Project: 140G0218F0176-MI_FEMAHQ_2018_D18
USGS Contract: G16PC00051

Lidar Report

December, 2018

EXECUTIVE SUMMARY

The U.S. Geological Survey (USGS) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services for Presque Isle 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 ~724mi² was completed on May 14th, 2018.

The Leica ALS70 - HP 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:

Shawn Benham, PMP
Program Manager Director
Sanborn Map Co., Inc.
1935 Jamboree Drive, Suite 100
Colorado Springs, CO
(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

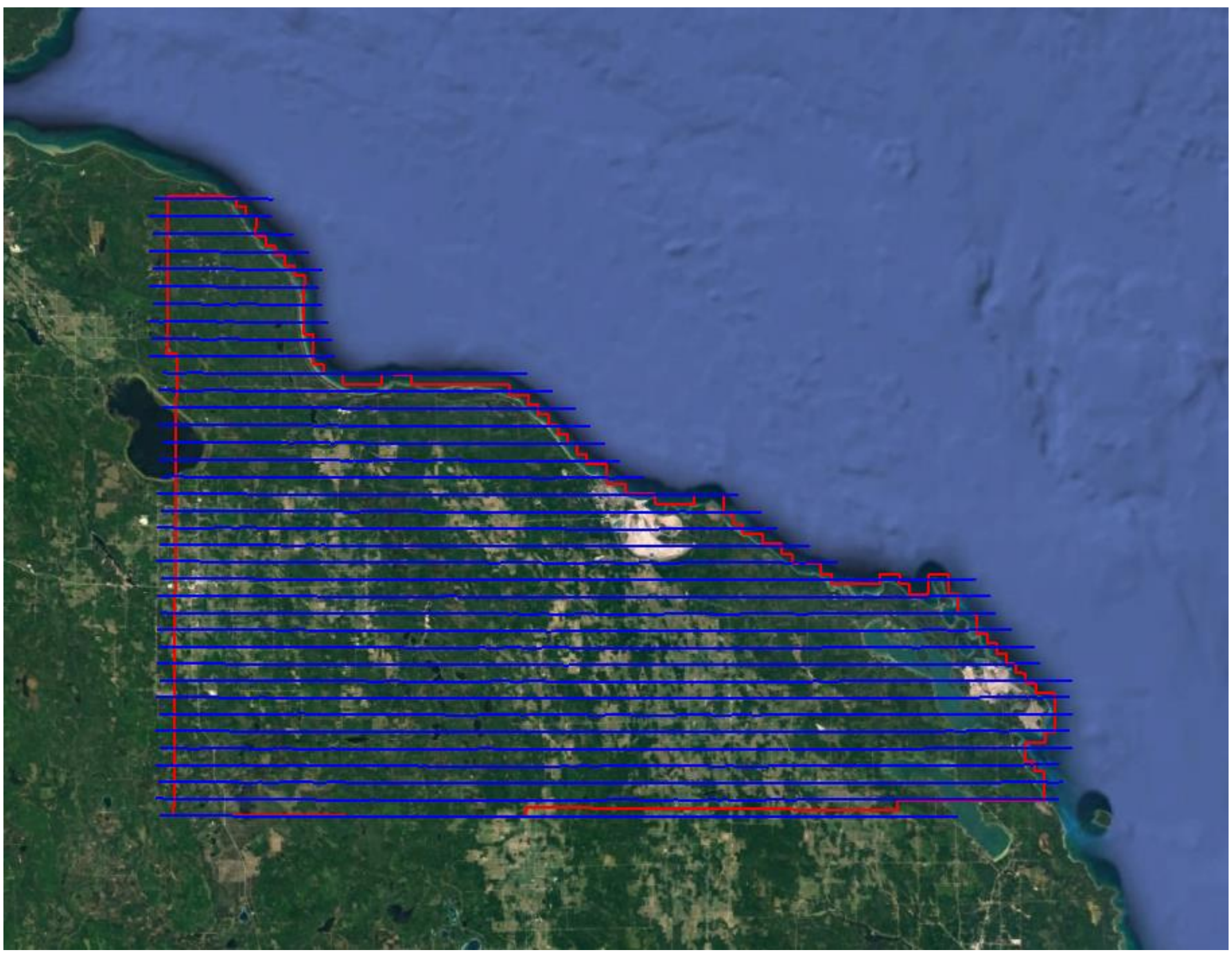


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Presque Isle 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	Leica ALS70 - HP
Aircraft	N603ET – CESSNA TU206F
Flying Height (AGL)	2099m
Air Speed (kts)	130
Field of View (degrees)	45
Overlap (%)	20
Pulse Rate (kHz)	256
Scan Rate (Hz)	42.1
Laser Footprint (m)	0.48
Mode (PIA)	Multi-Pulse
Point Spacing (m)	0.67
Point Density (pls/m²)	2.2
Swath Width (m)	1739

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 5 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)
5/12/2018	Leica ALS70 - HP	SN7220	N603ET	20180512 A	1.1	17:33:37	20:59:51
5/13/2018	Leica ALS70 - HP	SN7220	N603ET	20180513 A	1.2	12:50:21	16:31:55
5/13/2018	Leica ALS70 - HP	SN7220	N603ET	20180513 B	1.3	17:49:21	20:57:27
5/14/2018	Leica ALS70 - HP	SN7220	N603ET	20180514 A	1.2	12:12:26	16:17:46
5/14/2018	Leica ALS70 - HP	SN7220	N603ET	20180514 B	1.3	18:20:39	19:33:59

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
CHB5	CORS	DJ8965	45 39 12.54599	84 27 56.29961	146.223
CHB6	CORS	DJ7835	45 39 13.28060	84 27 57.01561	145.877
MIND	CORS	DL7802	45 23 05.38400	84 37 47.68261	184.407
NOR3	CORS	AJ5563	45 04 06.87262	83 34 07.10468	175.491

