sanborn
www.sanborn.com | 1.866.726.2676

140G0218F0176-MI_FEMAHQ_2018_D18 (Dickinson_Iron_Menominee)

USGS Contract: G16PC00051

Lidar Report

December, 2020

EXECUTIVE SUMMARY

The State of Michigan and the Michigan Statewide Authoritative Imagery & Lidar Program (MiSAIL) contracted with The Sanborn Map Company, Inc. (Sanborn) 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 ~2700mi² was completed on June 28th, 2020.

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. 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:

Shawn Benham, PMP
Vice President of Programs
The Sanborn Map Company, Inc.
1935 Jamboree Drive, Suite 100
Colorado Springs, CO 80920
(719) 502-1296
sbenham@sanborn.com

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

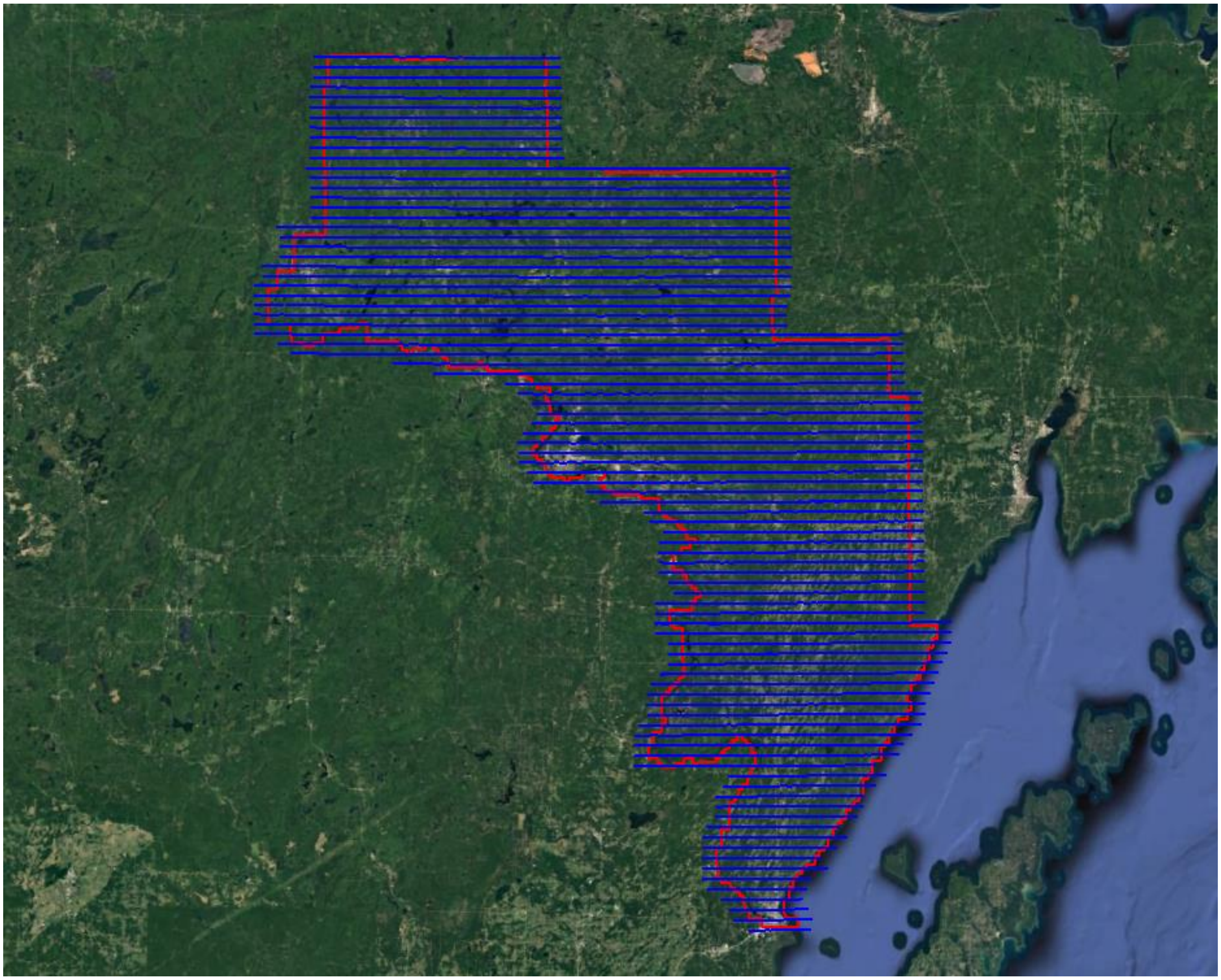


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Dickinson_Iron_Menominee 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	N2326B - CESSNA TU206G
Sensor	Leica TerrainMapper
Max Number of Returns	15
Point Spacing (m)	0.66
Point Density (pls/m²)	2.3
Flying Height (AGL) (m)	3050
Air Speed (kts)	160
Field of View (degrees)	40
Scan Rate (Hz)	87.9
Pulse Rate (kHz)	659
Laser Footprint (m)	0.71
Wavelength (nm)	1064
Multi-Pulse	Yes
Swath Width (m)	2220
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 in order to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of seventeen (17) mission(s). 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)
5/2/2020	TerrainMapper	TM91555	N2326B	20200502A_N2326B	1.1	20:51:48	21:36:15
