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VA_NorthernVA_2_B22

Lidar Mapping Report

February 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 ~ 663 mi² was completed on December 27th, 2022.

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

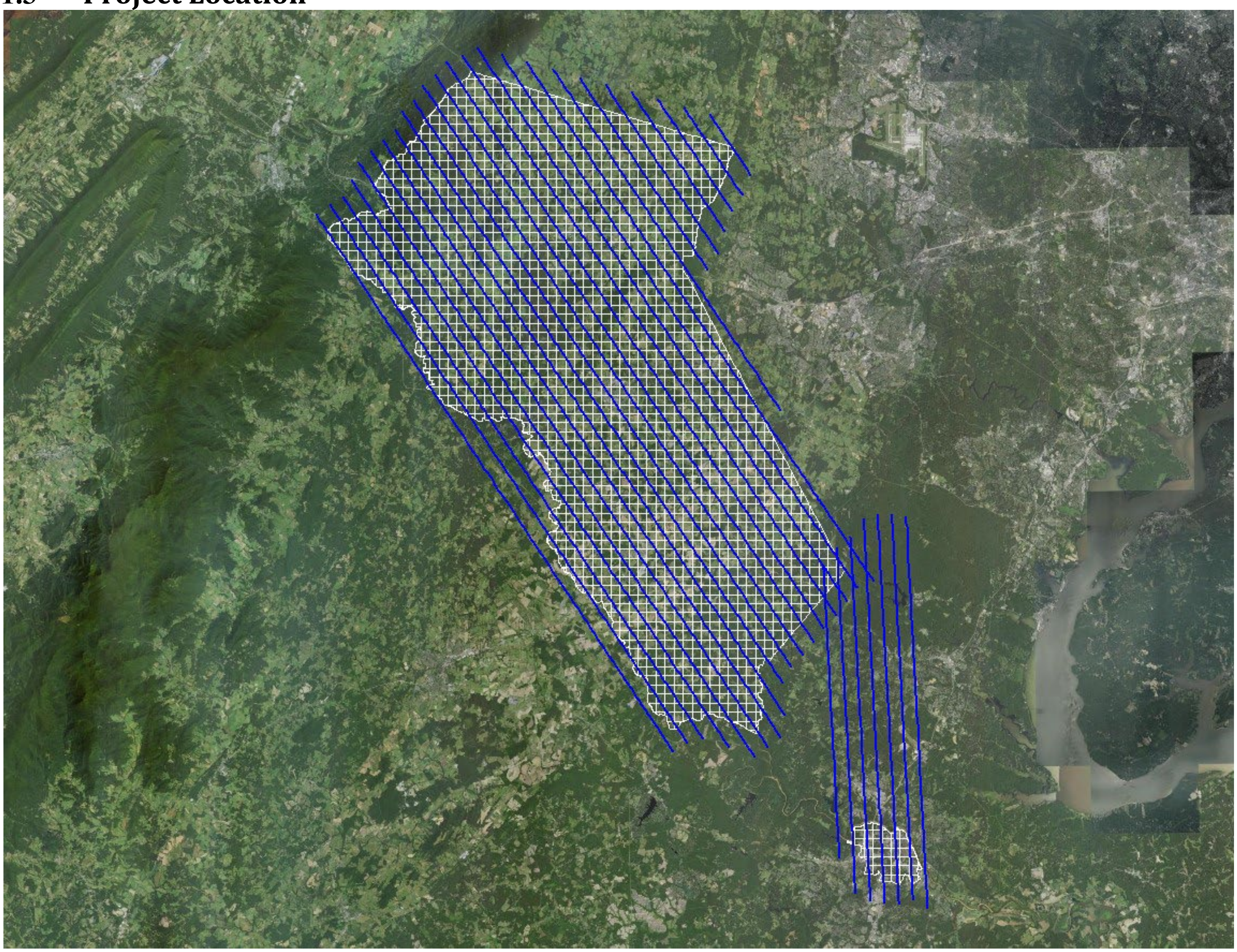


Figure 1: Tile Index and Trajectories As-Flown

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	N278RC - PIPER PA-31-310
Sensor	Leica TerrainMapper
Max Number of Returns	15
Point Spacing (m)	0.67
Point Density (pls/m²)	2.2
Flying Height (AGL) (m)	3300
Air Speed (kts)	160
Field of View (degrees)	40
Scan Rate (Hz)	86.6
Pulse Rate (kHz)	710
Laser Footprint (m)	0.77
Wavelength (nm)	1064
Multi-Pulse	Yes
Swath Width (m)	2402
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 three (3) 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.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
12/13/2022	Leica TerrainMapper	TM91512	N278RC	20221213A_N278RC_TM91512	1.5	15:04:54	21:42:17
12/20/2022	Leica TerrainMapper	TM91512	N278RC	20221220B_N278RC_TM91512	1.6	20:29:32	23:31:28
12/27/2022	Leica TerrainMapper	TM91512	N278RC	20221227A_N278RC_TM91512	1.6	17:20:38	23:43:28

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
CORB	CORS	AJ2122	38 12 07.85751	077 22 24.58747	35.931
LOY8	CORS	DH7954	38 16 58.72119	077 27 09.48584	-6.214
LOYC	CORS	DH8807	39 07 12.57593	078 12 02.62754	201.819
LOYJ	CORS	DL2308	38 28 20.92261	078 00 36.16468	103.865
LOYY	CORS	DL3476	38 53 18.57705	078 29 56.96218	220.888
ZDC1	CORS	DF9217	39 06 05.74479	077 32 33.88523	79.618

Table 3: GNSS Reference Station Coordinates

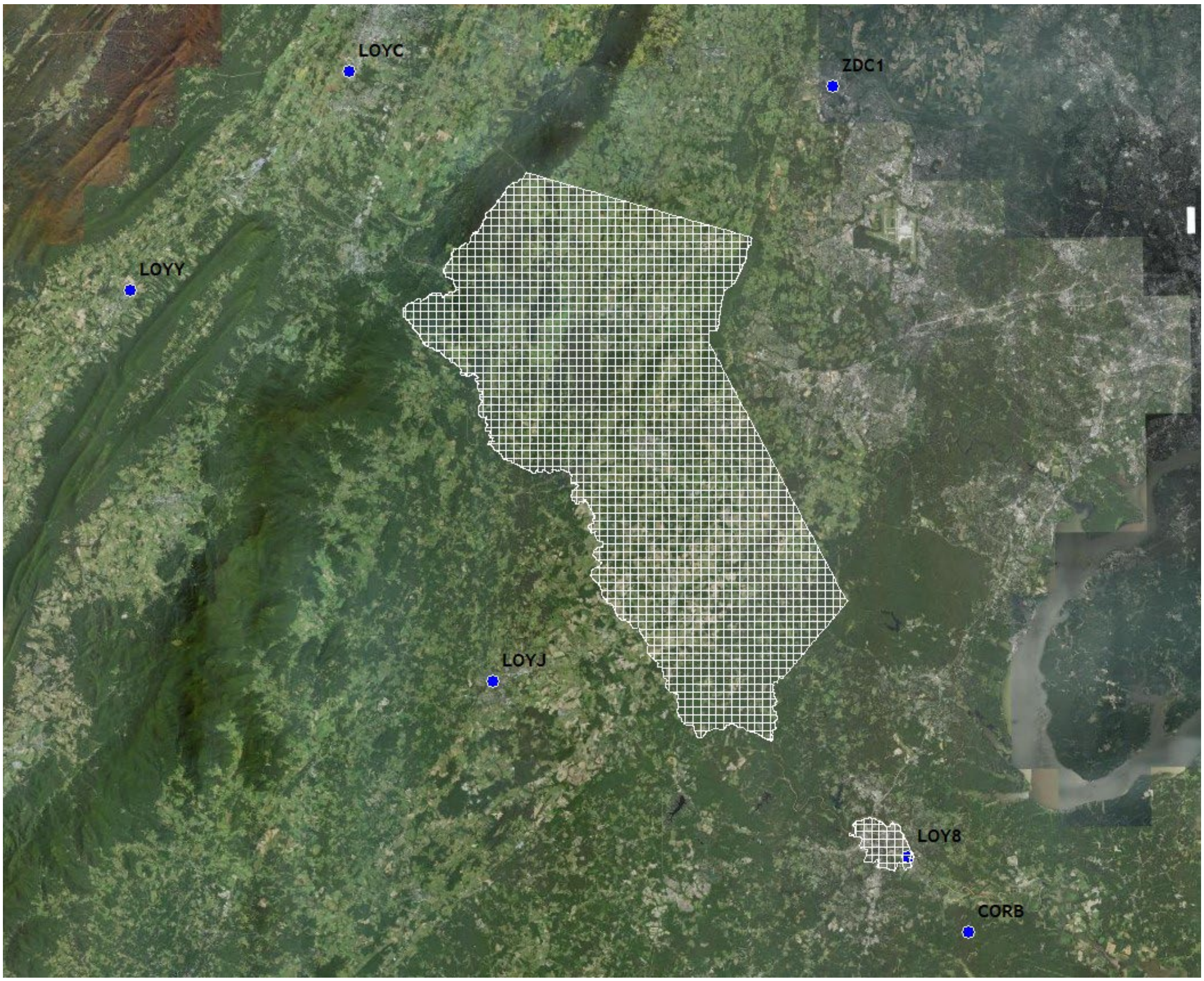


Figure 2: GNSS Reference Stations

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.

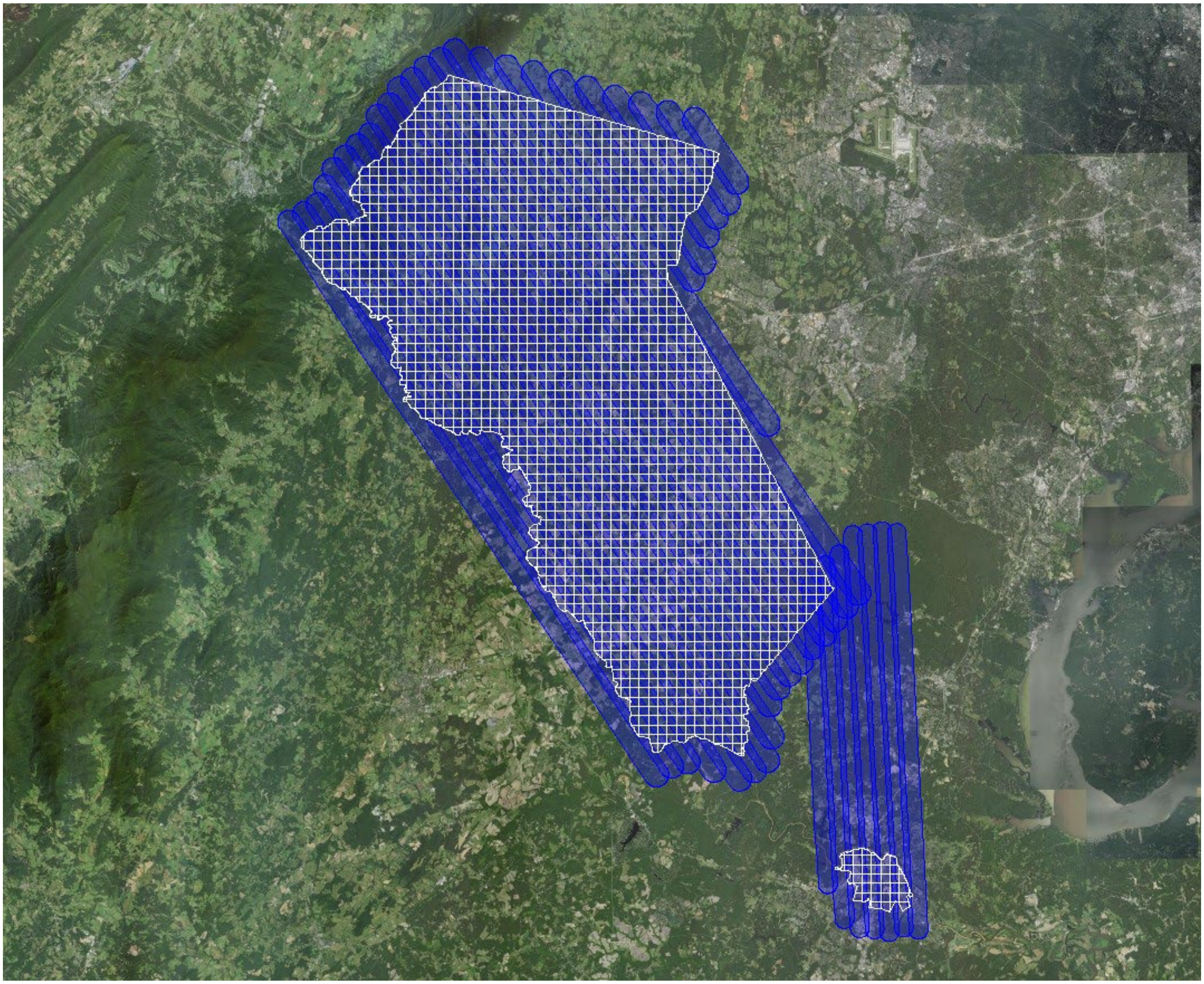


Figure 3: Raw Swath Coverage

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.

