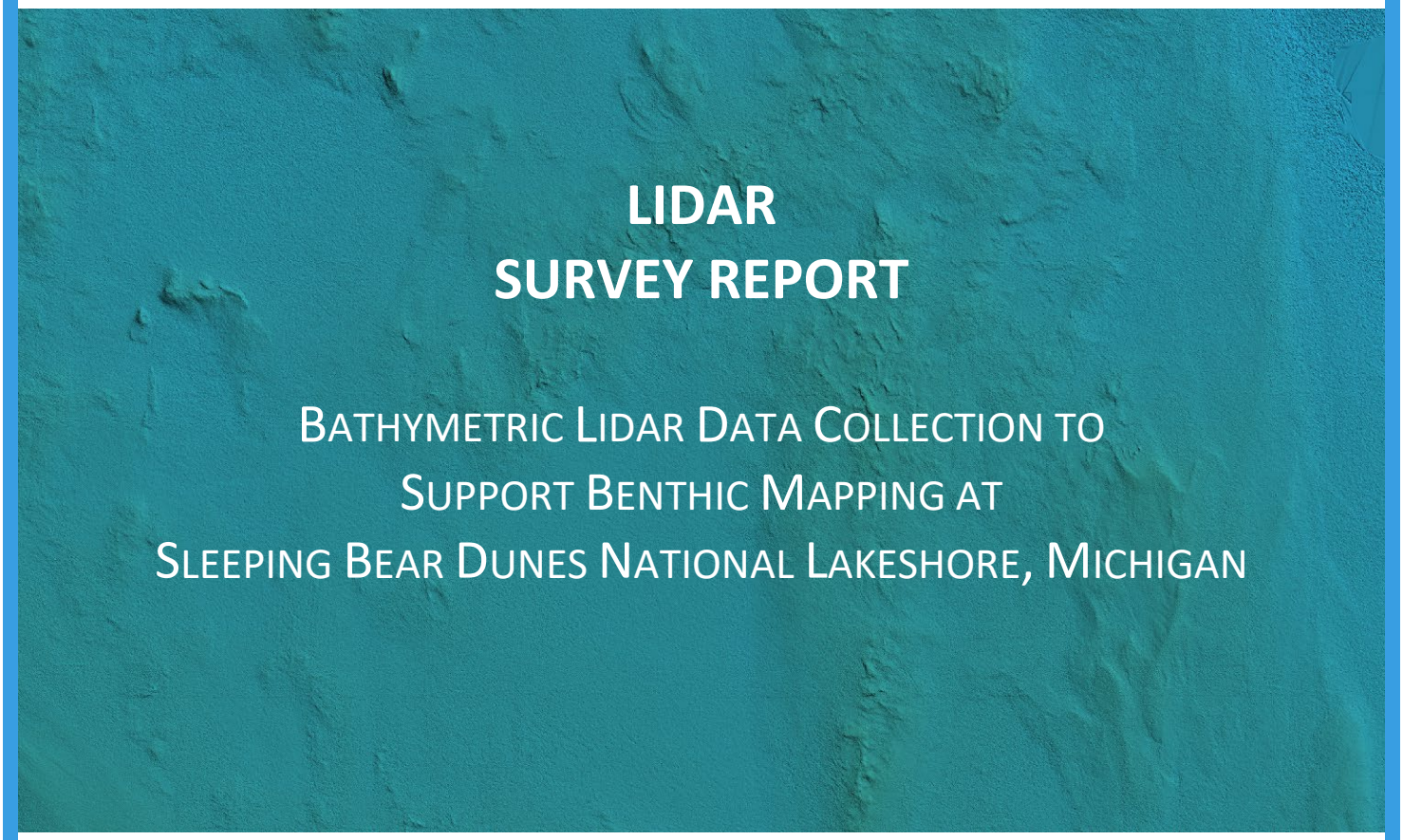
WOOLPERT



LIDAR SURVEY REPORT

BATHYMETRIC LIDAR DATA COLLECTION TO SUPPORT BENTHIC MAPPING AT SLEEPING BEAR DUNES NATIONAL LAKESHORE, MICHIGAN

Prepared For:

National Oceanic and Atmospheric Administration

NOAA Contract: EA-133C-16-CQ-0046
NOAA Task Order: 1305M221FNCNP0314
Woolpert Project Number: 82058

Revision	Date	Written	Approved	Distributed to	Comments
0	October 29, 2021	MC	CL	NOAA (Digital)	
1	January 13, 2022	MC	CL	NOAA (Digital)	Added Figure

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1. EXECUTIVE SUMMARY

Woolpert, Inc. was contracted to acquire and process high-resolution topo-bathy lidar to support mapping and modeling needs at the Sleeping Bear Dunes National Lakeshore (SLBE), which will be used for the creation of new benthic mapping products using the Coastal and Marine Ecological Classification Standard (CMECS).

Woolpert sub-contracted NV5 to acquire the lidar data using their HawkEye 4X topo-bathy lidar sensor, to provide high density topo lidar with an ANPS of ≥ 1 pulse per square meter with a vertical accuracy of ≤15cm RMSE for the bathymetric lidar.

Woolpert also collected topographic ground control and check points covering some extended survey lines.

This report details the data acquisition, processing and quality control conducted for the survey.

1.1. SURVEY AREA

The survey area (Figure 1: Survey Area) covers approximately 323 square kilometers.

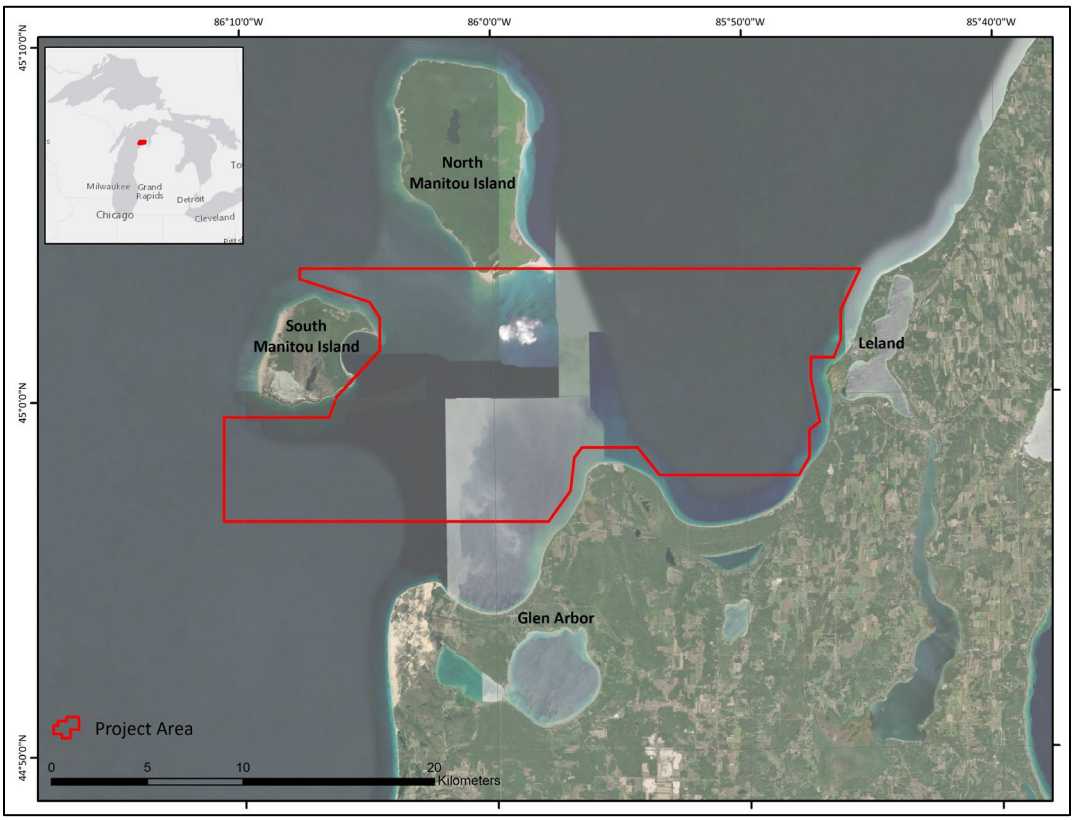

Figure 1: Survey Area

2. DATA ACQUISITION

Below are the details of the lidar collection and processing.

2.1. MOBILIZATION

The HE4X system was installed in a Reims-Cessna F406 (N406SD). The sensor was deployed to the project already calibrated. However, a calibration verification flight was collected over Sidney, OH on September 3, 2021. Three survey flights were conducted in the project area from August 31 to September 3, 2021.

