Indiana DNR 2023

Lidar Mapping Report

August 2023

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 ~136 mi² was completed on March 28th, 2023.

The Leica TerrainMapper 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 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 to survey assessments.

1.3 Project Location

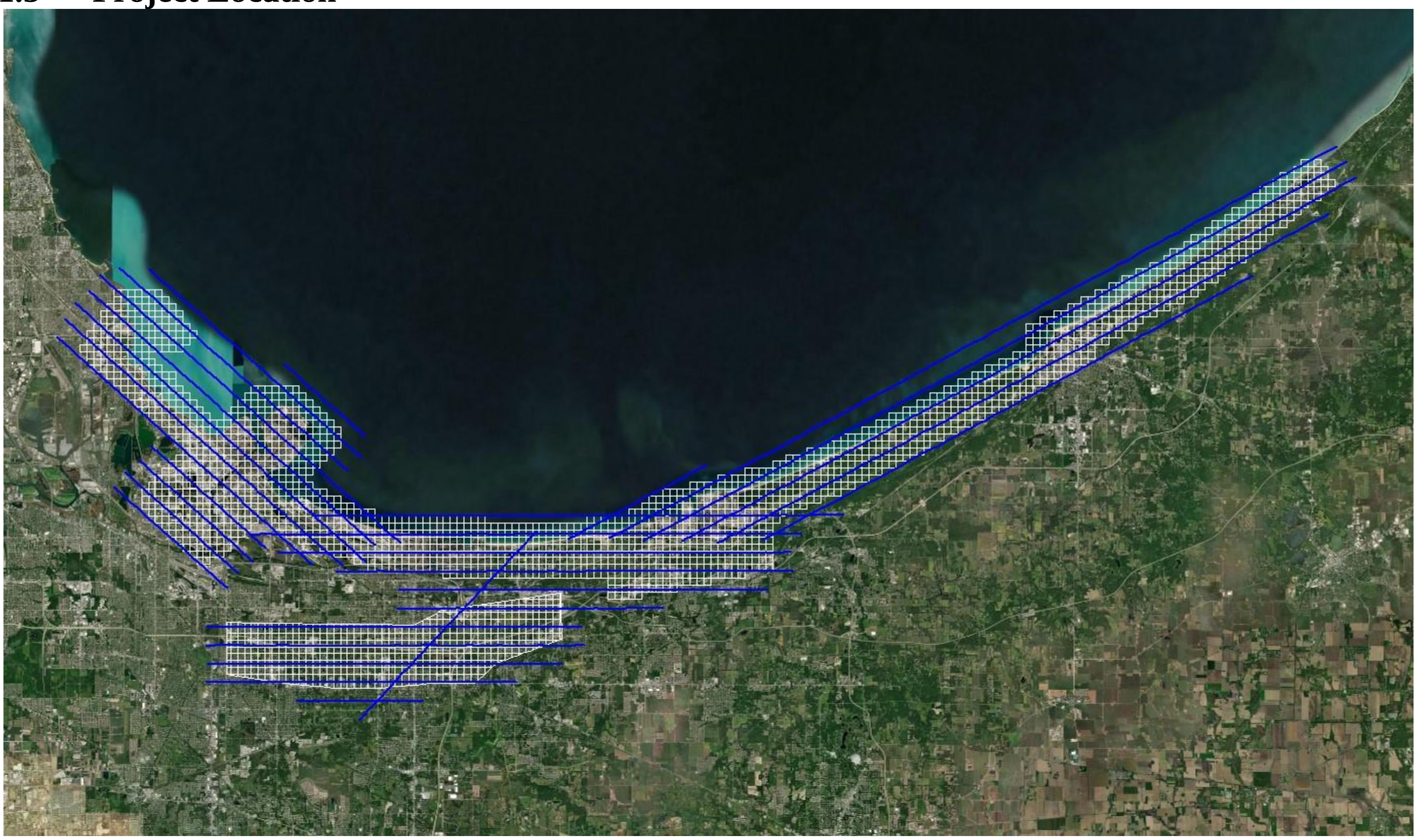


Figure 1: Tile Index and Trajectories As-Flown

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	N27282 - PIPER PA-31-325
Sensor	Leica TerrainMapper
Max Number of Returns	15
Point Spacing (m)	0.33
Point Density (pls/m²)	9.44
Flying Height (AGL) (m)	1800
Air Speed (kts)	170
Field of View (degrees)	40
Scan Rate (Hz)	150
Pulse Rate (kHz)	1700
Laser Footprint (m)	0.43
Wavelength (nm)	1064
Multi-Pulse	Yes
Swath Width (m)	1310
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 two (2) 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)**
3/27/2023	Leica TerrainMapper	TM91512	N27282	20230327_A_N27282_91512	1.4	21:53:11	0:43:20
3/28/2023	Leica TerrainMapper	TM91512	N27282	20230328_A_N27282_91512	1.6	12:32:23	17:10:18

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
INGY	CORS	DM5381	41 35 42.67802	087 14 47.69183	158.323
INLP	CORS	DM3501	41 35 06.76182	086 41 33.10182	216.262
INLW	CORS	DM5383	41 17 24.51225	087 18 57.48877	180.866
LCDT	CORS	AJ5873	42 17 42.19504	087 57 37.23567	189.368
MITO	CORS	DK6957	41 48 00.56887	086 36 12.77725	171.175

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.

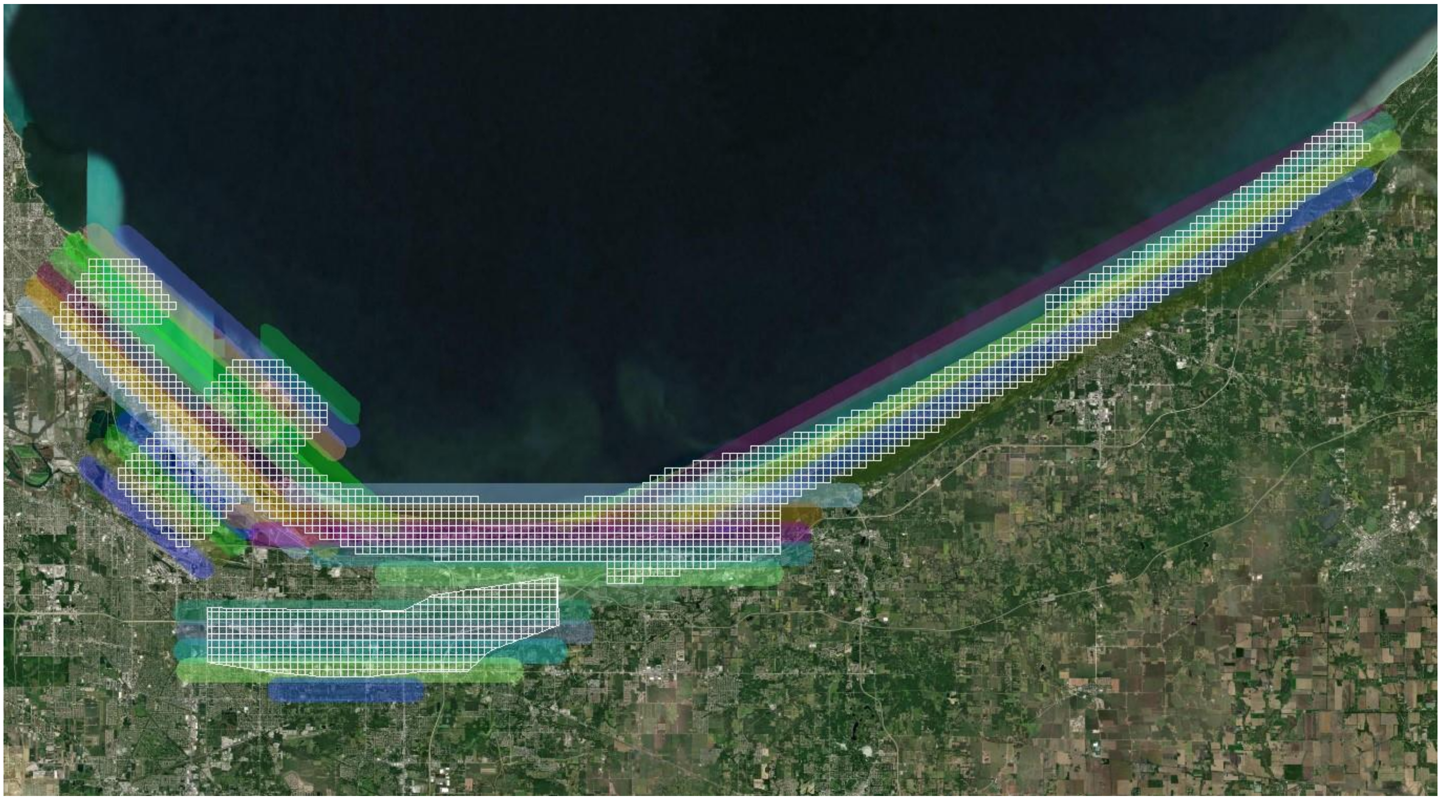


Figure 3: Raw Swath Coverage

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	3,894,472,577
Aggregate Nominal Pulse Spacing (m)	0.32
Aggregate Nominal Pulse Density (pls/m²)	9.7
Aggregate Nominal Pulse Spacing (ft)	1.05
Aggregate Nominal Pulse Density (pls/ft²)	0.9