Data was tested at 0.48 meter aggregate nominal pulse spacing and at 4.3 aggregate points per meter. The aggregate nominal pulse spacing was tested on classified tiled LAS using geometrically reliable first-return points without overlap. ANPS was tested using Delaunay Triangulation that produced average point spacing between all nearest neighbors.

Category	Value
Aggregate Total Points	8,257,169,367
Aggregate Nominal Pulse Spacing (m)	0.48
Aggregate Nominal Pulse Density (pls/m^2)	4.3
Aggregate Nominal Pulse Spacing (ft)	1.59
Aggregate Nominal Pulse Density (pls/ft^2)	0.4

Table 4: Point Cloud Statistics

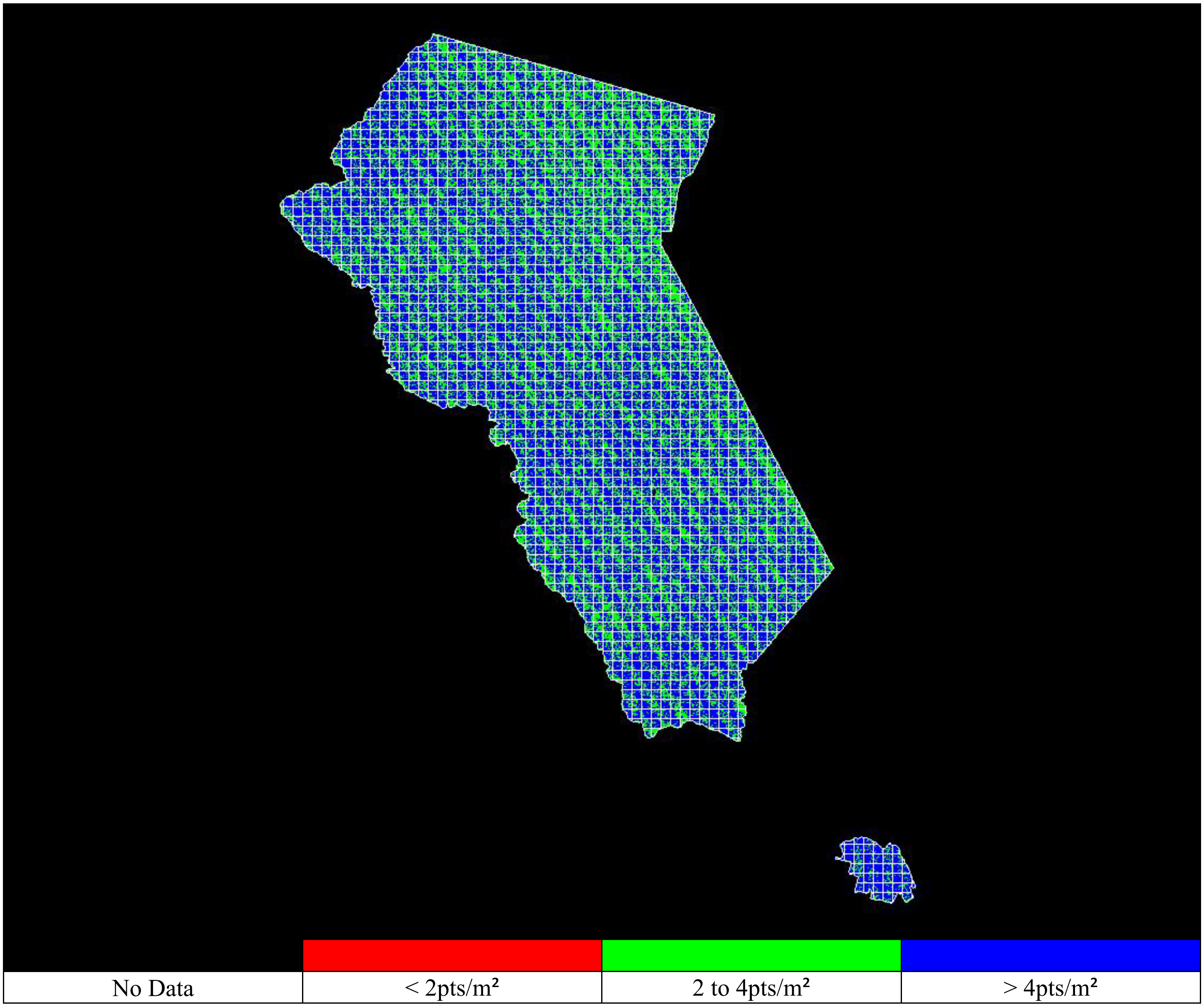


Figure 4: Point Cloud Density, of all points and all returns, no noise and no withheld points.

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (2011)
Projection: Virginia North
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid18
Units: Feet

3.3 Lidar Matching

Sanborn uses pre-processing Leica HexMap and GeoCue 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.

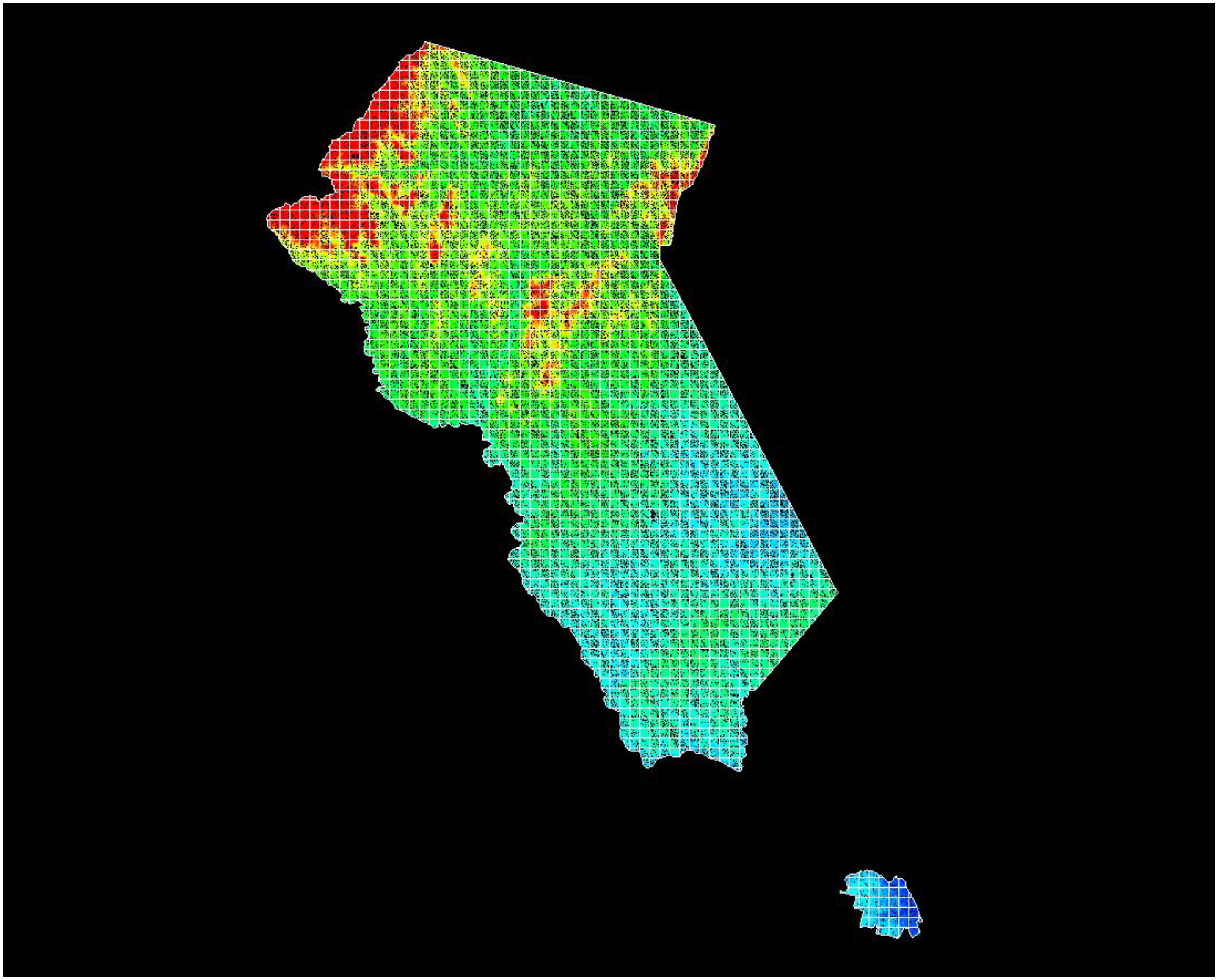


Figure 5: Point Cloud Elevation

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.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure both the individual precision and alignment of the lidar dataset. Swath Precision Images modulated by Intensity are representative of the intraswath alignment and provide a holistic qualitative look at the goodness of fit within each swath. 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. Furthermore, the set of TerraMatch Tie Lines are used to produce a Tie Line Report to statistically assess the X. Y. and Z offset averages and magnitudes for the whole project including each line individually. 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 (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

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
155	0.043	0.037	0.021	**204**	0.050	0.048	0.027	**215**	0.041	0.037	0.030
156	0.034	0.032	0.018	**205**	0.050	0.048	0.025	**216**	0.052	0.047	0.025
157	0.032	0.032	0.020	**206**	0.048	0.045	0.029	**217**	0.058	0.053	0.030
158	0.036	0.039	0.019	**207**	0.050	0.042	0.028	**218**	0.057	0.058	0.030
159	0.037	0.038	0.020	**208**	0.047	0.041	0.026	**219**	0.060	0.053	0.029
160	0.031	0.035	0.018	**209**	0.045	0.043	0.020	**220**	0.055	0.041	0.031
161	0.029	0.026	0.017	**210**	0.048	0.047	0.025	**221**	0.052	0.042	0.029
200	0.045	0.043	0.025	**211**	0.051	0.046	0.022	**222**	0.053	0.047	0.030
201	0.044	0.043	0.024	**212**	0.050	0.044	0.025	**223**	0.055	0.050	0.028
202	0.048	0.046	0.025	**213**	0.048	0.044	0.029				
203	0.051	0.048	0.025	**214**	0.051	0.046	0.029				

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.032	0.033	0.016
RMS Values	0.046	0.047	0.021
Maximum Values	0.495	0.475	0.500
Observation Weight	892609.0	892609.0	1286184.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.04386
Average XY Mismatch	0.05148
Average Z Mismatch	0.01626

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	151,739
Roof Lines	398,734

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 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 10** outlines a statistical summary of the point classes leveraged in the lidar dataset.

