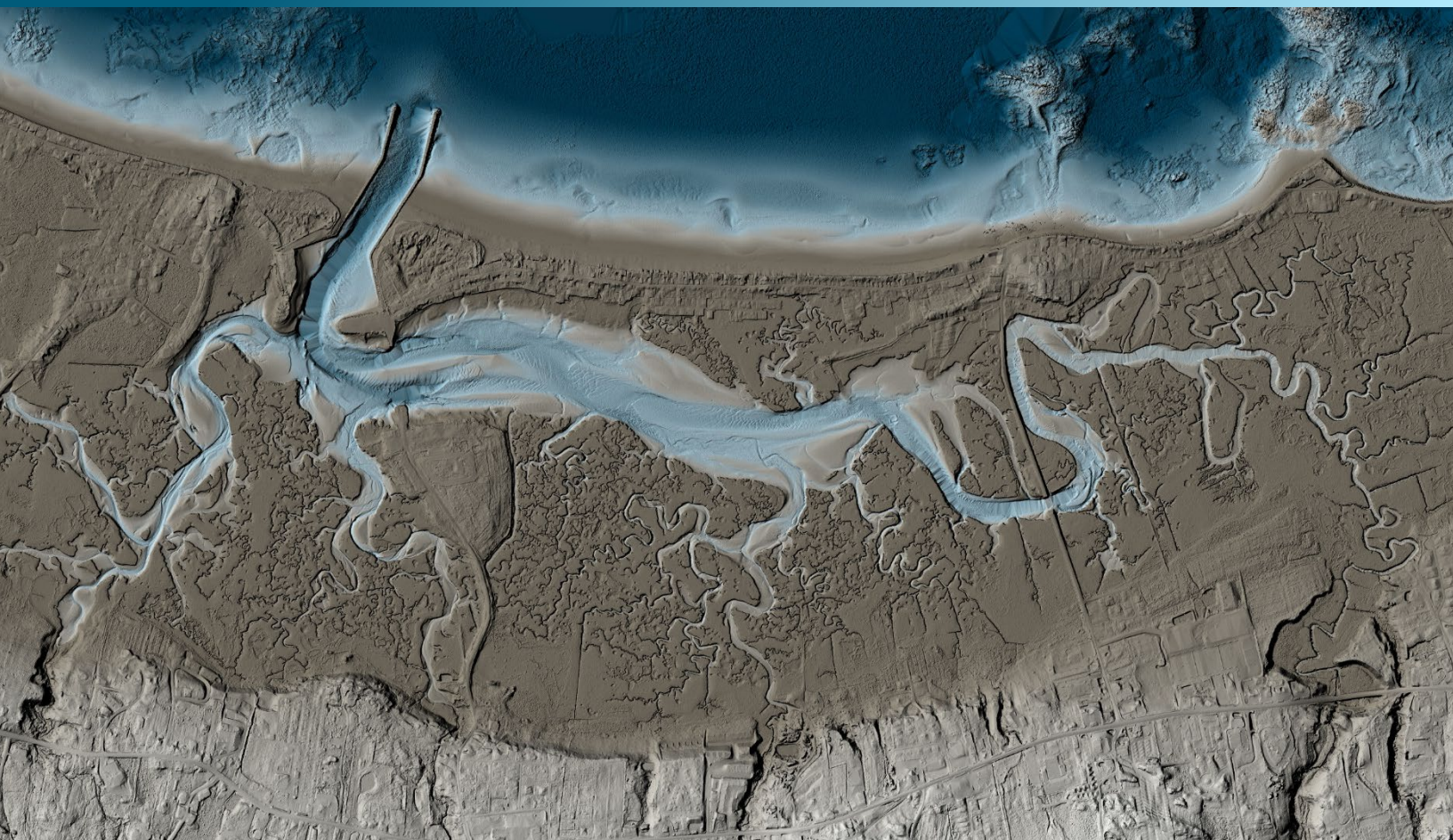




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NOAA Maine

Shoreline Mapping Projects: ME2201

Technical Data Report, NOAA Contract 1305M220DNCNL0064, Task Order 1305M22FNCNL0357

Prepared For:



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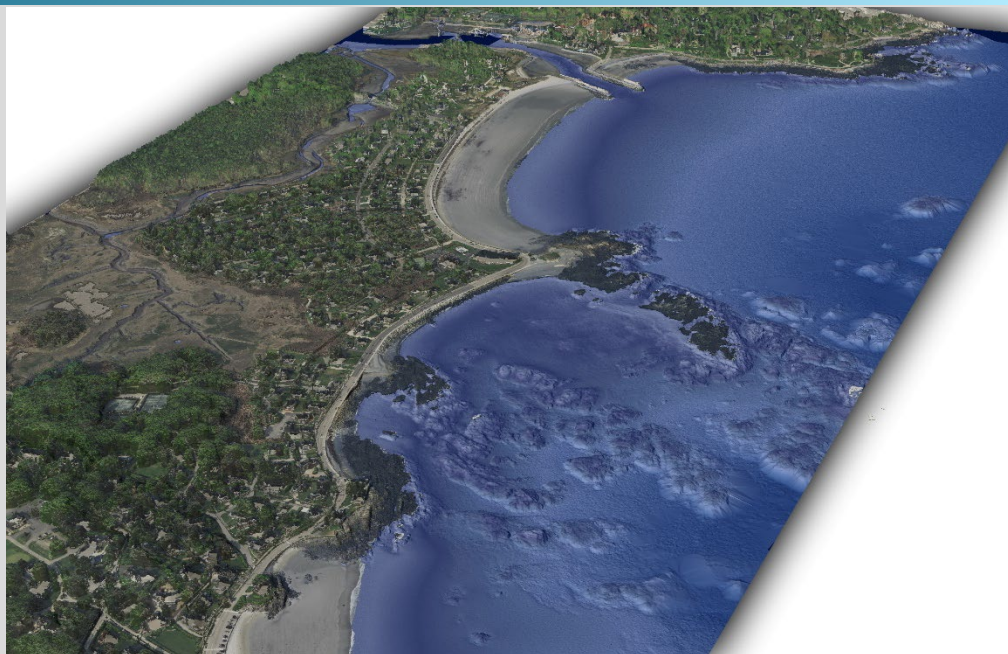
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INTRODUCTION

View of Gooches Beach, the bare earth topobathymetric model is colored by elevation overlaid by the aboveground lidar point cloud colored by 25cm imagery



In September 2022, NV5 was contracted by the National Oceanic and Atmospheric Administration (NOAA) to collect topobathymetric Light Detection and Ranging (lidar) data and digital imagery from October 2022 to December 2023 for the NOAA Maine site. The NOAA Maine area of interest encompasses a large portion of the coast of Maine as well as neighboring sections of shoreline in New Hampshire and northern tip of Massachusetts. In total, the base project area NOAA Maine project (ME2201) encompasses approximately 3,115 square statute miles and 4,460 miles of shoreline. The northern, inland extent of the area of interest (AOI) stretches from eastern Maine just south of the Ganong Nature Park in New Brunswick Canada to Newmarket New Hampshire. The southern extent of the AOI includes the Gulf of Maine in the east and follows the coast west to the Salisbury Beach Boardwalk in Massachusetts. Data was collected to aid NOAA in modeling the topographic and geophysical properties of the study area to support accurate measurement and mapping of the national shoreline and to support marine resource management.

This report accompanies the delivered topobathymetric lidar data and imagery, and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including lidar accuracy, depth penetration, and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to NOAA is shown in Table 3 with the coordinate reference system information for these deliverables shown in Table 2, the project extent is shown in Figure 1, and the project delivery areas are shown in Figure 2.

Table 1: Acquisition dates, acreage, and data types collected on the NOAA Maine site

Project Site	Contracted Acres	Contracted sq. miles	Buffered Acres	Buffered sq. miles	Aerial Acquisition Dates	Data Type
NOAA Maine	1,993,152	3,114.30	2,105,660	3,288.03	*10/6/2022 – 12/15/2023	Topobathymetric - Lidar
NOAA Maine	1,993,152	3,114.30	2,105,660	3,288.03	**10/22/2022, 10/23/2022, 10/31/2022, 11/02/2022 – 11/4/2022, 11/15/2022, 5/18/2023, 5/22/2023, 5/23/2023, 5/28/2023	4-band Imagery

*See Figure 10 for more detailed flight dates for lidar acquisition

**See the “Data Acquisition Summary” in Appendix B: Imagery Reports for more detailed flight information for imagery acquisition

Deliverable Products

Table 2: Deliverable product coordinate reference system information

Product Type	Projection	Horizontal Datum	Vertical Datum	Units
Classified LAS	UTM Zone 18 North	NAD83(2011)	GRS80 (Ellipsoidal Height)	Meters
Raster Model	UTM Zone 18 North	NAD83(2011)	NAVD88(GEOID18)	Meters

Table 3: Lidar and imagery products delivered for the NOAA Maine site

Product Type	File Type	Product Details
Points	LAS v.1.4 (*.las), Point Format 6	<ul style="list-style-type: none"> 500m x 500m tiled All Classified Returns with normalized seabed intensity
Rasters	1.0-meter Cloud Optimized GeoTIFFs (*.tif)	<ul style="list-style-type: none"> 500m x 500m tiled Topobathymetric Standard Deviation Models 5000m x 5000m tiled Void-Clipped Topobathymetric Bare Earth Digital Elevation Models (DEM) 5000m x 5000m tiled Normalized Seabed Intensity Rasters

Product Type	File Type	Product Details
Vectors	Shapefiles (*.shp)	<ul style="list-style-type: none"> • Delivery Boundary • Lidar Tile Index • DEM Tile Index • Bathymetric Void Shape • Feedback edits with Response • Ground Survey Points • Imagery Acquisition Flightlines • Imagery Footprints
Flightline & Sensor Trajectories	Trajectories (*.txt)	<ul style="list-style-type: none"> • Chiroptera 4X • HawkEye 4X • Chiroptera 5 • HawkEye 5
TPU Products	1.0-meter GeoTIFFs (*.tif)	<ul style="list-style-type: none"> • 2-band Total Propagated Uncertainty (TPU) Raster Model GeoTIFFs (*.tif) <ul style="list-style-type: none"> ○ Band 1 Total Horizontal Uncertainty (THU) at 95% Confidence ○ Band 2 Total Vertical Uncertainty (TVU) at 95% Confidence
Digital Imagery	GeoTIFFs (*.tif)	<ul style="list-style-type: none"> • 3000m x 3000m tiled Imagery Mosaics
Metadata	Extensible Markup Language (*.xml)	<ul style="list-style-type: none"> • LAS Metadata • Bare Earth DEM Metadata • TPU Raster Metadata • Normalized Seabed Intensity Metadata • Imagery Metadata • Project Boundary Metadata • Las Index Metadata • DEM Index Metadata
Reports	Adobe Acrobat (*.pdf)	<ul style="list-style-type: none"> • Imagery Reports • Field Data Collection Sheets • Ground Survey Report • Lidar Technical Data Report