2.1.1. AIRCRAFT OFFSET SURVEY

Physical mounting offsets between the GNSS antenna, IMU and gyro-stabilized mount were determined through a combination of manual measurements and iterative processing in NovAtel Inertial Explorer software.

Manual measurements were taken from the GNSS antenna to the reference point on the IMU in the CH4X sensor head. These measurements are added to the known offset between the IMU reference point and the rotation center of the gyro-stabilized mount to calculate the preliminary offset between the GNSS antenna and sensor reference point. This preliminary value was then used to seed the post-processing software which, through an iterative computation, uses the dynamic accelerations and rotations during flight to refine the offsets. Once the solution converges, the final offsets are entered into the flight management software and used in subsequent post-processing of the GNSS/IMU data for final trajectories.

This process is repeated for the deep channel sensor head where offsets are computed between the GNSS antenna and IMU center, as there is no gyro-stabilized mount.

Final offsets, shown in the Leica reference frame, are presented in Table 1.

Table 1: Aircraft Offsets

Sensor Head	Lever Arm	X (forward)	Y (right)	Z (down)
CH4X (Topo and Shallow Channel)	Reference to GNSS Antenna L1 Phase Center	0.146 m	-0.096 m	-1.330 m
	Reference to IMU	-0.003 m	-0.006 m	-0.296 m
	Reference to IMU Rotation	0 °	180 °	0 °
HE4X (Deep Channel)	IMU to GNSS Antenna L1 Phase Center	1.962 m	0.117 m	-0.931 m
	Reference to IMU Rotation	-90°	0°	0°

2.2. LIDAR CALIBRATION

Field calibration of the HE4X system is carried out to eliminate systematic errors by calculating corrections for boresight errors, scanner angle errors, remaining IMU angle errors and any necessary internal timing errors. In order to verify or compute the field calibration, the following lines are flown (Figure 2):

a. 2 x Line A over mixed terrain with flat or gentle slopes and features such as peaked roof buildings (1 x each direction)
b. 1 x Line B offset +50% from Line A in one direction
c. 1 x Line C offset -50% from Line A in the same direction as Line B
d. 2 x Line D orthogonal to previous lines (1 x each direction)

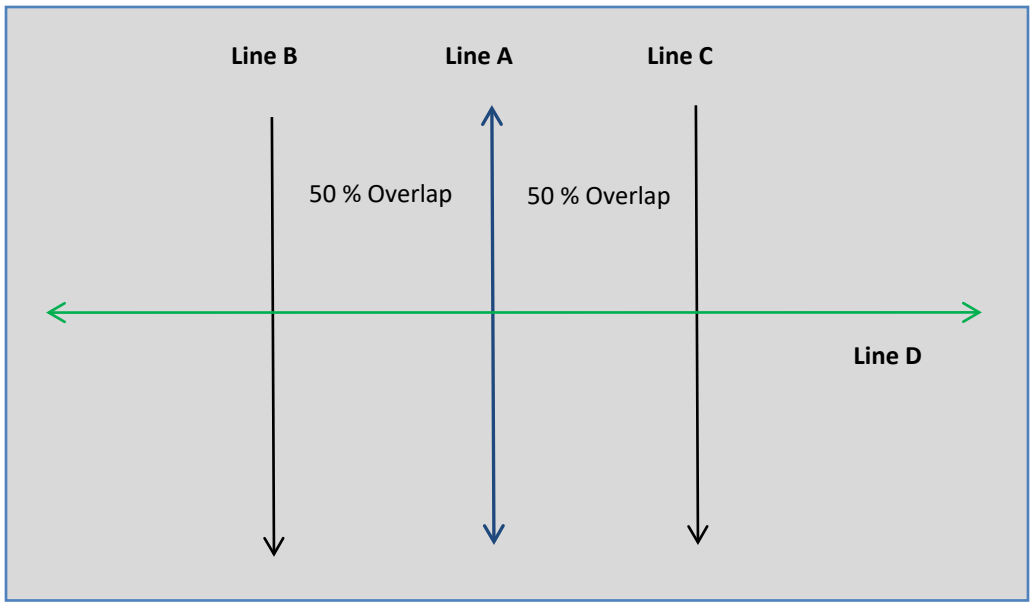

Figure 2: Schematic of HE4X Calibration Lines

A set of calibration lines were acquired at 1000m, 500m, and 400m for the calibration. All sets of lines are used to calibrate and verify the topographic lidar, while the 500m and 400m lines are used for the bathymetric lidar.

Calibration values are calculated using the automatic calibration routine within the Leica Lidar Survey Studio (LSS) software. This utility first identifies patches or areas of gentle slope within the overlap region of all the lines to use for calibration. Patch selection prevents areas of vegetation, side of cars or buildings, from being used in the calibration process. Next, the utility compares the front side and back side of the elliptical scan within the same line, as well as comparing all lines to each other, to identify suitable calibration parameters such that data within the patches match. The procedure is iterative and continues until the best possible solution is computed.

Calibration for each channel (topo, shallow bathy and deep bathy) is done independently. The topo and shallow channels were found to be calibrated with no adjustments required. The Deep channel calibration was computed using 500m altitude lines. The 400m lines were then used for verification.

At each step of the calibration process, quality assurance is conducted to ensure values being calculated are valid. This is done using the Leica LSS Quality Control Utility. Two types of checks are done; firstly, the front scan is compared to the back scan for every line. Secondly, a single line is chosen as a baseline and is compared to every other line. We would expect the average errors from both of these checks to be small; less than 5cm.

In addition, the data is visually reviewed. In particular, features are studied to ensure lines from different directions show structures in the same position, in other words, verifying horizontal accuracy is maintained. These tests all provide assurance of relative accuracy.

For this project, calibration lines were acquired over Sidney, OH on September 3, 2021. Results from the calibration are provided in Table 2. Results are good and indicate that the calibration was successful. Values computed were used for all data collected during the survey.

Table 2: September 3, 2021 Sidney, OH Calibration QA Results

Test		Topo 1000 m	Topo 500 m	Topo 400 m	Shallow 500 m	Shallow 400 m	Deep 500 m	Deep 400 m
Front to Back Scan Comparison	Average Error (m)	-0.0176	0.0050	0.0098	0.0038	0.0028	-0.0028	0.0222
	Std. Dev. of Error	0.0011	0.0015	0.0038	0.0004	0.0006	0.0050	0.0036
Line to Line Comparison	Average Error (m)	-0.0056	0.0011	0.0090	-0.0033	0.0037	-0.0048	0.0064
	Std. Dev. of Error	0.0057	0.0022	0.0047	0.0012	0.0014	0.0043	0.0064

Woolpert acquired a set of ground truth points with Real Time Kinematic (RTK) GNSS within the calibration area. Ground truth is not used within the automatic calibration routine; however, a comparison to the lidar data was used to verify absolute accuracy. Results presented Table 3 in show data is well within required accuracy specifications.

Table 3: September 3, 2021 Sidney, OH Calibration Ground Truth Comparison

	Topo			Shallow		Deep	
	1000m	500m	400m	500m	400m	500m	400m
Mean dz (m)	0.0352	0.0068	0.0100	0.0072	0.0170	-0.0073	-0.0090
Root Mean Square (m)	0.0369	0.0094	0.0110	0.0107	0.0174	0.0118	0.0115

2.3. Aerial Survey Operations

Actual flight lines flown, including start and end date and unique line ID, are provided in the flight line database included with the project deliverables. A summary of the daily operations is shown in Table 4. Detailed Flight Logs for each day are provided in Appendix A.

Table 4: Summary of Daily Operations

Flight (UTC Dates)	Engine Time	Airtime	Description
2021-08-29A	2:55:00	2:30:00	Sidney, OH Calibration
2021-08-31A	5:43:00	5:21:00	BL01, BL02
2021-09-01A	5:31:00	5:18:00	BL01
2021-09-01B	1:45:00	1:29:00	BL01
2021-09-03A	2:39:00	2:24:00	Sidney, OH Calibration
TOTAL	**18:33:00**	**17:02:00**	

2.3.1. The Hawkeye 4X Sensor

All lidar data were acquired using a HE4X sensor. The HE4X is unique in its ability to acquire deep bathymetric lidar, shallow bathymetric lidar, topographic lidar and 4-band digital camera imagery simultaneously.

The HE4X provided 300 kHz topographic data, an effective 140 kHz shallow bathymetric data and 40 kHz deep bathymetric data. 4-band 80 MP digital camera imagery was also collected simultaneously with the sensor's RCD-30 camera.