Code	Class	Points
1	Unclassified	3,818,814,866
2	Ground	4,420,111,907
7	Low Noise	14,956,661
9	Water	612,339
17	Bridge Decks	541,671
18	High Noise	1,963,939
20	Ignored Ground	167,984
Flag	Withheld	16,920,600

Table 10: Lidar Classification Statistics

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of 50 check points (27 NVA + 23 VVA). The result provided a vertical accuracy that fell within project specifications. Please see 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 (m)	Value (ft)
RMSEz	≤0.100	≤0.328
@ 95-Percent Confidence Level	≤0.196	≤0.643
@ 95^{th} Percentile	≤0.300	≤0.984

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	27	0.093	0.183	
NVA of Bare Earth	27	0.110	0.216	
NVA of DEM	27	0.100	0.196	
VVA of Bare Earth	23	0.198		0.304
VVA of DEM	23	0.191		0.300

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

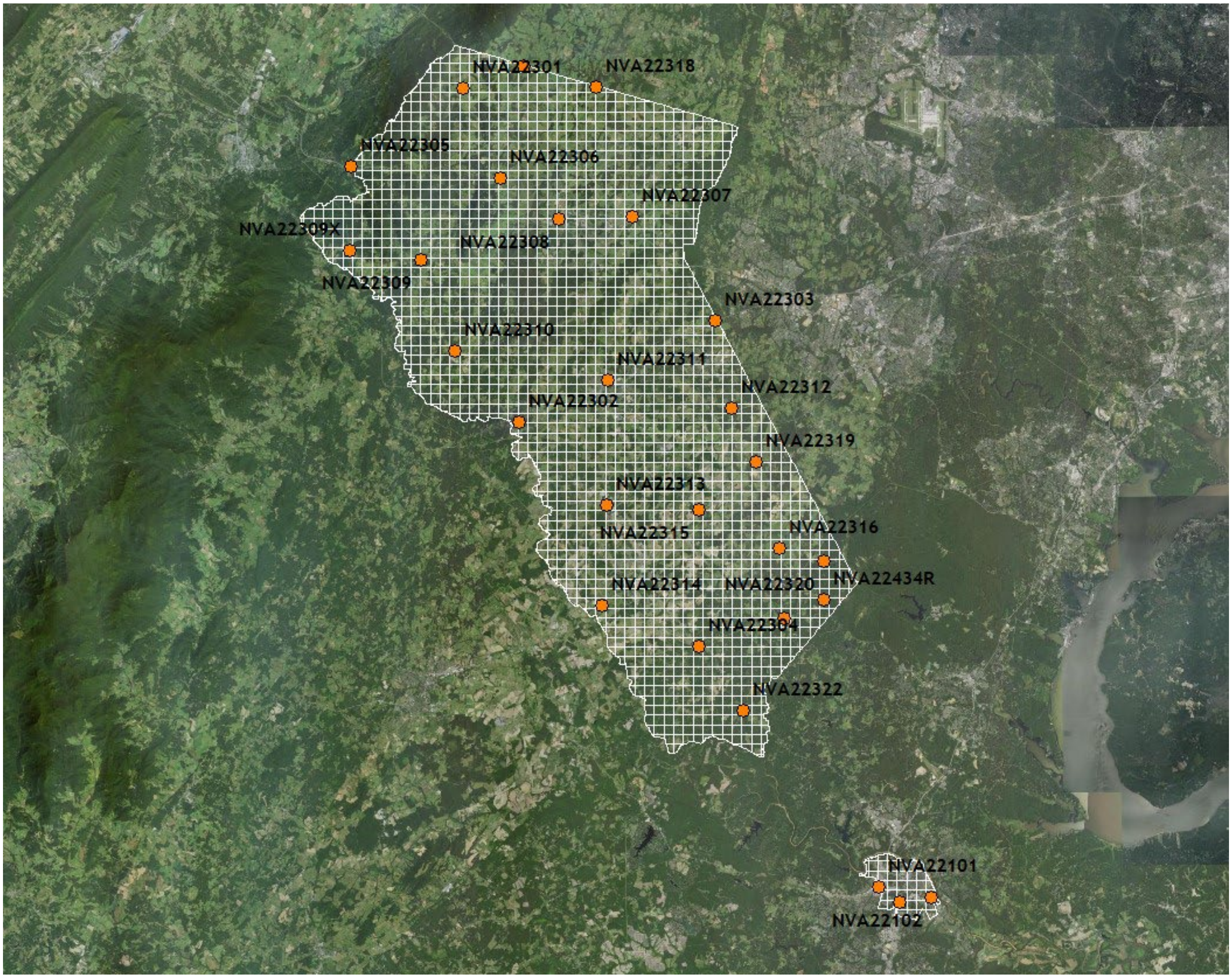


Figure 7: Non-vegetated Check Point Distribution

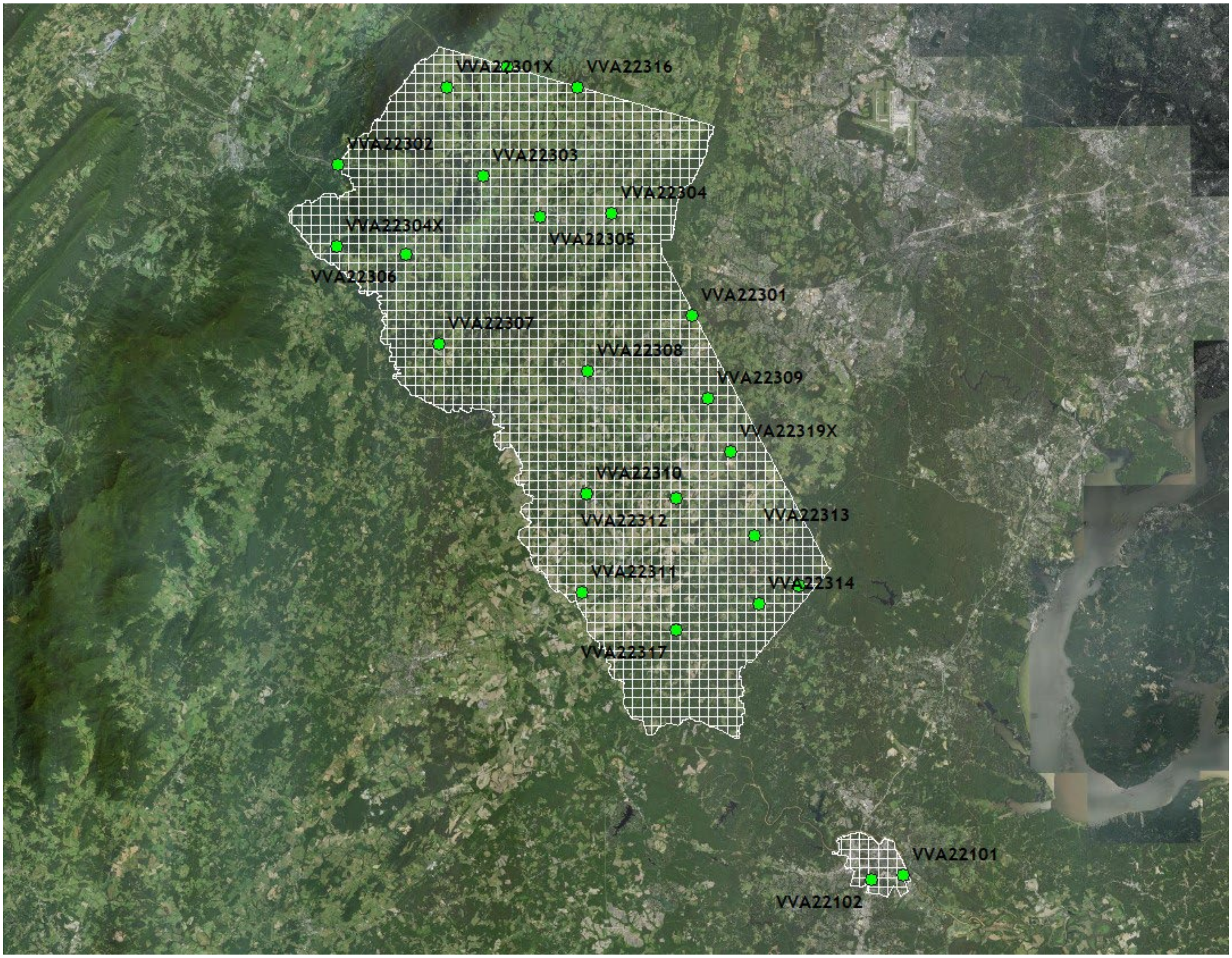


Figure 8: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

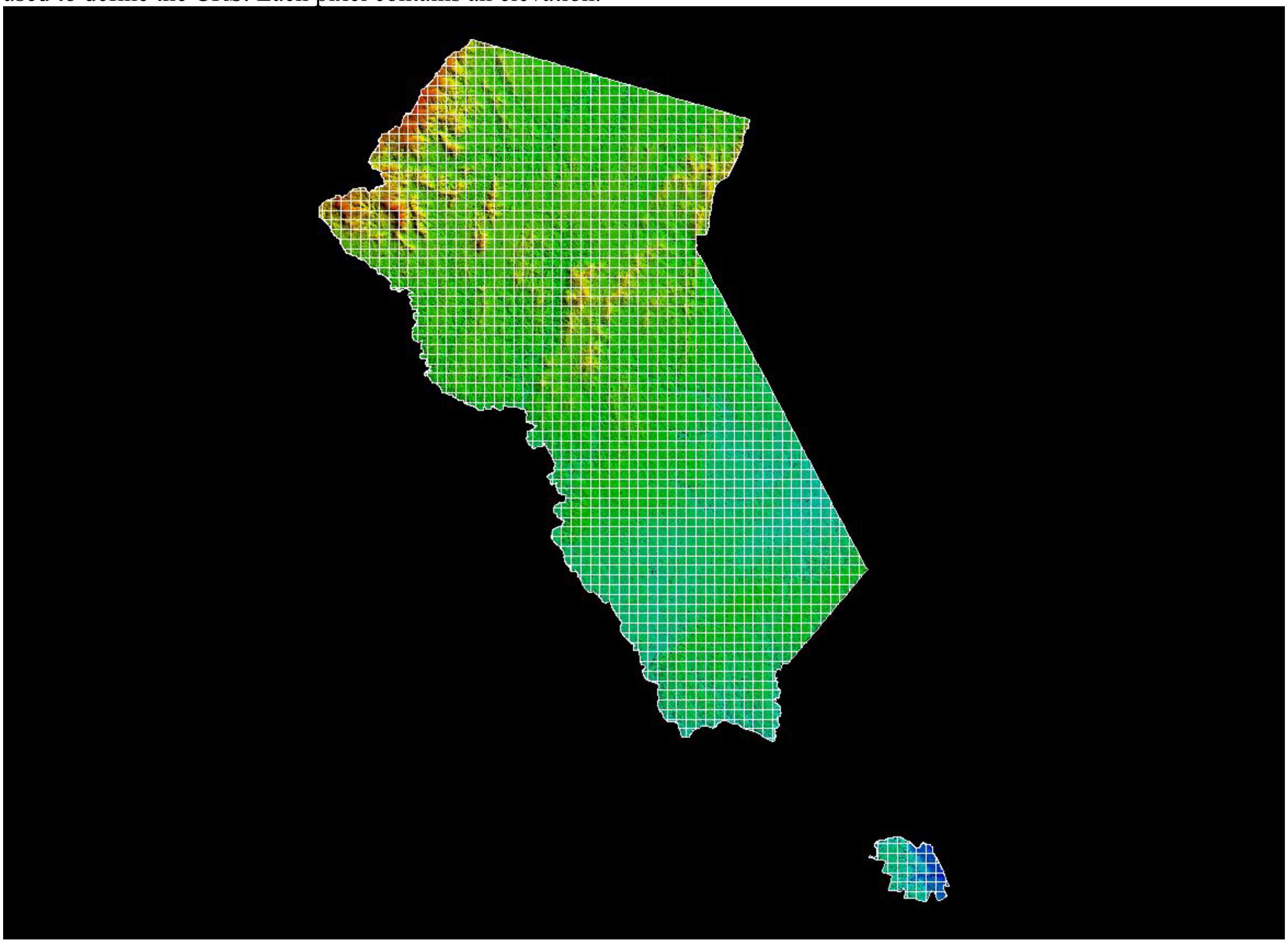
The following products were generated using the final coordinate system as defined in the contract:

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.