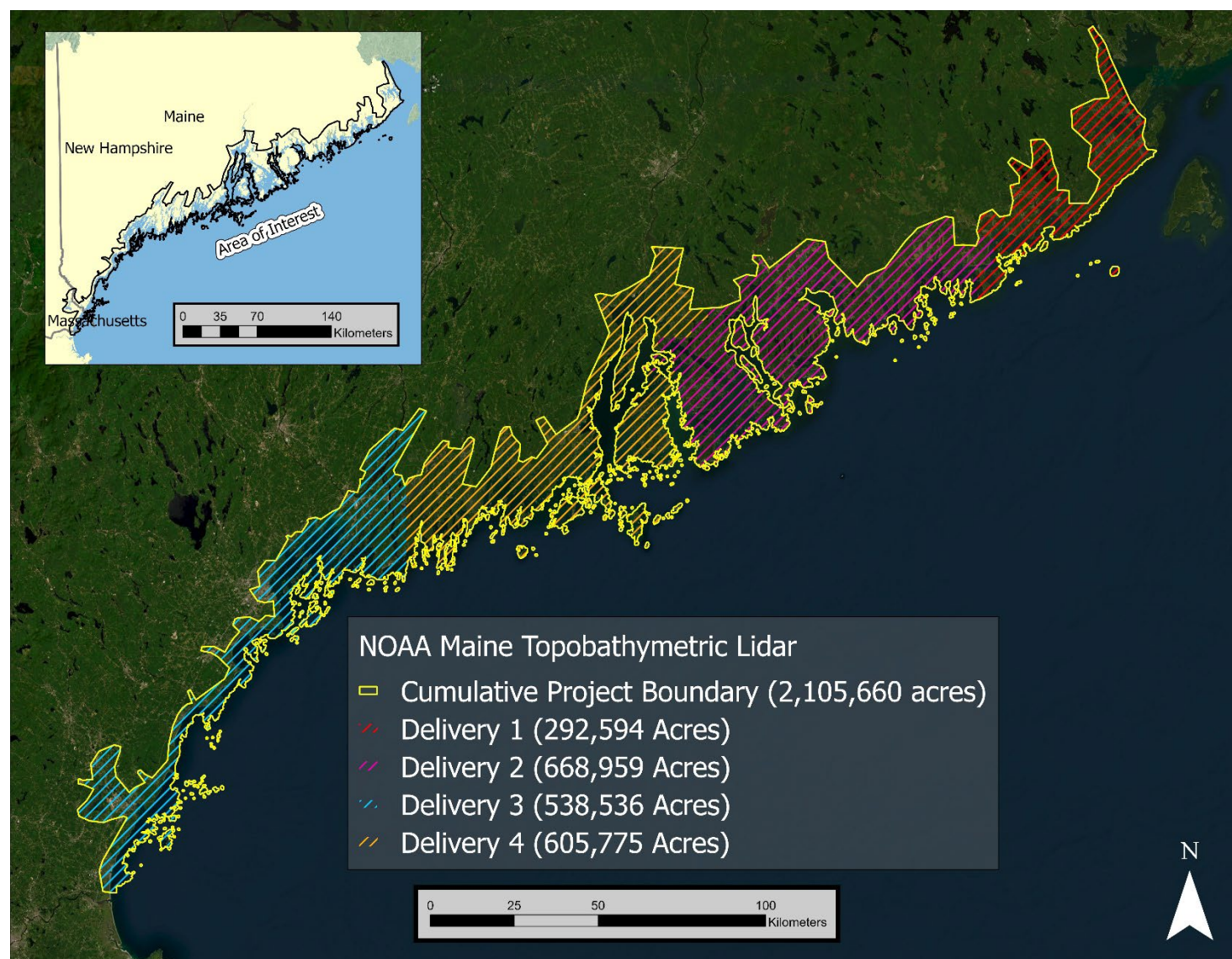


Figure 1: Delivery Area Location map of the NOAA Maine project area

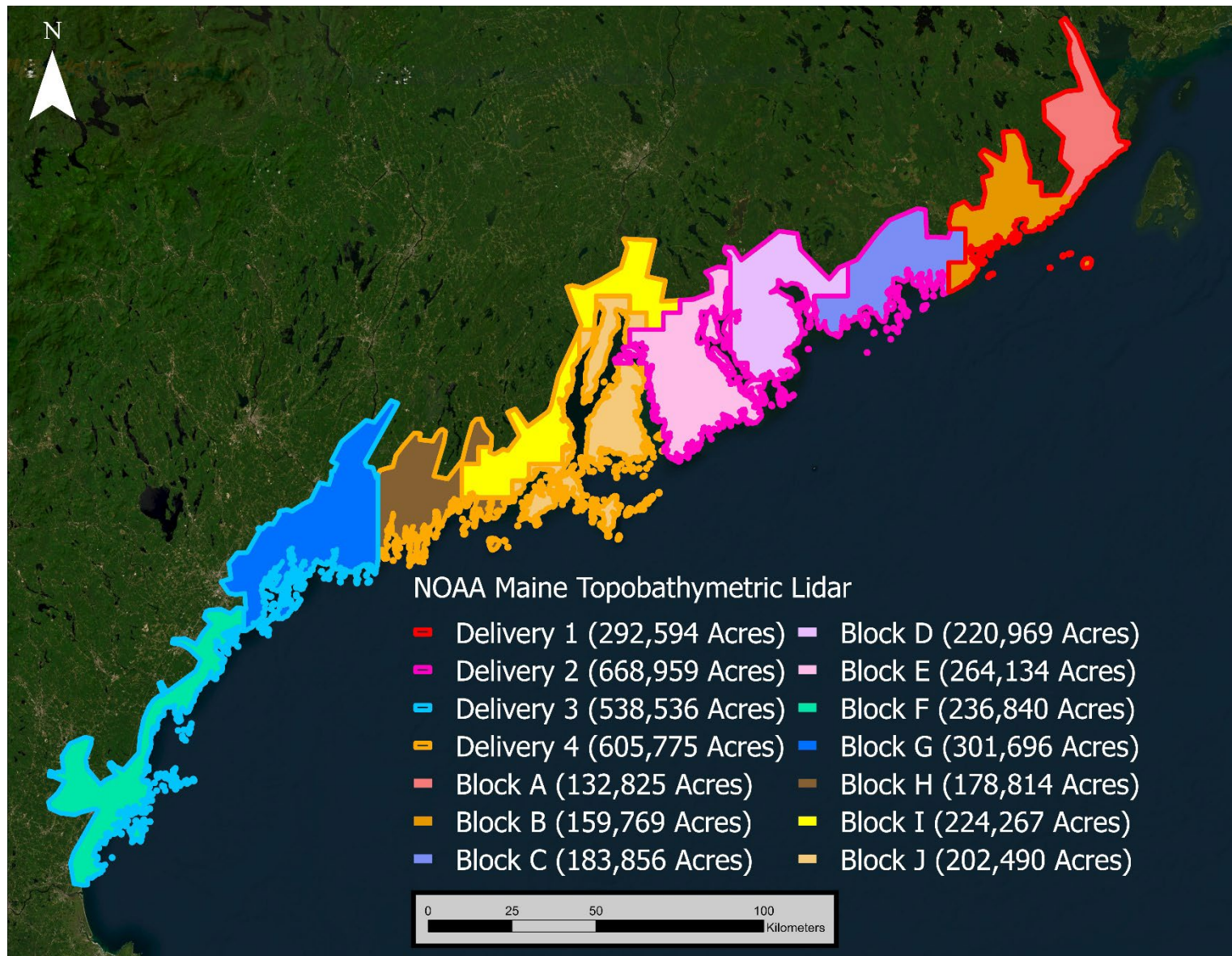


Figure 2: Deliveries divided into delivery blocks for the NOAA Maine project area

ACQUISITION

View of Merepoint Bay, the bare earth topobathymetric model is colored by elevation



Sensor Selection

Leica Chiroptera 4X and 5

NV5 Geospatial selected the Leica Chiroptera 4X (CH4X) and Chiroptera 5 (CH5) for the NOAA Maine project (Figure 3). The CH4X and CH5 sensors allow for a depth penetration of $K^*D_{max}=2.7/k$ and $3.2/k$ at 15% seabed reflectance, respectively. Chiroptera shallow green laser sensors perform well in dynamic wave action and automatically correct for water refraction, making them useful in collecting shallow coastal and shoreline data. These sensors detect obstructions, such as vegetation and anthropogenic features, with oblique lidar. This means they can provide additional information from multiple positions that more closely resemble the actual features and can allow for further analyses compared to traditional imagery. These systems provide seamless integration between the NIR and shallow green channels as well as between the onshore and shoreline data.



Figure 3: Leica Chiroptera 4X (top) and 5 (bottom) sensors

Leica Hawkeye 4X and 5

The CH4X and CH5 laser systems were dually mounted with Leica HawkEye 4X (HE4X) and HawkEye 5 (HE5) 40kHz and HawkEye5(HE5) 40kHz deep bathymetric channel sensors. Due to the deep green laser parameters, HawkEye sensors are not optimal for shallow bathymetry, but can provide better resolution and depth penetration in deeper bathymetric environments at the same wavelength (515 nm) as the Chiroptera shallow green laser. The HE4X and HE5 sensors allow for a depth penetration of $K \cdot D_{\max} = 4/k$ at 15% seabed reflectance. The bathymetric sub-systems of the HawkEye 4X use a Palmer scanner to produce a scan pattern of laser points with a degree of incidence ranging from $\pm 14^\circ$ (front and back) to $\pm 20^\circ$ (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 for bathymetric features (e.g., sides of narrow water channels; features on the seafloor such as smaller objects and wrecks). The bathymetric laser is a diode-pumped class 4 laser.

These Chiroptera sensors automatically correct for water refraction, making them useful in collecting shallow coastal and shoreline data. They can capture images, NIR, and bathymetric data at the same time. Sensor specifications and settings for the NOAA Maine acquisitions are displayed in Table 5.



Figure 4: Leica Hawkeye 4X (left) and 5 (right) sensors

Logistics Planning

In preparation for data collection, NV5 reviewed the project area and developed a specialized flight plan to ensure complete coverage of the NOAA Maine Lidar study area at the target combined point density of ≥ 3 points/m² for bathymetric areas and ≥ 4 points/m² for topographic areas. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications. Figure 10 shows these optimized flight paths and dates.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access, potential air space restrictions, tide conditions (Figure 5 through Figure 8), and water clarity were reviewed.

Turbidity Measurements, Tide Monitoring & Secchi Depth Readings

NV5’s acquisition team considered several environmental conditions during the planning stage of the project to target the best possible windows for capturing bathymetric bottom returns. Water clarity was monitored daily using handheld Hach turbidity meters, Secchi disks, and semi-portable water quality data loggers operated by NV5 ground operations professionals. Readings were collected at 99 locations throughout the project site from September 28 to November 17, 2022, and April 27 to June 1, 2023. Turbidity observations were often recorded three times to confirm measurements. Table 4 below provides turbidity and Secchi depth results per site on each day of data collection. A true Secchi depth reading is where the Secchi depth reaches extinction. However, some of the Secchi depth readings were noted to have reached the bottom surface. Some locations were also inaccessible for Secchi and/or turbidity measurements.

Table 4: Water Clarity Observations for Lidar flights

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
9/28/2022	10:08 AM	Inland Bay at the end of Fryeville Point Rd, Harrington, ME north of Coffins Point	67° 47' 6.84" W	44° 35' 13.30" N	1.98	1.04	1.06	2.05	6.20
9/29/2022	12:42 PM	Boat Ramp - UMaine	68° 40' 27.12" W	44° 53' 58.47" N	0.00	0.00	NA	NA	NA
10/5/2022	8:20 AM	local dock at the end of Bartlett's Landing Road in the Mount Desert Narrows	68° 25' 2.22" W	44° 20' 33.94" N	0.02	NA	NA	4.50	1.90
10/6/2022	9:49 AM	End of dock at the end of The Lane near the west side of Crowley Island	67° 39' 52.26" W	44° 32' 54.46" N	5.30	3.99	NA	1.00	0.60
10/6/2022	1:38 PM	End of dock near Old House Point Jonesport, ME in Sawyer Cove	67° 35' 41.61" W	44° 31' 53.53" N	1.27	1.54	1.17	3.50	2.70
10/7/2022	7:50 AM	Boat Ramp and End of Dock at the end of Town Landing Road Jonesboro, ME	67° 32' 49.13" W	44° 39' 20.59" N	2.32	NA	NA	1.50	2.50
10/7/2022	8:15 AM	Chandler River bank Jonesboro, ME	67° 34' 28.61" W	44° 39' 38.16" N	3.93	NA	NA	1.00	1.20
10/7/2022	8:58 AM	Beach at Beals Town Park	67° 35' 14.86" W	44° 30' 37.63" N	21.32	NA	NA	*NA	3.80
10/8/2022	7:41 AM	Boat ramp at the end of Town Landing Road Jonesboro, ME	67° 32' 49.02" W	44° 39' 20.95" N	3.89	NA	NA	0.90	5.20

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
10/8/2022	8:36 AM	Beach at Beals Town Park	67° 35' 15.57" W	44° 30' 37.69" N	1.94	NA	NA	*NA	5.20
10/9/2022	8:48 AM	Beach where Hamilton Brook flows into Boot Cove	67° 00' 37.35" W	44° 47' 17.89" N	1.82	8.21	NA	*NA	9.50
10/9/2022	2:10 PM	Beach at Quoddy Head State Park	66° 57' 6.49" W	44° 48' 49.10" N	0.66	8.21	NA	*NA	8.90
10/10/2022	2:07 PM	End of dock near Liberty Point Robbinston, ME	67° 06' 31.31" W	45° 05' 0.39" N	0.18	NA	NA	2.50	2.50
10/11/2022	6:45 AM	End of boat ramp near Gleason Point Perry, ME	67° 03' 13.43" W	44° 58' 22.89" N	3.41	NA	NA	*NA	1.40
10/14/2022	7:30 AM	Grass cove north of Wilders Way Jonesport, ME with ocean parted by Crowley Island	67° 38' 22.78" W	44° 33' 40.96" N	3.27	2.65	2.96	*NA	12.30
10/14/2022	11:33 AM	Grass cove north of Wilders Way Jonesport, ME with ocean parted by Crowley Island	67° 38' 22.78" W	44° 33' 40.96" N	0.54	0.47	0.44	*NA	16.70
10/15/2022	7:30 AM	Rocky cove with Crowley Island and other small islands in the distance to the west	67° 38' 32.59" W	44° 32' 14.49" N	2.30	2.80	2.24	NA	5.80
10/15/2022	11:20 AM	Rocky cove with Crowley Island and other small islands in the distance to the west	67° 38' 32.65" W	44° 32' 14.55" N	4.71	5.50	3.05	NA	4.80

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
10/15/2022	2:26 PM	Rocky cove with Crowley Island and other small islands in the distance to the west	67° 38' 32.55" W	44° 32' 14.57" N	4.08	5.57	5.56	NA	7.80
10/16/2022	10:32 AM	Ellsworth Harbor	68° 25' 17.07" W	44° 32' 5.41" N	1.88	1.07	1.83	4.25	1.70
10/16/2022	12:35 PM	Eagle Lake Boat Ramp	68° 25' 17.08" W	44° 32' 5.44" N	0.00	0.00	0.00	NA	1.80
10/16/2022	2:30 PM	Ellsworth Harbor Boat Ramp	68° 15' 3.29" W	44° 22' 30.90" N	1.24	2.18	1.85	4.25	1.40
10/17/2022	8:30 AM	Indian Point Reserve	68° 25' 13.23" W	44° 31' 59.08" N	22.08	17.67	16.60	NA	1.80
10/18/2022	1:08 PM	Gardner Lake Boat Dock	67° 21' 36.80" W	44° 45' 25.74" N	0.00	0.00	0.00	NA	8.50
10/18/2022	1:58 PM	Gardner Lake Boat Ramp	67° 21' 36.80" W	44° 45' 25.74" N	0.00	0.00	0.00	NA	7.50
10/19/2022	9:01 AM	Addison Town Landing (boat ramp)	67° 43' 30.96" W	44° 30' 7.62" N	0.25	0.16	0.37	1.47	11.50
10/19/2022	11:30 AM	Quoddy Head State Park	66° 59' 0.07" W	44° 54' 38.08" N	1.66	1.87	1.61	*NA	14.50
10/20/2022	10:40 AM	Harris Cove Boat Dock	66° 56' 49.98" W	44° 49' 0.88" N	0.11	0.00	0.00	NA	11.50
10/20/2022	10:41 AM	Eastport Port Authority Boat Dock	66° 59' 47.15" W	44° 55' 4.86" N	0.00	0.00	0.00	4.30	4.00
10/20/2022	11:43 AM	Shackford Head Cove	67° 00' 35.29" W	44° 54' 19.07" N	113.00	103.00	108.00	NA	NA
10/21/2022	10:00 AM	Reversing Falls Park	67° 07' 45.26" W	44° 52' 59.50" N	1.83	1.85	1.28	*NA	11.20
10/21/2022	10:59 AM	Reversing Falls Park	67° 07' 45.26" W	44° 52' 59.50" N	2.11	1.75	2.24	*NA	3.00

