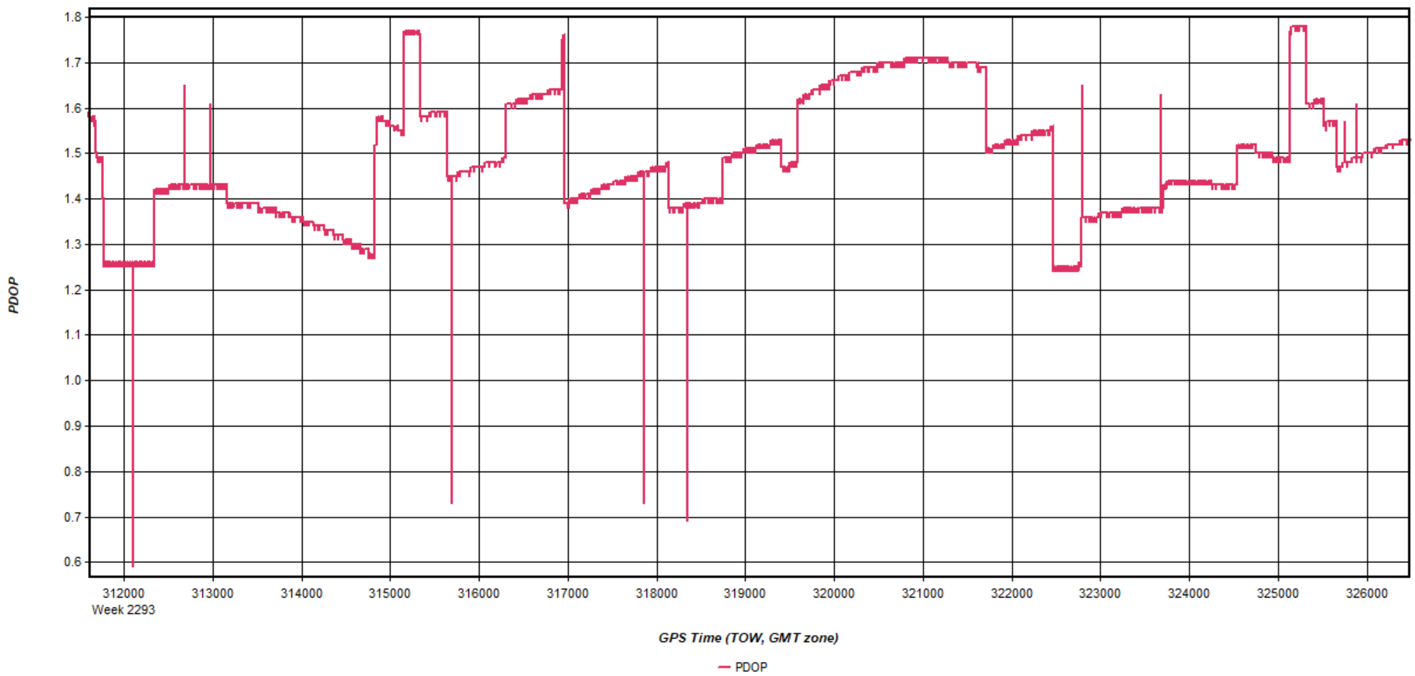
20231220_A_N117JP_91512






Num Sats
312000
Week 2293
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


Separation (m)
312000
Week 2293
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
GPS Time (TOW, GMT zone)
East
North
Up



PDOP
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
312000
Week 2293
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
325000
326000
GPS Time (TOW, GMT zone)
PDOP