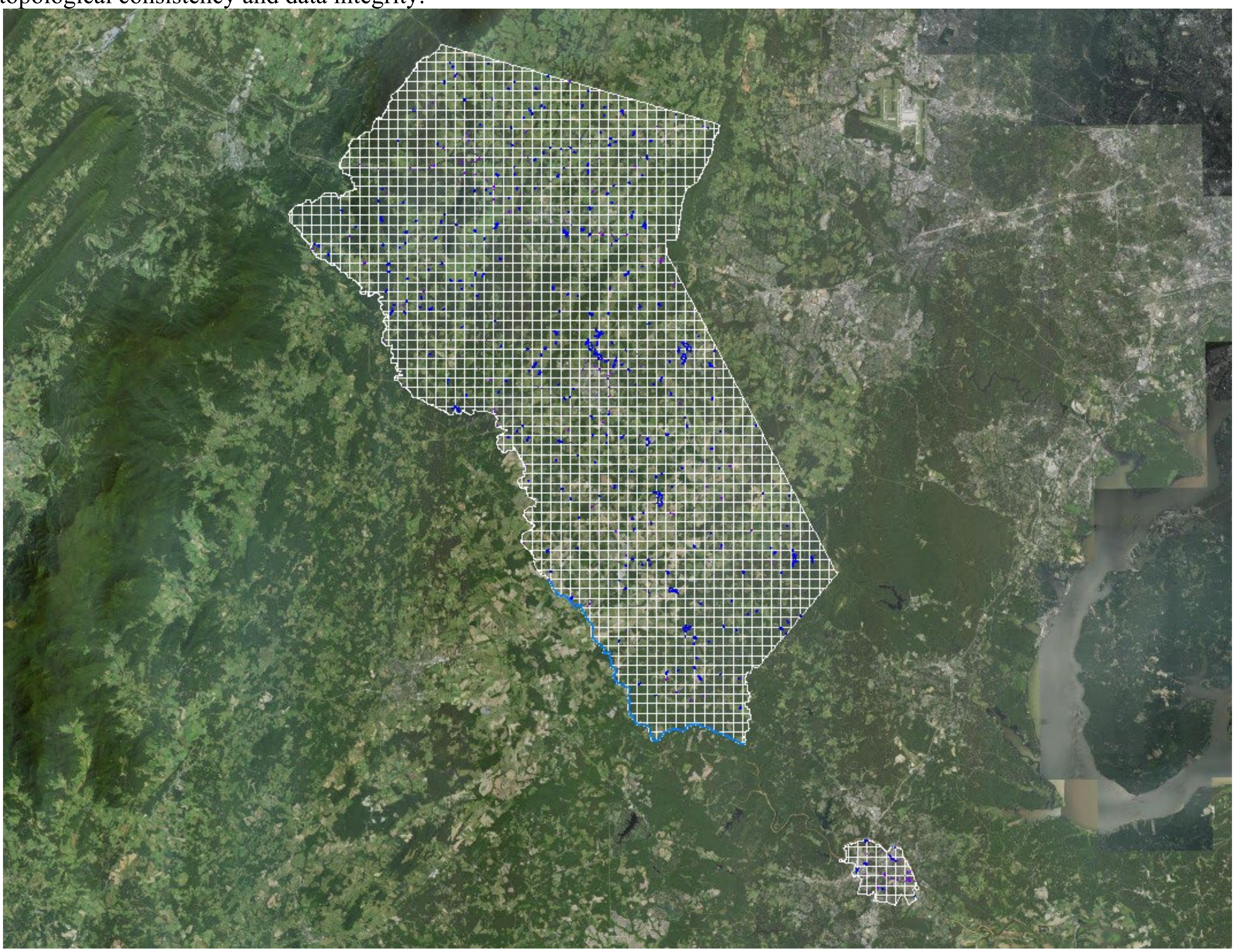
Bare-earth Digital Elevation Model (DEM)

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.



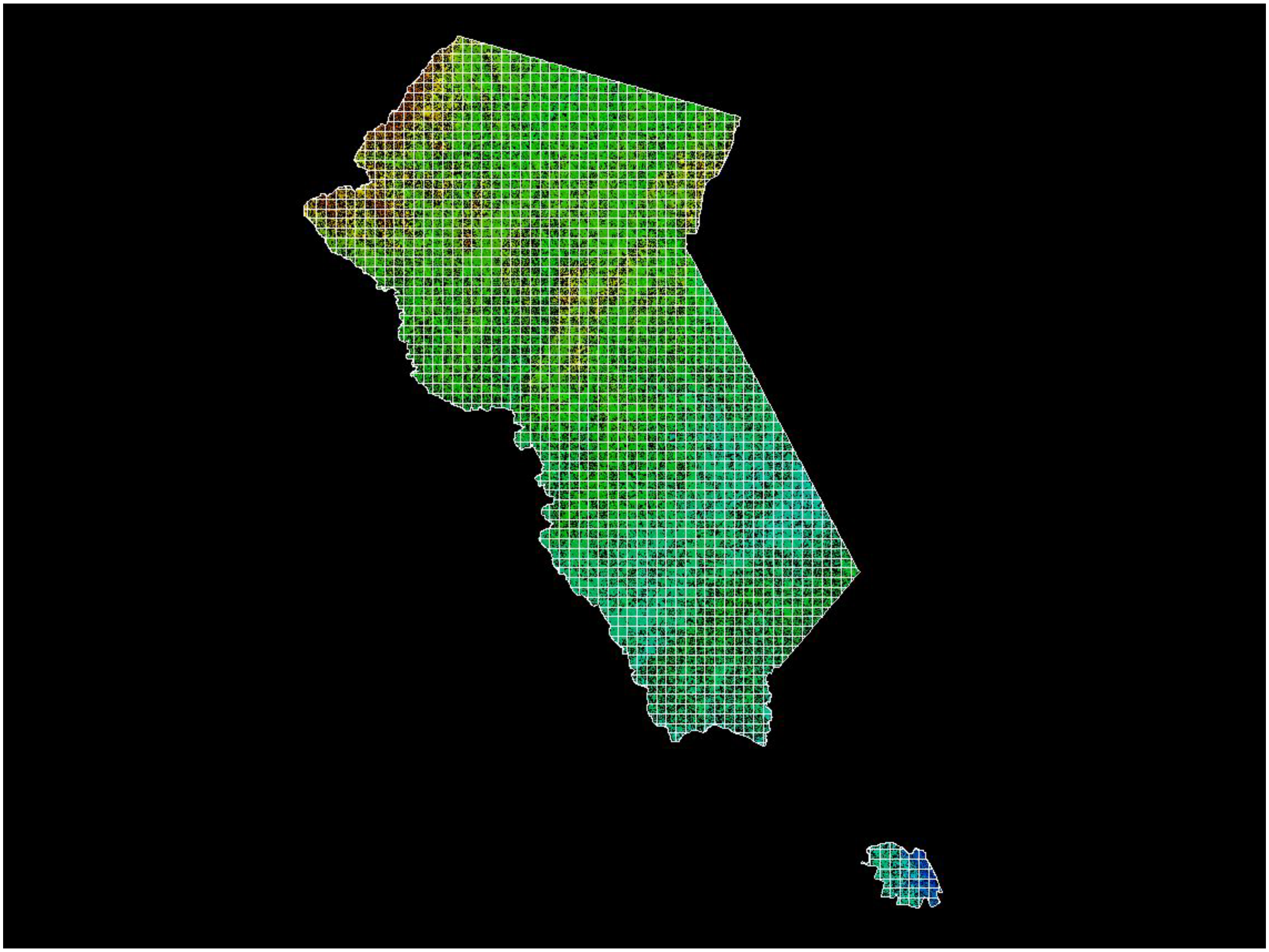
Breaklines

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. The surface model was used to heads-up digitize 2D breaklines of inland streams and rivers with a 100 foot nominal width and Inland Ponds and Lakes of 2 acres or greater surface area. Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Stream and River Islands, using LP360 functionality. Elevation values were assigned to all Inland streams and rivers using LP360 functionality. All ground (Class 2) lidar data inside of the collected inland breaklines were then classified to water (Class 9) using LP360 functionality. A buffer of 1 ft was also used around each hydro-flattened feature. These points were moved from ground (Class 2) to Ignored Ground (Class 20). The breakline files were then translated to ESRI File-Geodatabase format using ESRI conversion tools. Breaklines are reviewed against lidar intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to lidar elevations to ensure all breaklines match the lidar within acceptable tolerances. Some deviation is expected between breakline and lidar elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once completeness, horizontal placement, and vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity.



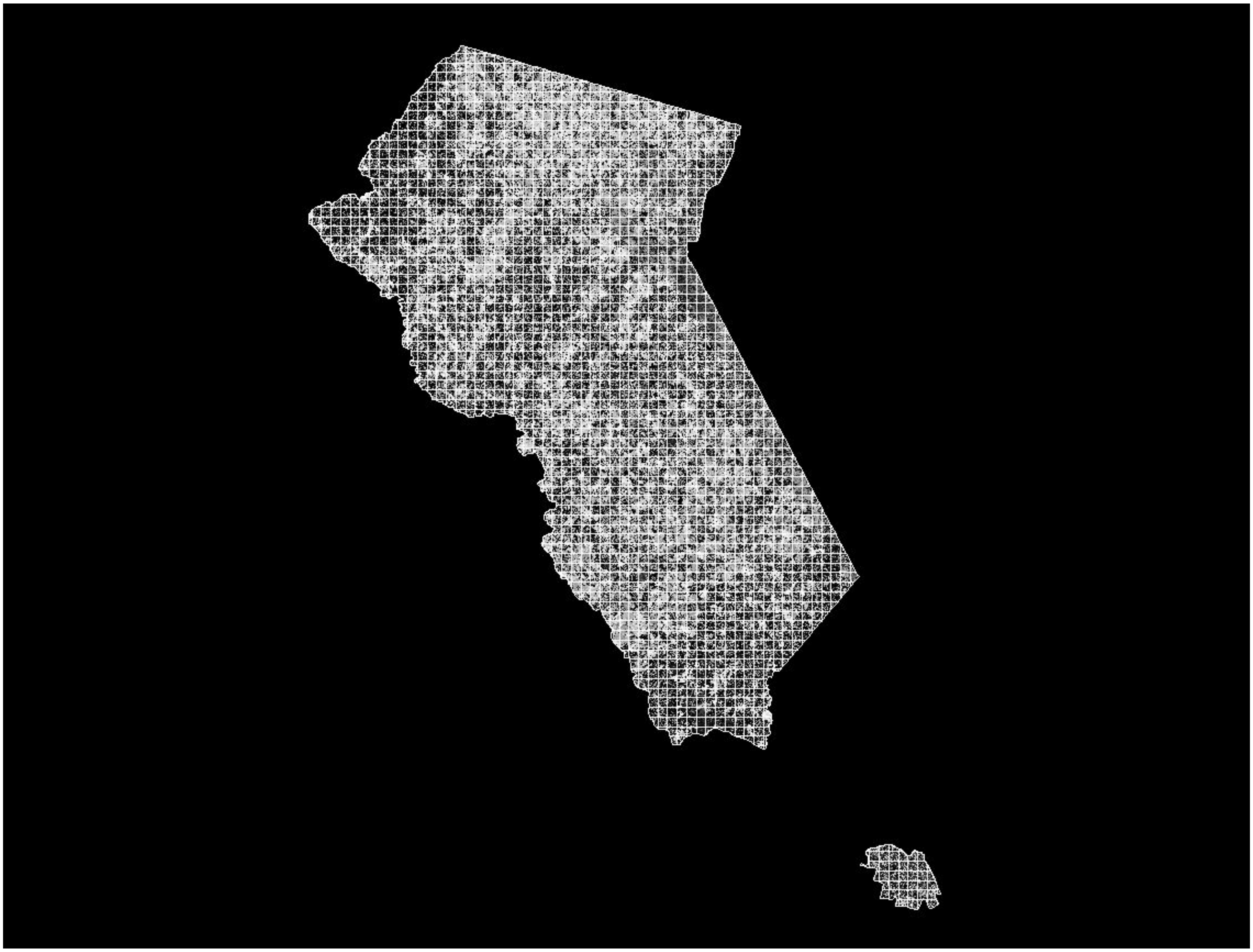
Maximum Surface Height Rasters (MSHR)

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.