The bathymetric and topographic lasers are independent and do not share an optical chain or receivers, so they are optimized for their specific function. As with any bathymetric lidar, maximum depth penetration is a function of water clarity and seabed reflectivity. The HE4X is designed to penetrate to 3 times the secchi depth. This is also represented as Dmax = 4/K, where K is the diffuse attenuation coefficient, and assuming K is between 0.1 and 0.3, a normal sea state and 15% seabed reflectance.

Both the topographic and bathymetric sub-systems use a palmer scanner to produce an elliptical scan pattern of laser points with a degree of incidence ranging from +/-14° (front and back) to +/-20° (sides), providing a 40° field of view. This has the benefit of providing multiple look angles on a single pass and helps to eliminate shadowing effects. This can be of particular use in urban areas, where all sides of a building are illuminated, or for bathymetric features such as the sides of narrow water channels or features on the seafloor such as smaller objects and wrecks. It also assists with penetration in the surf zone where the back scan passes the same ground location a couple of seconds after the front scan, allowing the areas of whitewater to shift.

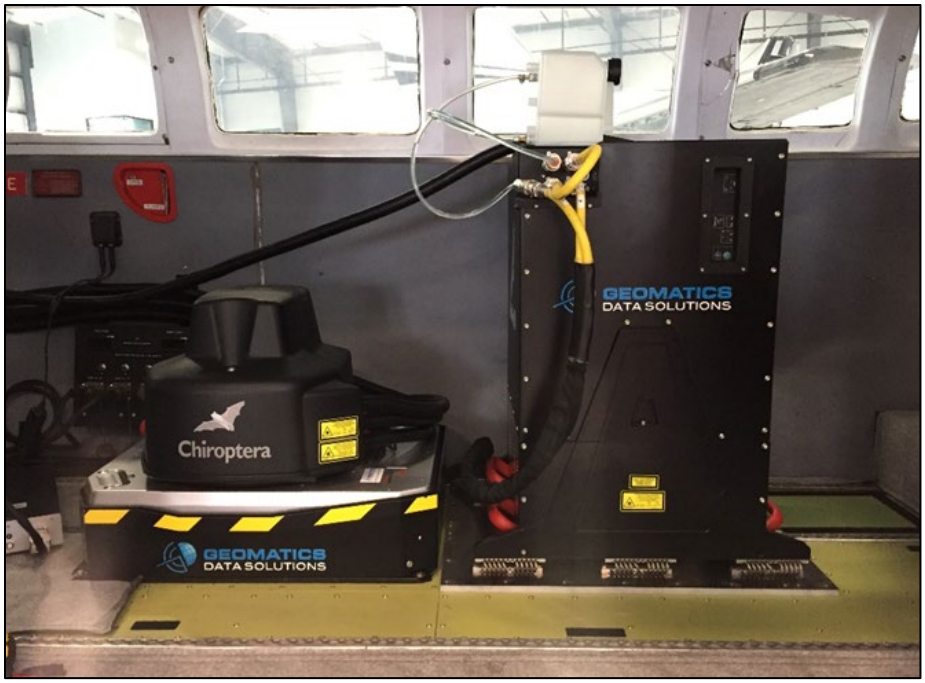

Figure 3: Typical Hawkeye 4X Bathymetric Lidar Sensor Installation

For this project, the flight parameters shown in Table 5 were used to provide 100% coverage.

During acquisition, flight lines are shown on a pilot's display, and the aircraft is controlled by the pilot at all times. The HE4X system includes a NovAtel SPAN GNSS system with an LCI-100C IMU for aircraft position and orientation. One IMU is in the main Chiroptera sensor head, which includes the topo channel, shallow channel and RCD30 camera. Information from this IMU are also used in real-time by the PAV100 gyro-stabilized mount to compensate for deviations in pitch and roll. A second IMU is contained within the deep channel sensor head, installed over a second hatch in the aircraft. This head does not include a gyro-stabilized mount. Aircraft bank angles were restricted to 20º to avoid any potential GNSS dropouts. No flights were planned if the PDOP was expected to go above 3.0.

Table 5: HE4X Survey Flight Parameters

Aerial System	Leica Hawkeye 4X (topo-bathy)
Nominal Survey Altitude	400m (1575 feet)
Nominal Survey Speed	130 knots
System Planned Sidelap	20%
Lidar	
Scan Angle	≤ 40° (+/-20° from Nadir)
Nominal Swath Width	290m (950 ft) at 400m altitude
PRF (Topo)	300 kHz
Effective PRF (Shallow)	140 kHz
Effective PRD (Deep)	40 kHz
Pulse Density (Topo)	≥ 8 pulses/m^2 (≤ 0.35 m NPS)
Pulse Density (Bathy)	≥ 2 pulses/m^2 (≤ 0.71 m NPS)
Returns Collected Per Laser Pulse (Topo)	Up to 4
Returns Collected Per Laser Pulse (Bathy)	Up to 4
Intensity Range	0 – 65535 (16-bit)

Data were monitored for quality during acquisition using the Operators Console running on the AHAB collection computer. The operator monitored system status of the scanners and receivers, waveforms, camera images, data coverage, flight lines and the health of the navigation system.

All data were recorded to a removable solid-state hard disk. At the end of the flight the hard disk was removed and taken to the field office where data was copied on to backup disks for transmittal back to the main processing office. Data was reviewed daily in the field for quality and coverage.

2.3.2. Positioning

Position and orientation data were acquired in the aircraft using a NovAtel SPAN with LCI-100C IMU. All data were post-processed using NovAtel Inertial Explorer software to provide a tightly coupled precise point position (PPP) and orientation solution.

No GNSS base stations were used as control for trajectory post-processing. Logs for the trajectory processing are provided in Appendix B.

3. SURVEY CONTROL AND CHECK POINTS

Topographic data were collected using RTK GNSS techniques in the area covered by the daily lidar QC line. A Trimble R8-3 base station was established on published NGS control point PID PL0300 while a second Trimble R8-2 was used as a rover, on a fixed 2-meter rod. Position checks were completed to published NGS control points PID DL6867 and QK0325 to verify accuracy. 274 points were recorded using a Trimble TSC3 data collector. 137 points were randomly chosen to control the survey and shift the lidar data while the remaining 137 were used to provide vertical accuracy checks for the survey.

4. DATA PROCESSING

An overview of Woolpert's established HE4X processing workflow is presented in Figure 4. Initial data coverage analysis and quality checks to ensure there were no potential system issues were carried out in the field prior to demobilization of the sensor. Final processing was conducted in Woolpert's offices.

In general, data were initially processed in Leica's Lidar Survey Studio (LSS) using final processed trajectory information. LAS files from LSS were then imported to a Terrascan project where spatial algorithms were used to remove noise and classify bare earth/ground. Manual review was conducted in Terrascan prior to product creation.

4.1. Position

Final trajectory data were post processed in NovAtel Inertial Explorer. Lever arms, shown in the NovAtel reference frame, are presented in Table 6. Inertial Explorer accounts for the fixed offset between the reference point and IMU and uses a multi-pass algorithm to compute a tightly coupled solution. Precise point positioning was used for processing, as described in Section 2.3.2. Trajectory processing logs are provided in Appendix B. Average Forward and Reverse Separation RMS for the project was 0.024m in Easting, 0.015m in Northing, and 0.030m in Height.

Table 6: Inertial Explorer Offsets

Sensor Head	Lever Arm	X (right)	Y (forward)	Z (up)
Chiroptera (Topo, Shallow, Camera)	Reference to GNSS Antenna L1 Phase Center	-0.035	0.030	0.994
	Reference to IMU Rotation	0°	180°	0°
Hawkeye (Deep)	Reference to GNSS Antenna L1 Phase Center	-0.091	0.738	0.888
	Reference to IMU Rotation	-90°	0°	0°