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
10/21/2022	11:42 AM	Reversing Falls Park	67° 07' 45.26" W	44° 52' 59.50" N	5.32	5.53	4.24	*NA	4.50
10/21/2022	12:30 PM	Cobscook Bay Boat Ramp	67° 08' 52.33" W	44° 51' 28.12" N	102.00	101.00	101.00	0.69	6.70
10/22/2022	11:30 AM	Whiting Bay, boat access	67° 09' 37.70" W	44° 48' 49.37" N	9.56	11.29	11.85	NA	4.50
10/22/2022	1:19 PM	Whiting Bay, boat access	67° 09' 37.65" W	44° 48' 49.30" N	41.30	37.60	38.60	NA	6.70
10/23/2022	11:06 AM	Whiting Bay, boat access	67° 08' 11.81" W	44° 50' 44.85" N	8.18	7.34	7.68	NA	2.10
10/23/2022	12:33 PM	Whiting Bay, boat access	67° 09' 50.29" W	44° 48' 24.88" N	6.05	6.91	6.48	NA	1.00
10/23/2022	2:25 PM	Machiasport Boat Dock	67° 09' 50.29" W	44° 48' 24.88" N	22.10	22.00	21.50	NA	4.20
10/28/2022	7:26 AM	Rogue bluffs state park	67° 08' 51.38" W	44° 51' 25.45" N	11.94	16.17	12.03	NA	9.50
10/28/2022	8:55 AM	Jonesport boat ramp	67° 23' 34.92" W	44° 41' 48.20" N	NA	NA	NA	2.29	NA
10/29/2022	7:19 AM	Rogue Bluffs State Park	67° 28' 56.27" W	44° 36' 37.51" N	14.46	20.40	16.75	NA	1.20
10/29/2022	8:32 AM	Off dock in Rogue Bluffs State Park near Shoppee Point Whitneyville, ME	67° 29' 49.14" W	44° 36' 53.71" N	NA	NA	NA	1.91	NA
10/30/2022	7:31 AM	Peninsula beach	67° 23' 38.11" W	44° 36' 30.66" N	10.55	11.82	9.57	NA	2.40
10/30/2022	11:39 AM	Off dock in Buck's Harbor south of Bucks Neck	67° 22' 22.21" W	44° 38' 18.92" N	NA	NA	NA	2.13	NA
10/31/2022	8:10 AM	Boat ramp and dock at the end of cove near Look Point	67° 45' 44.21" W	44° 33' 44.61" N	17.65	17.06	18.58	0.97	4.50

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
10/31/2022	8:27 AM	Beach near Township Rock Machiasport, ME	67° 20' 12.84" W	44° 41' 54.85" N	15.44	17.25	18.84	NA	1.20
10/31/2022	10:11 AM	Bold Coast Cutler, ME	67° 12' 23.25" W	44° 39' 22.04" N	8.92	13.30	14.73	*1.22	4.20
10/31/2022	12:10 PM	Fort O'Brien state historic site	67° 23' 48.39" W	44° 41' 8.90" N	37.60	35.30	38.00	NA	4.70
11/2/2022	9:18 AM	Town Boat Landing	67° 48' 14.16" W	44° 32' 44.33" N	29.90	33.80	36.50	0.30	5.80
11/3/2022	9:16 AM	Milbridge boat ramp	67° 52' 39.43" W	44° 32' 34.85" N	33.40	34.70	33.00	0.61	3.60
11/3/2022	10:27 AM	Chipman's Warf	67° 51' 33.75" W	44° 31' 10.47" N	16.77	20.10	20.50	*0.60	0.60
11/3/2022	11:40 AM	Yeaton Cove	67° 55' 46.56" W	44° 26' 14.43" N	13.01	11.98	21.10	*1.52	3.20
11/4/2022	9:46 AM	Tidal Falls Park	68° 13' 18.13" W	44° 31' 7.74" N	22.70	21.40	23.20	NA	1.20
11/4/2022	10:23 AM	Sorrento Harbor	68° 10' 59.99" W	44° 28' 15.66" N	13.16	18.87	12.89	*1.23	1.20
11/4/2022	12:04 PM	Corea Beach	67° 57' 35.25" W	44° 24' 9.34" N	8.03	8.03	11.09	NA	2.60
11/5/2022	11:05 AM	Winter Harbor Beach	68° 05' 32.80" W	44° 23' 19.20" N	17.36	19.17	20.40	NA	5.60
11/5/2022	11:16 AM	Winter Harbor Wharf	68° 05' 11.60" W	44° 23' 20.30" N	NA	NA	NA	2.43	NA
11/8/2022	12:42 PM	South Addison Beach	67° 44' 37.51" W	44° 30' 37.74" N	24.20	23.20	25.30	NA	10.20
11/11/2022	5:48 AM	Bar Island Land Bridge	68° 12' 37.18" W	44° 23' 33.79" N	0.00	0.00	0.00	*1.00	3.40
11/11/2022	8:09 AM	Bar Island Land Bridge	68° 12' 36.96" W	44° 23' 31.92" N	0.10	0.00	0.51	*2.00	10.80

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
11/11/2022	12:31 PM	Bar Island Land Bridge	68° 12' 36.62" W	44° 23' 33.32" N	0.26	0.33	0.51	2.00	2.50
11/14/2022	12:29 PM	municipal dock at Bar Harbor, ME	68° 12' 14.01" W	44° 23' 29.78" N	19.37	13.35	21.90	2.20	13.00
11/15/2022	5:53 AM	local dock at the end of Bartlett's Landing Road in the Mount Desert Narrows	68° 25' 2.42" W	44° 20' 34.20" N	6.40	8.35	7.72	3.15	4.90
11/15/2022	8:47 AM	local dock at the end of Bartlett's Landing Road in the Mount Desert Narrows	68° 25' 1.84" W	44° 20' 33.90" N	1.43	2.24	2.28	3.33	3.20
11/15/2022	11:56 AM	local dock at the end of Bartlett's Landing Road in the Mount Desert Narrows	68° 25' 1.68" W	44° 20' 33.76" N	2.02	2.72	3.68	4.27	3.00
11/16/2022	6:46 AM	Bar Harbor, ME town pier	68° 12' 12.40" W	44° 23' 27.81" N	19.98	22.00	22.30	3.53	15.20
11/17/2022	6:41 AM	Newbury Neck Beach	68° 28' 8.80" W	44° 26' 27.33" N	0.56	1.88	0.61	2.50	3.00
11/17/2022	8:42 AM	Tremont Municipal Floats at ferry terminal	68° 20' 55.10" W	44° 14' 6.35" N	0.00	0.41	0.00	1.91	5.80
11/17/2022	11:27 AM	Newbury Neck Beach	68° 28' 8.37" W	44° 26' 28.35" N	0.00	0.00	0.00	2.00	6.20
11/17/2022	1:11 PM	Tremont Municipal Floats at ferry terminal	68° 20' 55.31" W	44° 14' 6.18" N	0.00	0.00	0.00	2.79	8.00
4/27/2023	7:30 AM	Secchi 100:, Hampton Beach Bay boat ramp	70° 49' 1.62" W	42° 53' 57.12" N	3.61	3.32	NA	1.90	3.00

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
4/28/2023	7:34 AM	Secchi 105: Pierce Island boat ramp	70° 44' 54.30" W	43° 04' 27.79" N	5.52	5.00	3.15	**2.10	5.00
4/28/2023	8:35 AM	Secchi 06: York Bay	70° 38' 22.79" W	43° 07' 54.18" N	3.23	2.01	2.01	*NA	5.00
4/28/2023	8:14 AM	Setpoint Beach	70° 39' 43.51" W	43° 05' 24.26" N	5.29	4.40	4.23	*NA	5.00
4/28/2023	9:10 AM	Cape Neddick Harbor Beach	70° 36' 14.04" W	43° 11' 24.02" N	3.57	3.68	2.49	*NA	5.00
4/28/2023	9:39 AM	Secchi 107: Footbridge Beach	70° 35' 28.97" W	43° 15' 47.49" N	4.08	2.98	3.15	1.00	5.00
4/28/2023	10:07 AM	Secchi108: Wells Harbor boat ramp	70° 33' 50.34" W	43° 19' 13.27" N	9.88	11.80	11.00	1.40	5.00
4/28/2023	11:06 AM	Secchi 109: Kennebunk Beach	70° 29' 13.13" W	43° 20' 40.99" N	3.83	3.10	3.57	*NA	5.00
4/28/2023	11:55 AM	Secchi 110: Goose Rocks Beach	70° 25' 48.93" W	43° 23' 17.57" N	3.02	5.66	3.24	*NA	5.00
5/4/2023	2:05 PM	Thomas Point Beach SW of Brunswick, ME	69° 53' 25.47" W	43° 53' 36.67" N	20.90	17.80	18.40	**0.33	5.00
5/5/2023	4:43 PM	Secchi 112: taken at the southern tip of Orr's Island, immediately north of Bailey Island, ME	69° 59' 18.86" W	43° 44' 56.03" N	5.24	5.12	5.49	3.50	10.00
5/8/2023	3:15 PM	Ocean Point Beach southeast of Boothbay, ME	69° 35' 43.66" W	43° 48' 56.18" N	2.12	1.66	1.53	**1.00	5.00

Date	Time (EDT - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (kt)
5/9/2023	4:22 PM	Bayville Community Dock and Beach Bayville, ME	69° 36' 5.66" W	43° 51' 31.06" N	7.10	10.80	9.13	**1.60	3.00
5/21/2023	5:18 AM	Pemaquid Beach Park	69° 31' 27.55" W	43° 52' 17.94" N	4.14	4.10	4.04	**1.32	NA
5/21/2023	9:52 AM	Padebco Custom Boats dock	69° 27' 26.96" W	43° 56' 45.58" N	4.08	3.84	3.26	2.84	NA
5/22/2023	5:04 AM	Wayfarer Marine Dock, Camden, Maine	69° 03' 29.14" W	44° 12' 31.56" N	3.98	5.81	4.48	**1.86	NA
5/22/2023	6:13 AM	City of Belfast Harbor Department dock	69° 00' 10.81" W	44° 25' 44.63" N	5.01	4.28	3.71	3.21	NA
5/23/2023	5:31 AM	Drift Inn Beach	69° 14' 31.61" W	43° 55' 52.96" N	2.03	3.46	1.74	**1.32	NA
5/30/2023	9:26 AM	Kennebec Tavern dock	69° 48' 45.15" W	43° 54' 56.37" N	39.90	43.80	42.80	0.70	NA
5/31/2023	5:31 AM	Look Out Point	69° 59' 37.81" W	43° 48' 29.99" N	8.62	7.33	6.98	**1.32	NA
5/31/2023	9:22 AM	CTC ferry dock	70° 08' 23.27" W	43° 45' 7.24" N	3.82	4.35	2.90	**3.46	NA
5/31/2023	9:42 AM	Dock at the end of Cove Rd, Freeport, ME	70° 05' 45.47" W	43° 50' 31.85" N	17.90	16.10	18.20	0.60	NA
6/1/2023	6:16 AM	Maine Yacht Center	70° 15' 6.87" W	43° 40' 43.33" N	4.50	5.89	5.34	3.01	NA
6/1/2023	7:16 AM	Stern Seafood Dock	70° 20' 0.82" W	43° 32' 42.71" N	4.14	4.59	5.32	**3.49	NA
6/1/2023	8:24 AM	Wood Island Lighthouse Dock	70° 21' 21.58" W	43° 26' 46.10" N	5.18	2.65	2.82	**4.15	NA

* These locations did not have a dock or pier, or the area was inaccessible because of privacy restrictions or large waves for Secchi disk and/or turbidity measurements

** Measurement is depth to the bottom surface due to observational depth limitations

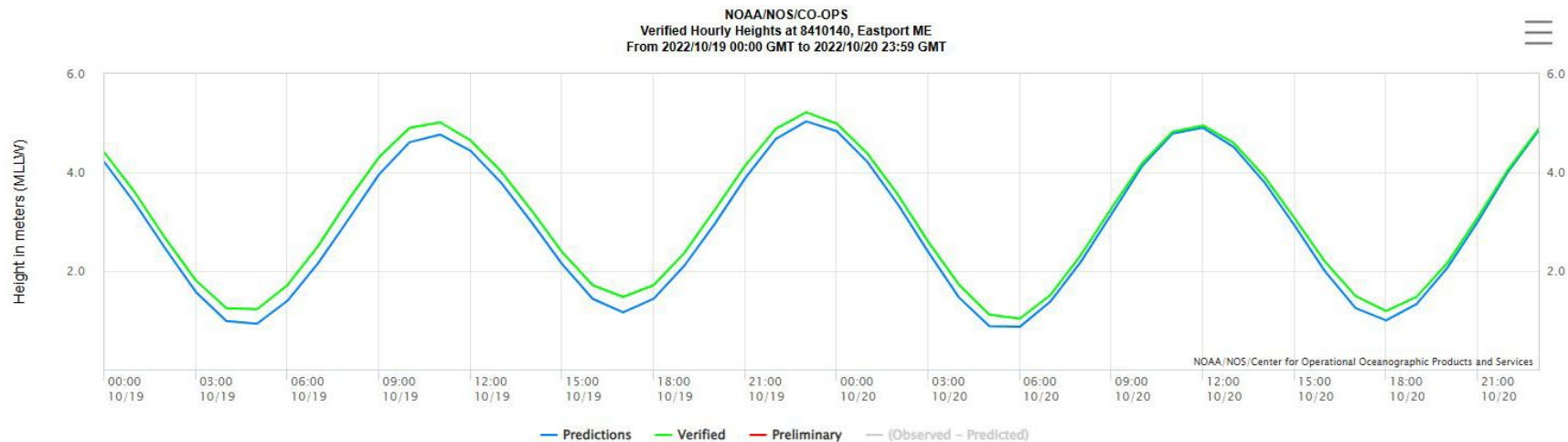


Figure 5: Tide Predictions and verified water levels at 8410140 during the time of turbidity and lidar acquisition near Eastport, ME