Table 3: GNSS Reference Station Coordinates

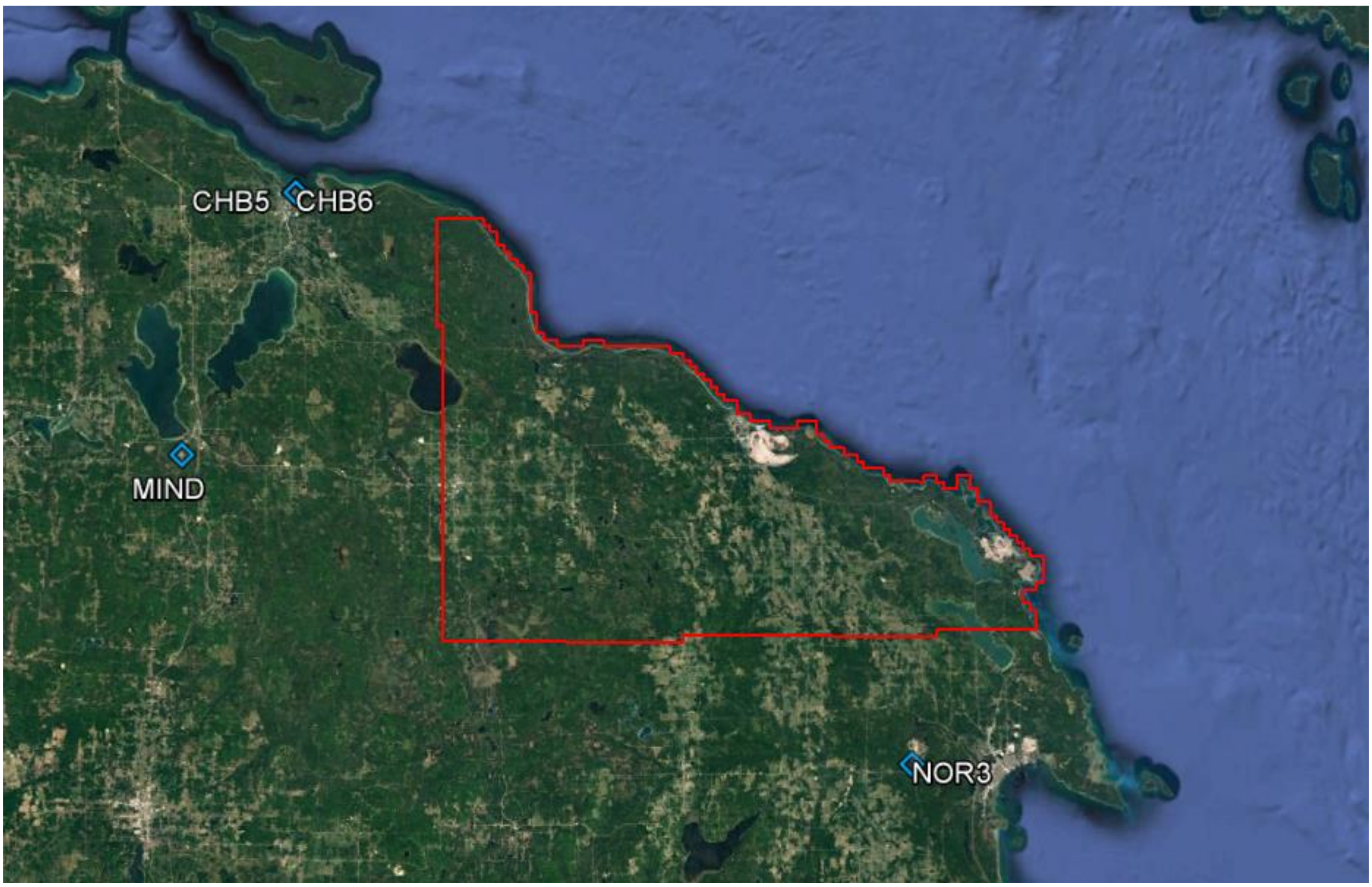


Figure 2: GNSS Reference Stations

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). The SBET was then combined with the laser range measurements in Leica CloudPro 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 Leica CloudPro 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	7,664,702,175
Aggregate Nominal Pulse Spacing (m)	0.49
Aggregate Nominal Pulse Density (pls/m²)	4.2
Aggregate Nominal Pulse Spacing (ft)	1.61
Aggregate Nominal Pulse Density (pls/ft²)	0.4