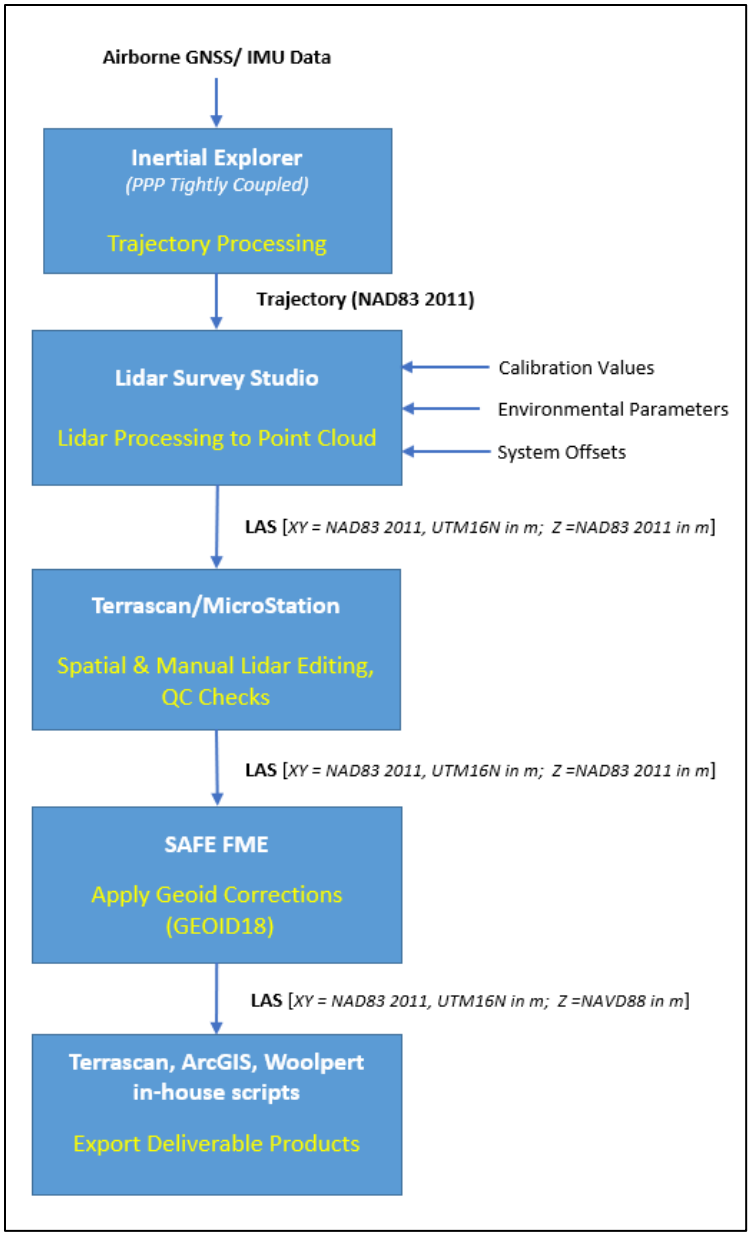

Figure 4: Overview of Processing Workflow

4.2. PPP Shifts

In order to account for any potential trajectory shifts between each survey day, a lidar QC flightline was acquired over the same area for every flight. The line also crossed the ground control discussed in Section 3.

The topo control was compared to each lidar daily QC line and the daily mean shift computed. During lidar processing any line to line vertical mismatches are removed. Therefore, an average PPP shift for the entire survey was computed and applied to remove any remaining errors in the ellipsoid height due to the use of PPP processing of the trajectories.

5. LIDAR

5.1.1. Raw Data Processing

Lidar processing was conducted using the Leica Lidar Survey Studio (LSS) software. Calibration information, along with processed trajectory information were combined with the raw laser data to create an accurately georeferenced lidar point cloud for the entire survey in LAS v1.4 format. All points from the topographic and bathymetric laser include 16-bit intensity values.

During this LSS processing stage, an automatic land/water discrimination is made for the bathymetric waveforms. This allows the bathymetric (green) pulses over water to be automatically refracted for the pulse hitting the water surface and travelling through the water column, producing the correct depth. Another advantage of the automatic land/water discrimination is that it permits calculation of an accurate water surface over smaller areas, allowing simple bathymetric processing of smaller, narrower streams and drainage channels. Sloping water surfaces are also handled correctly.

Prior to processing, the hydrographer can adjust processing settings dependent on the environment encountered and enter a value for the refraction index to be used for bathymetry. The index of refraction is an indication of the water type. A value 1.336 was used for the index of refraction, indicating fresh water.

In order to determine the optimal processing settings, sample areas were selected and processed with multiple different settings, to iteratively converge on the best possible settings. This is done by reviewing the processed point cloud and waveforms within sample areas. A sample waveform is provided in Figure 5, while a sample LSS editing screen is provided in Figure 6. Settings affect which waveform peaks are classified as valid seabed, and which peaks are classified as noise. Optimal settings strike a balance between the amount of valid data that is classified as seabed bottom, and the amount of noise that is incorrectly classified due to peaks in the waveforms. Ideally all valid data is selected, while only a small amount of noise remains to be edited out. Once optimal processing settings were chosen, these were used for the entire project.

It is important to note that all digitized waveform peaks are available to be reviewed by the hydrographer; both valid seabed bottom and peaks classed as noise. This allows the hydrographer to review data during Terrascan editing for valid data such as objects that may have been misclassified as noise.

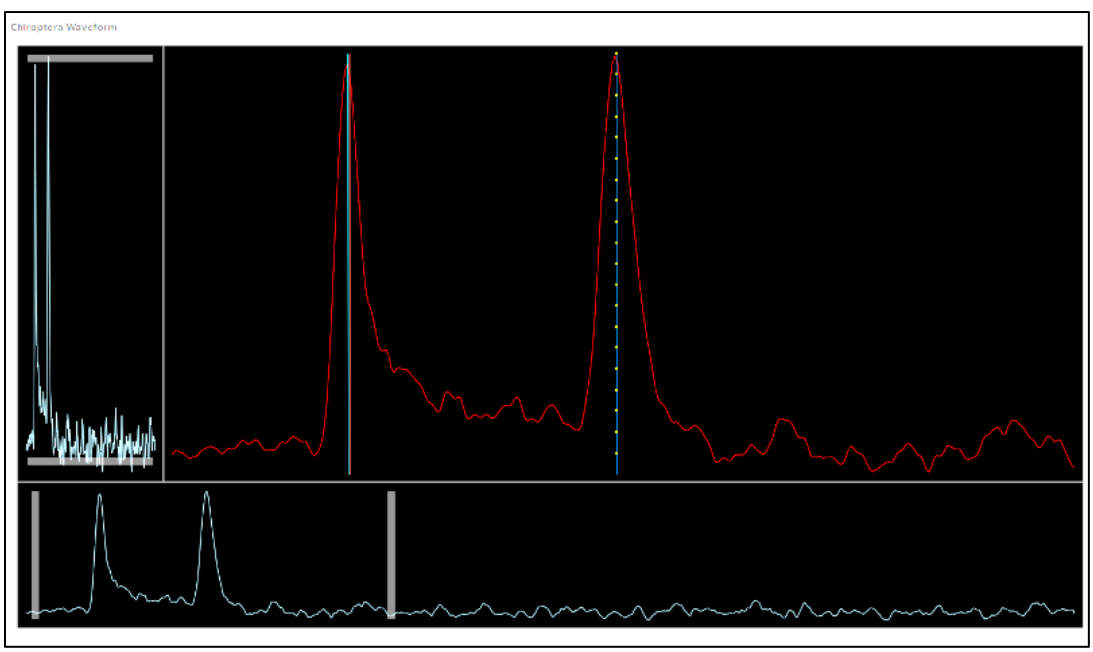

Figure 5: Sample Waveform

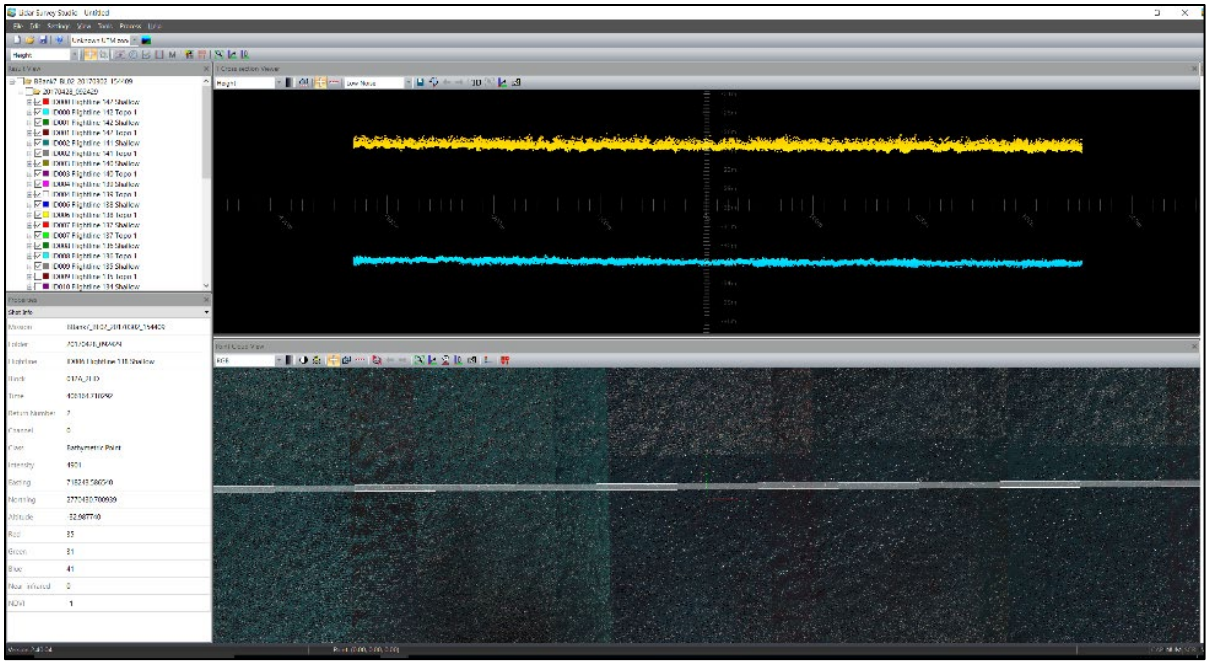

Figure 6: Sample LSS Processing Screen

LSS processing produced LAS files in 1.4 format.