First-return 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.



Last-return 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. Sanborn has identified the issue with orthogonal intersecting lines in the SSI. This issue is caused by the proprietary sensor software misattribution to a selection of last-returns outlining the lidar processing blocks, particularly in highly vegetated areas. Sanborn has confirmed there is no impact to the spatial accuracy of the points, nor to the minimum classification schemes in the applicable USGS specification. This issue is only visible when the last return value is acknowledged in an export, such as SSI.

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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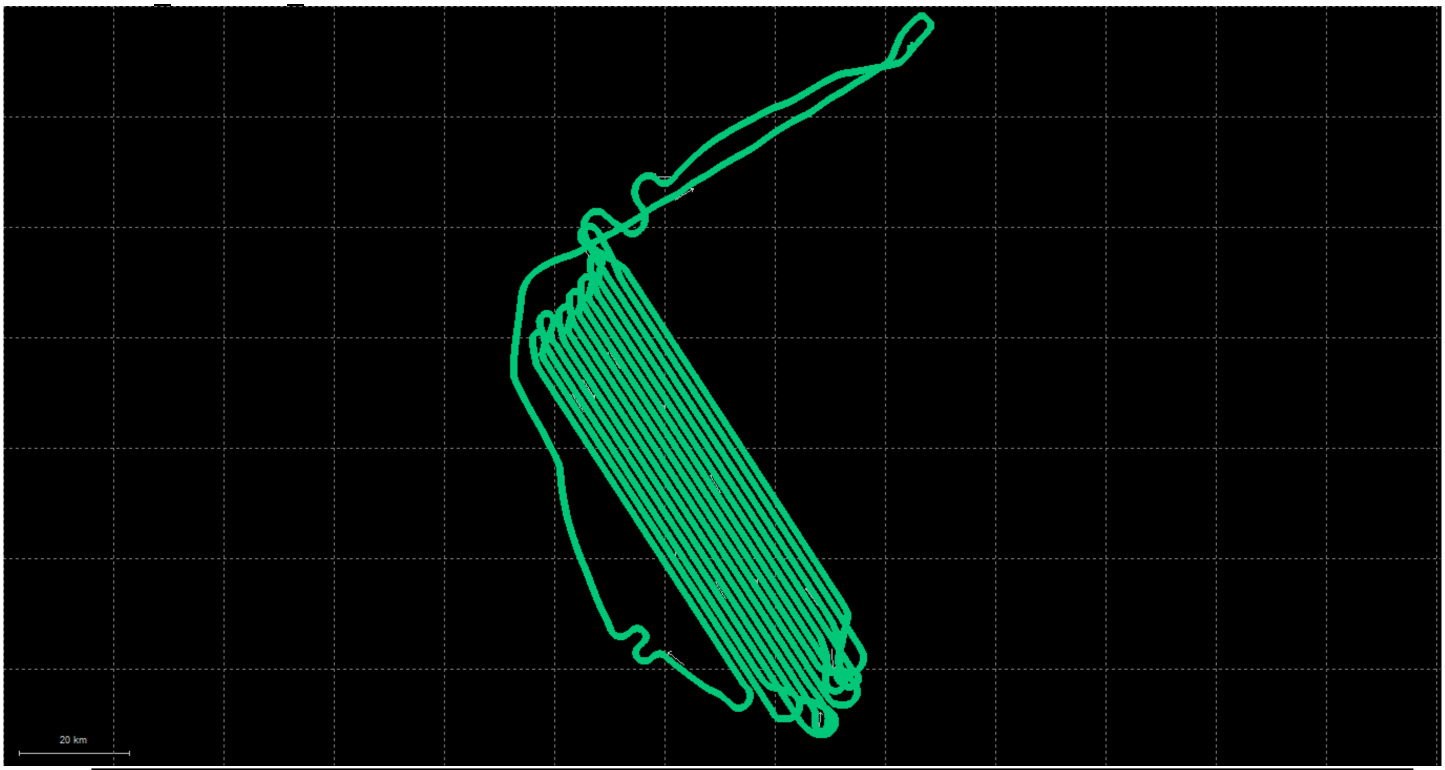