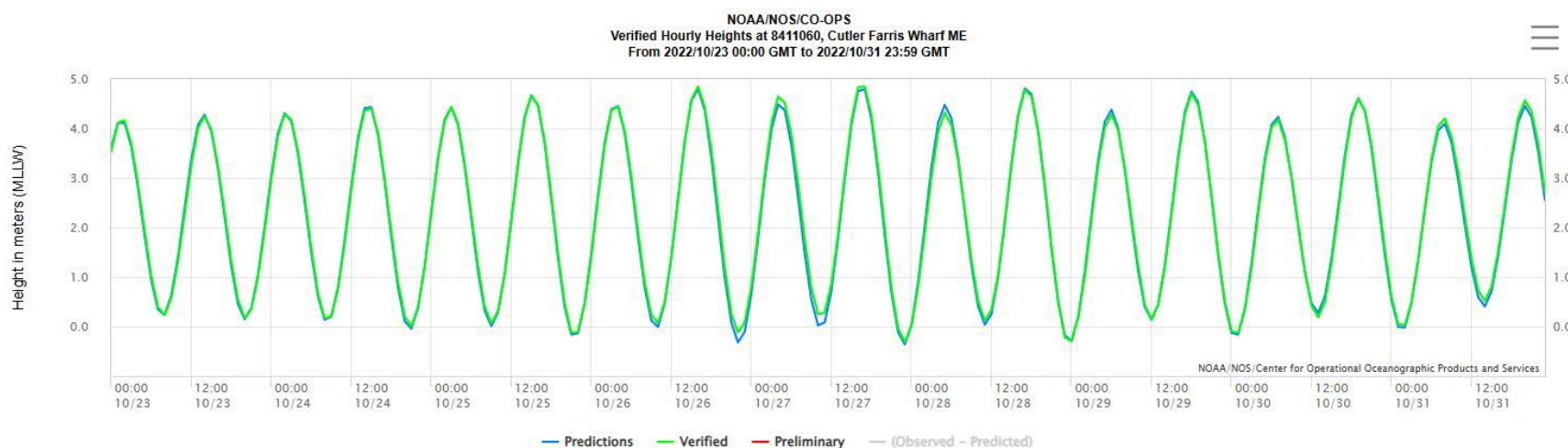


Figure 6: Tide Predictions and verified water levels at 8411060 during the time of turbidity and lidar acquisition near Cutler Farris Wharf, ME

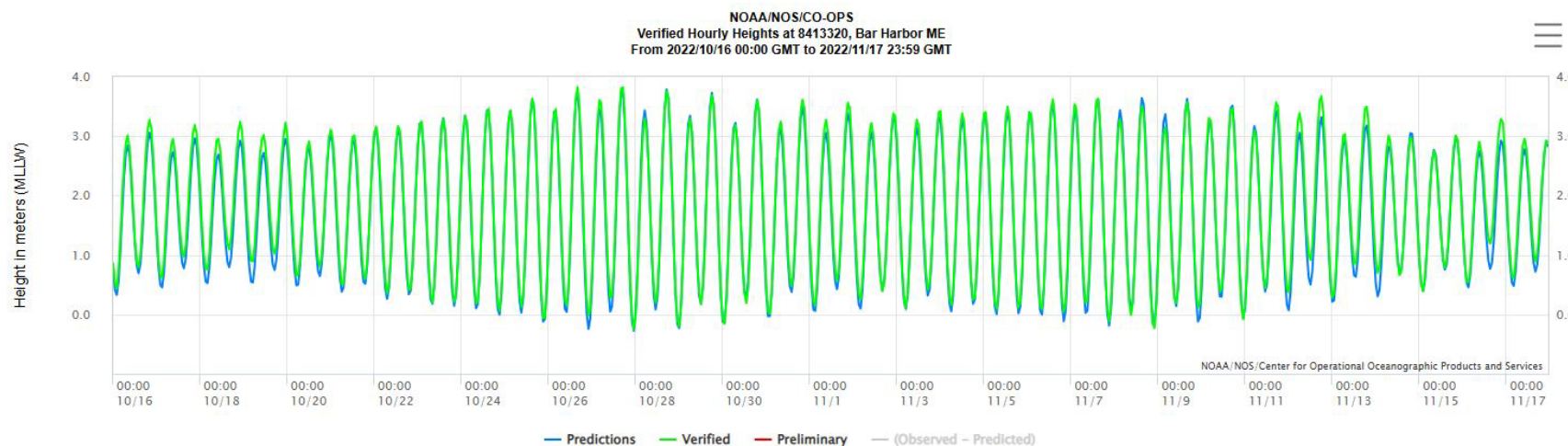


Figure 7: Tide Predictions and verified water levels at 8413320 during the time of turbidity and lidar acquisition near Bar Harbor, ME

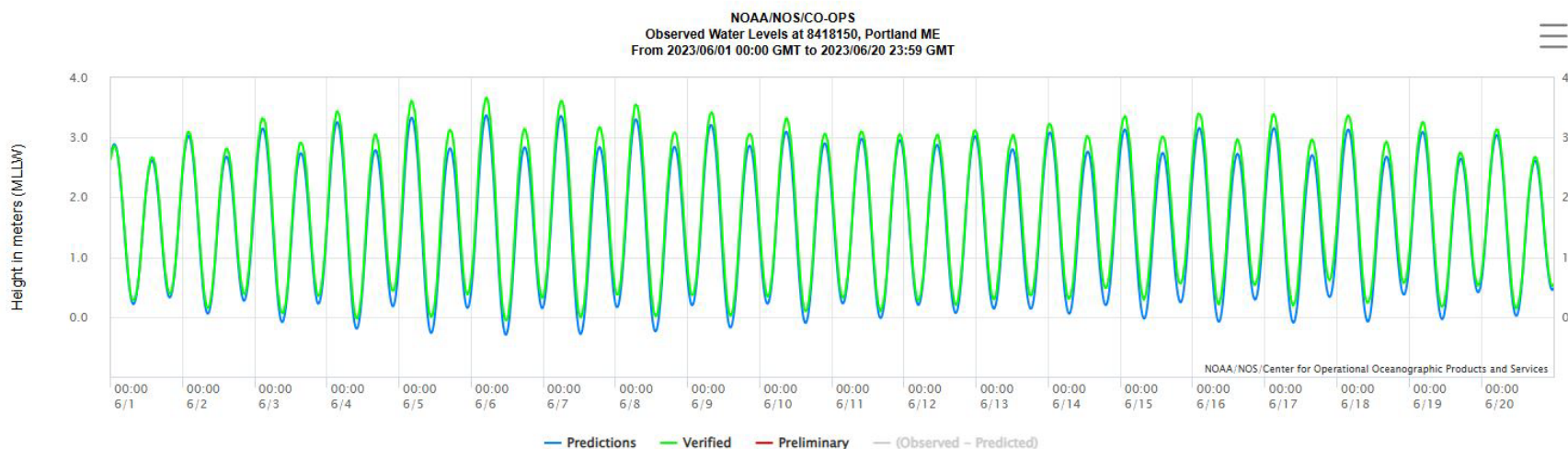
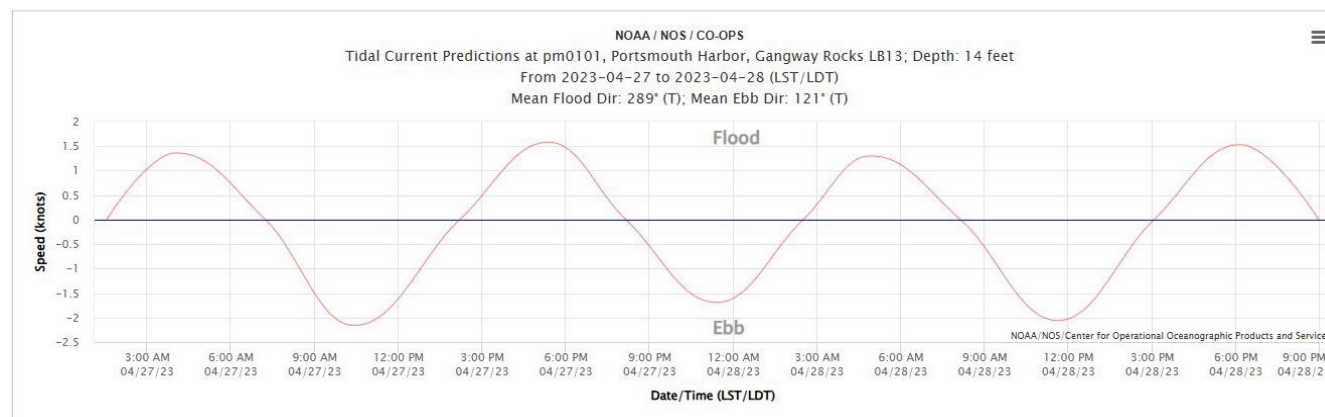


Figure 8: Tide Predictions and verified water levels at 8418150 during the time of turbidity and lidar acquisition near Portland, ME

Portsmouth Harbor, Gangway Rocks LB13 (pm0101) Depth: 14.4 feet

LAT/LON: 43.0784° N 70.7467° W

Note: Depth source is measured below surface.



Portsmouth Harbor, Gangway Rocks LB13 (pm0101) Depth: 14.4 feet

LAT/LON: 43.0784° N 70.7467° W

Note: Depth source is measured below surface.

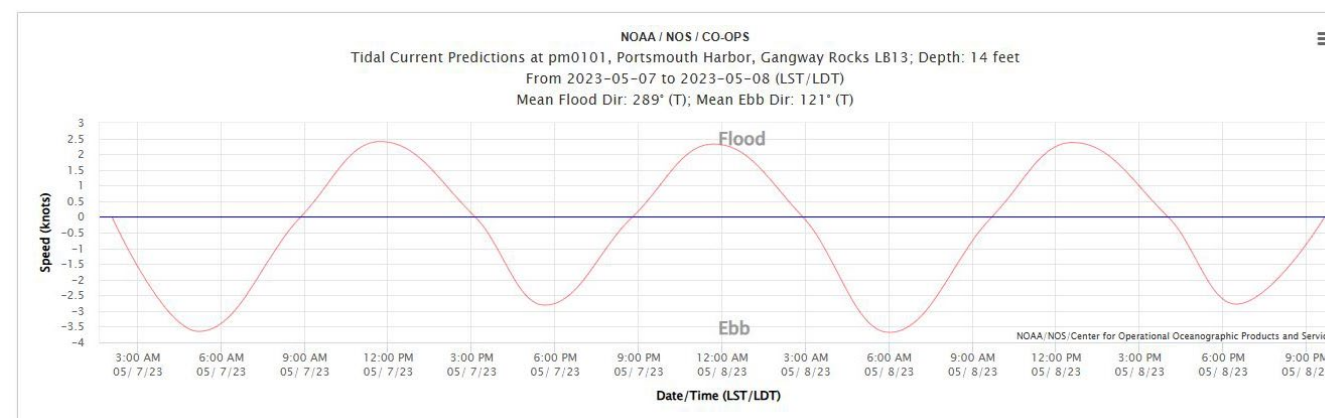


Figure 9: Tide Predictions at pm0101 during the time of turbidity (top) and lidar (bottom) acquisition near Portsmouth Harbor, ME

Airborne Survey

Lidar

The lidar survey was accomplished using the Leica Chiroptera/HawkEye 4X (CH4X/HE4X) and Leica Chiroptera/Hawkeye 5 (CH5/HE5) laser systems mounted in a Piper Navajo or Cessna Grand Caravan. Both Chiroptera and HawkEye systems acquire full waveform data for every pulse. The recorded waveform enables range measurements for all discernible targets for a given pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the lidar sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset. Table 5 summarizes the settings used to yield an average pulse density of ≥ 3 and ≥ 4 pulses/m² for bathymetric and NIR returns, respectively, over the NOAA Maine project area. Figure 10 shows the flightlines acquired using these lidar specifications.

Table 5: Lidar specifications and aerial survey settings

Parameter	NIR Sensor	Shallow Green Sensor	Deep Green Sensor
Acquisition Dates	10/6/2022 –12/15/2023	10/6/2022 –12/15/2023	10/6/2022 –12/15/2023
Aircraft Used	Piper Navajo Chieftan and Cessna Grand Caravan	Piper Navajo Chieftan and Cessna Grand Caravan	Piper Navajo Chieftan and Cessna Grand Caravan
Sensor	Leica Chiroptera 4X and 5	Leica Chiroptera 4X and 5	Leica HawkEye 4X and 5
Laser Channel	NIR	Green (shallow)	Green (deep)
Maximum Returns	5	15	4
Resolution/Density	Average 4 pulses/m ²	Average 3 pulses/m ²	Average 3 pulses/m ²
Nominal Pulse Spacing	0.50 m	0.57 m	0.57 m
Survey Altitude (AGL)	400 m	400 m	400 m
Survey speed	145 knots	145 knots	145 knots
Field of View	40°	40°	40°
Mirror Scan Rate	4200 RPM	3430 RPM	1833 RPM
Target Pulse Rate	250 kHz	35 kHz	10 kHz
Pulse Length	2.5 ns	2.5 ns	2.5 ns
Laser Pulse Footprint Diameter	20 cm	190 cm	300 cm
Central Wavelength	1064 nm	515 nm	515 nm
Beam Divergence	0.25 mrad, 0.50 mrad	4.00 mrad, 4.75 mrad	7.20 mrad, 7.50 mrad
Swath Width	291m	291 m	291 m
Swath Overlap	30%	30%	30%
Intensity	16-bit	16-bit	16-bit

All areas were surveyed with an opposing flight line side-lap of $\geq 30\%$ ($\geq 60\%$ overlap) to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y, and z), the positional coordinates of the airborne sensor and the orientation of the aircraft to the horizon (attitude) were recorded continuously throughout the lidar data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

Digital Imagery

Imagery was collected using a Leica ADS 100 orthoimagery sensor mounted in a Cessna Grand Caravan (Table 5). The ADS 100 is a large format digital aerial camera manufactured by Leica. The system allows for the collection of multispectral orthoimagery from nadir as well as forwards and backwards.