Table 4: Point Cloud Statistics

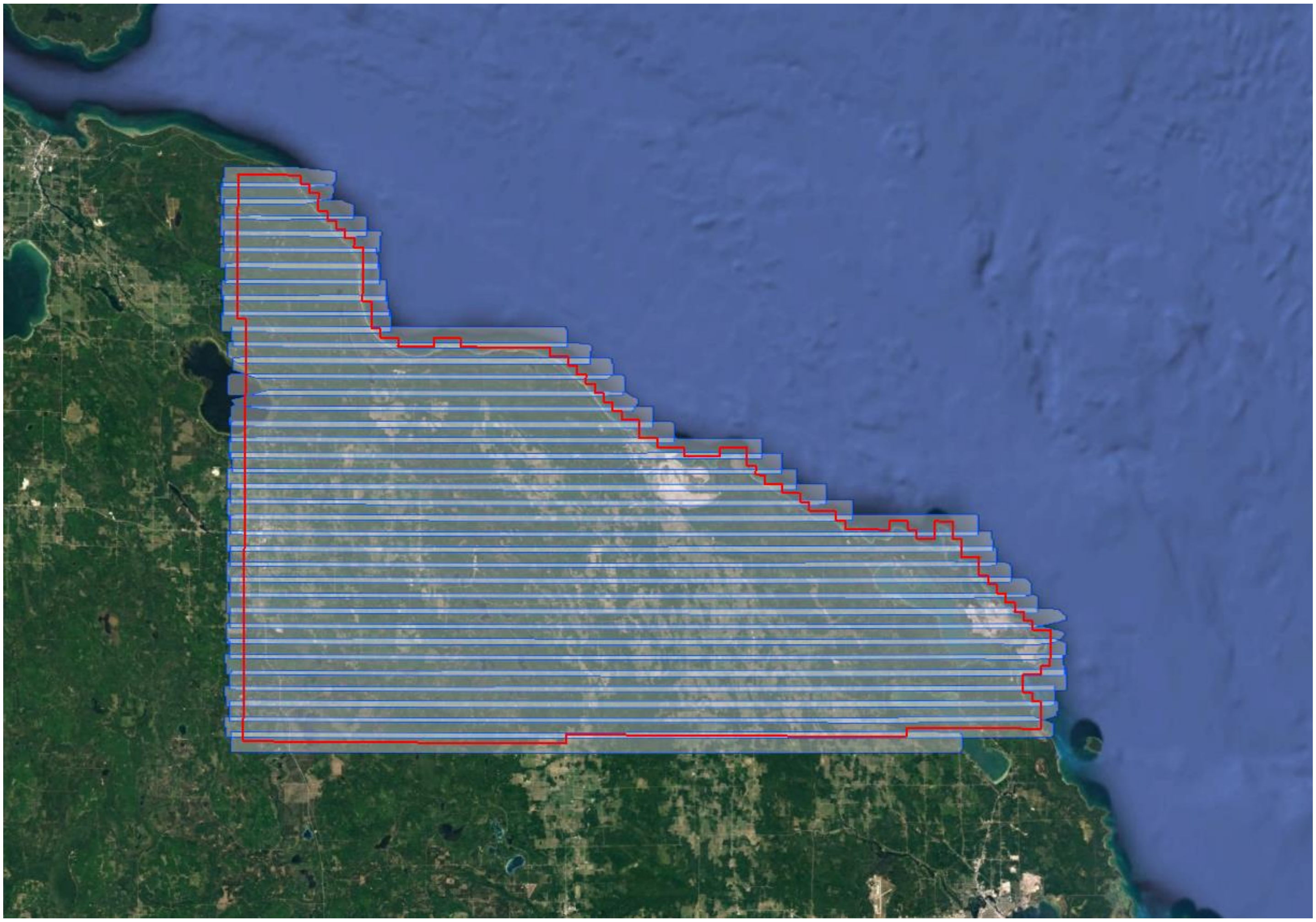


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Projection:	State Plane Michigan Central (FIPS 2112)
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units:	International Feet

3.3 Calibration

Sanborn uses Leica CloudPro 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.