5/5/2020	TerrainMapper	TM91555	N2326B	20200505A_N2326B	1.2	21:26:00	0:42:32
5/6/2020	TerrainMapper	TM91555	N2326B	20200506A_N2326B	1.2	14:01:42	17:41:21
5/7/2020	TerrainMapper	TM91555	N2326B	20200507A_N2326B	1.3	14:07:09	15:32:38
5/11/2020	TerrainMapper	TM91555	N2326B	20200511A_N2326B	1.1	16:18:06	18:53:28
5/12/2020	TerrainMapper	TM91555	N2326B	20200512A_N2326B	1.2	14:54:24	18:33:34
5/12/2020	TerrainMapper	TM91555	N2326B	20200512B_N2326B	1.1	19:48:39	22:42:40
5/13/2020	TerrainMapper	TM91555	N2326B	20200513A_N2326B	1.2	15:36:36	19:46:33
5/16/2020	TerrainMapper	TM91555	N2326B	20200516A_N2326B	1.1	11:53:15	13:51:48
5/16/2020	TerrainMapper	TM91555	N2326B	20200516B_N2326B	1.2	18:50:12	21:25:42
5/20/2020	TerrainMapper	TM91555	N2326B	20200520A_N2326B	1.2	13:51:54	16:40:26
5/20/2020	TerrainMapper	TM91555	N2326B	20200520B_N2326B	1.3	19:32:00	23:48:03
5/21/2020	TerrainMapper	TM91555	N2326B	20200521A_N2326B	1.2	14:15:06	18:13:26
5/21/2020	TerrainMapper	TM91555	N2326B	20200521B_N2326B	1.1	19:53:18	21:18:04
5/21/2020	TerrainMapper	TM91555	N2326B	20200521C_N2326B	1.1	23:29:48	2:38:49
5/22/2020	TerrainMapper	TM91555	N2326B	20200522A_N2326B	1.2	12:17:57	14:50:29
6/28/2020	TerrainMapper	TM91555	N2326B	20200628A_N2326B	1.2	12:08:06	14:36:19

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
SUP2	CORS	AJ5569	45 44 58.14001	087 04 24.63098	153.810
MIST	CORS	DK6955	45 25 18.14312	087 35 58.63691	187.831
MINW	CORS	DH7129	45 47 24.35921	087 55 05.78174	255.884
MIIR	CORS	DI0208	46 04 49.40250	088 38 00.14606	470.032
MIBX	CORS	DI1836	46 45 50.80696	088 30 46.87470	193.773