Table 5: Camera manufacturer’s specifications for an ADS 100

Parameter	ADS 100 Specification
Focal Length	62.5 mm
Spectral Bands	RGB NIR
Pixel Size	5.0 μm
Image Size	20,000 pixels wide
Frame Rate	1.8 seconds
FOV	65.2° forward, 77.3° nadir, and 71.4° backward
Image Format	8bit TIFF

For the NOAA Maine site, images were collected in four spectral bands (red, green, blue, and NIR) with 60% along track overlap and 30% sidelap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 25 cm. Orthophoto specifications particular to the NOAA Maine project are in Table 6.

Table 6: Project-specific orthophoto specifications

Parameter	Digital Orthophotography Specification
Ground Sampling Distance (GSD)	≤ 25 cm
Along Track Overlap	$\geq 60\%$
Cross Track Overlap	$\geq 30\%$
Height Above Ground Level (AGL)	304.8 meters

Additional information can be found in the “Data Acquisition Summary” report found in Appendix B: Imagery Reports.

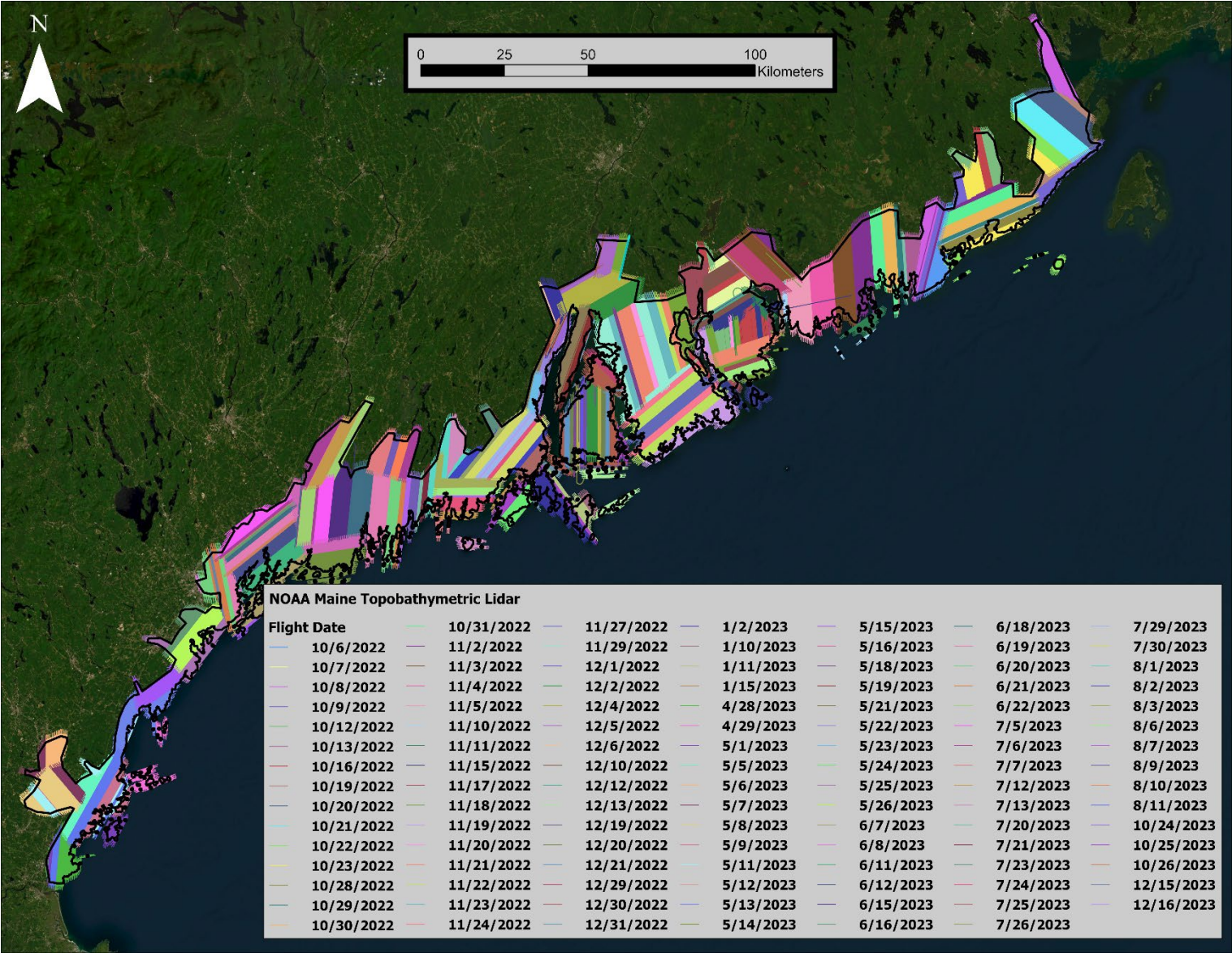


Figure 10: Flightlines map

Ground Survey

Ground control surveys, including aerial targets and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final lidar data and orthoimagery products.

Base Stations

Base stations were used for collecting ground survey points using real time kinematic (RTK) and total station (TS) survey techniques.

Base station locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NV5 utilized 18 permanent real-time network (RTN) base stations for the NOAA Maine Lidar project: 9 from the Hexagon SmartNet network¹ and 9 from the KeyNet network (Table 6, Figure 12). NV5's professional land surveyor, Steven J. Hyde (MEPLS#2600), oversaw and certified the ground survey. No physical monuments were utilized for this project.

¹ <https://hxgnsmartnet.com/0000000>

Table 6: Base station positions for the NOAA Maine acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Latitude	Longitude	Ellipsoid (meters)	Owner
BARH	44° 23' 42.13729"	-68° 13' 18.07884"	7.916	SMARTNET
GEOR	45° 07' 40.07861"	-66° 48' 31.41332"	53.896	KEYNET
MEBA	43° 54' 57.76359"	-69° 49' 32.11369"	3.580	KEYNET
MECC	44° 49' 33.20982"	-68° 44' 38.60212"	20.584	KEYNET
MEEL	43° 35' 37.20493"	-70° 13' 41.65873"	7.170	SMARTNET
MEGO	43° 40' 52.06769"	-70° 27' 03.72407"	89.967	SMARTNET
MELN	44° 05' 15.83631"	-70° 13' 55.24383"	46.066	SMARTNET
MEMA	44° 42' 35.48069"	-67° 27' 29.75473"	19.736	KEYNET
MEOW	44° 17' 45.93589"	-69° 44' 43.56967"	37.326	KEYNET
MEPH	44° 24' 18.25522"	-68° 01' 53.76231"	5.357	KEYNET
MERO	44° 06' 49.62298"	-69° 07' 07.12296"	8.770	KEYNET
MESB	43° 14' 05.59463"	-70° 48' 35.14744"	21.925	SMARTNET
MESN	43° 26' 51.55551"	-70° 46' 14.85949"	75.932	SMARTNET
MEWA	44° 27' 15.19254"	-69° 05' 49.48907"	50.726	SMARTNET
MEYA	43° 47' 54.60823"	-70° 11' 20.29914"	14.073	SMARTNET
NHPM	43° 02' 34.61765"	-70° 46' 29.12498"	-2.349	SMARTNET
STS2	45° 10' 43.26794"	-67° 18' 57.70506"	31.043	KEYNET
SVT1	43° 04' 01.29119"	-70° 46' 34.68683"	2.188	KEYNET

NV5 utilized static Global Navigation Satellite System (GNSS) data collected at 1 Hz recording frequency for each base station. During post-processing, the static GNSS data was triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS²) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

² OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions: [OPUS website](https://www.ngs.noaa.gov/OPUS/)

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic (RTK) and total station (TS) survey techniques. For RTK surveys, a roving receiver receives corrections from a nearby base station or Real-Time Network (RTN) via radio or cellular network, enabling rapid collection of points with relative errors less than 1.5 cm horizontal and 2.0 cm vertical. RTK surveys record data while stationary for at least five seconds, calculating the position using at least three one-second epochs. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. See Table 7 for NV5 ground survey equipment information.

Forested checkpoints are collected using total stations to measure positions under dense canopy. Total station backsight and setup points are established using GNSS survey techniques.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however, the distribution of GSPs depended on ground access constraints and monument locations and may not be equably distributed throughout the study area (Figure 12).

Table 7: NV5 ground survey equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R10	Integrated Antenna	TRMR10	Rover
Trimble M3 Total Station	NA	NA	VVA

Aerial Targets

Air target points (ATP) were collected throughout the project area prior to imagery acquisition to refine the exterior orientation parameters of the camera and conduct an accuracy assessment of the final orthophoto product (Figure 11). ATPs are typically collected over hard surface ground features or temporary vinyl chevrons. Hard surface points consist of high contrast road markings such as stop bars and turn arrows and cement corners. Each corner of the road marking is surveyed, in this way only one point was used for aerial triangulation while the remaining points are used for quality assurance purposes. Each ATP was surveyed using RTK techniques.




Figure 11: Example of an aerial target in the NOAA Maine project area. The image shows a dock near Buck's Harbor in Brooksville, Maine.

Land Cover Class

In addition to ground survey points, land cover class checkpoints were collected throughout the study area to evaluate vertical accuracy. Vertical accuracy statistics were calculated for all land cover types to assess confidence in the lidar derived ground models across land cover classes (Table 8, see Lidar Accuracy Assessments, page 46).

Table 8: Land Cover Types and Descriptions

Land cover type	Land cover code	Example	Description	Accuracy Assessment Type
Shrub	SH		Low growth shrub	VVA
Tall Grass	TG		Herbaceous grasslands in advanced stages of growth	VVA
Forest	FR		Forested areas	VVA
Bare Earth	BE		Areas of bare earth surface	NVA
Urban	UA		Areas dominated by urban development, including parks	NVA

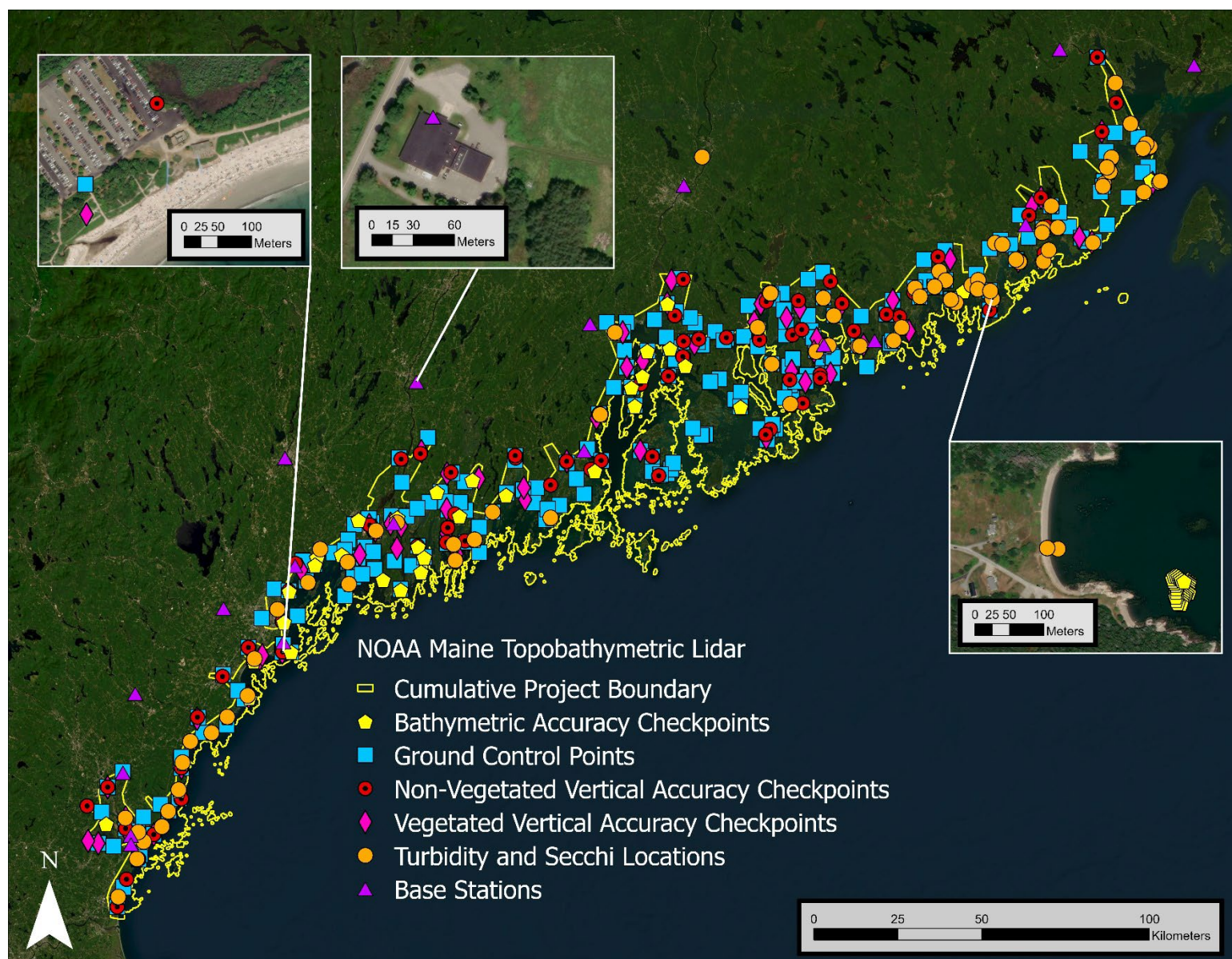


Figure 12: Ground survey location map

PROCESSING

This 30-meter lidar cross section shows a view of a local dock at the end of Bartlett's Landing Road in the Mount Desert Narrows in the NOAA Maine project area, colored by point classification.

- Default
- Ground
- Bathymetric Bottom
- Water Surface
- Water Column

Topobathymetric Lidar Data

Sensor calibration was performed for each system installation to minimize systematic errors. Upon lidar data acquisition, NV5 processing staff initiated a suite of automated and manual techniques to validate the data and create the contracted project deliverables. Processing tasks included GPS control computations, kinematic corrections, smoothed best estimate trajectory (SBET) calculations, laser point positioning, data calibration and adjustment for optimal relative and absolute accuracy, and lidar point classification, as shown in Table 10.