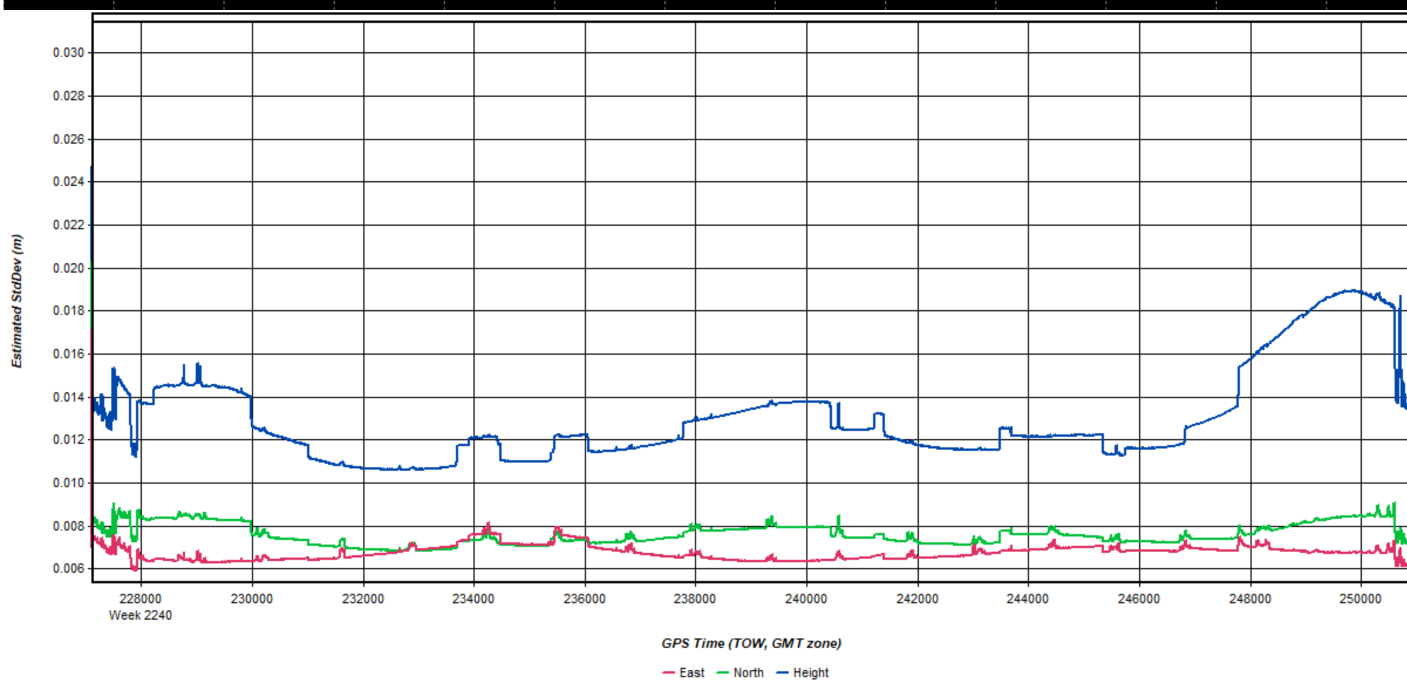

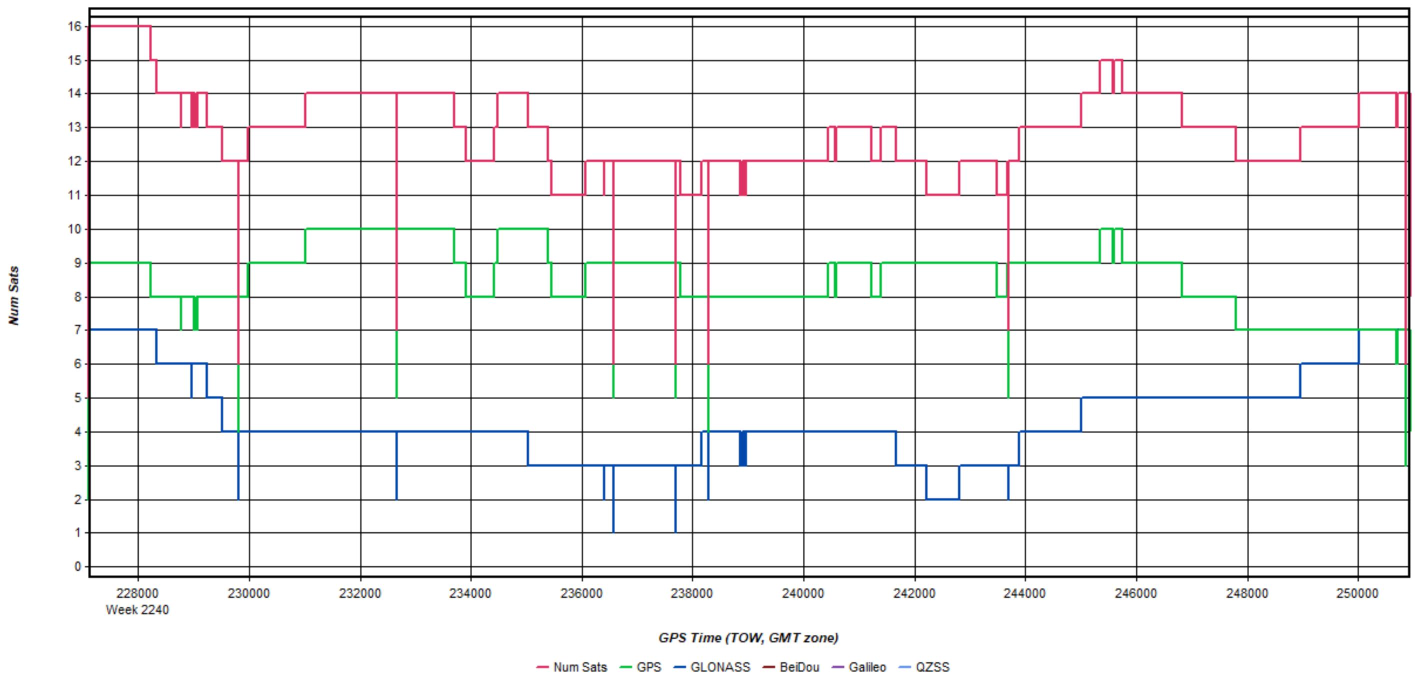
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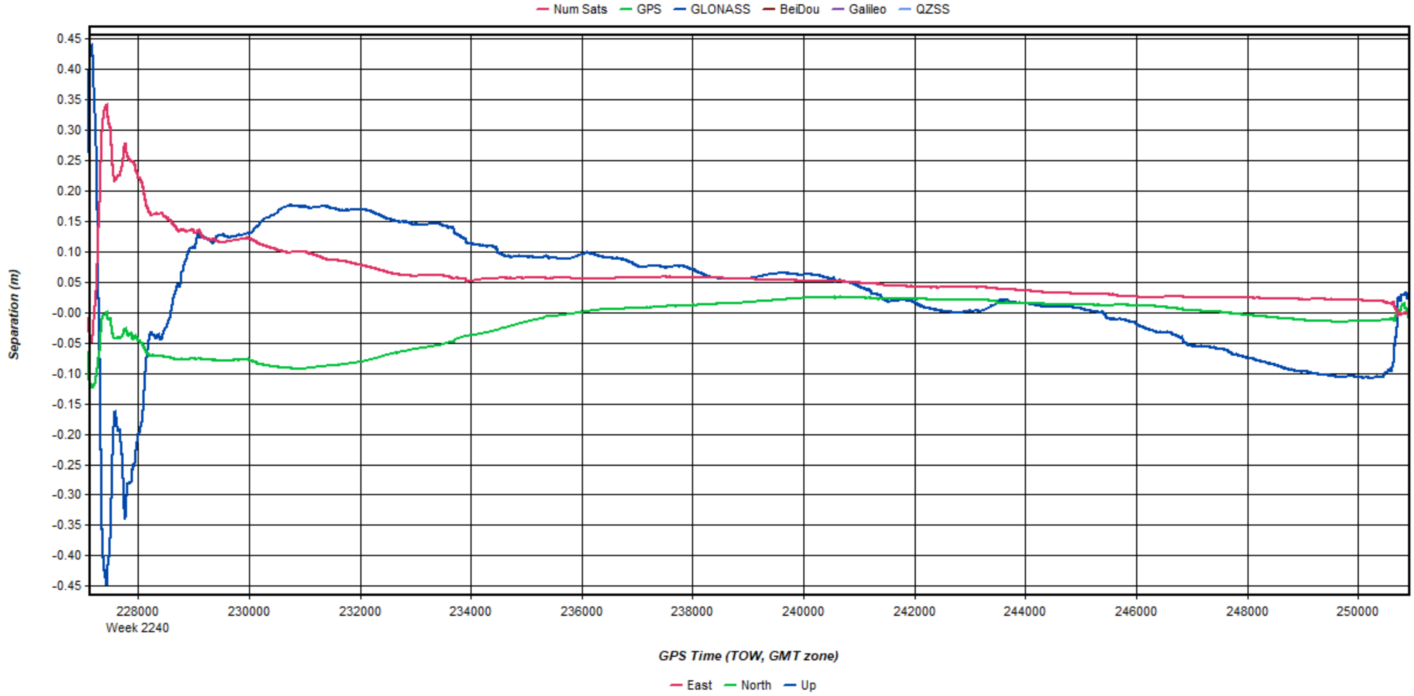
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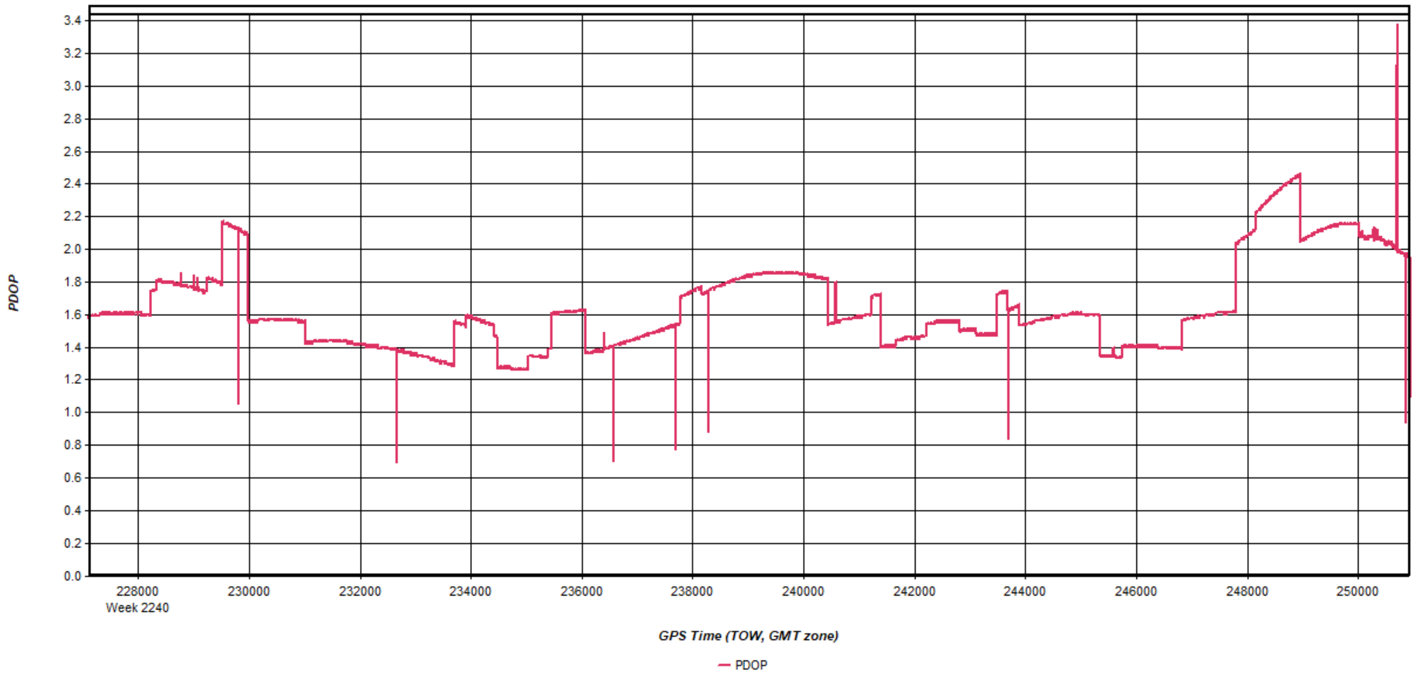

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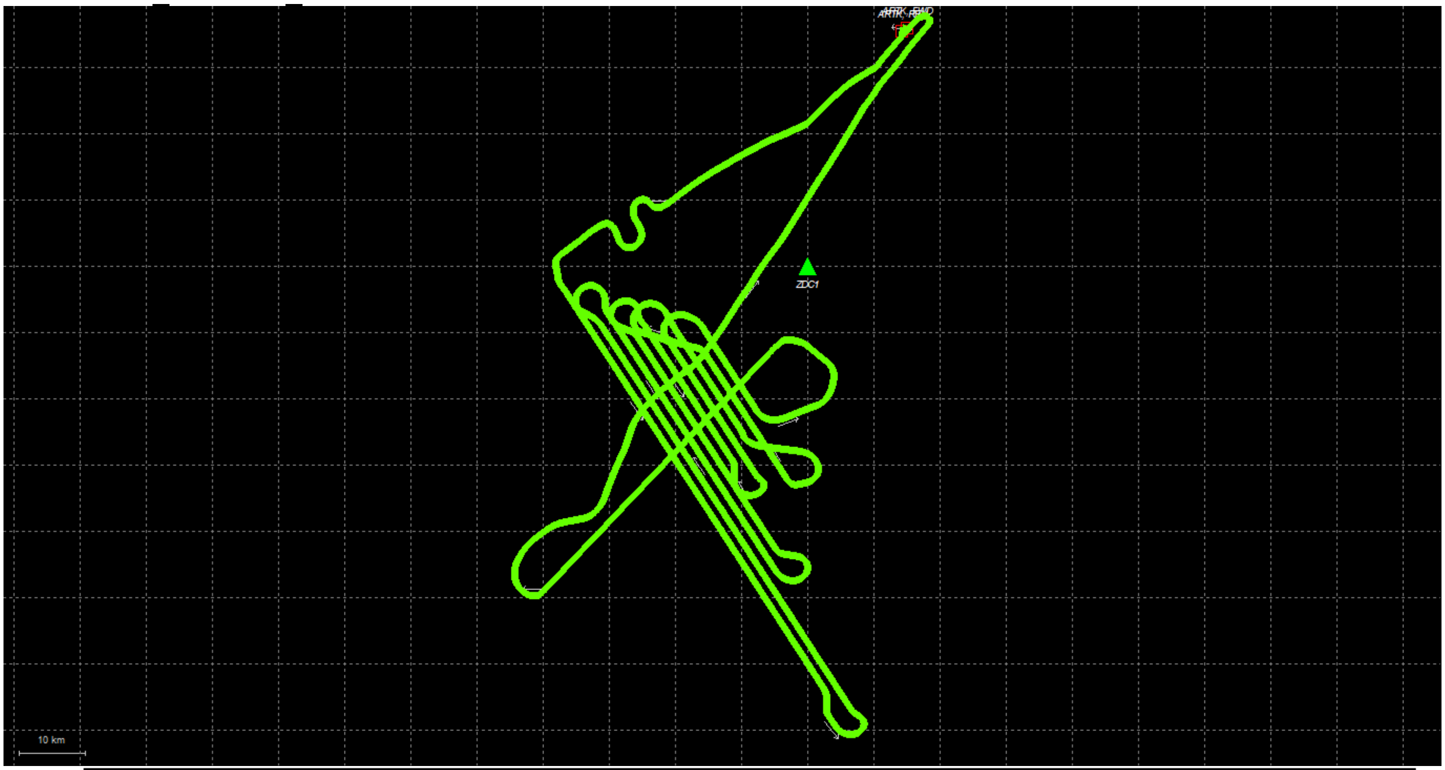