Table 3: GNSS Reference Station Coordinates

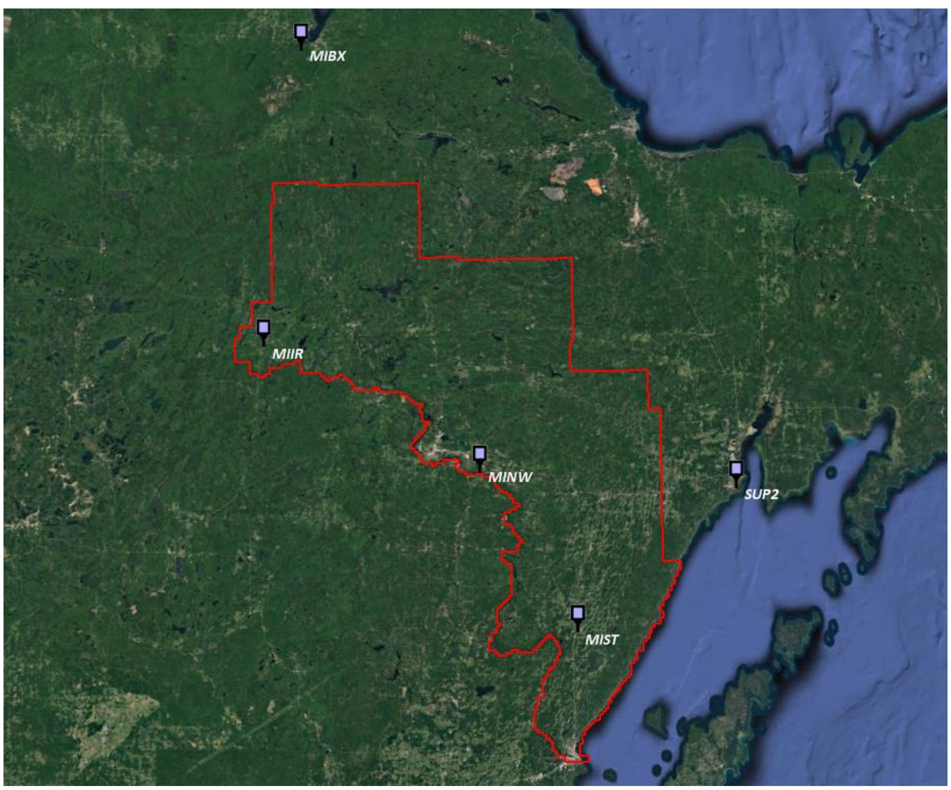


Figure 2: GNSS Reference Stations

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 HxMap 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.

The Leica HxMap 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	44,679,362,800
Aggregate Nominal Pulse Spacing (m)	0.51
Aggregate Nominal Pulse Density (pls/m²)	3.9
Aggregate Nominal Pulse Spacing (ft)	1.67
Aggregate Nominal Pulse Density (pls/ft²)	0.4