Bathymetric Lidar Data

Lidar Survey Studio (LSS) was used to perform bathymetric return processing. Synthetic water surface points were derived automatically by LSS based topographic channel information. Bathymetric returns were differentiated based on their location relative to the water surface model, then were spatially corrected for refraction through the water column based on the angle of incidence of the laser and the refractive index of the water. Additionally, a water scatter compensation factor was applied as described in the Lidar Boresight and Calibration Report deliverables.

The refracted returns were reviewed for errors and the resulting point cloud was classified using both manual and automated techniques. Processing methodologies were tailored to the Maine landscape. Brief descriptions of these tasks are shown in Table 10, and example raster layers for processing and review can be visualized in Figure 13.

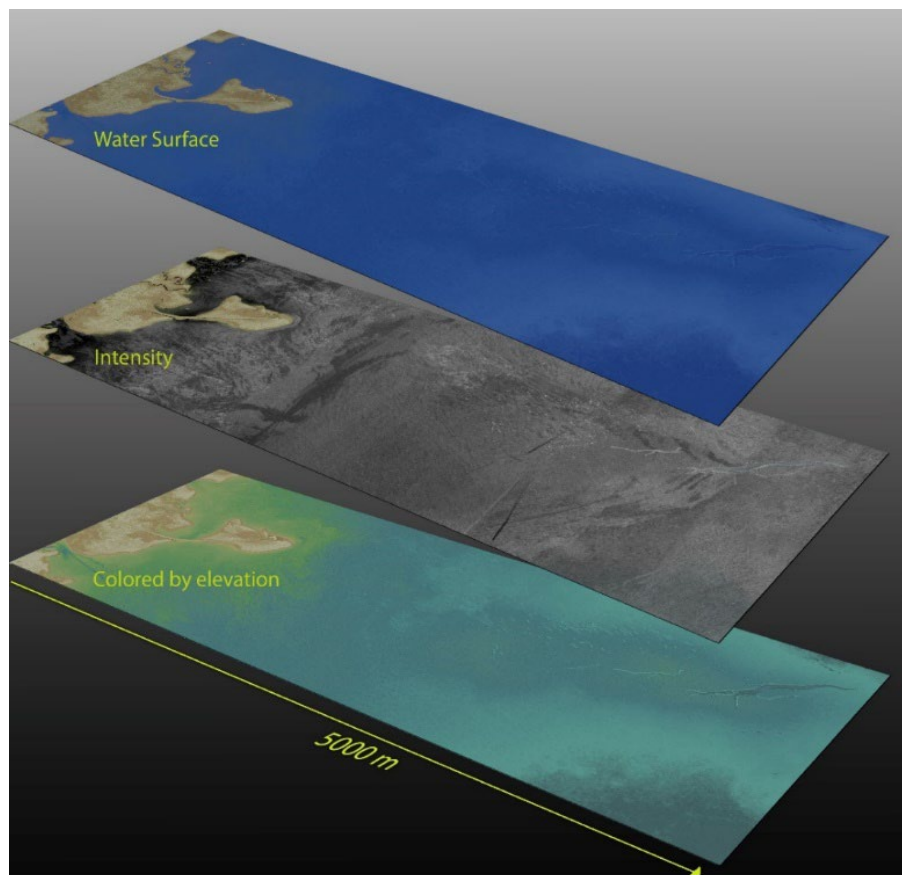


Figure 13: Example processing data layers

Table 9: ASPRS LAS classification standards applied to the NOAA Maine dataset

Classification Number	Classification Name	Classification Description
1	Unclassified	Processed, but unclassified
2	Ground	Bare-earth ground
7 Withheld	Low Noise	Noise (low manually identified)
18 Withheld	High Noise	Noise (high manually identified)
40	Bathymetric Bottom	Bathymetric point (e.g., seafloor or riverbed; also known as submerged topography)
41	Water Surface	Water's surface (sea/river/lake surface from topographic-bathymetric lidar).
42- Synthetic	Derived Water Surface	Synthetic water surface location used in computing refraction at water surface
43	Submerged Feature	Submerged object, not otherwise specified (e.g., wreck, rock, submerged piling)
44	S-57 Object	International Hydrographic Organization (IHO) S-57 object, not otherwise specified
45	Water Column	Refracted returns not determined to be water surface or bathymetric bottom
64	Submerged Aquatic Vegetation	Benthic vegetation in submerged, refracted areas
65	Overlap Bathymetric Bottom	Denotes bathymetric bottom temporal changes from varying lifts, not utilized in the bathymetric point class
71	Adjacent Lift Unclassified	Adjacent lift Unclassified associated with areas of overlap bathy bottom where temporal bathymetric differences are present
72	Adjacent Lift Ground	Adjacent lift Ground associated with areas of overlap bathy bottom where temporal bathymetric differences are present
81	Adjacent Lift Water Surface	Adjacent lift Water Surface associated with areas of overlap bathy bottom where temporal bathymetric differences are present
82-Synthetic	Adjacent Lift Derived Water Surface	Adjacent lift Synthetic derived water surface associated with areas of overlap bathy bottom where temporal bathymetric differences are present
85	Adjacent Lift Water Column	Adjacent lift Water Column associated with areas of overlap bathy bottom where temporal bathymetric differences are present

Classification Number	Classification Name	Classification Description
1-Withheld	Edge Clip	Unclassified points flagged as withheld. These are primarily “edge” points from the higher scan angle being removed.
1-Overlap Withheld	Unrefracted Green Chiroptera/HawkEye Points	Unrefracted green data from the Chiroptera/HawkEye systems.
Original SOW classification scheme		Delivered in LAS files
Additional classification codes		Delivered in LAS files
Original SOW classification code not used		Not delivered in LAS files
Deleted points		Not delivered in LAS files

Table 10: Lidar processing workflow

Lidar Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Inertial Explorer v.8.9
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	Lidar Survey Studio v.3.4.0 Las Projector 1.3 (NV5 proprietary software)
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.19.005
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale), and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	Lidar Survey Studio v.3.4.0
Apply refraction correction to all subsurface returns.	Lidar Survey Studio v.3.4.0
Classify resulting data to ground and other client designated ASPRS classifications (Table 9). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.19.005 TerraModeler v.19.003
Generate bare earth models as triangulated surfaces. Export all surface models as Cloud-Optimized GeoTIFFs at a 1-meter pixel resolution.	LasTools Software Suite Las Product Creator 4.0 (NV5 proprietary software) ArcMap v. 10.8
Normalize seabed intensity values for angle of incidence and depth and export intensity images as cloud optimized GeoTIFFs at a 1-meter pixel resolution.	Las Monkey v.2.6.8 (NV5 proprietary) Inpho OrthoVista v.14.0.3 Las Product Creator 4.0 (NV5 proprietary software)
Output standard deviation raster mosaics of ground, bathymetric bottom, and submerged objects as cloud optimized GeoTIFF format at a 1-meter pixel resolution.	LasTools Software Suite

Lidar-Derived Products

Because hydrographic laser scanners penetrate the water surface to map submerged topography, this affects how the data should be processed and presented in derived products from the lidar point cloud. The following section discusses certain derived products that vary from the traditional (NIR) specification and delivery format.

Topobathymetric DEMs

Bathymetric bottom returns can be limited by depth, water clarity, and bottom surface reflectivity. Water clarity and turbidity affect the depth penetration capability of the green wavelength laser by returning laser energy diminishing by scattering throughout the water column. Additionally, the bottom surface must be reflective enough to return the remaining laser energy back to the sensor at a detectable level. The predicted depth penetration range of the Chiroptera CH4X and CH5 sensors are 1.5- and 1.8-times the recorded Secchi depth, respectively, and both HawkEye sensors are 3 times the recorded Secchi depth on brightly reflective surfaces. Therefore, it is not unexpected to have no bathymetric bottom returns in turbid or non-reflective areas. Since the HawkEye sensor is designed specifically for deeper waters, it is expected to have fewer returns in shallower waters.

As a result, creating digital elevation models (DEMs) presents a challenge with respect to interpolation of bathymetric areas without returns. Traditional DEMs are “unclipped,” meaning areas lacking ground returns are interpolated from neighboring ground or bathymetric bottom returns, with the assumption that the interpolation is close to reality. In bathymetric modeling, these assumptions are prone to error because a lack of bathymetric returns can indicate an increase in depth that the sensor cannot detect. The resulting bathymetric void areas may suggest greater depths, rather than similar elevations from neighboring bathymetric bottom returns. Therefore, a shapefile delineating bathymetric voids was created to control the extent of the delivered bare earth topobathymetric model to avoid false triangulation (interpolation from TIN’ing) across areas without mapped bathymetry.

Normalized Seabed Reflectance

A lidar echo return signal has a recorded amplitude associated for each point and is logged in LAS files as an Intensity record. Laser return intensity is generally a unitless measure of discrete return signal strength, stored as a 16-bit integer value (0 to 65,535). Intensity values roughly correspond to the reflectivity of the surface, which is a function of surface material composition. The magnitude of intensity values can vary across similar surfaces due to variability in atmospheric conditions, water clarity, range, submerged depth, and the angle of incidence on the object. The result is line to line inconsistency and streaking in the images that can reduce the utility of these data for analytics. The Intensity value in the LAS file has been updated with corrected values that have normalized the effects of the variables described above.

When a laser pulse enters the water column, the return signal fades exponentially with depth (Figure 14, Figure 15); the diminishing rate depends on water properties such as turbidity and composition. This exponential decay can be corrected after determining the rate of decline by comparing similar

substrates across multiple flightlines and varying depths. The seabed intensity values for this dataset have been normalized for depth, angle of incidence, and absolute flying altitude (Figure 16). Please note that intensity values are still subject to localized changes of water properties within the water column across a water body.