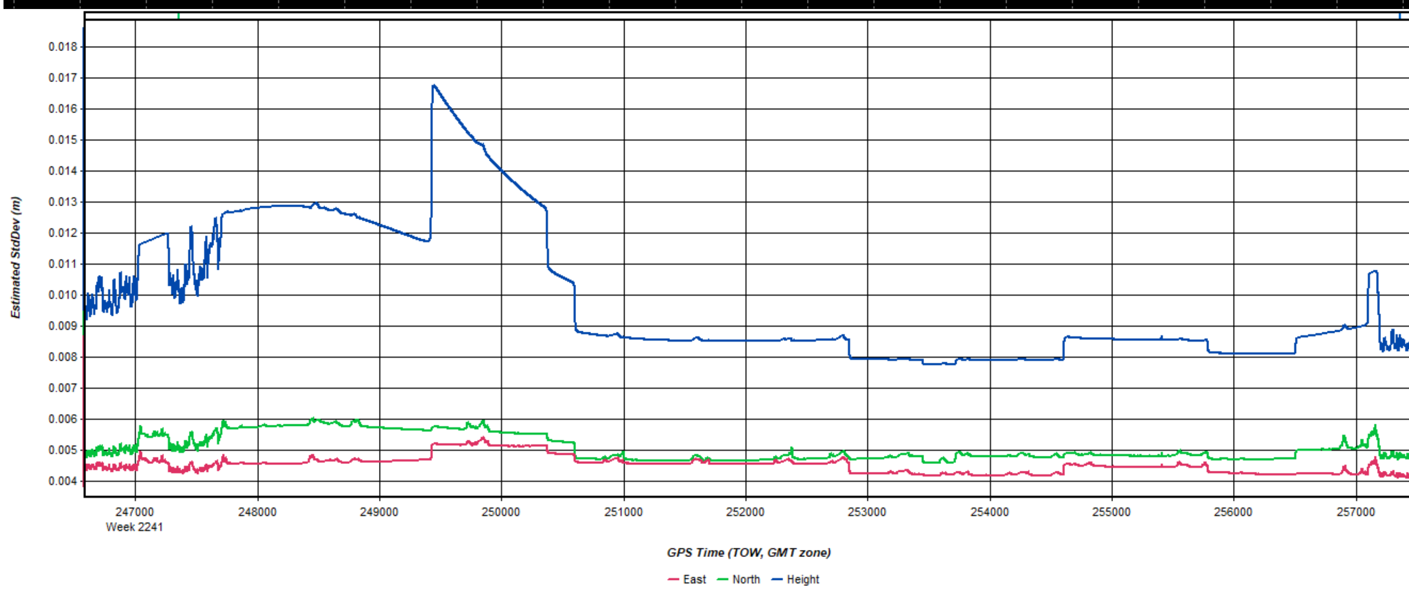

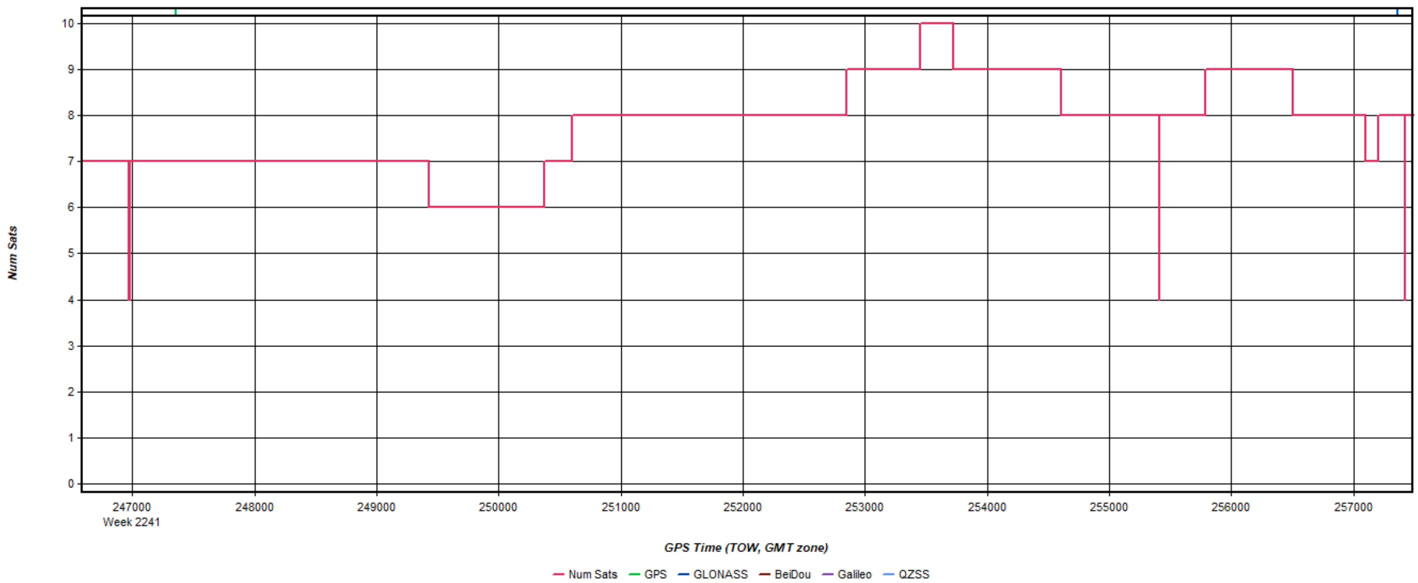
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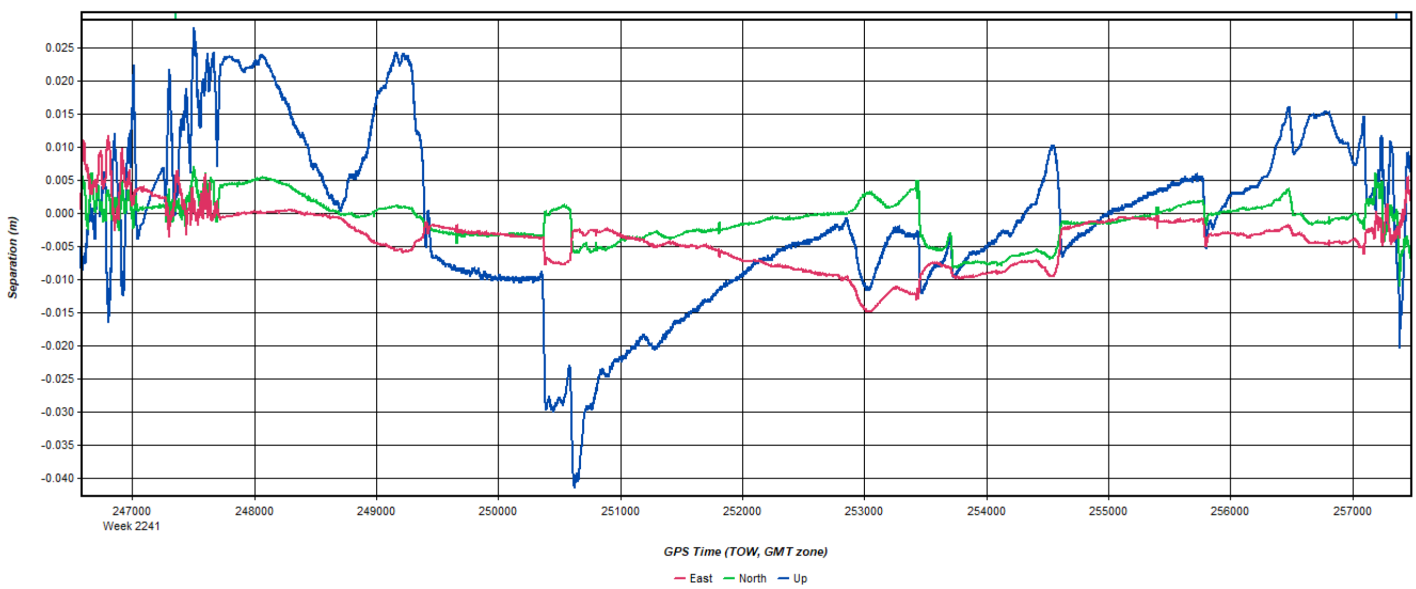
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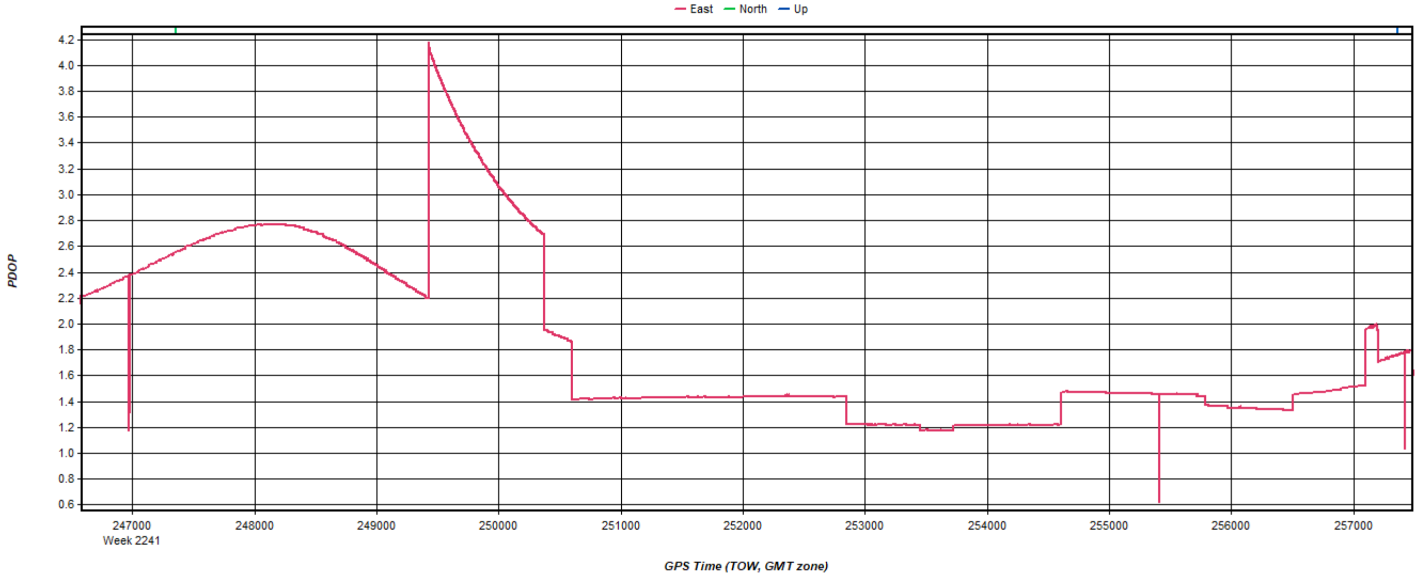
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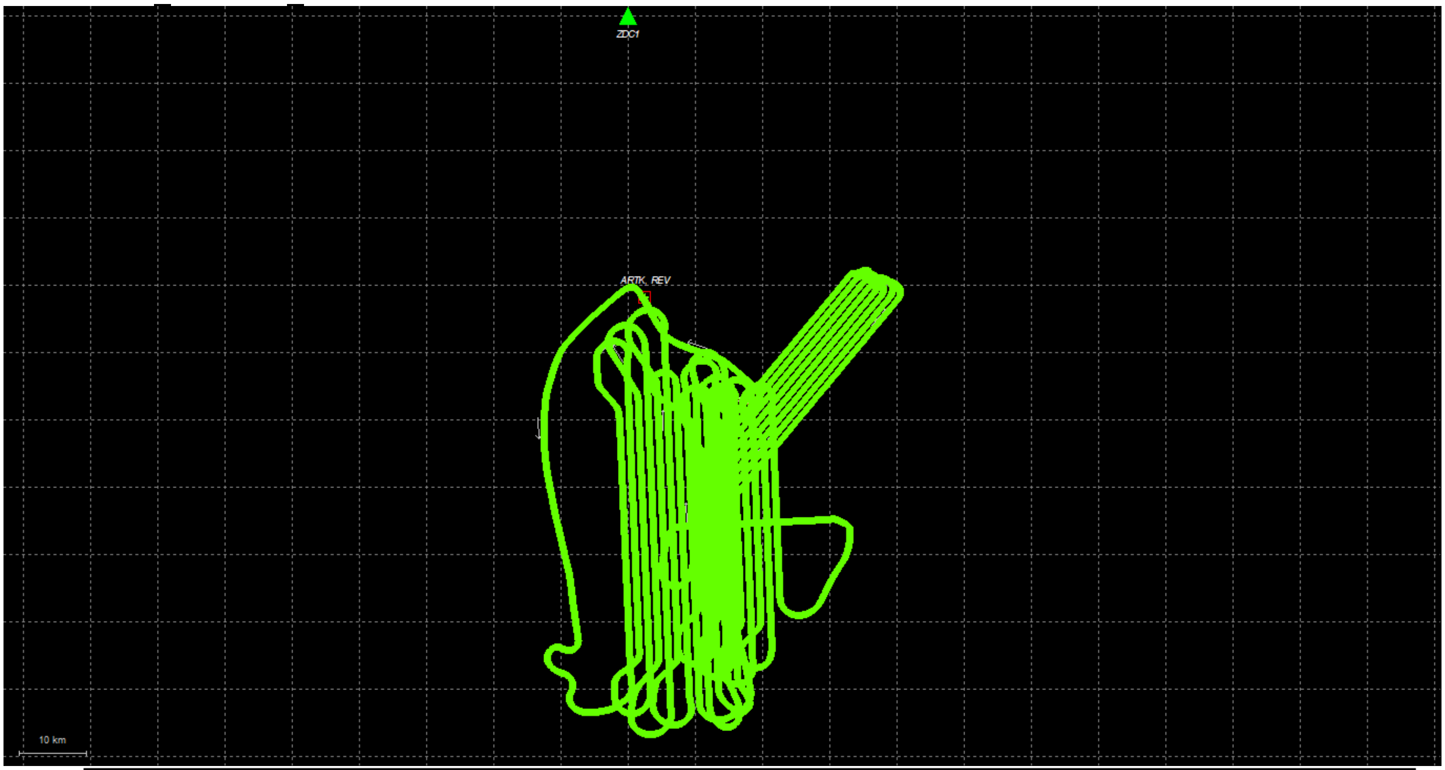
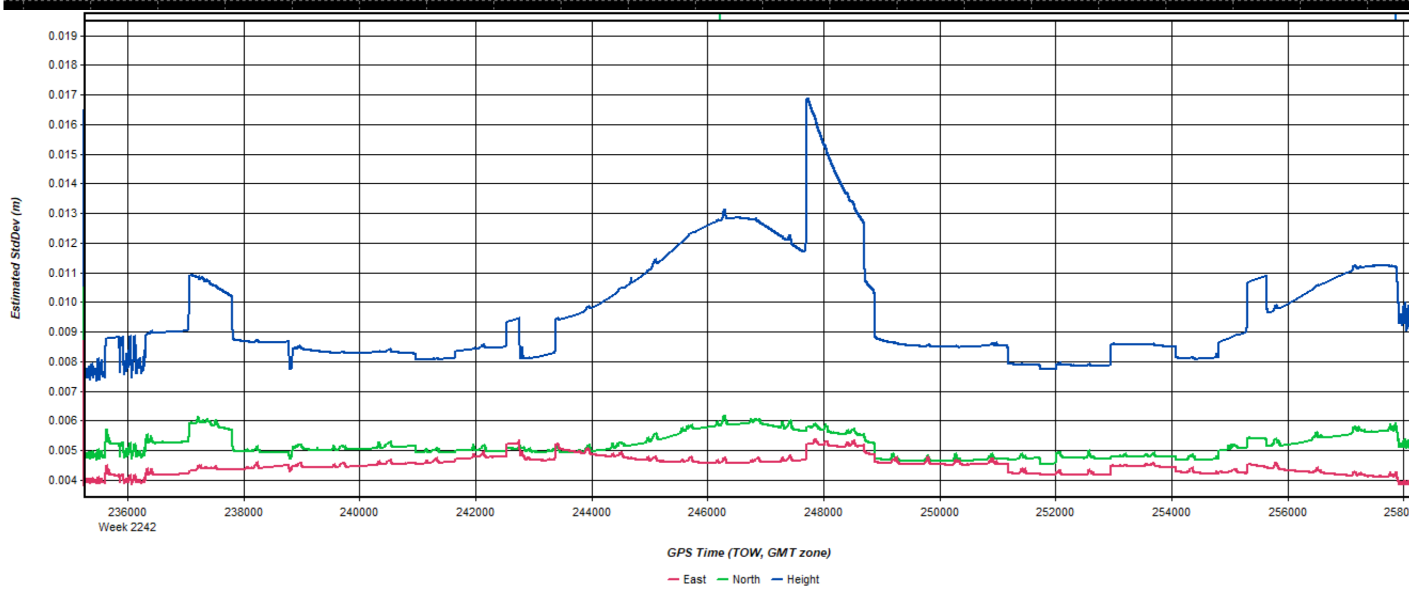
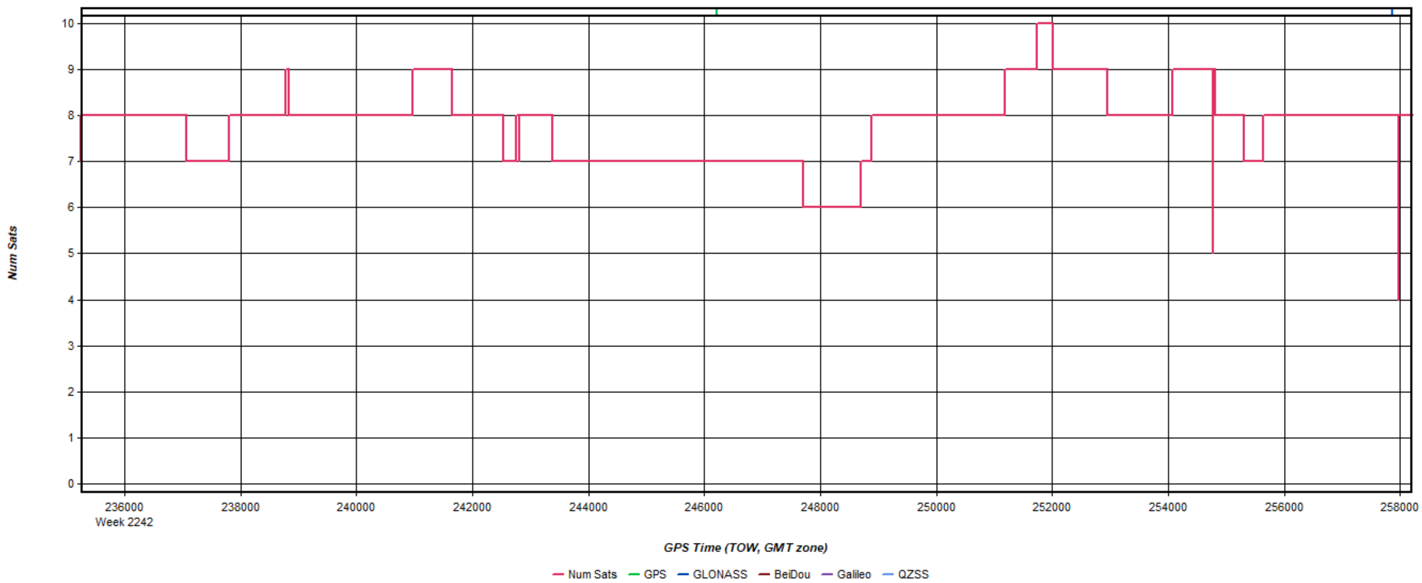
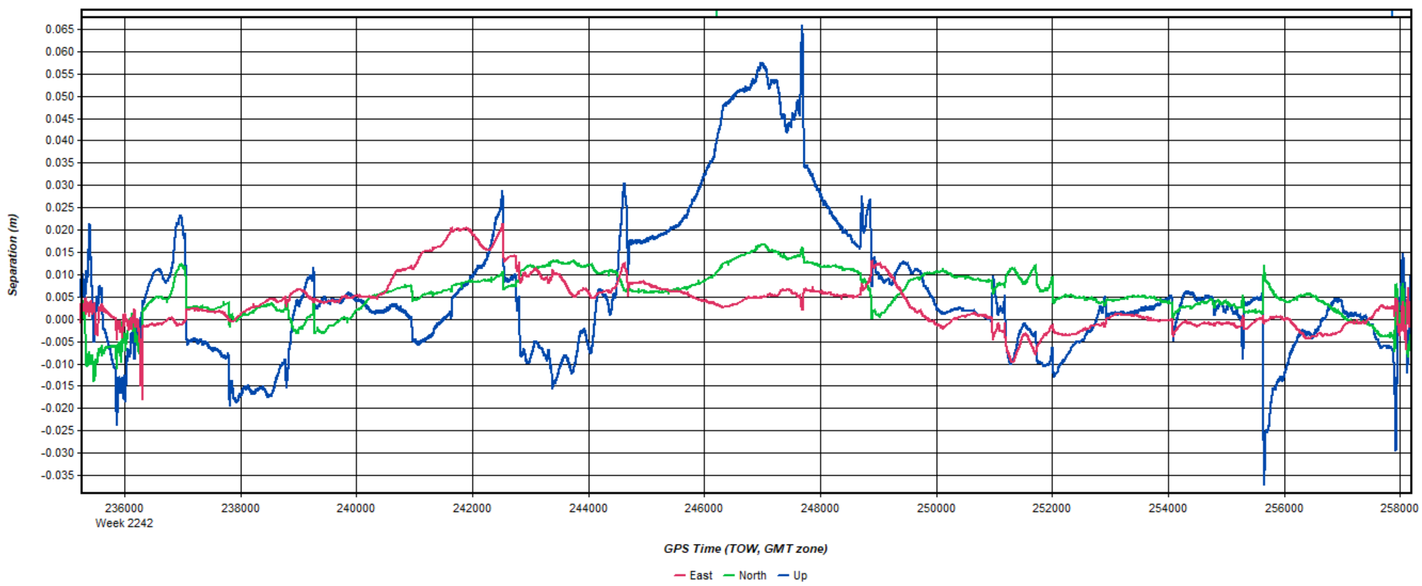
PDOP