Table 4: Point Cloud Statistics

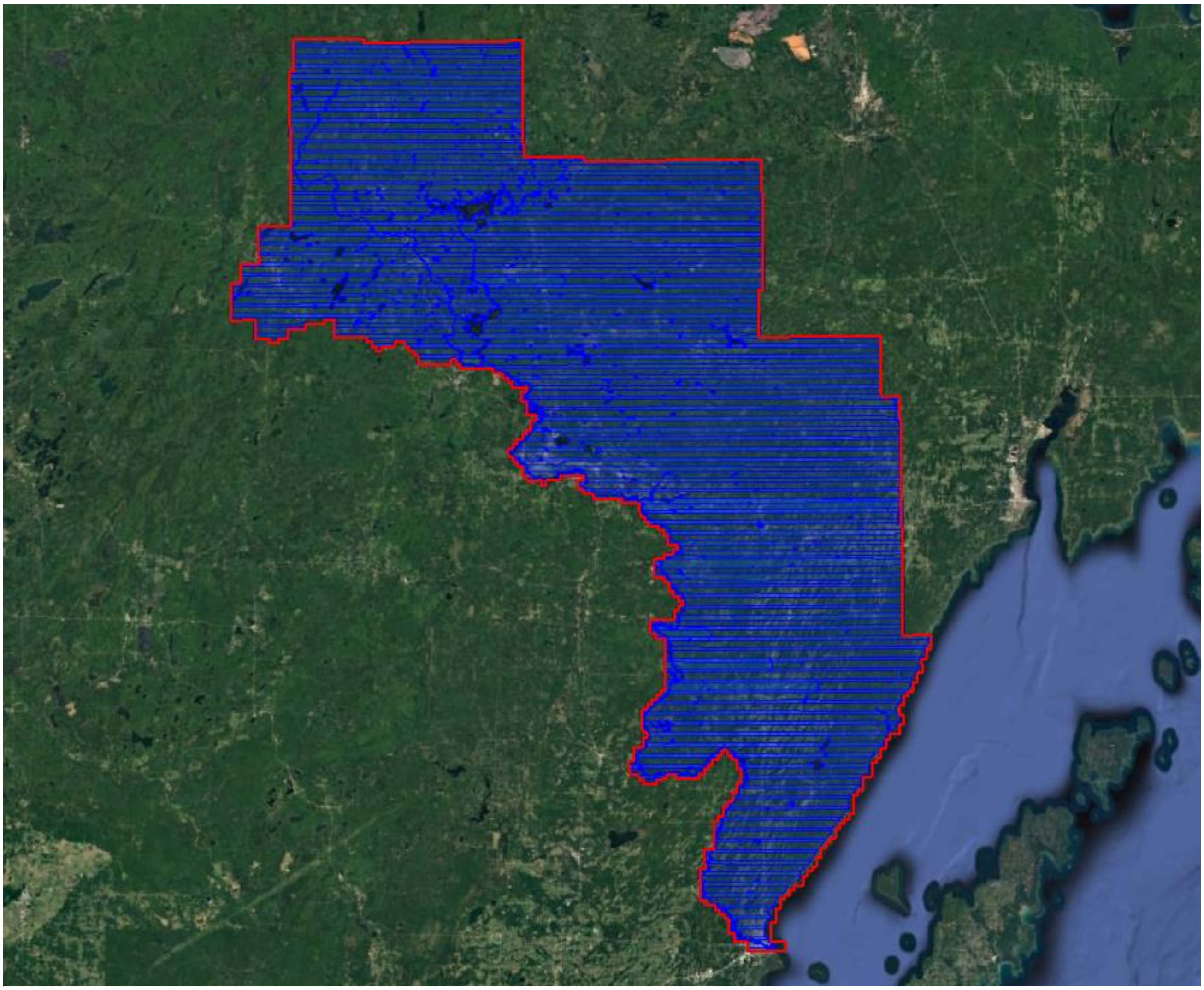


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Projection:	State Plane Michigan North (FIPS 2111)
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units:	International Feet

3.3 Lidar Matching

Sanborn uses Leica HxMap 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.