LSS stores data in multiple LAS files for a single flight line. Each file corresponds to a single .dat file from the raw airborne data. Woolpert merged these multiple files into a single file per flight line and moved data into a standard class definition in preparation for data editing using proprietary in-house scripts.

5.1.2. LIDAR DATA EDITING

After data were processed in LSS and the data integrity reviewed, data were organized into tiles within a Terrascan project. The tile layout is provided with the project deliverables.

Data classification and spatial algorithms were applied in Terrasolid's Terrascan software. Customized spatial algorithms, such as isolated points and low point filters, were run to remove gross fliers in the topographic and bathymetric data. A grounding algorithm was also run on the topographic data to distinguish between points representing the bare earth, and other valid topo lidar points representing features such as vegetation and buildings. Algorithms were run on the entire dataset.

Data were reviewed manually to reclassify any valid bathy points incorrectly identified by the automated routines in LSS as invalid, and vice versa. In addition, any topo points over the water were reclassified to a Water class to correct the ground representation. Manual editing was conducted in Terrascan. Steps for manual editing included:

- Re-class any topo unclassified laser data and bathy seabed data from the water surface to a water surface class
- Review gaps in seabed coverage and re-class suitable data to Seabed (Class 40)
- Re-class any noise in the bathy ground class to bathy noise (Class 45)
- Re-class man made submerged objects to Submerged Object (Class 43)

One charted wreck was found during data editing. The approximate location of this wreck is 45°02'21.6"N, 85°59'6.5"W and is captured in the anomalies shapefile included with the project deliverables.

Once editing was completed in TerraScan the average PPP shift was applied and then the lidar data was compared to the survey ground control and vertically transformed to match the control. Subsequently the lidar data was transformed to the NAVD88 datum using GEOID18.

Digital Elevation Models (DEMs) were then created using TerraScan from the Topo Ground, Seabed, and Submerged Object Classes (Class 2, 40, 43) at a 2m resolution on a 500m x 500m tile layout provided in the project deliverables.

5.2. Reflectance

Although the bathymetry data includes intensity values, these are raw values. For intensity (reflectance) to correctly represent the reflectance of the seabed, the intensities must be normalized for any losses in signal as the light travels through the water column, so that the intensity value better reflects the intensity of the seabed itself.

One of the fundamental issues that exists with reflectance imagery is the variance in return due to water clarity differences occurring spatially along line, and temporally from day to day. This is challenging for any bathymetric lidar sensor.

If water clarity is relatively consistent along a line, then it is possible to achieve an overall homogenous reflectance image for an area. To a certain extent, variation in reflectivity intensity can be minimized by limiting the size of flight blocks and trying to ensure similar environmental parameters exist within a single flight block. In other words, where changes in water clarity or environment may be expected, flight blocks should be split to allow different normalization parameters to be used per block for the reflectance processing. Where this is not possible, and water clarity varies significantly along a line, variation in reflective intensity will be seen in the output imagery. While this imagery can still be analyzed and used for manual seabed classification, it prohibits the use of unsupervised, or semi-automated classification.

Woolpert used proprietary in-house scripts to compute project specific correction parameters and normalize the raw intensity data for depth. This provides intensities that more closely represent the reflectance of the actual seabed. Corrected values were used to create 2m reflectance images per flightline. Individual flightline reflectance images were then used in Trimble's OrthoVista software to create a final reflectance image for the entire area.

6. QUALITY CONTROL

Quality control is carried out through every phase of the project. Several checks were used to ensure data integrity and quality was maintained. Specific statistics were generated from lidar check points and image air targets.

6.1. Calibration

This is fundamental to good data accuracy. Calibration is discussed in detail in Section 2.2.

6.2. Online Checks

The airborne operator monitored system status of the scanners and receivers, waveforms, camera images, data coverage, flight lines and health of the navigation system during data acquisition. Flight logs are maintained during data acquisition. Logs not only track lines acquired, but also any relevant information on weather or water clarity, instances when sensor issues occur, and so on. These logs are a valuable resource during processing. They are provided in Appendix A.

6.3. Positioning

During acquisition, aircraft bank angles were restricted to 20º to avoid any potential GNSS dropouts. No flights were planned if the PDOP was expected to go above 3.0. Separation plots and additional statistics were reviewed for each flight trajectory processed.

6.4. Comparison to Adjacent Lines

Throughout data editing adjacent survey lines of data are compared to ensure there are no data busts, or system artifacts. During processing Terrasolid's TMatch software is run to examine the Delta Z differences between overlapping lines, then a simple Z correction is applied per flight line to remove any vertical differences between

flight lines. TMatch can then be run again once all corrections are applied to ensure adjacent lines agree within specification. This provides a measure of inter-swath accuracy.

Interswath or overlap consistency for the topographic laser was assessed in all areas of overlap with slopes of less than 10 degrees. The topographic RMSDz for the project lines is 0.022m.

Interswath or overlap consistency for the bathymetric laser was assessed in all areas of overlap with slopes of less than 10 degrees. The bathymetric RMSDz for the project lines is 0.064m.

6.5. Absolute Vertical Accuracy Checks

Absolute vertical accuracy for the lidar points was calculated using the check points. All check points were located on flat surfaces with no vegetation. No check points were used to adjust the lidar data. For each known location a small TIN was created from the surrounding lidar points and the elevation difference from the TIN plane to the point computed. Data shows good agreement with the check points. General location of the check points is shown in Figure 7.

This dataset was tested to meet 0.032m RMSEz, equating to 0.063 meters at a 95% confidence interval.

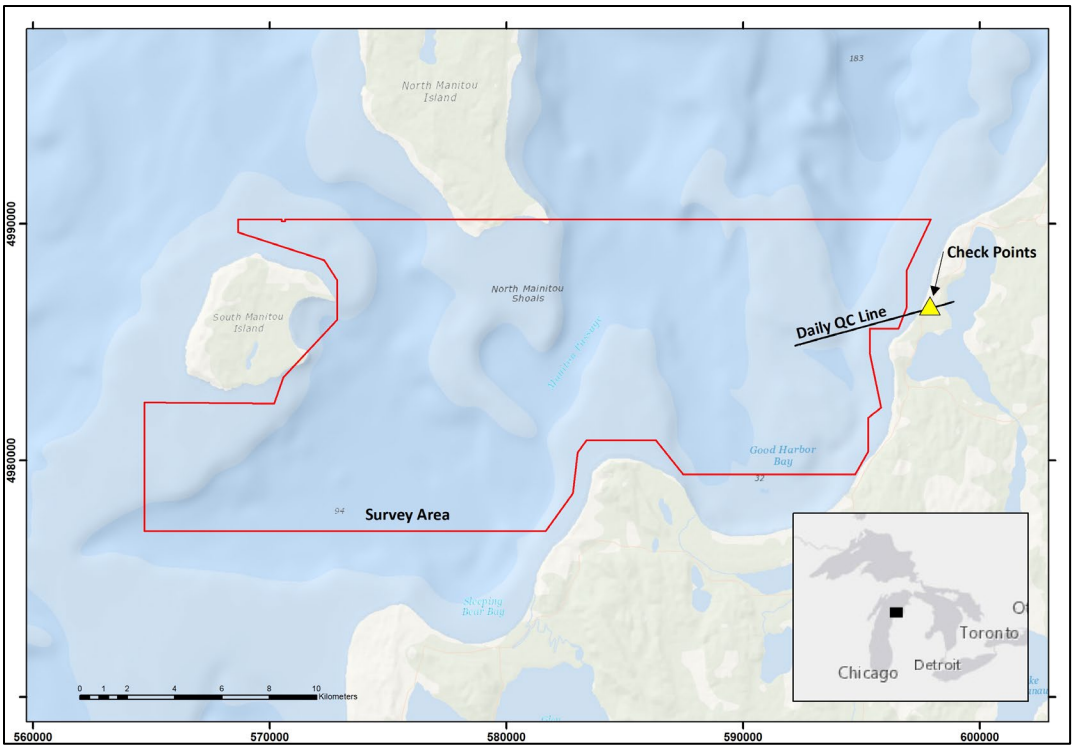

Figure 7: Check Points Location

7. DELIVERABLES

All data are provided in the horizontal datum and projection shown in Table 7. Deliverables are listed in Table 8.