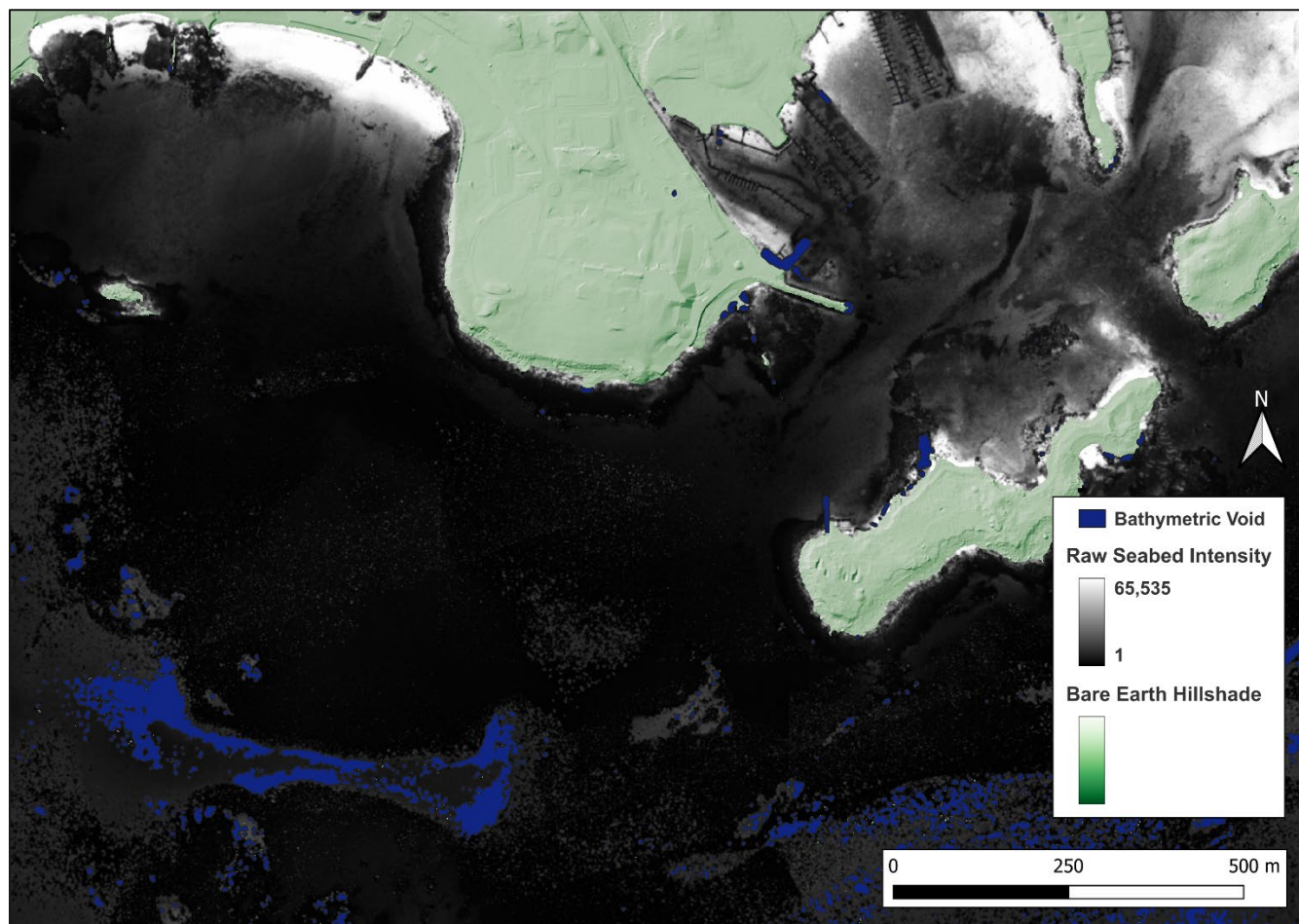


Figure 14: An Example of Raw Seabed Intensity values

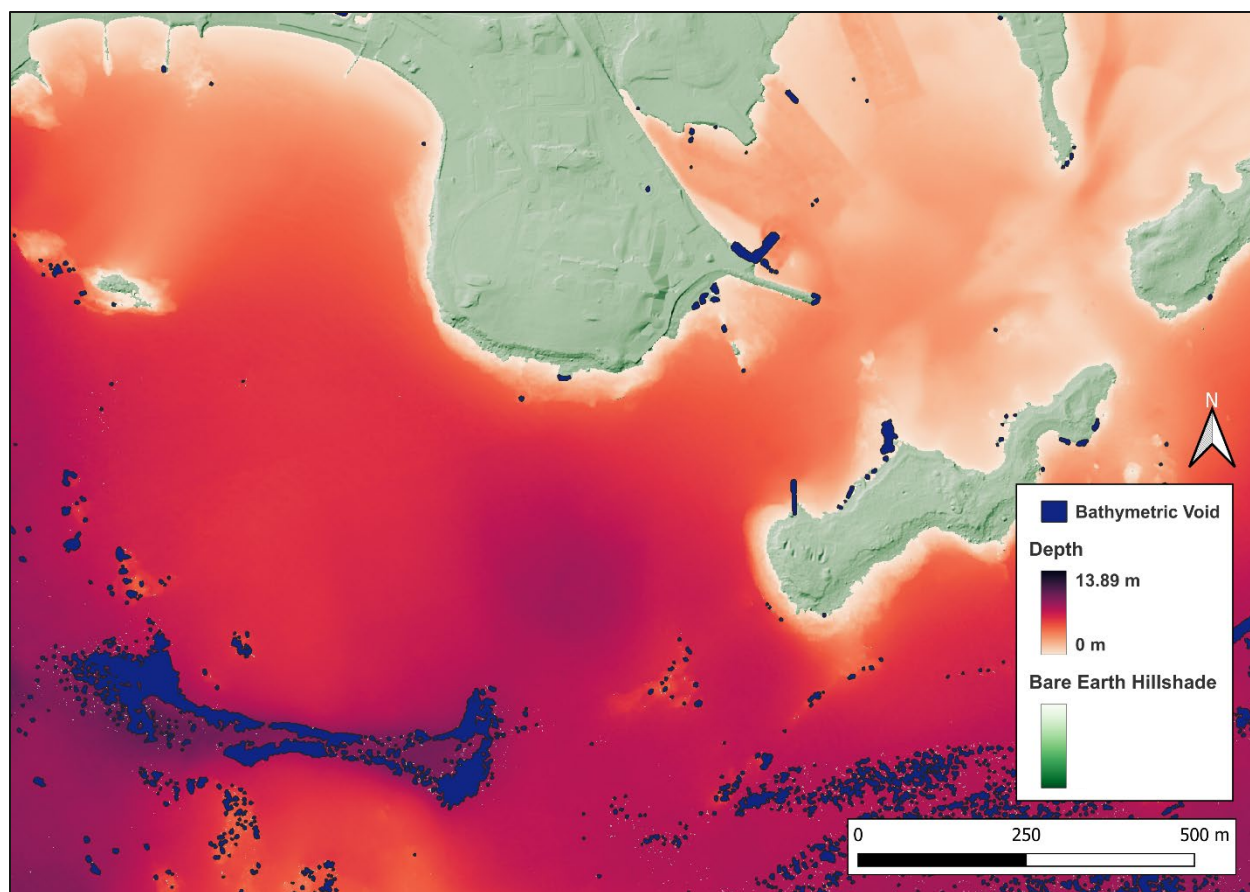


Figure 15: Depth raster shows an example of areas of deeper bathymetry which correlated to diminished seabed intensity values.

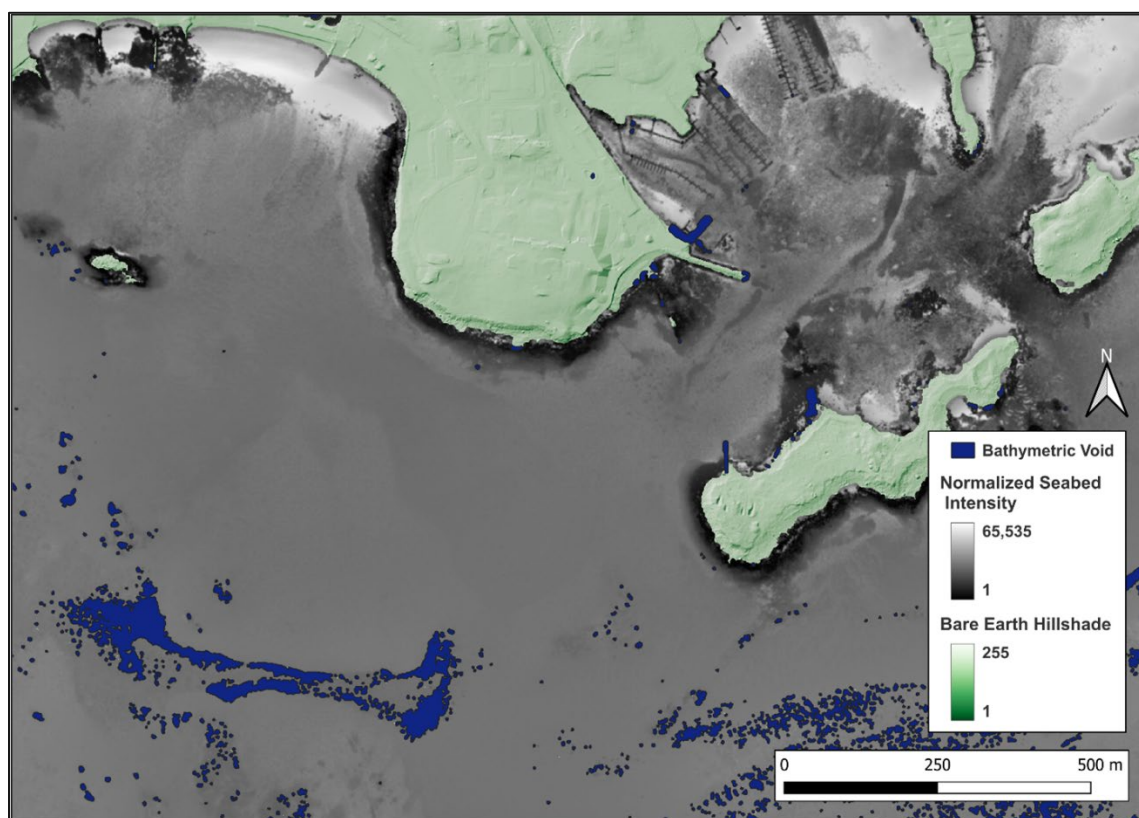


Figure 16: An example of seabed Intensity values that were normalized for depth, angle of incidence, and absolute flying altitude.

Total Propagated Uncertainty

In conjunction with NOAA NGS's effort to maintain and update nautical charts, NV5 supports the need for mapping total propagated uncertainty (TPU) of the NOAA Maine Bathymetric Lidar data. Total propagated uncertainty (TPU) values are dependent on both horizontal and vertical uncertainty calculations for bathymetric bottom lidar returns. NOAA's cBlue software was used for calculating the uncertainty estimates.³ The cBlue tool computes subaerial components of the laser pulse's travel path utilizing information from associated smoothed best estimate of trajectories (SBETs) and lidar sensor model. cBLUE calculates the subaqueous components of a bathymetric laser pulse with Monte Carlo ray tracing simulations that consider environmental factors at the time of lidar acquisition such as wind speed, water clarity, and depth. The resulting subaerial and subaqueous estimates of uncertainty are combined to produce total propagated horizontal and vertical uncertainty values at 95% confidence.

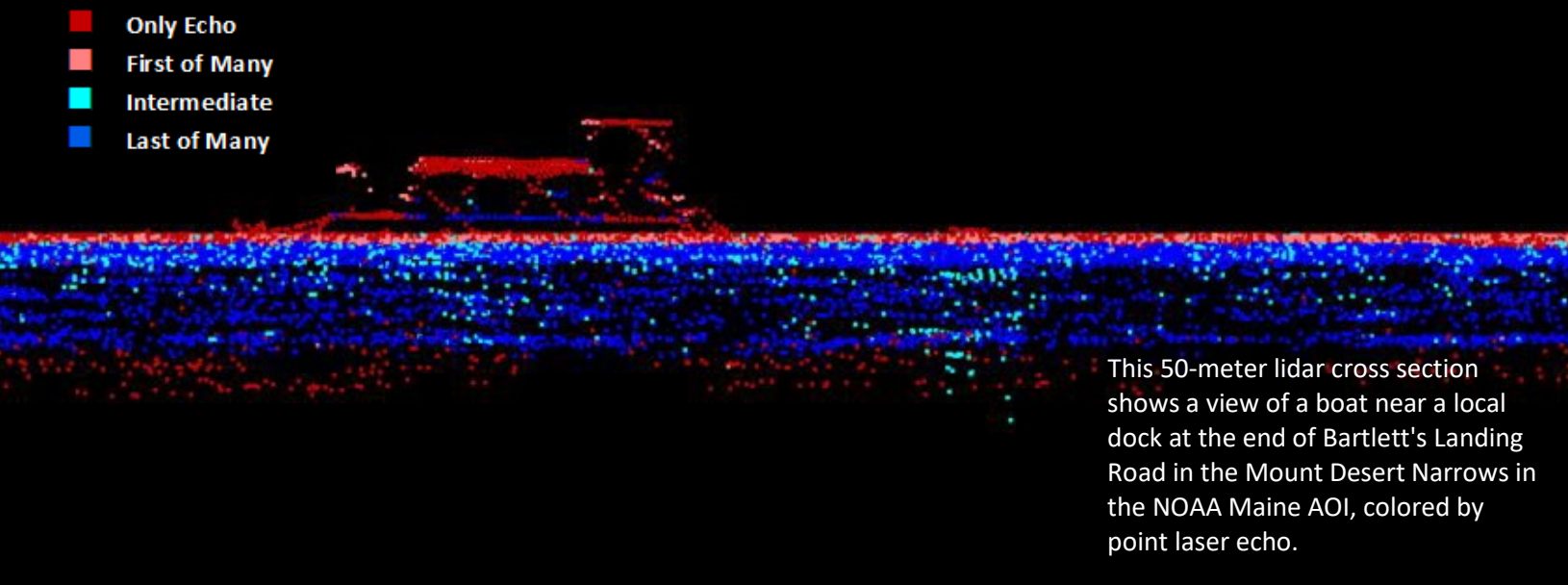
cBLUE outputs javascript object notation (json) metadata files and LAS files appended with TPU data stored in extra bytes. NV5 created 2-band raster models with 1 square meter resolution using bathymetric bottom or submerged object classified points. Band 1 holds the total horizontal uncertainty (THU) 95% confidence values; Band 2 holds the total vertical uncertainty (TVU) 95% confidence values.

Digital Imagery

Novatel SPAN GNSS/ IMU processing was used to orient the plane. The GNSS and IMU were processed using Inertial Explorer. Please see the "Airborne Positioning and Orientation" report for more details on this process. The GNSS/ IMU were used as control and to refine aerotriangulation of the imagery to provide the best accuracy and quality of the images. For more information on the aerotriangulation process used, refer to the "Aerotriangulation Report" in Appendix B: Imagery Reports.

³ NOAA cBlue: <https://noaa-rsd.github.io/cBLUE.github.io/index.html>

RESULTS & DISCUSSION



Bathymetric Lidar

An underlying principle for collecting hydrographic lidar data is to survey near-shore areas that can be difficult to collect with other methods, such as multi-beam sonar, particularly over large areas. The capability and effectiveness of the bathymetric lidar is impacted by several parameters including depth penetrations below the water surface, bathymetric return density, and spatial accuracy.

Mapped Bathymetry

Under optimal conditions, the specified depth penetration range of the CH 4X is about 1.5 Secchi depths, the CH5 about 1.8 Secchi depths, and both HawkEye sensors are about 3 Secchi depths; therefore, bathymetry data below these depths at the time of acquisition are not to be expected. Since the HawkEye sensors are designed specifically for deeper waters, there were fewer returns from these sensors in shallower areas, which were acquired using the shallow green sensor. To assist in evaluating performance results of the sensor, a polygon layer was created to delineate areas where bathymetry was successfully mapped.

This shapefile was used to control the extent of the delivered clipped topo-bathymetric model and to avoid false triangulation across areas in the water with no returns. Insufficiently mapped areas were identified by triangulating bathymetric bottom points with an edge length maximum of 4.56 meters. This ensured all areas of no returns ($> 9 \text{ m}^2$), were identified as data voids.

Lidar Point Density

First Return Point Density

The acquisition parameters were designed to acquire an average first-return density of 4 points/m² in terrestrial areas and 3 points/m² for bathymetric areas. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in the first return density analysis. Some types of surfaces (e.g., breaks in terrain, water, and steep slopes) may have returned fewer pulses than originally emitted by the laser.

First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas, the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The average first-return density for the NOAA Maine Lidar project was 8.93 points/m² for the NIR sensor and 2.75 points/m² for the green sensors (Table 11). First return density for green channel pulses is reduced over deep, calm water due to limited bottom detection and lower water surface reflectivity, resulting in fewer detected returns than pulses emitted. All areas within the AOI, including zones of full extinction, were included in the density reporting, which contributed to a lower overall average. The statistical and spatial distributions of all first return densities per 100 m x 100 m cell are portrayed in Figure 17 through Figure 19 and Figure 21.

Bathymetric and Ground Classified Point Densities

The density of ground classified lidar returns and bathymetric bottom returns were also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may have penetrated tree canopy, resulting in lower ground density. Similarly, the density of bathymetric bottom returns was influenced by turbidity, depth, and bottom surface reflectivity. In turbid areas, fewer pulses may have penetrated the water surface, resulting in lower bathymetric density.

The ground and bathymetric bottom classified density of lidar data for the NOAA Maine project was 3.63 points/m². The return density for each delivery is shown in Table 11. The statistical and spatial distributions per 100 m x 100 m cell of the ground and bathymetric bottom classified return densities are portrayed in Figure 20 and Figure 22.

Additionally, for the NOAA Maine project, density values of only bathymetric bottom returns were calculated for areas containing at least one bathymetric bottom return. Areas lacking bathymetric returns (voids) were not considered in calculating an average density value. Within the successfully mapped area, a bathymetric bottom return density of 5.05 points/m² was achieved.