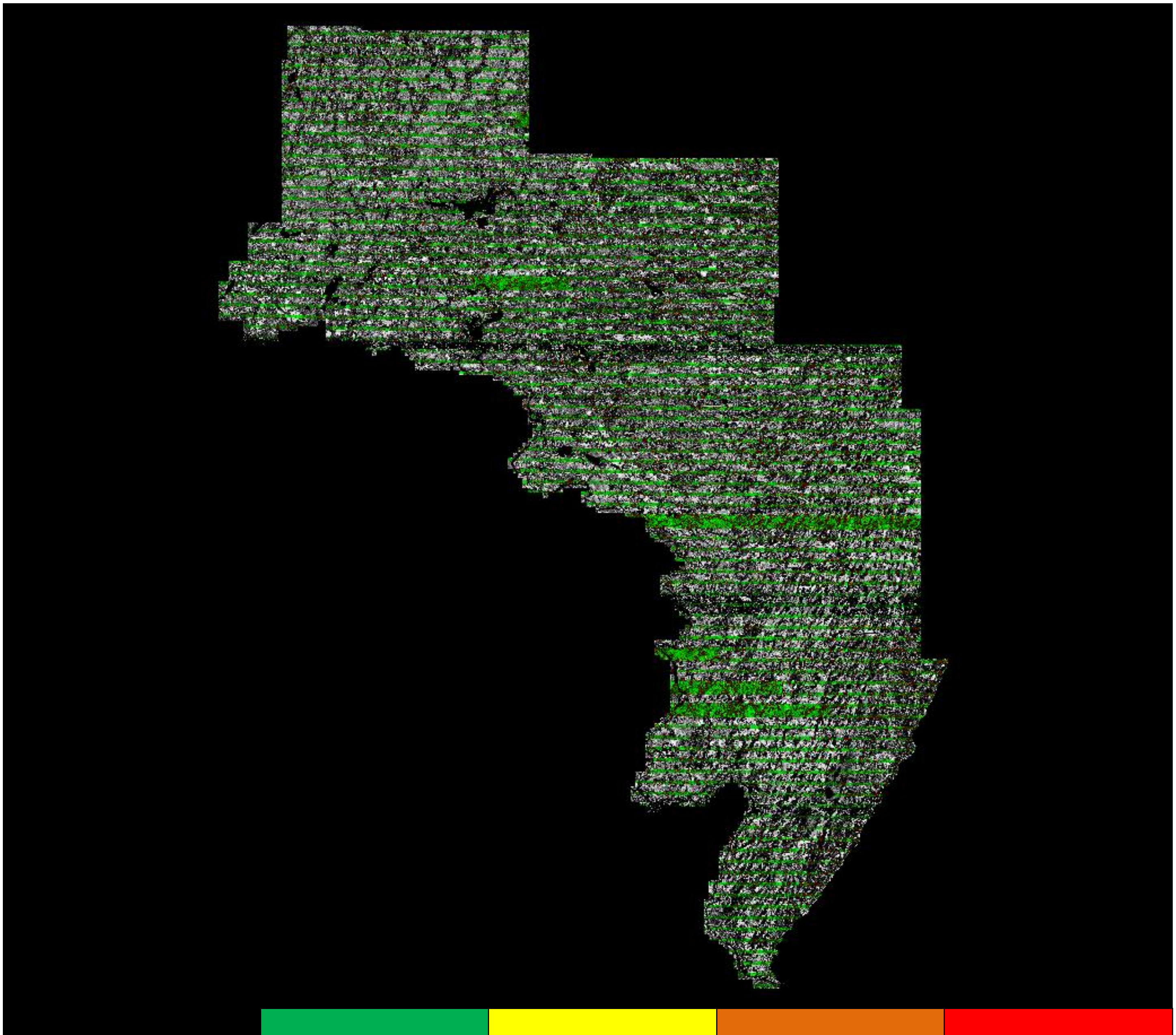
Each mission is imported into GeoCue where each individual flight line is assigned a unique Source ID number. The SBET is cut per swath into TerraScan Trajectory files based on Source ID number and timestamp; these are utilized during the lidar matching process. The project area(s) are broken into logical 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.

After successful point cloud filters have been run on the lidar matching dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar point cloud intended to reduce the overwhelming data size to a more manageable number. 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 correlate to the same observation of an overlapping flight line.