Table 7: Project Datum and Projection

Horizontal Datum	NAD83 (2011) Epoch 2010.0
Vertical Datum	NAVD88 (Geoid 18)
Projection	UTM 16N
Units (Horizontal and Vertical)	Meters

Table 8: Product Deliverables

Item	Format	Cell Size	Tiled	Delivery Folder
Classified Point Cloud	LAS 1.4		✓	01_LAS
Topo-Bathy DEM	GeoTIFF	2m	✓	02_DEM
Topo-Bathy DEM Hillshade	GeoTIFF	2m	✓	03_Hillshade
Reflectance	GeoTIFF	2m	✓	04_Reflectance_Bathy
Intensity	GeoTIFF	2m	✓	05_Intensity_Topo
Metadata	XML	--		06_Metadata_Report
Survey Report	PDF	--		06_Metadata_Report
Anomolies	SHP	--		07_GIS_SHP
Bathy Voids	SHP	--		07_GIS_SHP
Flightline Index	SHP	--		07_GIS_SHP
Survey Boundary	SHP	--		07_GIS_SHP
Tile Index	SHP	--		07_GIS_SHP
Flight Logs	PDF	--		08_FlightLogs

7.1. Classified Point Cloud (LAS Files)

The classified point cloud LAS 1.4 files are delivered using standard ASPRS Classification Levels, with the LAS Topo-Bathy Domain Profile (July 17, 2013) classes. Final LAS classes included are provided in Table 9.

All LAS files include intensity values. LAS data are provided in Point Record Format 6.

Class 2, 40 and 43 provide the ground model for the project.

Table 9: Delivered LAS Classes

Class Number	Class Name	Description
1	Unclassified	Processed, but not classified.
2	Ground	Bare Earth
W7	Low Point (Noise)	Spurious high/low point returns from topographic laser. Set withheld bit.
9	Water Surface	Water surface (sea/river/lake surface from the topographic laser)
W18	High Noise	Noise over land from the bathymetric lidar (if any)
40	Bathymetric Point	Bathymetric Bottom (e.g., seafloor or riverbed; also known as submerged topography)
41	Water Surface	Water surface (sea/river/lake surface from bathymetric laser)
S42	Derived Water Surface	Derived water surface (synthetic water surface location used in computing refraction at water surface)
43	Submerged Object	Submerged Object (e.g. wreck)
W45	No Bottom Found At	Water Column (returns not determined to be water surface or bathymetric bottom)

APPENDIX A : FLIGHT LOGS

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Traverse City (TVC)
LOCATION / AREA:	Dayton / BL01, BL02, QC61	**DATE:**	31 August 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	PPP	**WIND:**	Calm @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	14:37	**ENGINE OFF:**	20:20	**ENGINE TIME:**	05:43
TAKEOFF:	14:50	**LANDING:**	20:11	**AIR TIME**	05:21

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF | PWR		REMARKS
		14:50:00					Takeoff
		15:03:09					DS: QC61_20210831_150527
000_FL5	6101	15:03:12	15:04:58	400	300	10	
		15:09:28					DS: BL01_20210831_151146
000_FL1	0101	15:09:35	15:17:12	400	300	10	
001_FL2	0102	15:19:34	15:27:29	400	300	10	
002_FL3	0103	15:30:02	15:37:53	400	300	10	
003_FL4	0104	15:40:11	15:47:59	400	300	10	
004_FL5	0105	15:50:20	15:57:45	400	300	10	
005_FL6	0106	16:00:10	16:07:29	400	300	10	
006_FL7	0107	16:09:59	16:16:54	400	300	10	
007_FL8	0108	16:19:38	16:26:19	400	300	10	
008_FL9	0109	16:28:49	16:35:21	400	300	10	
009_FL10	0110	16:37:39	16:40:44	400	300	10	BAD: Reflown
010_FL10	0110	16:46:19	16:52:57	400	300	10	
011_FL11	0111	16:55:38	17:01:58	400	300	10	
012_FL12	0112	17:04:18	17:10:39	400	300	10	
013_FL13	0113	17:13:11	17:19:31	400	300	10	
014_FL14	0114	17:21:49	17:28:10	400	300	10	
015_FL15	0115	17:30:32	17:36:51	400	300	10	
016_FL16	0116	17:39:03	17:45:51	400	300	10	
017_FL17	0117	17:48:04	17:54:46	400	300	10	
018_FL18	0118	17:57:13	18:03:52	400	300	10	
019_FL19	0119	18:06:24	18:11:51	400	300	10	
020_FL20	0120	18:14:06	18:19:44	400	300	10	
021_FL21	0121	18:22:08	18:27:44	400	300	10	
022_FL22	0122	18:29:50	18:34:50	400	300	10	
023_FL23	0123	18:37:22	18:42:15	400	300	10	
024_FL24	0124	18:44:35	18:49:33	400	300	10	
025_FL25	0125	18:52:06	18:56:59	400	300	10	
026_FL26	0126	18:59:22	19:00:38	400	300	10	BAD: Reflown

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Traverse City (TVC)
LOCATION / AREA:	Dayton / BL01, BL02, QC61	**DATE:**	31 August 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	PPP	**WIND:**	Calm @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	14:37	**ENGINE OFF:**	20:20	**ENGINE TIME:**	05:43
TAKEOFF:	14:50	**LANDING:**	20:11	**AIR TIME**	05:21

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF	TOPO PWR	REMARKS
027_FL26	0126	19:04:04	19:09:09	400	300	10	
028_FL27	0127	19:11:36	19:16:36	400	300	10	
029_FL28	0128	19:18:49	19:24:00	400	300	10	
030_FL57	0195	19:28:48	19:32:15	400	300	10	
		19:35:24					DS: BL02_20210831_193742
000_FL1	0201	19:35:30	19:37:25	400	300	10	
001_FL2	0202	19:39:46	19:41:42	400	300	10	
002_FL3	0203	19:44:19	19:45:59	400	300	10	
003_FL4	0204	19:47:59	19:50:00	400	300	10	
		20:11:00					Landing

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Traverse City (TVC)
LOCATION / AREA:	Dayton / BL01, QC61	**DATE:**	1 September 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	PPP	**WIND:**	Calm @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	12:30	**ENGINE OFF:**	18:01	**ENGINE TIME:**	05:31
TAKEOFF:	12:35	**LANDING:**	17:53	**AIR TIME**	05:18

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF | PWR		REMARKS
		12:35:00					Takeoff
		12:54:58					DS: QC61_20210901_125717
000_FL5	6101	12:54:59	12:56:45	400	300	10	BAD: System Reboot
		12:58:55					DS: BL01_20210901_130114
000_FL28	0128	12:58:56	13:00:42	400	300	10	BAD: System Reboot
001_FL28	0128	13:07:26	13:08:30	400	300	10	BAD: System Reboot
		13:33:45					DS: QC61_20210901_133603
000_FL5	6101	13:33:47	13:35:26	400	300	10	
		13:37:21					DS: BL01_20210901_133939
000_FL28	0128	13:37:22	13:42:25	400	300	10	
001_FL29	0129	13:44:45	13:49:43	400	300	10	
002_FL30	0130	13:52:16	13:58:42	400	300	10	
003_FL31	0131	14:00:57	14:07:17	400	300	10	
004_FL32	0132	14:09:43	14:13:12	400	300	10	BAD: Reflown
		14:27:14					DS: BL01_20210901_142933
000_FL32	0132	14:27:15	14:27:37	400	300	10	BAD: Reflown
001_FL32	0132	14:30:50	14:37:22	400	300	10	
002_FL33	0133	14:39:46	14:46:13	400	300	10	
003_FL34	0134	14:48:34	14:55:07	400	300	10	
004_FL35	0135	14:58:56	15:06:51	400	300	10	
005_FL36	0136	15:09:32	15:17:26	400	300	10	
006_FL37	0137	15:19:54	15:27:43	400	300	10	
007_FL38	0138	15:30:13	15:38:14	400	300	10	
008_FL39	0139	15:40:43	15:48:28	400	300	10	
009_FL40	0140	15:50:41	15:58:37	400	300	10	
010_FL41	0141	16:00:52	16:08:40	400	300	10	
011_FL42	0142	16:10:58	16:18:49	400	300	10	
012_FL43	0143	16:21:11	16:29:09	400	300	10	
013_FL44	0144	16:31:37	16:39:29	400	300	10	
014_FL45	0145	16:42:16	16:50:00	400	300	10	
015_FL46	0146	16:52:25	17:00:13	400	300	10	