Table 4: Point Cloud Statistics

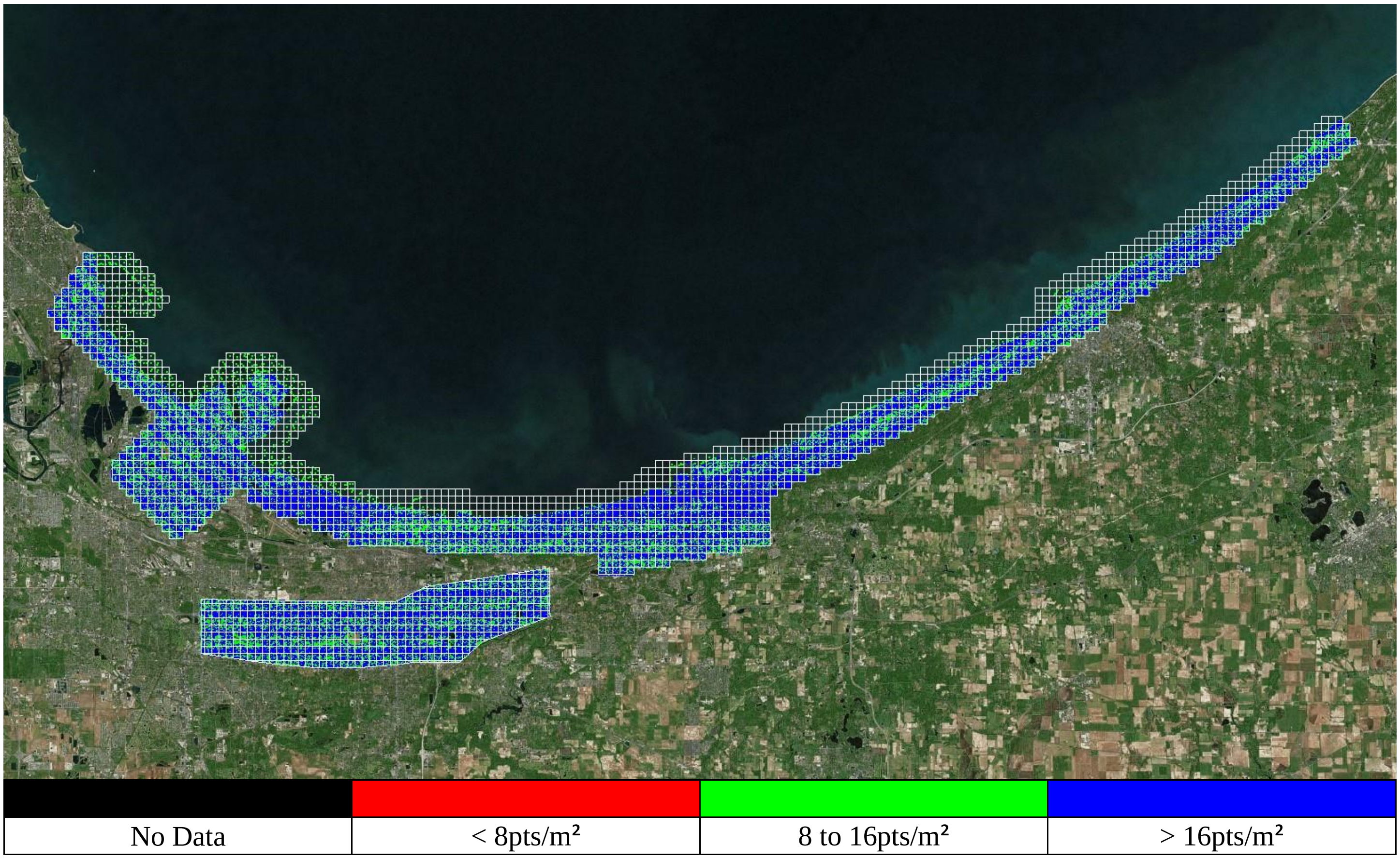


Figure 4: Point Cloud Density

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (HARN)
Projection: State Plane Indiana West
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid18
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.

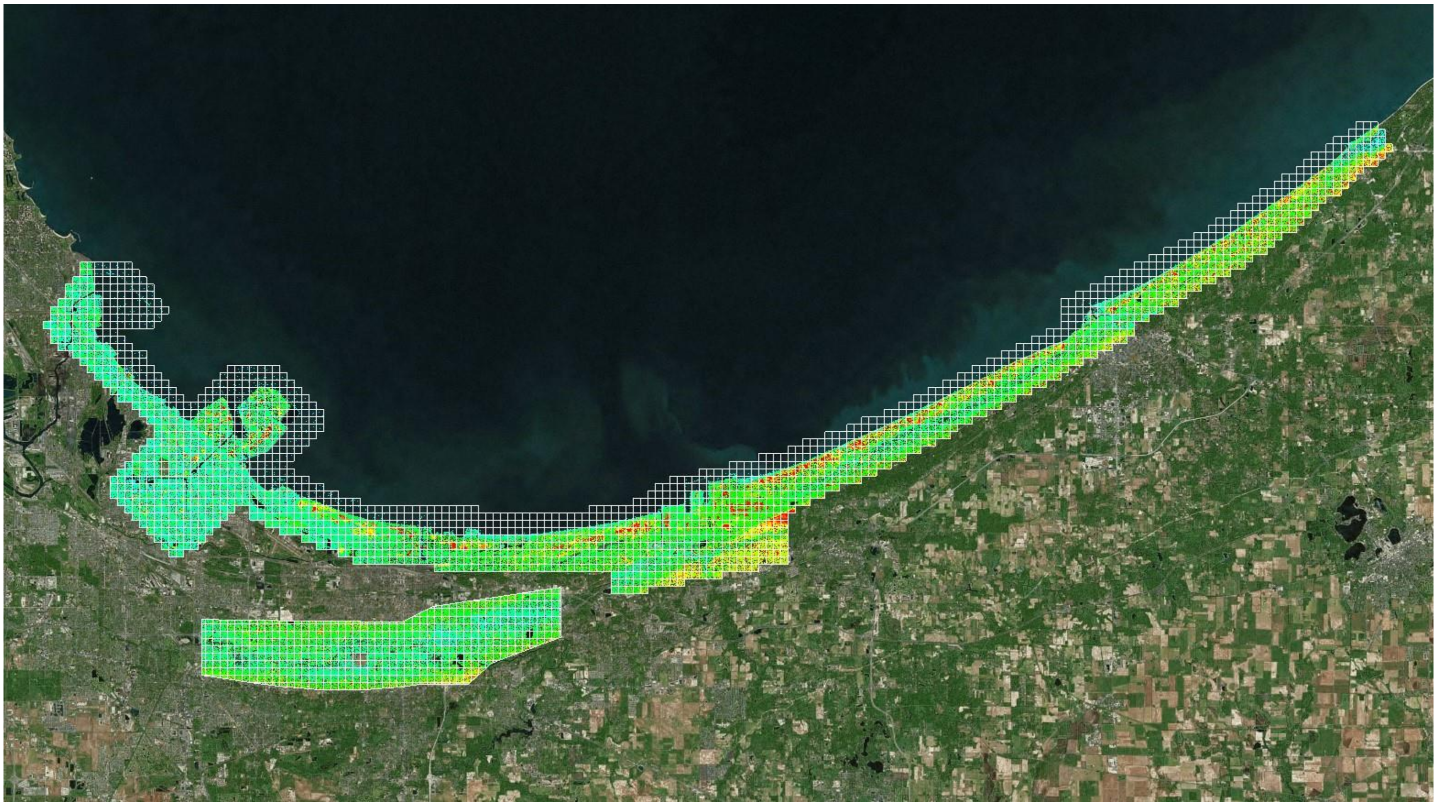
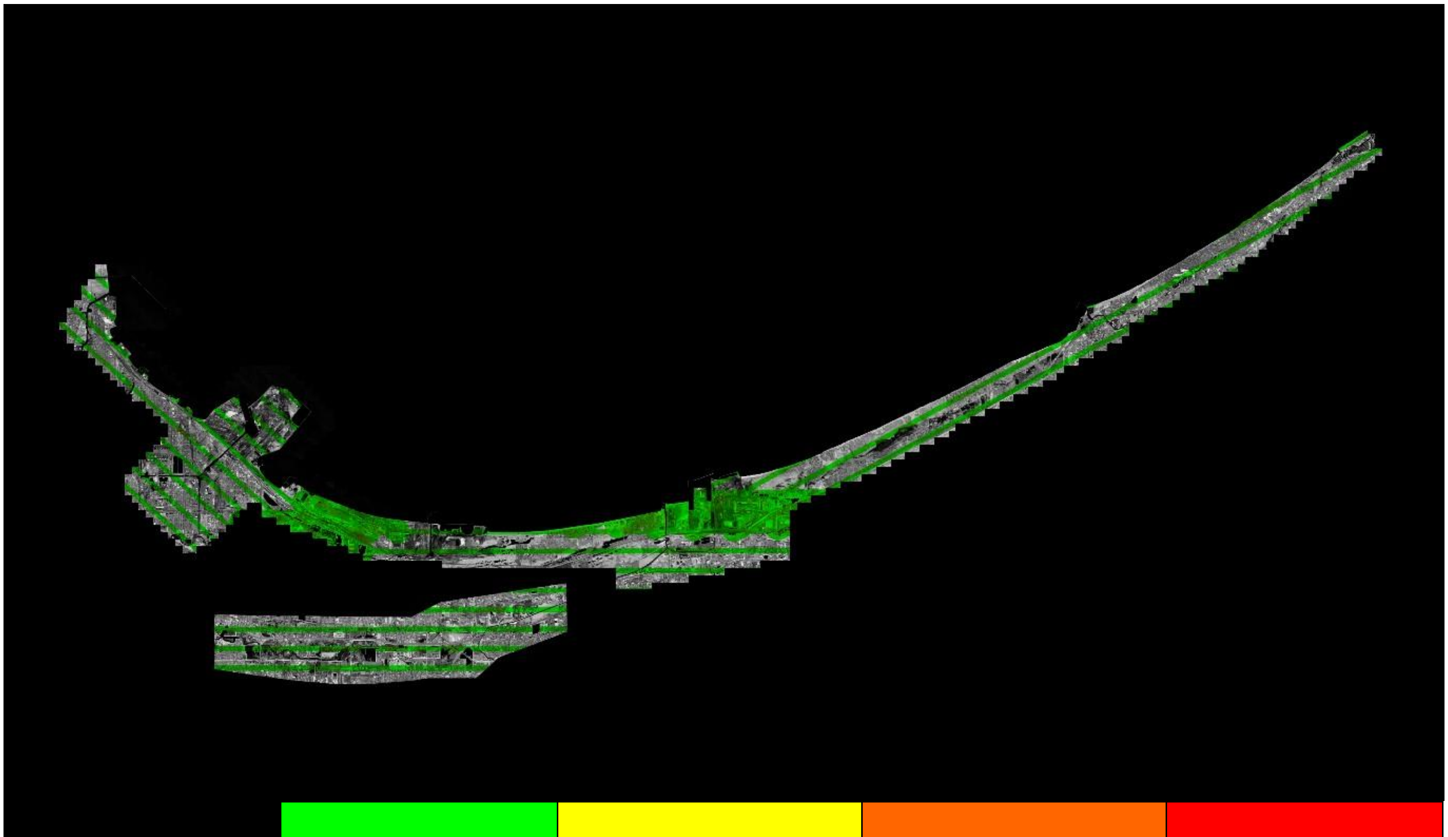


Figure 5: Point Cloud Elevation

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.

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. **Tables 5 – 8** are the relative accuracies achieved.