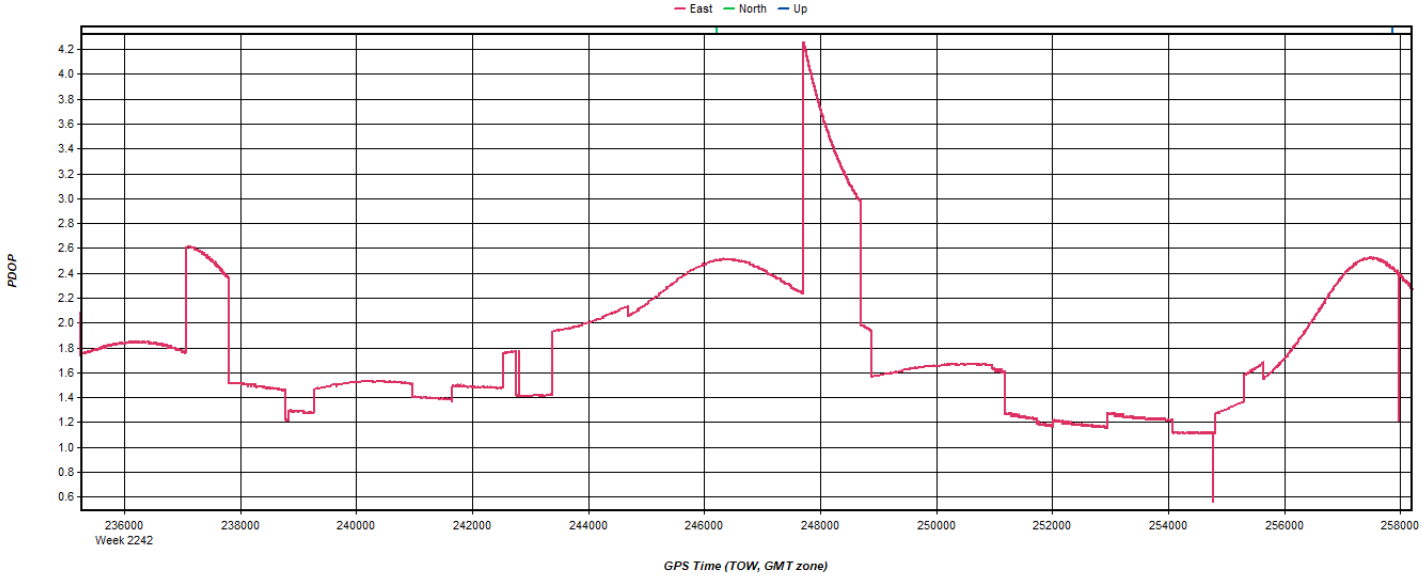
20221227A_N278RC_TM91512






Num Sats
10
9
8
7
6
5
4
3
2
1
0
236000
Week 2242
238000
240000
242000
244000
246000
248000
250000
252000
254000
256000
258000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou
Galileo
QZSS


Separation (m)
0.065
0.060
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
236000
Week 2242
238000
240000
242000
244000
246000
248000
250000
252000
254000
256000
258000
GPS Time (TOW, GMT zone)
East
North
Up


PDOP
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
236000
Week 2242
238000
240000
242000
244000
246000
248000
250000
252000
254000
256000
258000
GPS Time (TOW, GMT zone)
PDOP