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Traverse City (TVC)
LOCATION / AREA:	Dayton / BL01, QC61	**DATE:**	1 September 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	PPP	**WIND:**	Calm @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	12:30	**ENGINE OFF:**	18:01	**ENGINE TIME:**	05:31
TAKEOFF:	12:35	**LANDING:**	17:53	**AIR TIME**	05:18

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF | PWR		REMARKS
016_FL47	0147	17:02:54	17:10:39	400	300	10	
017_FL48	0148	17:13:02	17:20:44	400	300	10	
018_FL49	0149	17:23:13	17:27:58	400	300	10	
019_FL58	0196	17:32:21	17:36:49	400	300	10	
		17:53:00					Landing

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Traverse City (TVC)
LOCATION / AREA:	Dayton / BL01, QC61	**DATE:**	1 September 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	PPP	**WIND:**	Calm @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	18:44	**ENGINE OFF:**	20:29	**ENGINE TIME:**	01:45
TAKEOFF:	18:52	**LANDING:**	20:21	**AIR TIME**	01:29

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF | PWR		REMARKS
		18:52:00					Takeoff
		19:04:26					DS: QC61_20210901_190645
000_FL5	6101	19:04:27	19:04:56	400	300	10	BAD: Reflown
001_FL5	6101	19:07:45	19:09:25	400	300	10	
		19:11:52					DS: BL01_20210901_191410
000_FL49	0149	19:11:57	19:16:43	400	300	10	
001_FL50	0150	19:19:11	19:23:58	400	300	10	
002_FL51	0151	19:26:04	19:30:50	400	300	10	
003_FL52	0152	19:32:47	19:37:35	400	300	10	
004_FL53	0153	19:39:42	19:44:28	400	300	10	
005_FL54	0154	19:49:52	19:50:42	400	300	10	
006_FL55	0155	19:52:58	19:53:44	400	300	10	
007_FL56	0156	19:56:26	19:57:05	400	300	10	
008_FL58	0196	20:01:11	20:03:30	400	300	10	
009_FL56	0156	20:05:37	20:06:18	400	300	10	
		20:21:00					Landing

FLIGHT LOG

PROJECT NAME:	2021-82058 NOAA Sleeping Bear	**BASE AIRPORT:**	Dayton (DAY)
LOCATION / AREA:	Dayton / 1000, 400m, 500m	**DATE:**	3 September 2021
AIRCRAFT:	N406SD	**PILOT:**	NV5
SYSTEM:	Hawkeye 4X	**OPERATOR:**	NV5

MISSION ID:	SleepingBear	**CLOUDS:**	Clear
BASE STATION:	SIDN	**WIND:**	5 kts @ 0
LIDAR DRIVE:	HE4X-01	**RCD DRIVE:**	RCD-01

ENGINE START:	14:20	**ENGINE OFF:**	16:59	**ENGINE TIME:**	02:39
TAKEOFF:	14:28	**LANDING:**	16:52	**AIR TIME**	02:24

FL #	LINE #	START TIME	END TIME	ALTITUDE	TOPO PRF	TOPO PWR	REMARKS
		14:28:00					Takeoff
		14:40:51					DS: 1000m_20210903_144051
000_FL1	6301	14:40:51	14:43:58	1000	270	30	BAD: Base Initialize
001_FL1	6301	14:46:31	14:49:38	1000	270	30	BAD: Base Initialize
		14:57:16					DS: 1000m_20210903_145716
000_FL5	6305	14:57:16	14:59:24	1000	270	30	
001_FL3	6303	15:01:24	15:03:32	1000	270	30	
002_FL6	6306	15:04:59	15:07:05	1000	270	30	
003_FL4	6304	15:11:48	15:13:51	1000	270	30	
004_FL2	6302	15:17:16	15:19:30	1000	270	30	
005_FL1	6301	15:20:58	15:23:09	1000	270	30	
		15:28:56					DS: 400m_20210903_152856
000_FL5	6345	15:28:56	15:30:10	400	300	10	
001_FL3	6343	15:32:00	15:33:13	400	300	10	
002_FL6	6346	15:42:21	15:43:31	400	300	10	
003_FL4	6344	15:47:00	15:48:14	400	300	10	
004_FL2	6342	15:51:20	15:52:38	400	300	10	
005_FL1	6341	15:56:38	15:57:53	400	300	10	
		16:09:12					DS: 500m_20210903_160912
000_FL5	6355	16:09:12	16:10:44	500	500	13	
001_FL3	6353	16:12:33	16:14:04	500	500	13	
002_FL6	6356	16:15:47	16:17:18	500	500	13	
003_FL4	6354	16:21:21	16:22:58	500	500	13	
004_FL2	6352	16:25:41	16:27:16	500	500	13	
005_FL1	6351	16:28:48	16:30:18	500	500	13	
006_FL3	6353	16:33:25	16:34:52	500	500	13	
		16:38:51					DS: 1000m_20210903_163851
000_FL1	6301	16:38:51	16:42:01	1000	270	13	BAD: Base Close
001_FL1	6301	16:43:29	16:46:36	1000	270	13	BAD: Base Close
		16:52:00					Landing

APPENDIX B : PROCESSING LOGS

SURVEY PROGRESS

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

MISSION ID: Various
SURVEY BLOCKS: BL01-XX

LINES: 64
LINE KM: 1,396

Flight	Engine Time	Air Time	Flown km	Flown %	Reflown km	Reflown %	Comments
2021-08-29A	2:55:00	2:30:00					Sidney, OH Calibration
2021-08-31A	5:43:00	5:21:00	770.8	55.2%			BL01, BL02
2021-09-01A	5:31:00	5:18:00	682.9	48.9%			BL01
2021-09-01B	1:45:00	1:29:00	128.2	9.2%			BL01
2021-09-03A	2:39:00	2:24:00					Sidney, OH Calibration
TOTAL	**18:33:00**	**17:02:00**	**1582**	**113.3%**	**0**	**0.0%**	

CHIROPTERA LEVER ARMS

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

Axis	Ref to IMU In the system	Ref to GNSS In the system	IMU to Gimble Inertial Explorer	IMU to GNSS Inertial Explorer	Gimble to GNSS Inertial Explorer	Differences from Previous	Differences from Start
Manual Measure						**Flight Pro**	**Inertial Explorer**
X	-0.003	0.006	0.005	0.055	0.050	+ tve forward	+ tve stbd
Y	-0.006	0.000	0.003	0.164	0.161	+ tve stbd	+ tve forward
Z	-0.296	-1.305	-0.296	1.057	1.353	+ tve down	+ tve up
Lever Arm Estimate in Inertial Explorer - Test1							
X		0.154	0.005	0.074	0.069	0.019	0.019
Y		0.069	0.003	0.157	0.154	-0.007	-0.007
Z		-1.331	-0.296	1.035	1.331	-0.022	-0.022
Lever Arm Estimate in Inertial Explorer - Test2							
X		0.151	0.005	0.085	0.080	0.011	0.030
Y		0.080	0.003	0.154	0.151	-0.003	-0.010
Z		-1.330	-0.296	1.034	1.330	-0.001	-0.023
Lever Arm Estimate in Inertial Explorer - Test3							
X		0.149	0.005	0.092	0.087	0.007	0.037
Y		0.087	0.003	0.152	0.149	-0.002	-0.012
Z		-1.330	-0.296	1.034	1.330	0.000	-0.023
Lever Arm Estimate in Inertial Explorer - Test4							
X		0.148	0.005	0.096	0.091	0.004	0.041
Y		0.091	0.003	0.151	0.148	-0.001	-0.013
Z		-1.330	-0.296	1.034	1.330	0.000	-0.023
Lever Arm Estimate in Inertial Explorer - Test5							
X		0.147	0.005	0.098	0.093	0.002	0.043
Y		0.093	0.003	0.150	0.147	-0.001	-0.014
Z		-1.330	-0.296	1.034	1.330	0.000	-0.023
Lever Arm Estimate in Inertial Explorer - Test6							
X		0.146	0.005	0.100	0.095	0.002	0.045
Y		0.095	0.003	0.149	0.146	-0.001	-0.015
Z		-1.330	-0.296	1.034	1.330	0.000	-0.023
Lever Arm Estimate in Inertial Explorer - Test7							
X		0.146	0.005	0.101	0.096	0.001	0.046
Y		0.096	0.003	0.149	0.146	0.000	-0.015
Z		-1.330	-0.296	1.034	1.330	0.000	-0.023
Lever Arm Estimate in Inertial Explorer - Use for Processing							
X	-0.003	0.146	0.005	0.101	0.096	0.000	0.046