No Data	< 0.08m	0.08m to 0.16m	0.16m to 0.24m	> 0.24m
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
1	0.030	0.020	0.014	**11**	0.026	0.030	0.014	**21**	0.017	0.025	0.011
2	0.029	0.030	0.015	**12**	0.027	0.031	0.013	**22**	0.016	0.022	0.014
3	0.028	0.031	0.018	**13**	0.025	0.031	0.012	**23**	0.014	0.023	0.012
4	0.034	0.037	0.015	**14**	0.026	0.030	0.013	**24**	0.011	0.031	0.014
5	0.033	0.036	0.012	**15**	0.030	0.029	0.017	**25**	0.011	0.032	0.016
6	0.021	0.023	0.010	**16**	0.028	0.032	0.014	**26**	0.014	0.027	0.012
7	0.025	0.022	0.014	**17**	0.020	0.024	0.017	**27**	0.038	0.035	0.009
8	0.022	0.024	0.014	**18**	0.023	0.025	0.012	**28**	-	-	0.012
9	0.027	0.026	0.013	**19**	0.023	0.025	0.013	**29**	-	-	-
10	0.025	0.029	0.013	**20**	0.011	0.030	0.010				

Table 5: Average Magnitudes by Line (Meters)

Category	X	Y	Z
Average Magnitude	0.024	0.028	0.014
RMS Values	0.041	0.044	0.018
Maximum Values	0.471	0.403	0.162
Observation Weight	42257.0	42257.0	82176.0

Table 6: Internal Observation Statistics (Meters)

Category	Mismatch
Average 3D Mismatch	0.03240
Average XY Mismatch	0.04796
Average Z Mismatch	0.01351

Table 7: Overall Relative Accuracy (Meters)

Category	Observations
Section Lines	16,096
Roof Lines	20,534

Table 8: 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 9** outlines a statistical summary of the point classes leveraged in the lidar dataset.

Code	Class	Points
1	Unclassified	1,779,210,279
2	Ground	2,061,065,837
7	Low Noise	36,034,730
9	Water	9,203,055
17	Bridge Decks	6,386,516
18	High Noise	2,223,962
20	Ignored Ground	348,198
Flag	Withheld	38,258,692

Table 9: Lidar Classification Statistics

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of twenty-five (25) check points. 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 10** outlines the absolute accuracy requirements of the project. **Table 11** 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 10: Absolute Accuracy Requirements

Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)				
Broad Land Cover Type	**# of Points**	**RMSEz**	**95% Confidence Level**	**95th Percentile**
NVA of Point Cloud	20	0.083	0.163	
NVA of Bare Earth	20	0.100	0.196	
NVA of DEM	20	0.099	0.194	
VVA of Bare Earth	5	0.132		0.196
VVA of DEM	5	0.132		0.195

Table 11: Vertical Accuracy Assessment of Check Points (Feet)