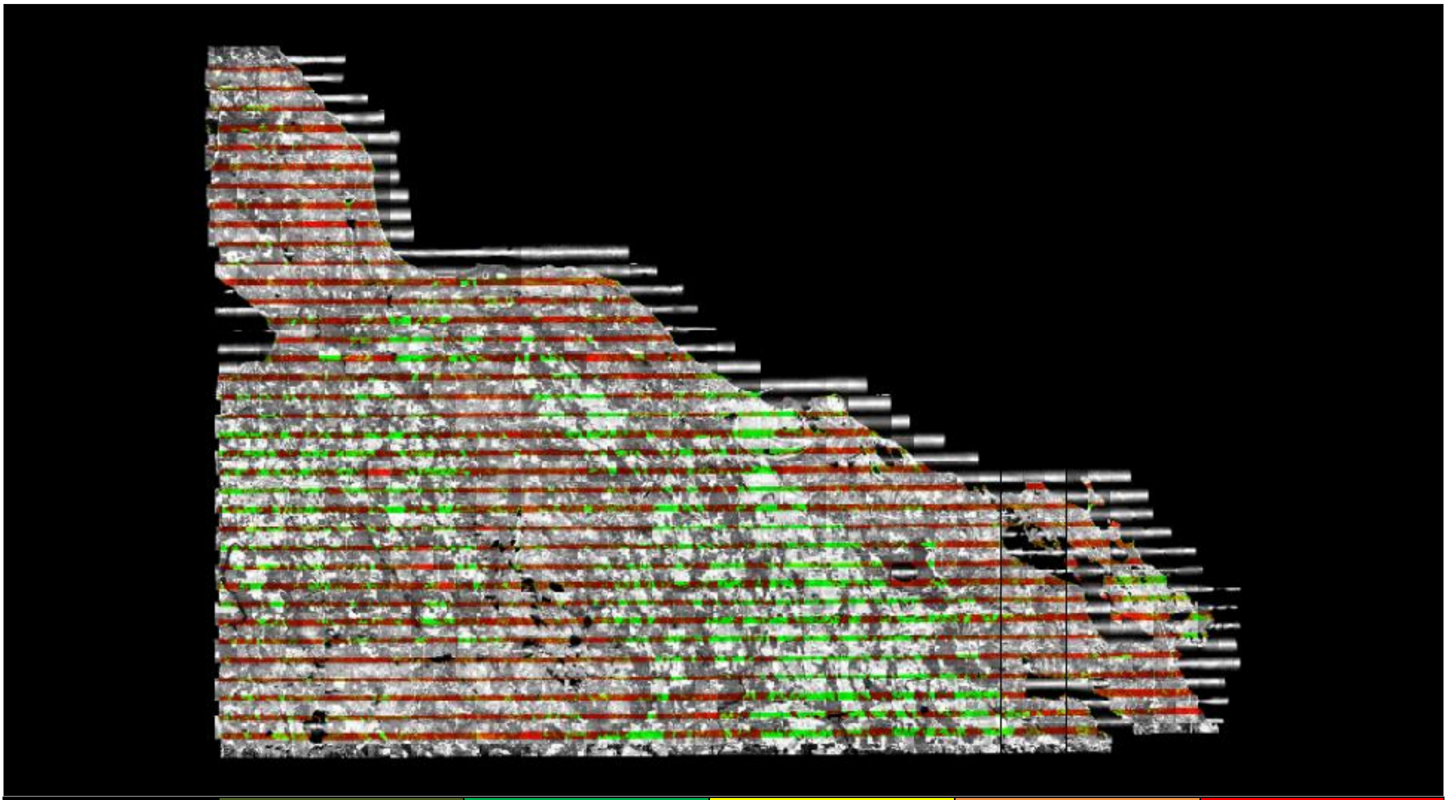
Each mission in imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the calibration process. The project area(s) are broken into logical 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 (ft)	≤0.197
Swath overlap difference, RMSDz (ft)	≤0.262
Swath overlap difference, Maximum (ft)	±0.525

Table 5: Relative Accuracy Requirements



No Data	0ft to 0.131ft	0.131ft to 0.262ft	0.262ft to 0.393ft	0.393ft to 0.524ft	> 0.524ft

Figure 4: dZ Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	0.324	0.047	0.036	**14**	0.283	0.098	0.038	**28**	0.160	0.188	0.037
2	0.321	0.069	0.039	**15**	0.318	0.081	0.035	**29**	0.065	0.199	0.037
3	0.276	0.083	0.036	**16**	0.301	0.094	0.035	**30**	0.074	0.322	0.036
4	0.227	0.066	0.039	**17**	0.248	0.073	0.036	**31**	0.118	0.292	0.038
5	0.180	0.033	0.037	**18**	0.355	0.056	0.036	**32**	0.147	0.129	0.041
6	0.225	0.023	0.037	**19**	0.355	0.042	0.036	**33**	0.145	0.199	0.041
7	0.207	0.068	0.038	**20**	0.349	0.053	0.038	**34**	0.211	0.246	0.037
8	0.171	0.083	0.038	**21**	0.339	0.067	0.040	**35**	0.182	0.183	0.038
9	0.179	0.130	0.036	**22**	0.141	0.068	0.036	**36**	0.210	0.189	0.036
10	0.142	0.199	0.040	**23**	0.247	0.149	0.037	**37**	0.266	0.270	0.035
11	0.182	0.174	0.038	**25**	0.192	0.180	0.035	**42**	0.219	0.196	0.038
12	0.169	0.137	0.040	**26**	0.193	0.190	0.036				
13	0.209	0.134	0.038	**27**	0.230	0.211	0.037				