CHIROPTERA LEVER ARMS

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

Axis	Ref to IMU In the system	Ref to GNSS In the system	IMU to Gimble Inertial Explorer	IMU to GNSS Inertial Explorer	Gimble to GNSS Inertial Explorer	Differences from Previous	Differences from Start
Y	-0.006	0.096	0.003	0.149	0.146	0.000	-0.015
Z	-0.296	-1.330	-0.296	1.034	1.330	0.000	-0.023

DEEP CHANNEL LEVER ARMS

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

Axis	Ref to IMU In the system	Ref to GNSS In the system	IMU to Gimble Inertial Explorer	IMU to GNSS Inertial Explorer	Gimble to GNSS Inertial Explorer	Differences from Previous	Differences from Start
Start Values						**Flight Pro**	**Inertial Explorer**
X	-0.003	0.006	0.005	0.120	0.115	+ tve forward	+ tve stbd
Y	-0.006	0.000	0.003	1.950	1.947	+ tve stbd	+ tve forward
Z	-0.296	-1.305	-0.296	0.927	1.223	+ tve down	+ tve up
Lever Arm Estimate in Inertial Explorer - Test 1							
X		1.953	0.005	0.118	0.113	-0.002	-0.002
Y		0.113	0.003	1.956	1.953	0.006	0.006
Z		-1.227	-0.296	0.931	1.227	0.004	0.004
Lever Arm Estimate in Inertial Explorer - Test 2							
X		1.956	0.005	0.118	0.113	0.000	-0.002
Y		0.113	0.003	1.959	1.956	0.003	0.009
Z		-1.227	-0.296	0.931	1.227	0.000	0.004
Lever Arm Estimate in Inertial Explorer - Test 3							
X		1.958	0.005	0.117	0.112	-0.001	-0.003
Y		0.112	0.003	1.961	1.958	0.002	0.011
Z		-1.227	-0.296	0.931	1.227	0.000	0.004
Lever Arm Estimate in Inertial Explorer - Test 4							
X		1.962		0.117	0.117	0.000	-0.003
Y		0.117		1.962	1.962	0.001	0.012
Z		-0.931		0.931	0.931	0.000	0.004
Lever Arm Estimate in Inertial Explorer - Test 5							
X		1.962		0.117	0.117	0.000	-0.003
Y		0.117		1.962	1.962	0.000	0.012
Z		-0.931		0.931	0.931	0.000	0.004

GNSS BASE SUMMARY

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

PID	Project Name	Latitude			Longitude			Height (m)	XY Datum	Z Datum	Source	Comments
		Deg	Min	Sec	Deg	Min	Sec					
AJ7196	**SIDN**	40	18	37.26523	84	10	15.90683	293.415	NAD83(2011)	NAD83(2011)	NGS	Epoch: 2010 (CORS)

TRAJECTORY PROCESSING

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

Project Name	Download Airborne Data	Create IE Project Directory	Copy Data to IE Project /Raw	Run Project Wizard	Base Station			Check Base Coordinate & Datum	Check Lever Arms	Process Time Window		Process TC	Review QC Plots	Separation			Solution Status	Comments
					Station ID	Receiver Type	Antenna (ARP) Height (m)			Start Time (GPS Week Time)	End Time (GPS Week Time)			East RMS (m)	North RMS (m)	Up RMS (m)		
2021-08-31A_CH4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.060	0.021	0.053	Final	
2021-08-31A_HE4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.065	0.022	0.050	Final	
2021-09-01A_CH4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.015	0.015	0.022	Final	
2021-09-01A_HE4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.013	0.010	0.022	Final	
2021-09-01B_CH4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.007	0.007	0.017	Final	
2021-09-01B_HE4X	DA	DA	DA	DA	PPP			DA	DA			DA	DA	0.004	0.007	0.030	Final	
2021-09-03A_CH4X	DA	DA	DA	DA	SIDN	TRM	0.000	DA	DA			DA	DA	0.005	0.009	0.020	Final	Dayton Calibration (NV5-2)
2021-09-03A_HE4X	DA	DA	DA	DA	SIDN	TRM	0.000	DA	DA			DA	DA	0.004	0.010	0.019	Final	Dayton Calibration (NV5-2)

PROJECT NAME: 2021-82058 NOAA Sleeping Bear
LOCATION: Sleeping Bear, MI
AIRCRAFT: Cessna 406 (N406SD)
SYSTEM: Hawkeye 4X

Mission	Copied to Disk	Nav Session	Nav Type	Calibration File	Cal Type	Processing Parameters	Check Processing Parameters	Processing Session	Number of FL	Process Topo	Process Shallow	Process Deep	Run QC Stats in FME	Comments
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r0	Initial	ProcCalibration_1000m	MC	r0/Cal-SidneyOH_1000m_20210903_145716	6	6	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r0	Initial	ProcCalibration_500m	MC	r0/Cal-SidneyOH_500m_20210903_160912	6	6	6	6	MC	Topo, Shallow, Deep
								Cal_Deep_500m	--	--	--	--	--	Deep - Update Slant Range and Angles (r1)
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r0	Initial	ProcCalibration_400m	MC	r0/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r1	Interim	ProcCalibration_1000m	MC	r1/Cal-SidneyOH_1000m_20210903_145716	6	--	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r1	Interim	ProcCalibration_500m	MC	r1/Cal-SidneyOH_500m_20210903_160912	6	--	--	--	MC	Topo, Shallow, Deep
								Cal_Deep_500m	--	--	--	--	--	Deep - Update Slant Range and Angles (r2)
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r1	Interim	ProcCalibration_400m	MC	r1/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r2	Interim	ProcCalibration_1000m	MC	r2/Cal-SidneyOH_1000m_20210903_145716	6	--	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r2	Interim	ProcCalibration_500m	MC	r2/Cal-SidneyOH_500m_20210903_160912	6	--	--	--	MC	Topo, Shallow, Deep
								Cal_Deep_500m	--	--	--	--	--	Deep - Update Slant Range and Angles (r3)
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r2	Interim	ProcCalibration_400m	MC	r2/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r3	Interim	ProcCalibration_1000m	MC	r3/Cal-SidneyOH_1000m_20210903_145716	6	--	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r3	Interim	ProcCalibration_500m	MC	r3/Cal-SidneyOH_500m_20210903_160912	6	--	--	--	MC	Topo, Shallow, Deep
								Cal_Deep_500m	--	--	--	--	--	Deep - Update Slant Range and Angles (r4)
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r3	Interim	ProcCalibration_400m	MC	r3/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r4	Interim	ProcCalibration_1000m	MC	r4/Cal-SidneyOH_1000m_20210903_145716	6	--	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r4	Interim	ProcCalibration_500m	MC	r4/Cal-SidneyOH_500m_20210903_160912	6	--	--	--	MC	Topo, Shallow, Deep
								Cal_Deep_500m	--	--	--	--	--	Deep - Mirror Cal (r5)
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r4	Interim	ProcCalibration_400m	MC	r4/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Cal-SidneyOH_1000m_20210903_145716	MC	2021-09-03A	Final	Cal_r5	Final	ProcCalibration_1000m	MC	r5/Cal-SidneyOH_1000m_20210903_145716	6	--	--	--	MC	Topo Only
Cal-SidneyOH_500m_20210903_160912	MC	2021-09-03A	Final	Cal_r5	Final	ProcCalibration_500m	MC	r5/Cal-SidneyOH_500m_20210903_160912	6	--	--	--	MC	Topo, Shallow, Deep
Cal-SidneyOH_400m_20210903_152856	MC	2021-09-03A	Final	Cal_r5	Final	ProcCalibration_400m	MC	r5/Cal-SidneyOH_400m_20210903_152856	6	6	6	6	MC	Topo, Shallow, Deep
Rename Cal_r5 to Cal_TSD_Survey_20210831 for survey														