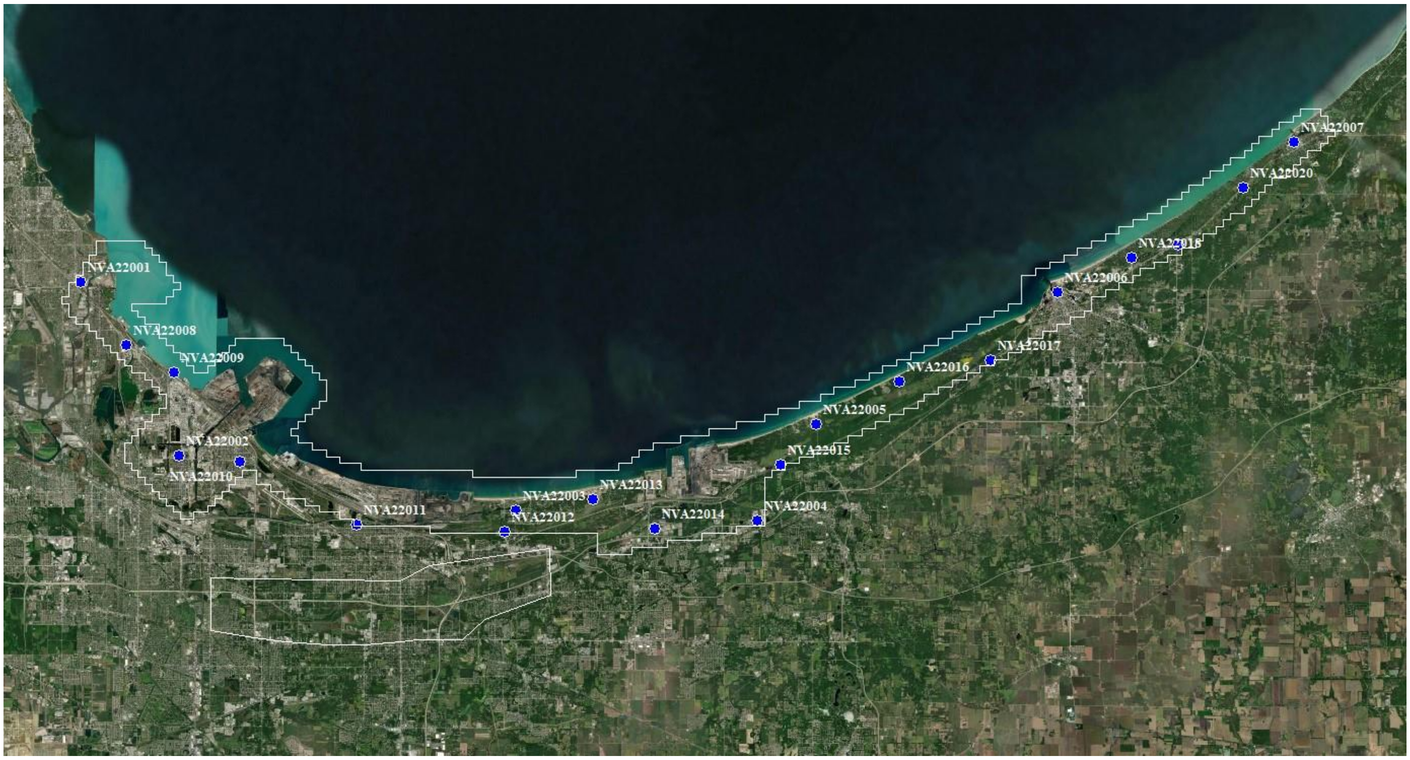


Figure 7: NVA Check Point Distribution

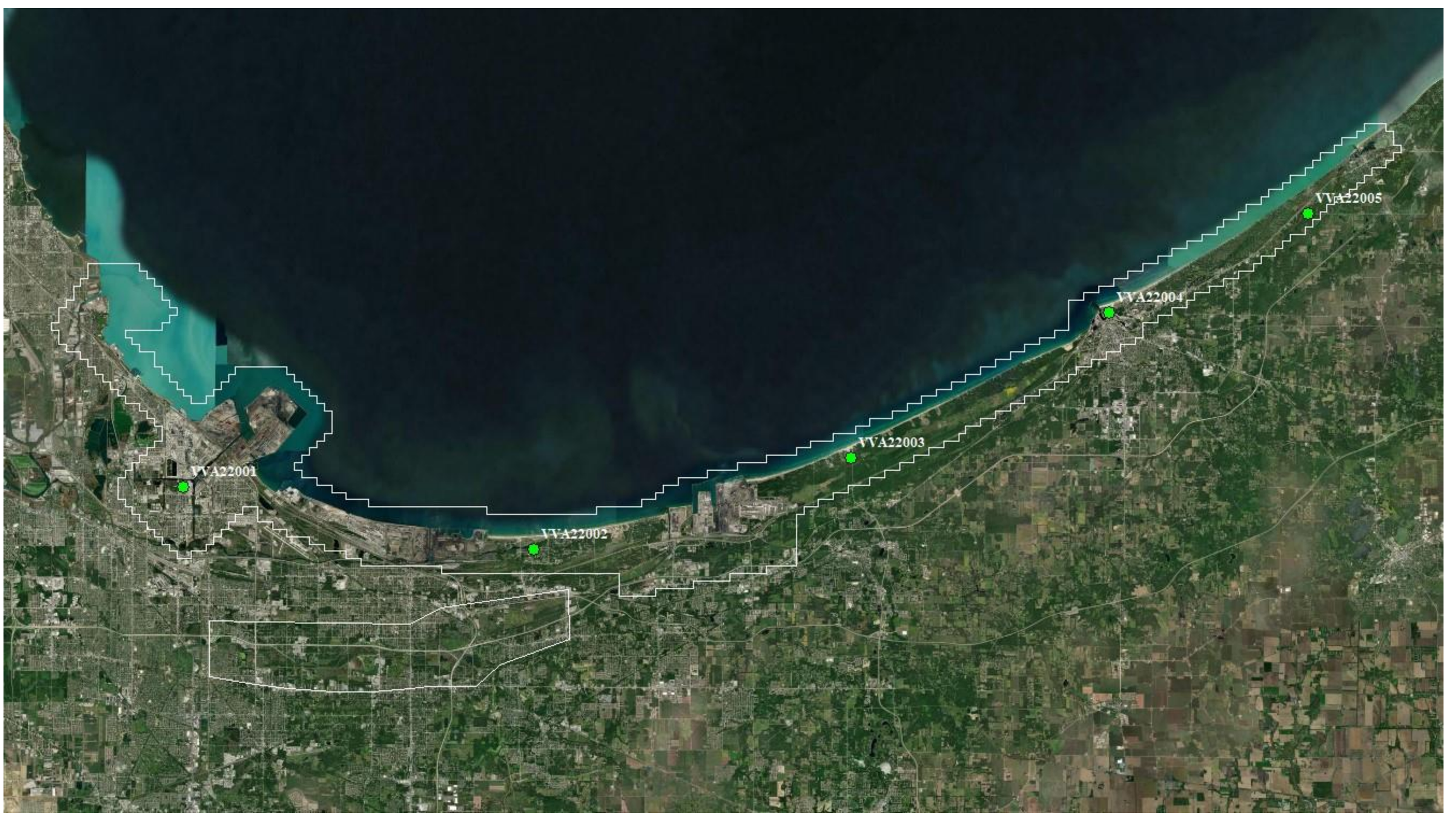


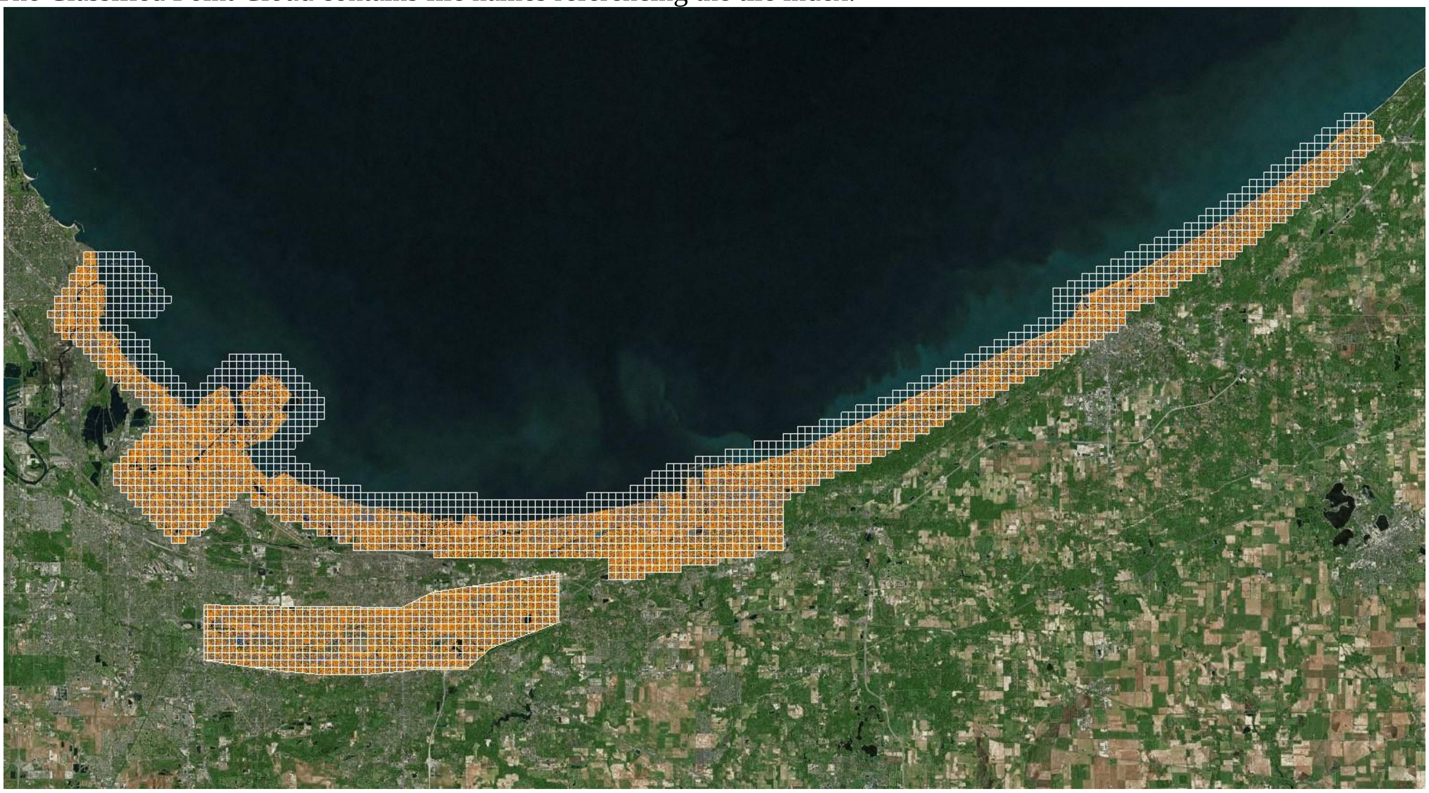
Figure 8: VVA Check Point Distribution

4.0 PRODUCT GENERATION

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

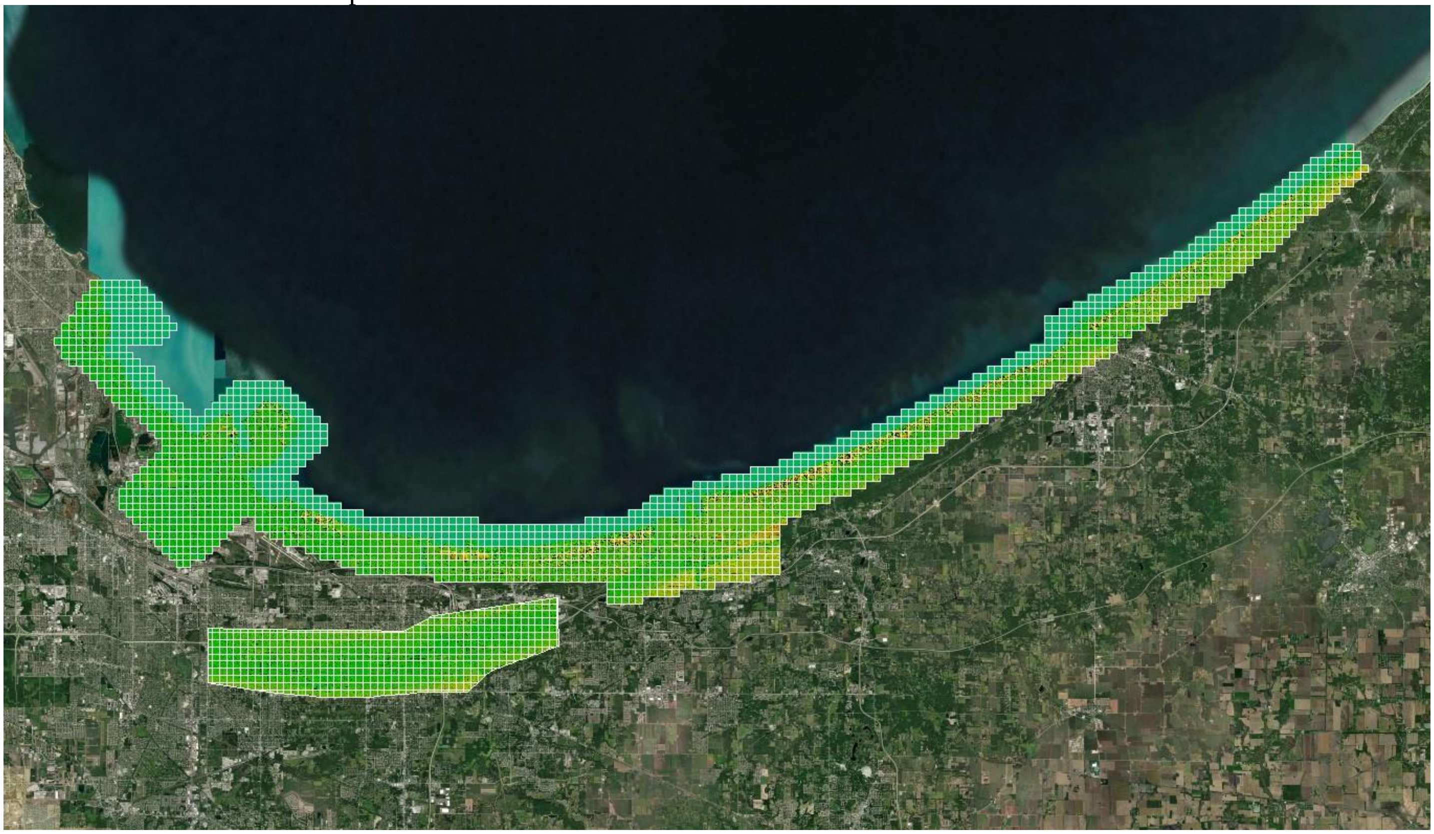
Classified Point Cloud

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.



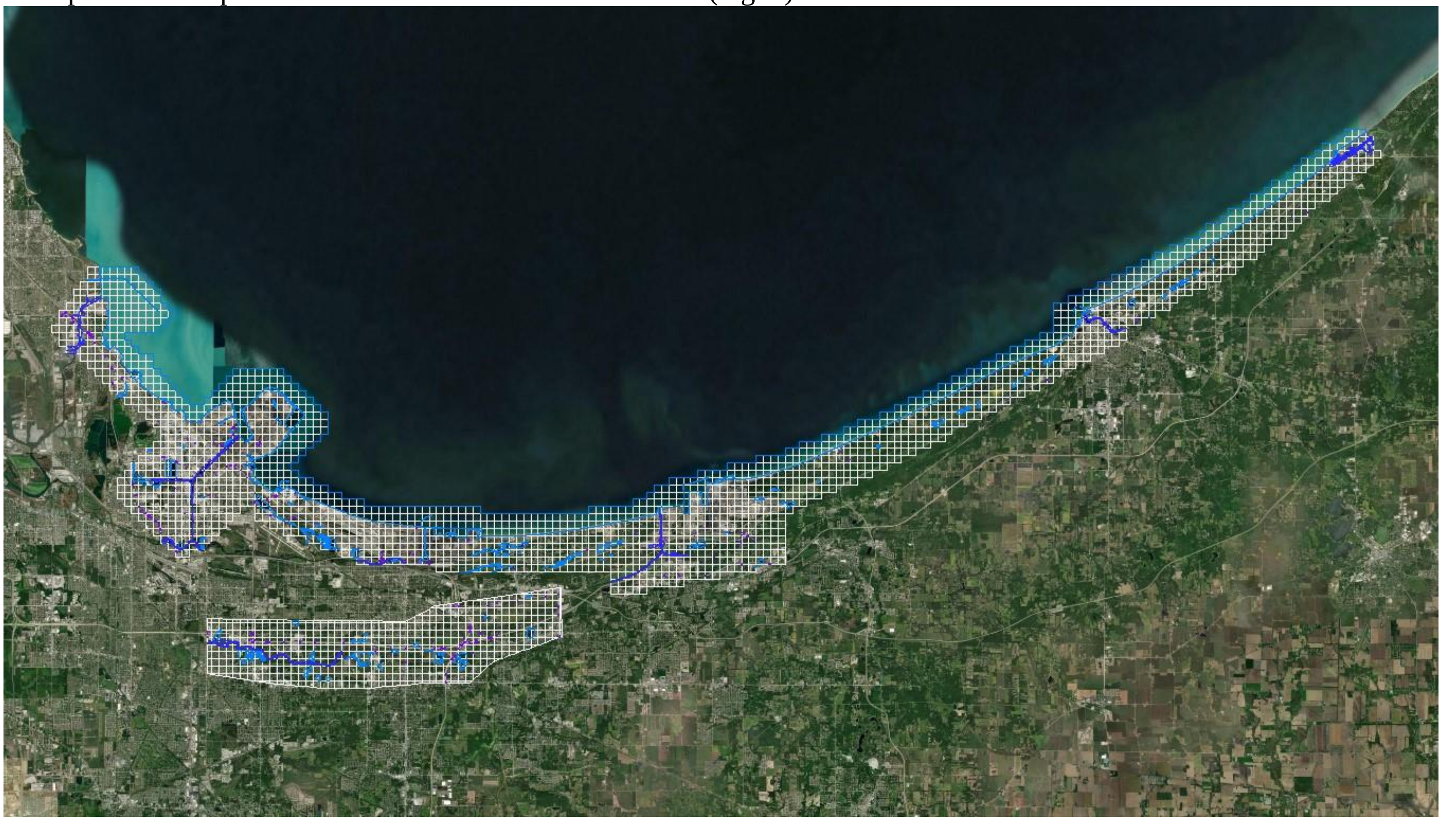
Bare-earth Digital Elevation Model (DEM)

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.