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.210	0.130	0.037
RMS Values	0.255	0.196	0.050
Maximum Values	0.529	0.522	0.480
Observation Weight	1460.0	1460.0	1831143.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.03750
Average XY Mismatch	0.28644
Average Z Mismatch	0.03733

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	875,592
Roof Lines	730

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
20	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 80 check points (45 NVA + 35 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 (ft)	≤0.328
@ 95-percent confidence level (ft)	≤0.984

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	45	0.230	0.450	
NVA of Bare Earth	45	0.226	0.442	
NVA of DEM	45	0.223	0.438	
VVA of Bare Earth	35	0.224		0.450
VVA of DEM	35	0.233		0.466

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

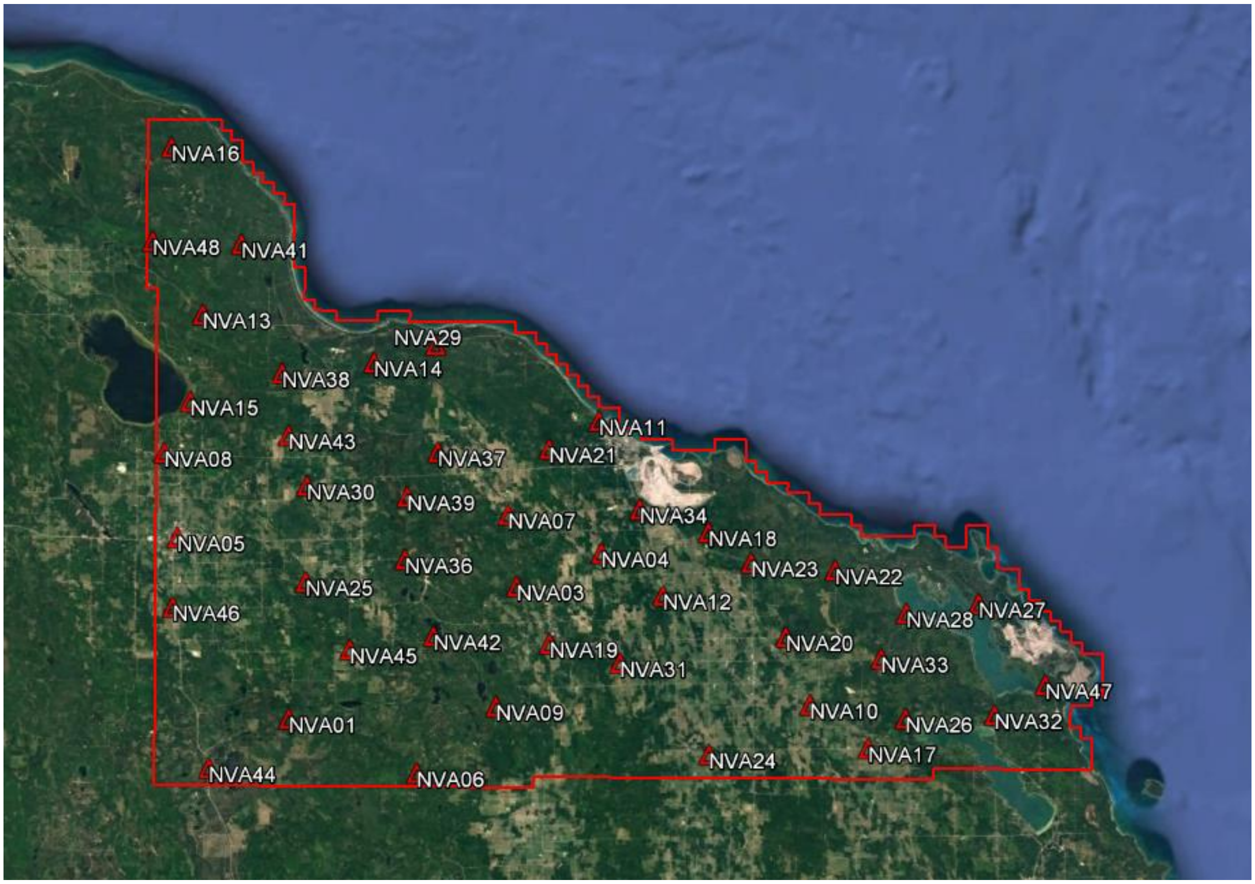


Figure 5: Non-vegetated Check Point Distribution

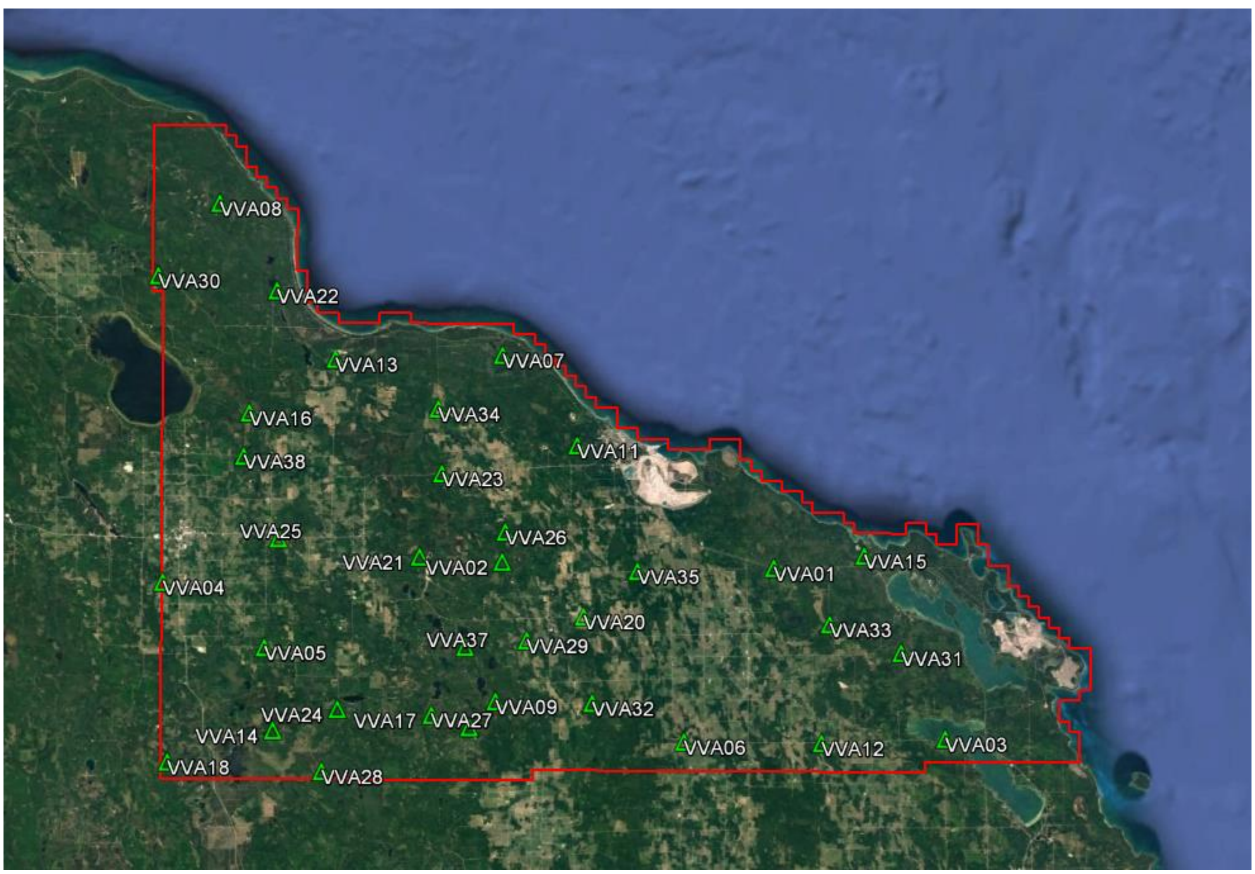


Figure 6: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

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) 2 ft 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) 2 ft 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.