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. Height Separation Rasters modulated by Intensity are representative of the interswath alignment and provide a holistic qualitative look at the positional quality of the point cloud. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSDz. 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	< 0.08m	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 4: Swath Separation Images

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
478	0.048	0.048	0.035	**512**	0.063	0.070	0.032	**546**	0.055	0.054	0.031
479	0.091	0.104	0.033	**513**	0.096	0.096	0.034	**547**	0.080	0.090	0.030
480	0.079	0.098	0.032	**514**	0.069	0.080	0.032	**548**	0.051	0.064	0.031
481	0.079	0.085	0.032	**515**	0.053	0.048	0.034	**549**	0.070	0.099	0.029
482	0.075	0.090	0.031	**516**	0.067	0.084	0.032	**550**	0.050	0.080	0.030
483	0.069	0.066	0.031	**517**	0.059	0.077	0.031	**551**	0.059	0.095	0.034
484	0.089	0.084	0.031	**518**	0.087	0.111	0.034	**552**	0.078	0.060	0.029
485	0.071	0.094	0.031	**519**	0.071	0.082	0.033	**553**	0.080	0.067	0.029
486	0.063	0.094	0.031	**520**	0.041	0.043	0.030	**554**	0.076	0.053	0.029

487	0.061	0.079	0.030	**521**	0.066	0.135	0.032	**555**	0.072	0.073	0.029
488	0.063	0.077	0.031	**522**	0.072	0.082	0.033	**556**	0.093	0.086	0.030
489	0.066	0.074	0.031	**523**	0.135	0.039	0.032	**557**	0.091	0.093	0.030
490	0.051	0.064	0.032	**524**	0.132	0.027	0.030	**558**	0.069	0.074	0.030
491	0.058	0.059	0.032	**525**	0.108	0.038	0.031	**559**	0.072	0.083	0.030
492	0.061	0.064	0.034	**526**	0.096	0.058	0.031	**560**	0.078	0.094	0.030
493	0.065	0.075	0.032	**527**	0.103	0.070	0.032	**561**	0.065	0.082	0.029
494	0.055	0.052	0.033	**528**	0.039	0.034	0.027	**562**	0.069	0.085	0.031
495	0.076	0.092	0.035	**529**	0.044	0.033	0.025	**563**	0.046	0.051	0.030
496	0.061	0.091	0.032	**530**	0.066	0.079	0.033	**564**	0.077	0.074	0.031
497	0.057	0.093	0.031	**531**	0.046	0.051	0.032	**565**	0.062	0.079	0.030
498	0.060	0.085	0.031	**532**	0.065	0.073	0.032	**566**	0.054	0.077	0.030
499	0.066	0.072	0.031	**533**	0.070	0.085	0.030	**567**	0.050	0.055	0.032
500	0.071	0.071	0.032	**534**	0.054	0.093	0.032	**568**	0.060	0.070	0.030
501	0.090	0.084	0.032	**535**	0.069	0.073	0.035	**569**	0.059	0.075	0.030
502	0.072	0.099	0.033	**536**	0.078	0.066	0.032	**570**	0.057	0.083	0.030
503	0.075	0.070	0.037	**537**	0.058	0.095	0.031	**571**	0.057	0.079	0.030
504	0.105	0.106	0.033	**538**	0.062	0.059	0.032	**572**	0.065	0.094	0.030
505	0.098	0.083	0.038	**539**	0.071	0.065	0.034	**573**	0.071	0.111	0.032
506	0.073	0.071	0.039	**540**	0.090	0.081	0.029	**574**	0.081	0.097	0.033
507	0.097	0.084	0.035	**541**	0.048	0.071	0.030	**575**	0.079	0.081	0.035
508	0.061	0.064	0.032	**542**	0.068	0.101	0.030	**576**	0.096	0.071	0.037
509	0.068	0.079	0.030	**543**	0.078	0.085	0.030	**577**	0.090	0.071	0.038
510	0.073	0.093	0.032	**544**	0.074	0.079	0.031	**578**	0.053	0.071	0.045
511	0.077	0.097	0.033	**545**	0.082	0.096	0.029				

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.063	0.073	0.031
RMS Values	0.097	0.120	0.042
Maximum Values	0.492	0.498	0.499
Observation Weight	33323.0	33323.0	3229451.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.03241
Average XY Mismatch	0.11895
Average Z Mismatch	0.03142