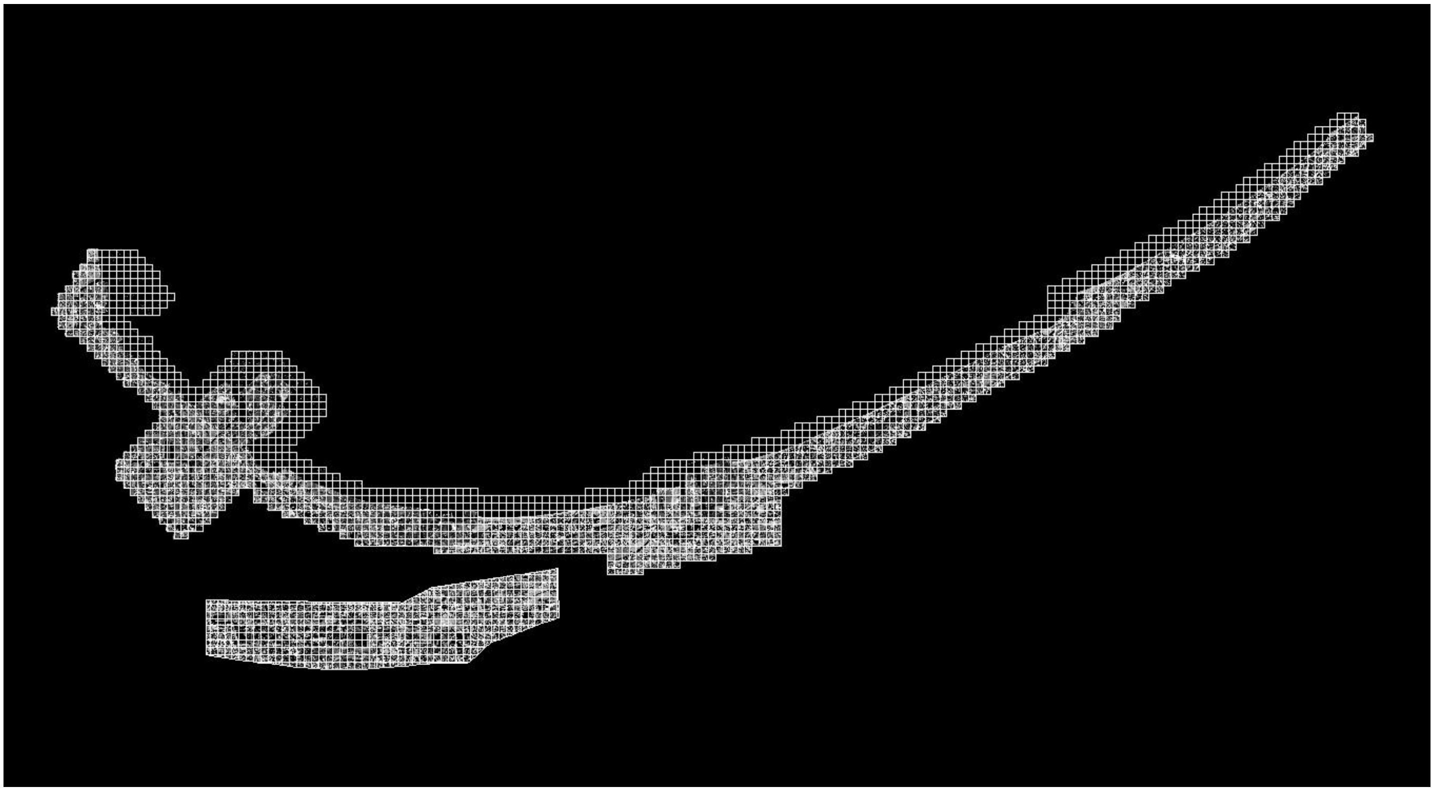
Breaklines

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.



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.

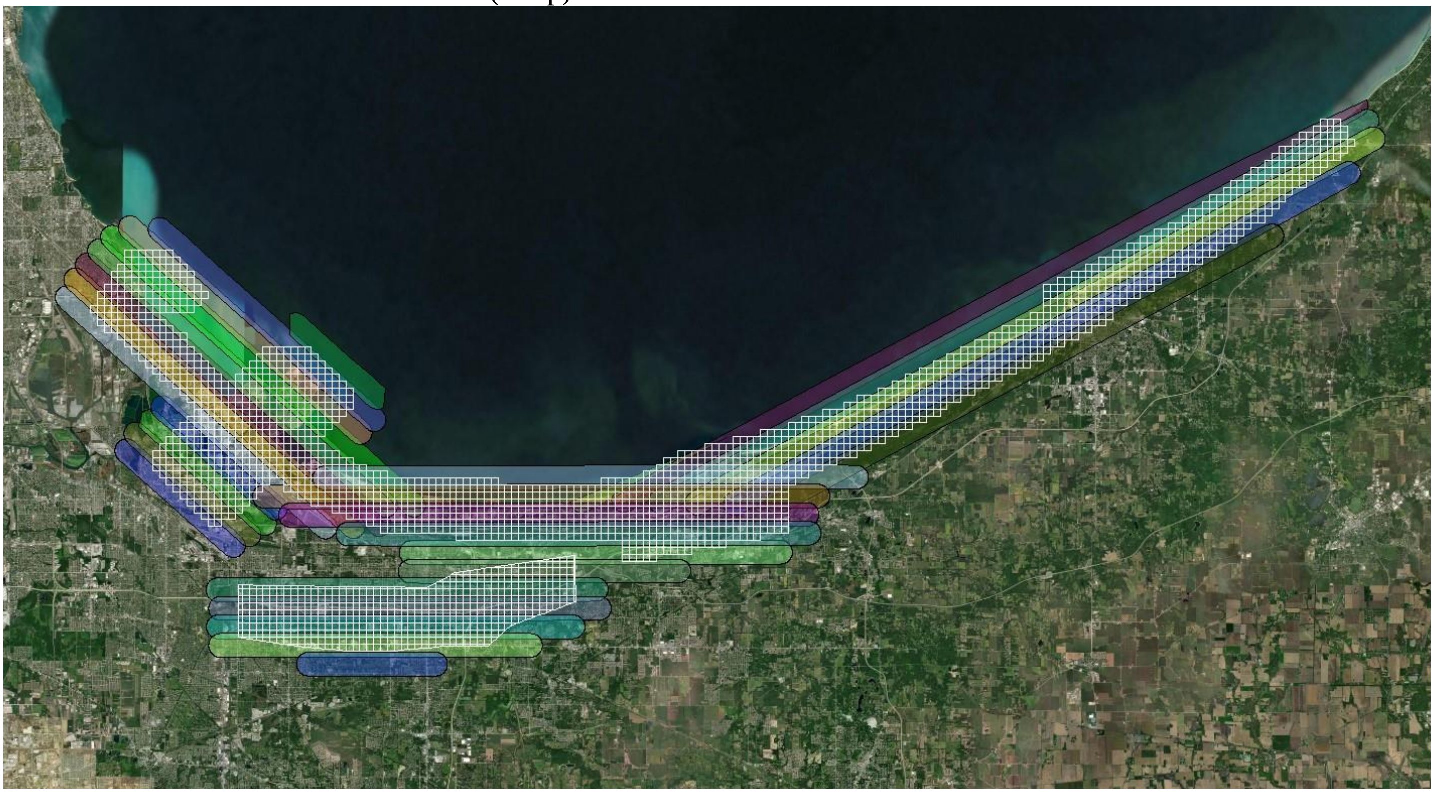


Hillshades

8-bit GeoTIFF (*.tif) hillshade rasters were created from the hydro-flattened bare-earth DEM. GDAL v2.4.0 was used to define the CRS.

Swath Polygons

Polygon features representing either the convex or concave hull of swaths, where each record is an individual swath or channel within a swath. Delivered in Esri (*.shp) format.



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.