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	1,436,408
Roof Lines	15,812

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 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
17	Bridge Decks	Structure carrying a means of transit of higher
18	High Noise	Erroneous atmospheric returns above bare-earth
20	Ignored Ground	Bare-earth points near breaklines
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 eighty seven (87) check points (51 NVA + 36 VVA). The end result provided a vertical accuracy 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 (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	51	0.242	0.474	
NVA of Bare Earth	51	0.239	0.468	
NVA of DEM	51	0.236	0.463	
VVA of Bare Earth	36	0.333		0.750
VVA of DEM	36	0.334		0.745

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

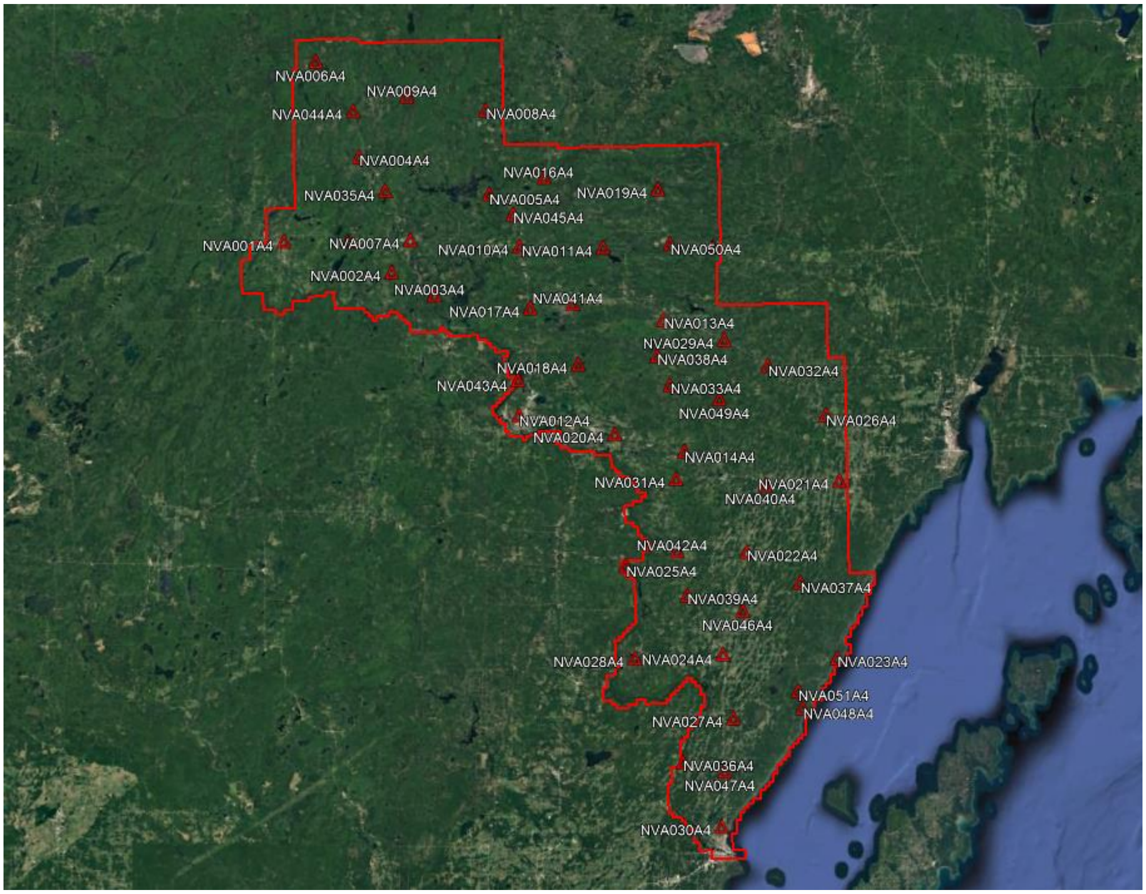


Figure 5: Non-vegetated Check Point Distribution

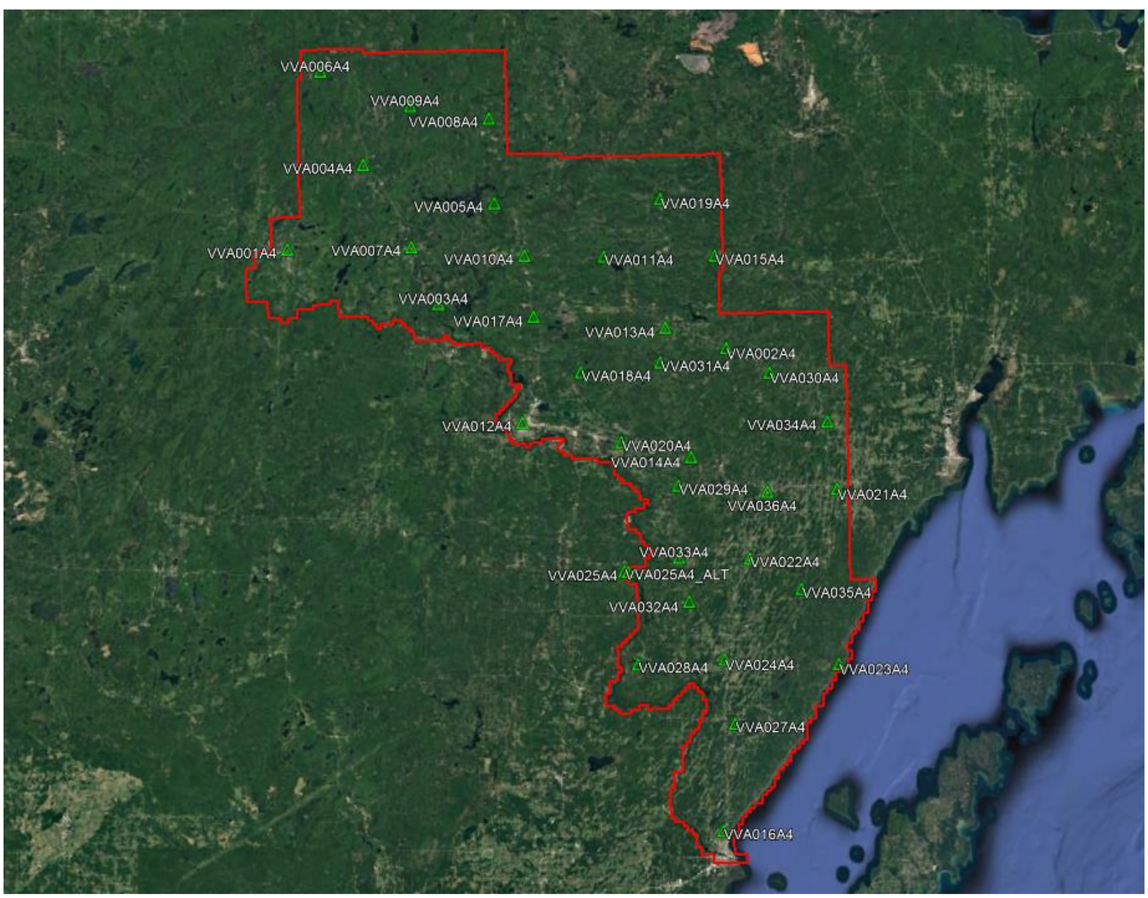


Figure 6: Vegetated Check Point Distribution

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
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 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 Digital Surface Model
32-bit GeoTIFF (*.tif) elevation rasters were created from the first-return points in the processed lidar dataset. All overlap classes were ignored during this process. First-return rasters were produced 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. All overlap classes were ignored during this process. 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.

Swath Polygons
Polygons 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.