OUTPUT RESULTS FOR 20230327A_GNSSIMU

Inertial Explorer Version 8.90.2124
04/06/2023

Figure 1: Smoothed TC Combined - Map

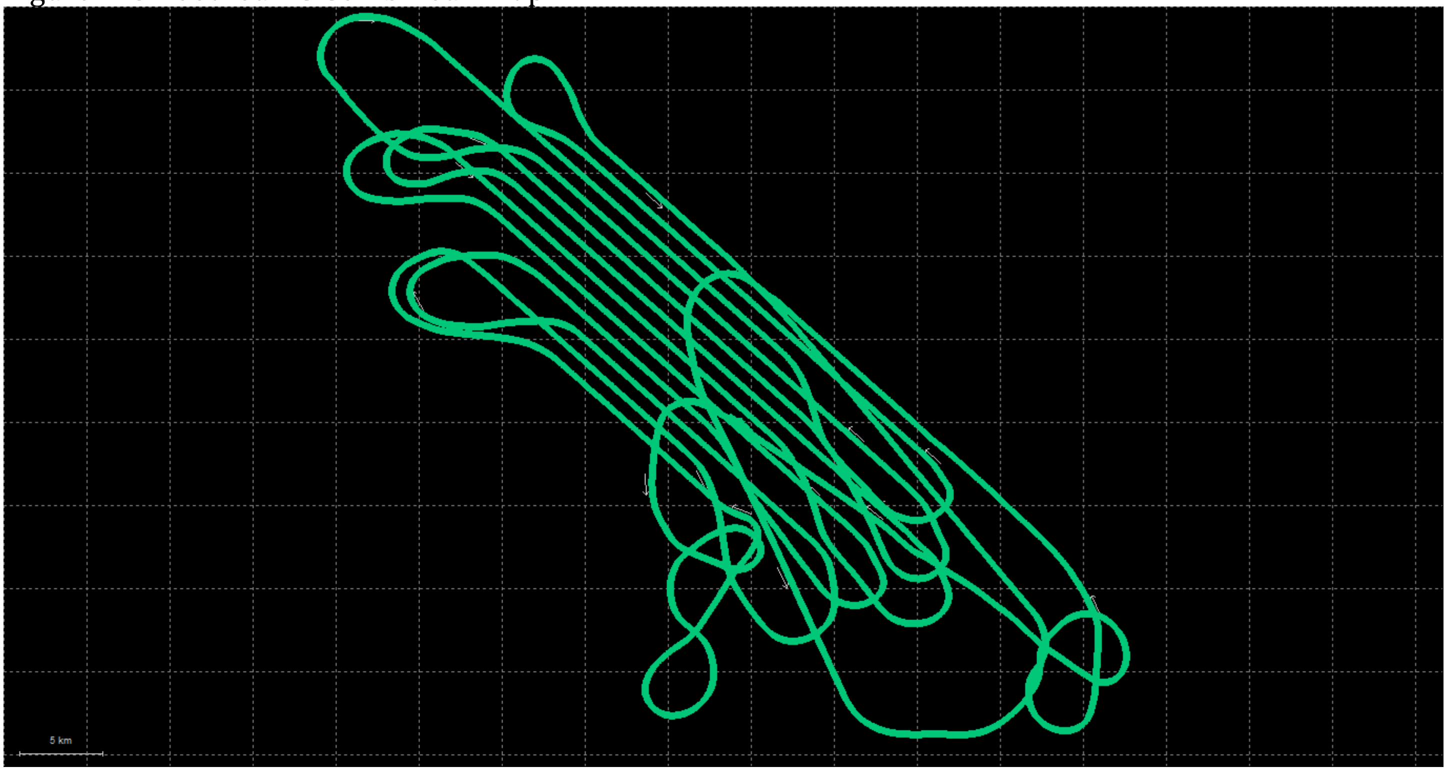


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Figure 2: 20230327A_GnssImu [Smoothed TC Combined] - Estimated Position Accuracy Plot

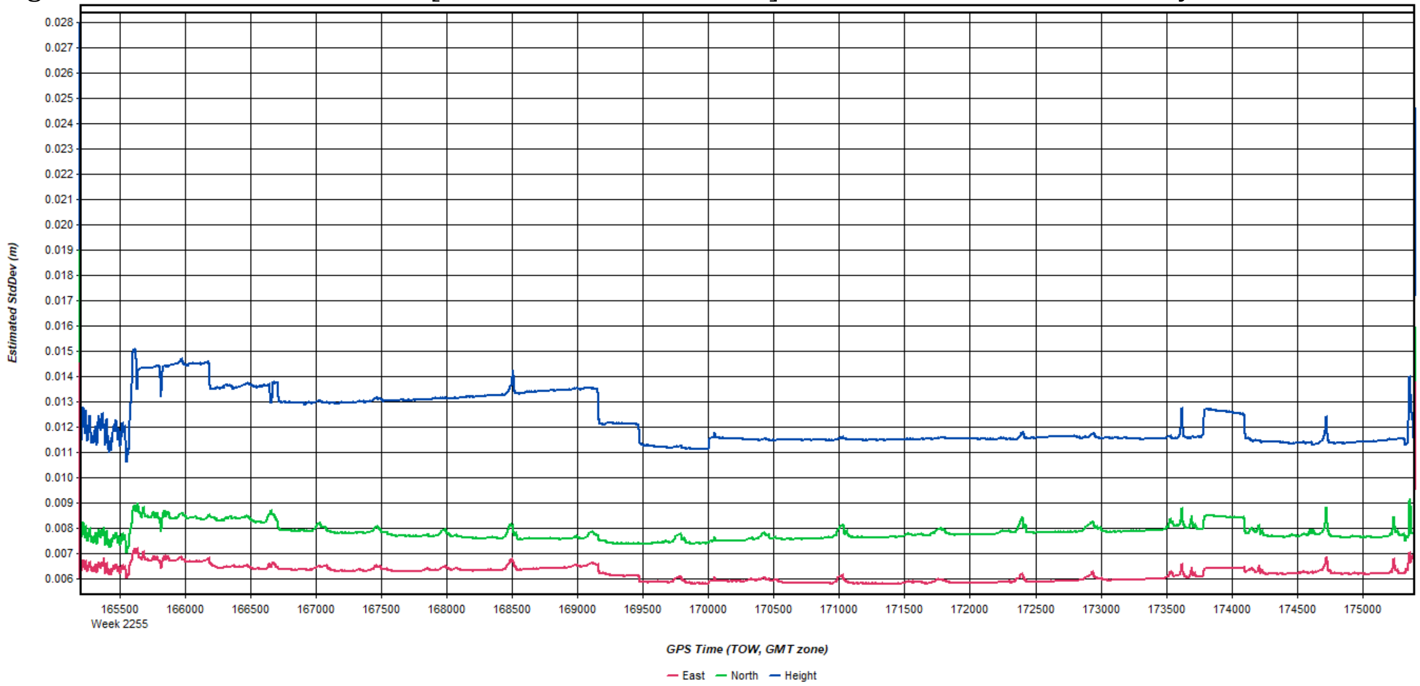

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Figure 3: 20230327A_GnssImu [Smoothed TC Combined] - Number of Satellites Line Plot

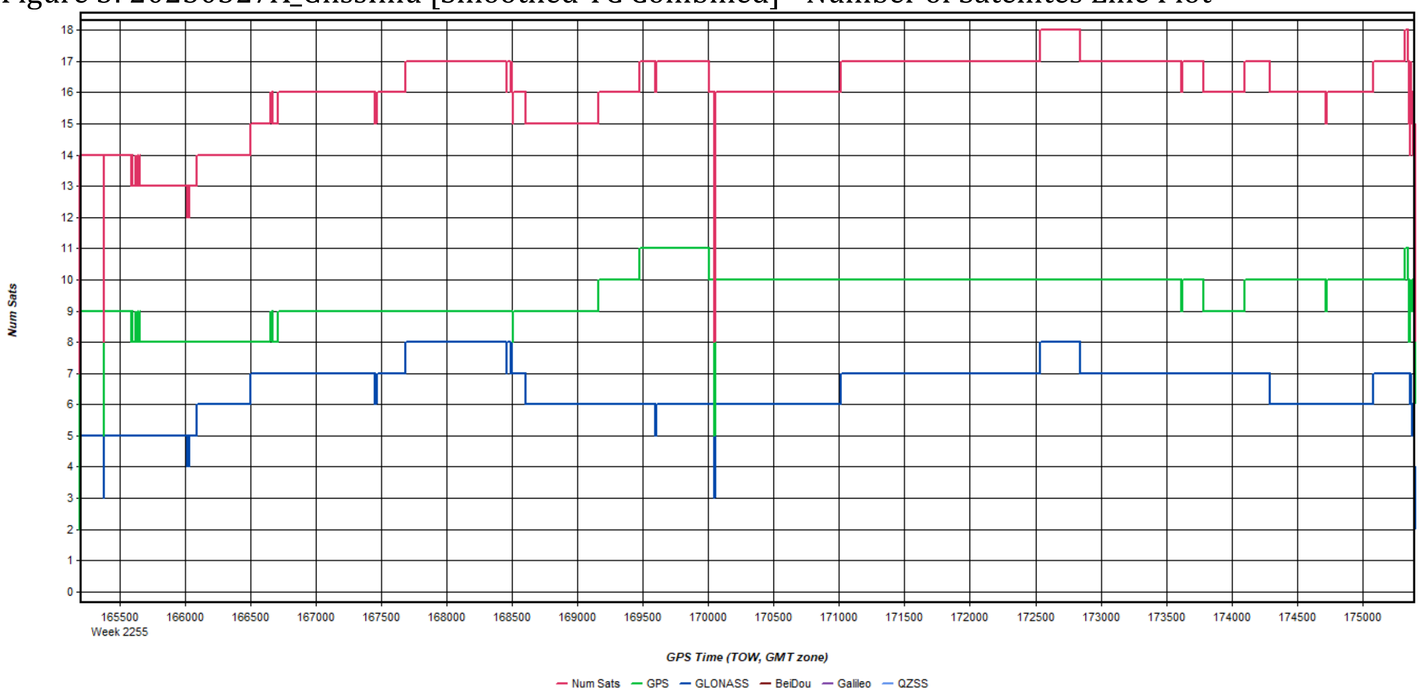

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Figure 4: 20230327A_GnssImu [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot

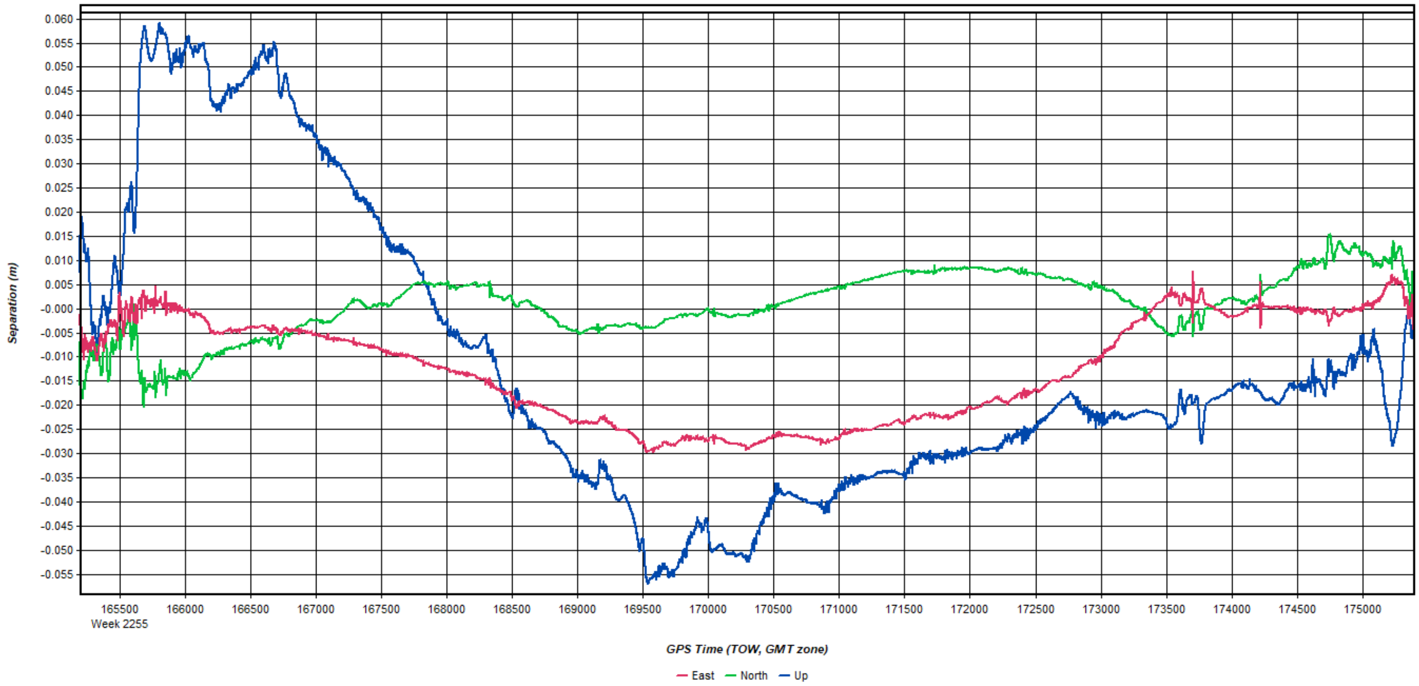

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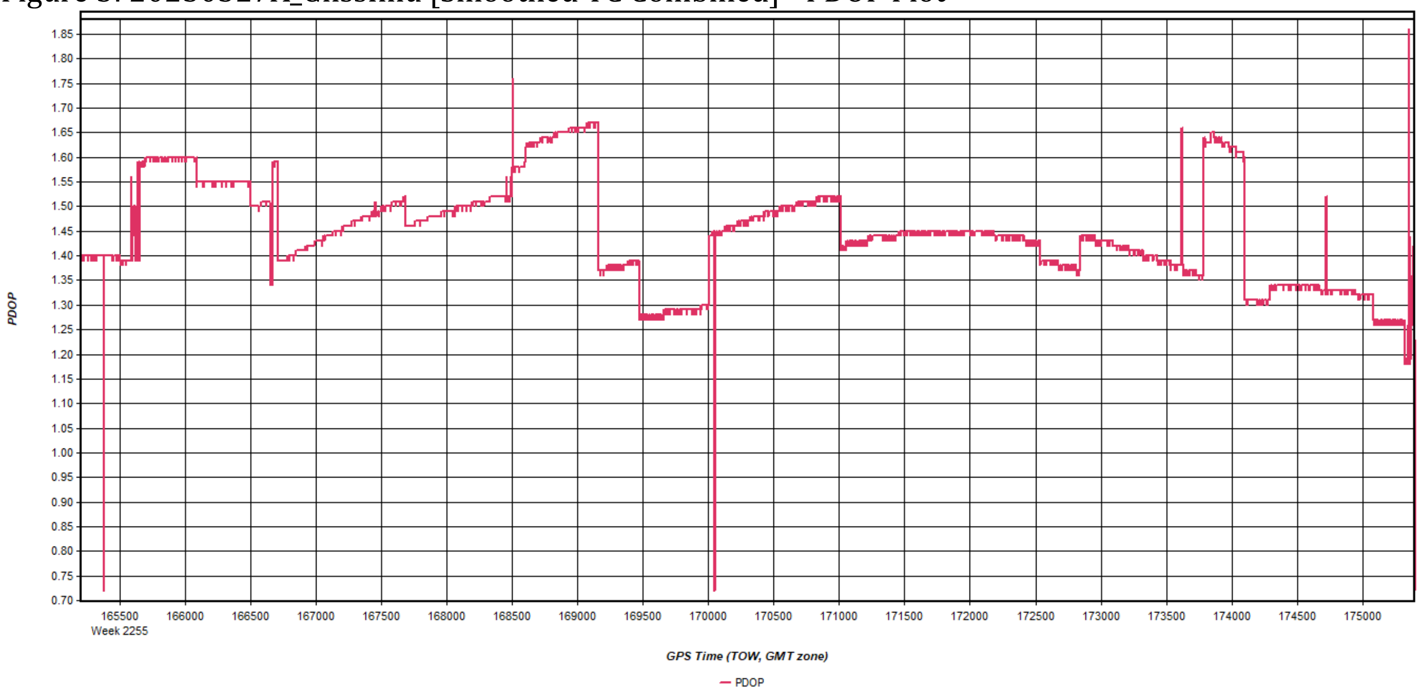
Figure 5: 20230327A_GnssImu [Smoothed TC Combined] - PDOP Plot



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Inertial Explorer Version 8.90.2124
04/06/2023

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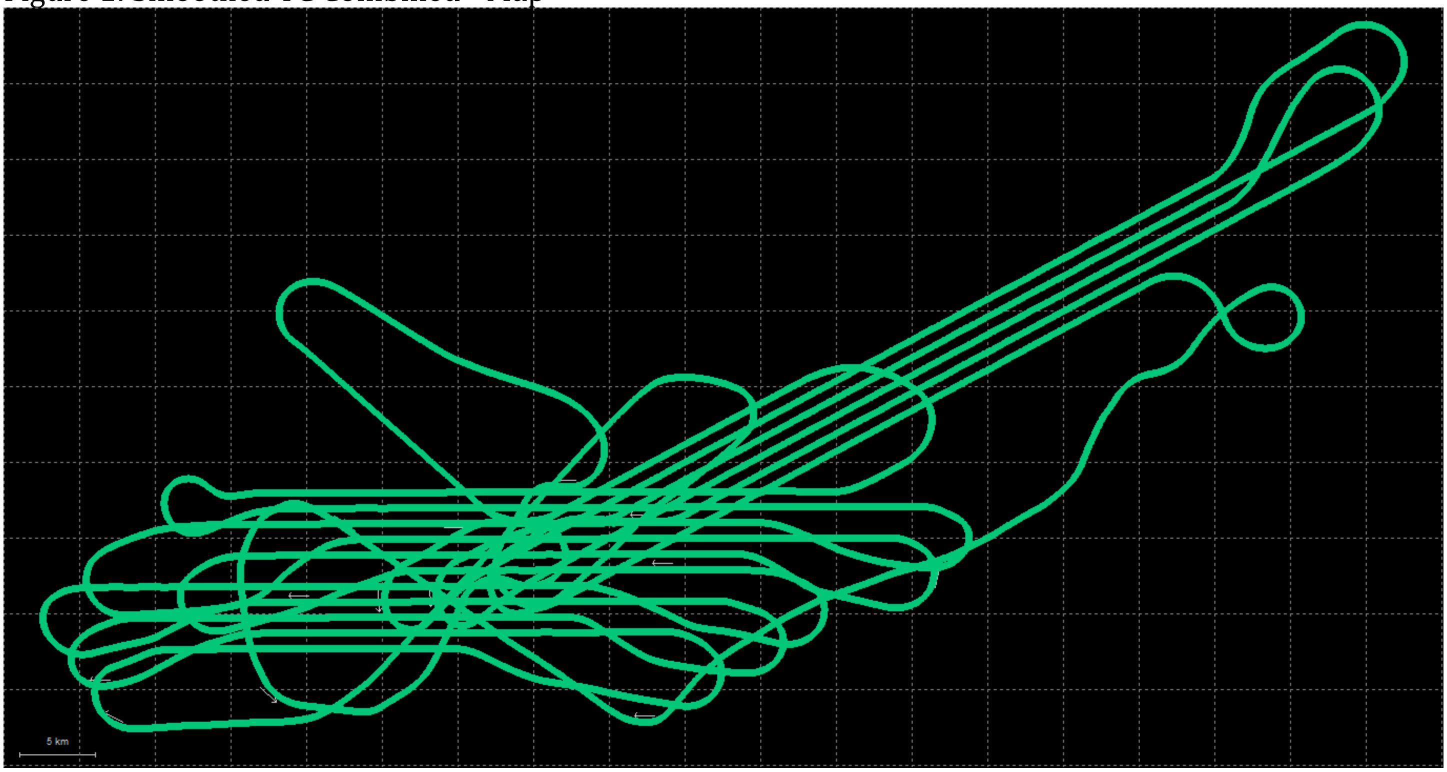

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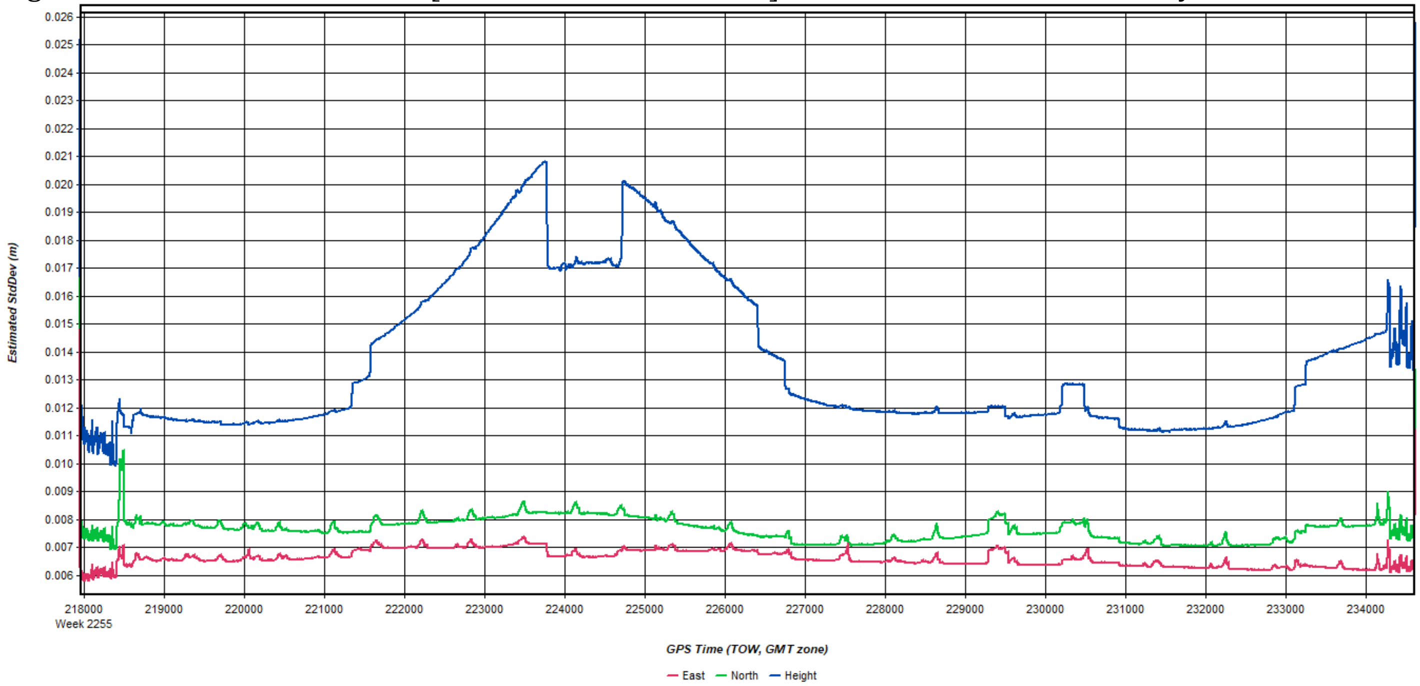
Figure 2: 20230328A_GnssImu [Smoothed TC Combined] - Estimated Position Accuracy Plot



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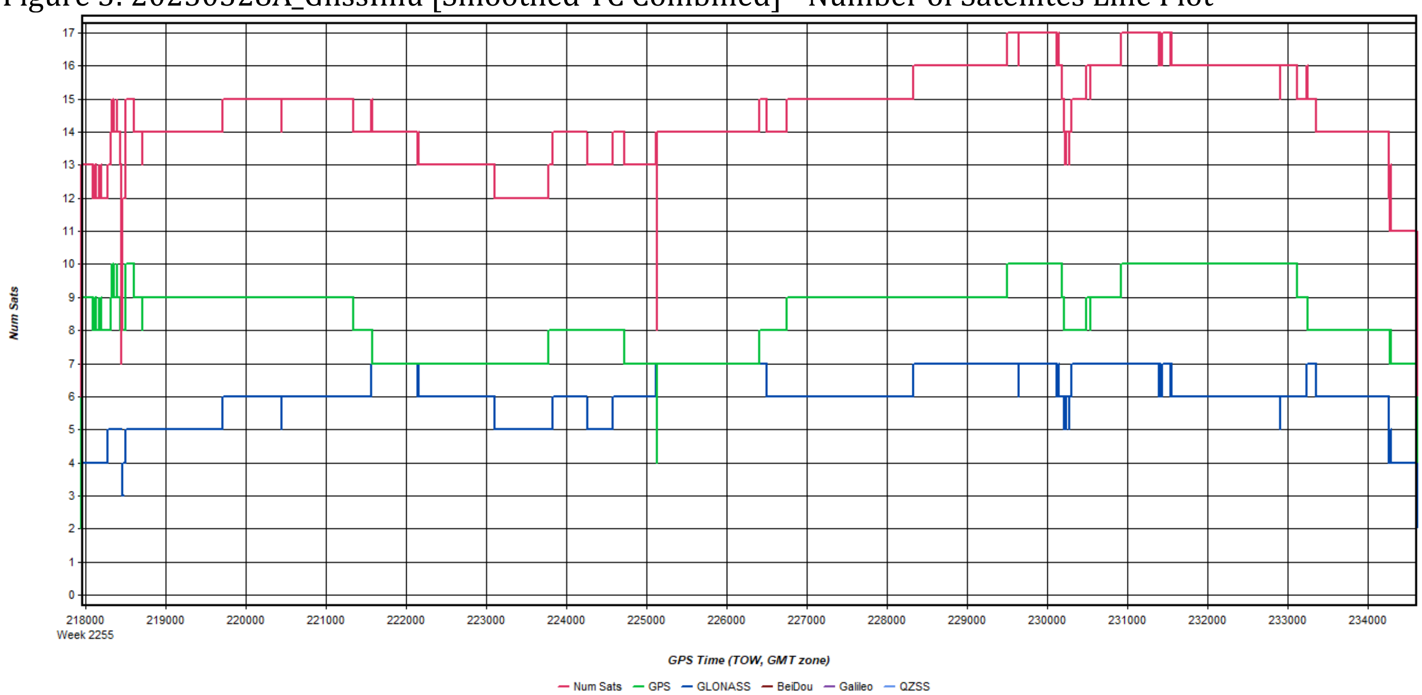

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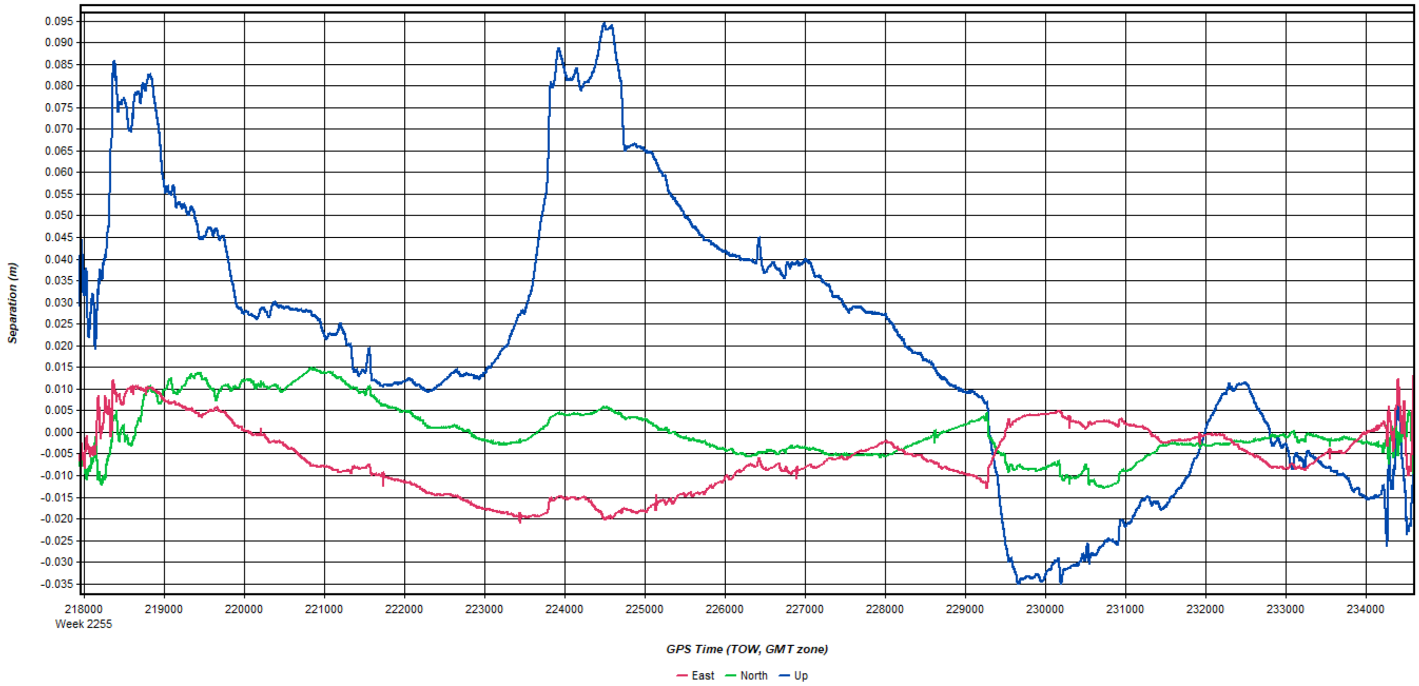
Figure 4: 20230328A_GnssImu [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot



Process	20230328A_GnssImu	by Unknown	on 4/6/2023	at 12:26:37

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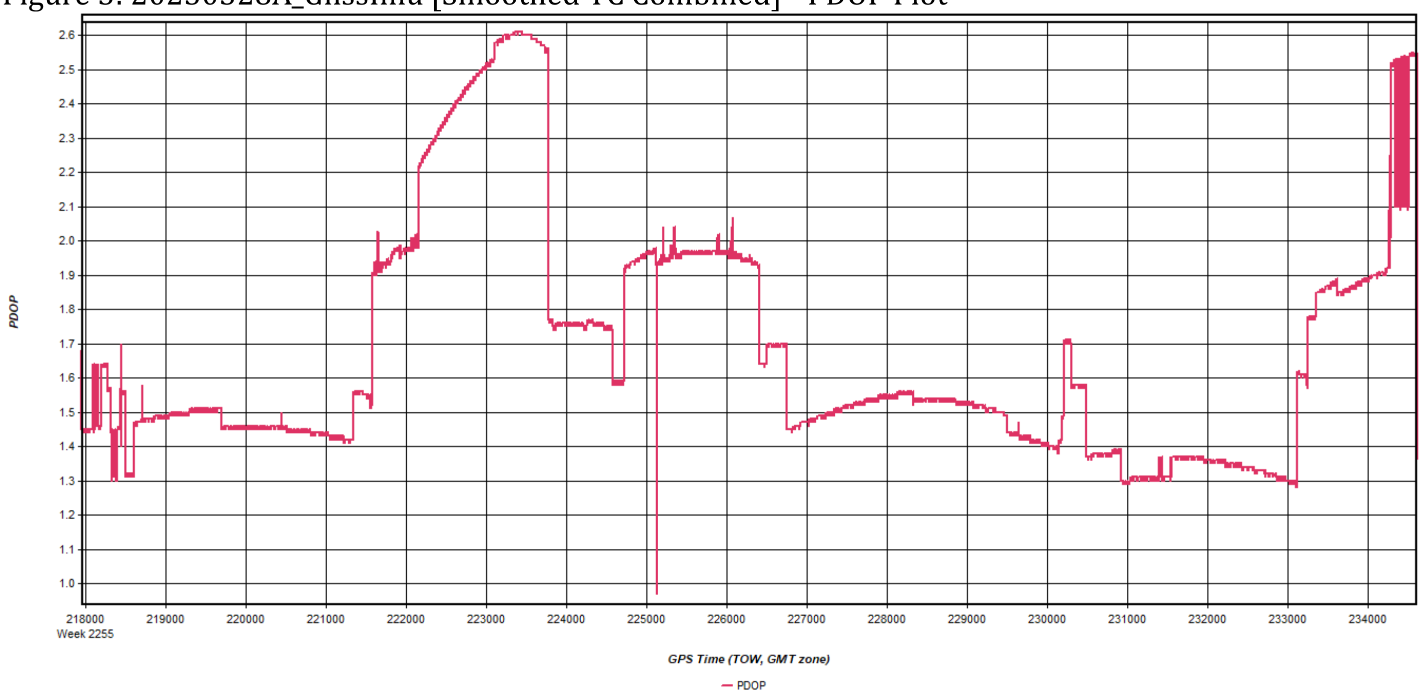

Process	20230328A_GnssImu	by Unknown	on 4/6/2023	at 12:26:37