Table 11: Average lidar point densities

Delivery	Block	NIR First Returns	Green First Returns	Combined First Returns	Ground and Bathymetric Bottom Classified Returns	Bathymetric Bottom Classified Returns
D1	A	11.57 points/m ²	1.67 points/m ²	13.24 points/m ²	4.70 points/m ²	0.62 points/m ²
D1	B	9.46 points/m ²	2.56 points/m ²	12.01 points/m ²	3.42 points/m ²	0.66 points/m ²
D2	C	9.30 points/m ²	2.34 points/m ²	11.64 points/m ²	3.96 points/m ²	0.66 points/m ²
D2	D	11.38 points/m ²	1.87 points/m ²	13.25 points/m ²	4.63 points/m ²	0.86 points/m ²
D2	E	7.18 points/m ²	3.58 points/m ²	10.76 points/m ²	3.08 points/m ²	3.81 points/m ²
D3	F	8.93 points/m ²	2.56 points/m ²	11.48 points/m ²	4.68 points/m ²	0.63 points/m ²
D3	G	8.62 points/m ²	2.99 points/m ²	11.61 points/m ²	3.35 points/m ²	0.73 points/m ²
D4	H	8.93 points/m ²	2.23 points/m ²	11.15 points/m ²	2.81 points/m ²	0.54 points/m ²
D4	I	10.27 points/m ²	2.07 points/m ²	12.34 points/m ²	4.31 points/m ²	0.32 points/m ²
D4	J	5.52 points/m ²	4.69 points/m ²	10.21 points/m ²	1.90 points/m ²	0.68 points/m ²
Cumulative	A-J	8.93 points/m ²	2.75 points/m ²	11.68 points/m ²	3.65 points/m ²	0.69 points/m ²

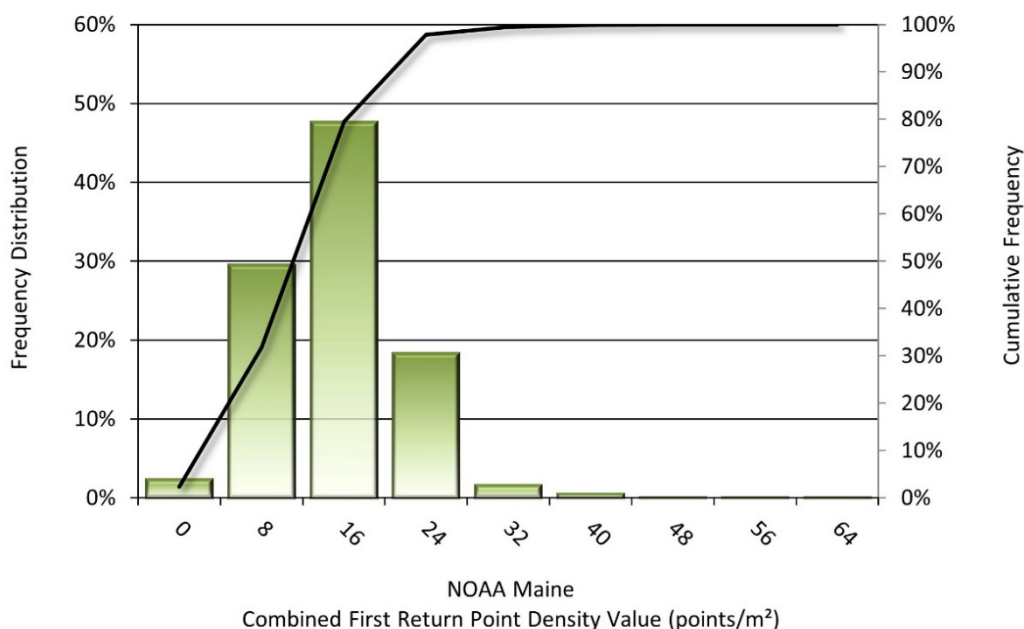


Figure 17: Frequency distribution of first return densities per 100 x 100 m cell for all the sensors

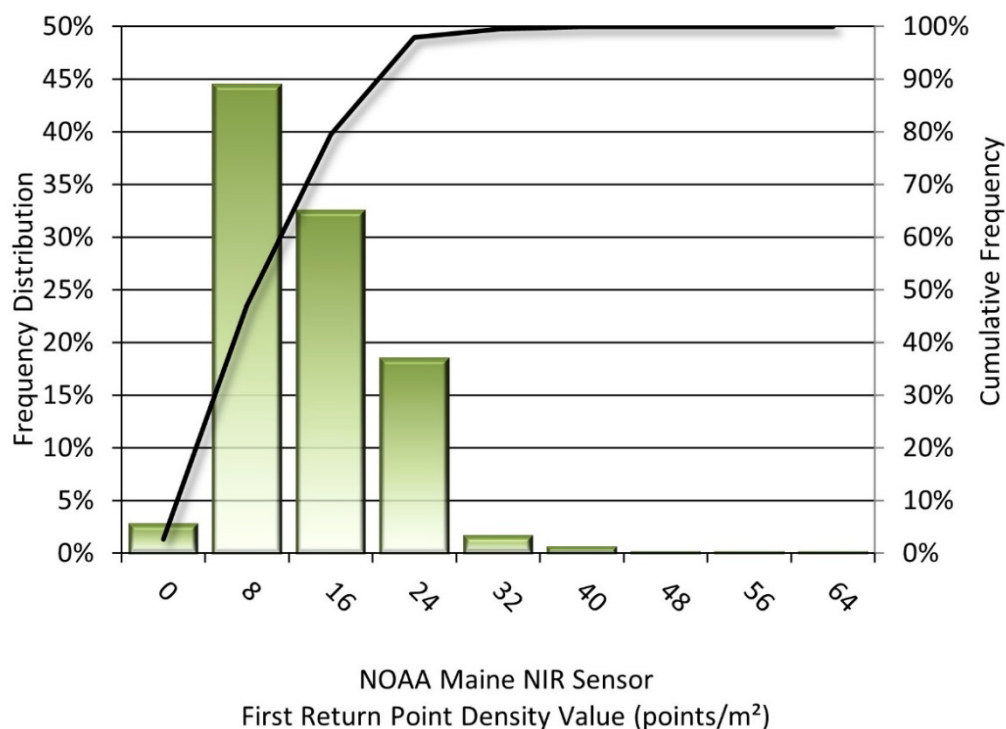


Figure 18: Frequency distribution of NIR sensor first return densities per 100 x 100 m cell for the NIR sensor

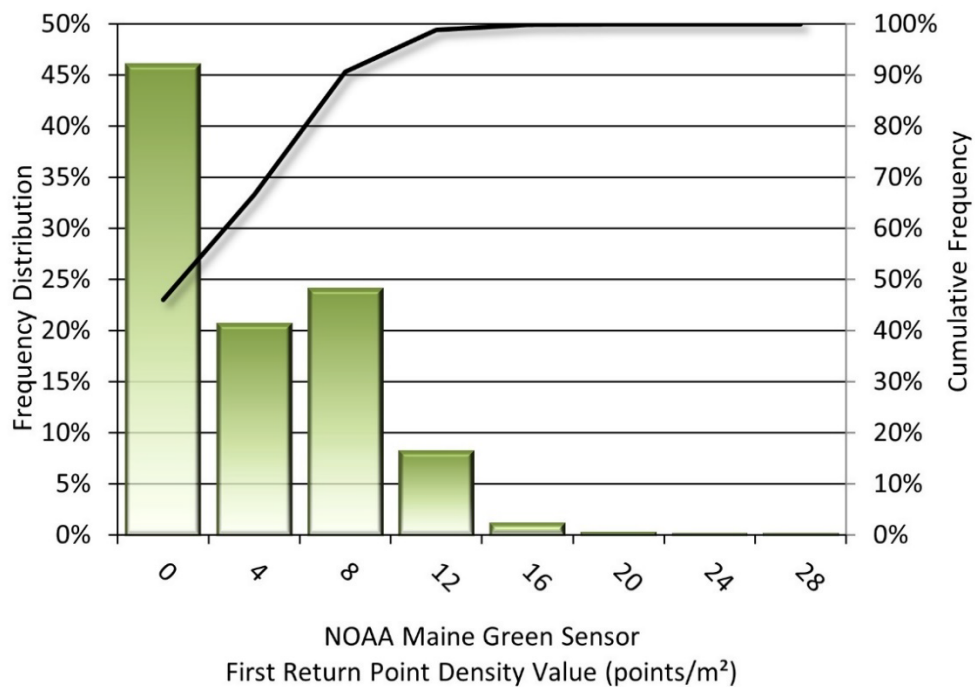


Figure 19: Frequency distribution of Green sensor first return densities per 100 x 100 m cell for the green sensor

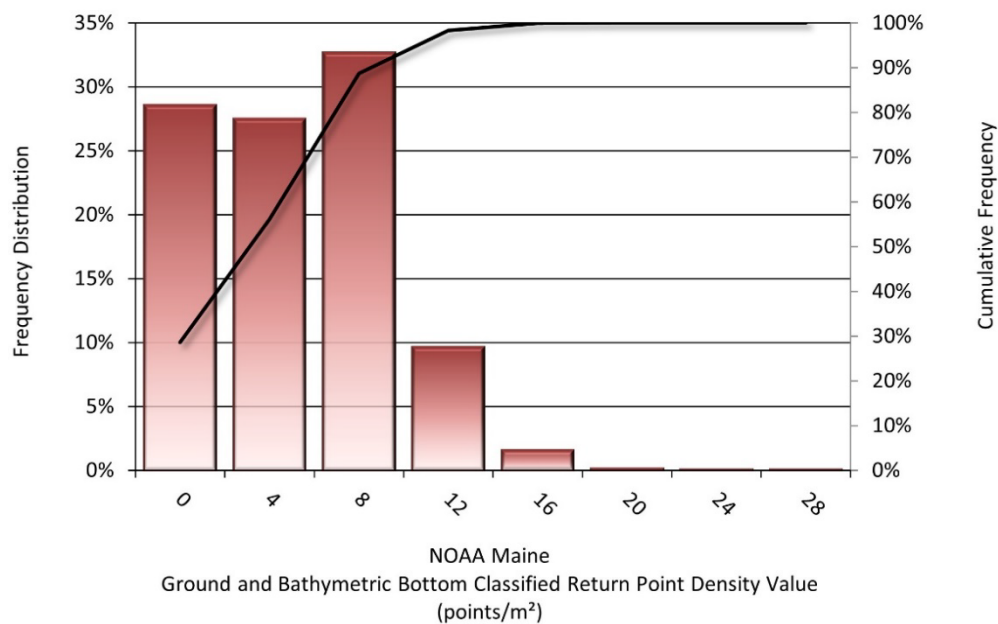


Figure 20: Frequency distribution of ground and bathymetric bottom classified return densities per 100 x 100 m cell for all the sensors

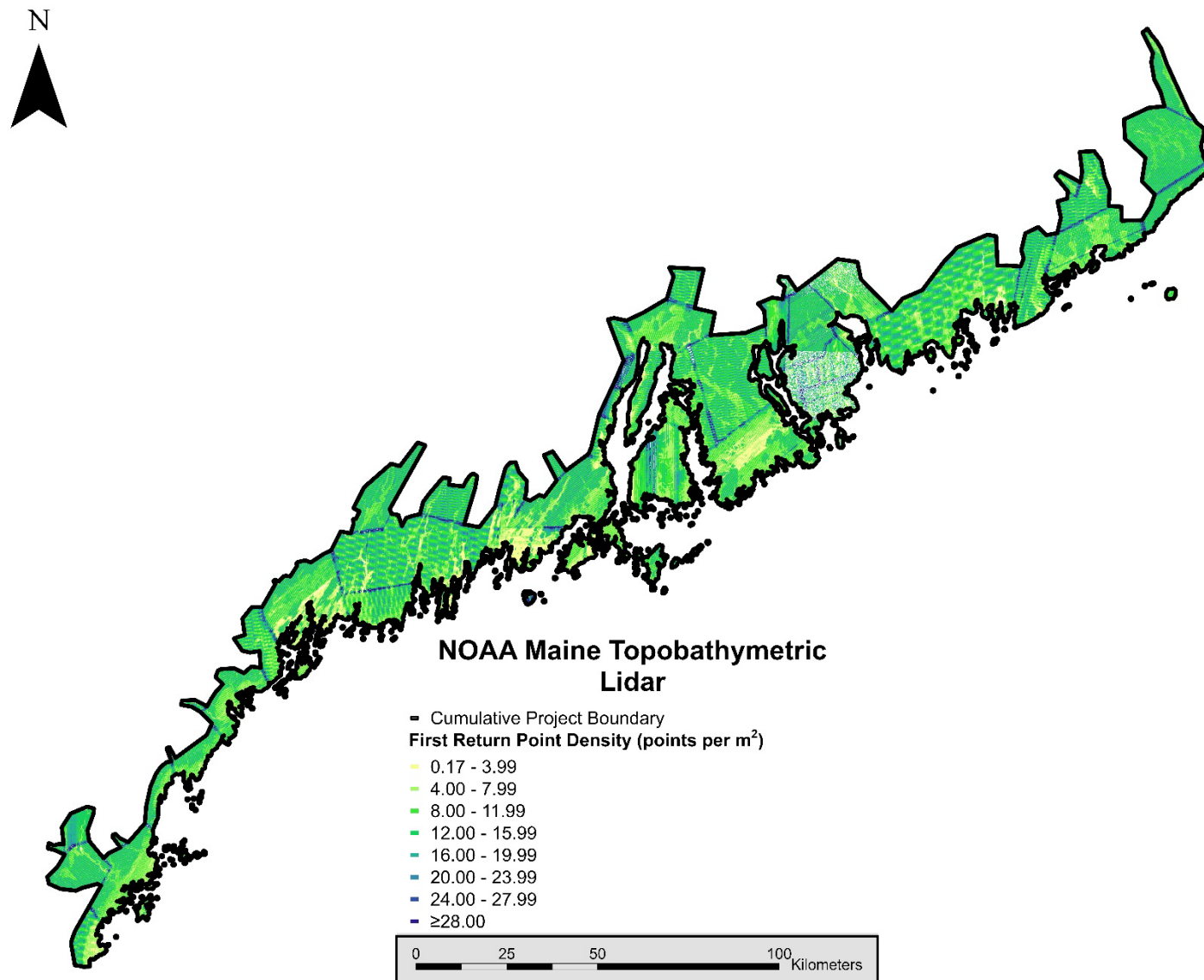


Figure 21: First return density map for the NOAA Maine site (100 m x 100 m cells)

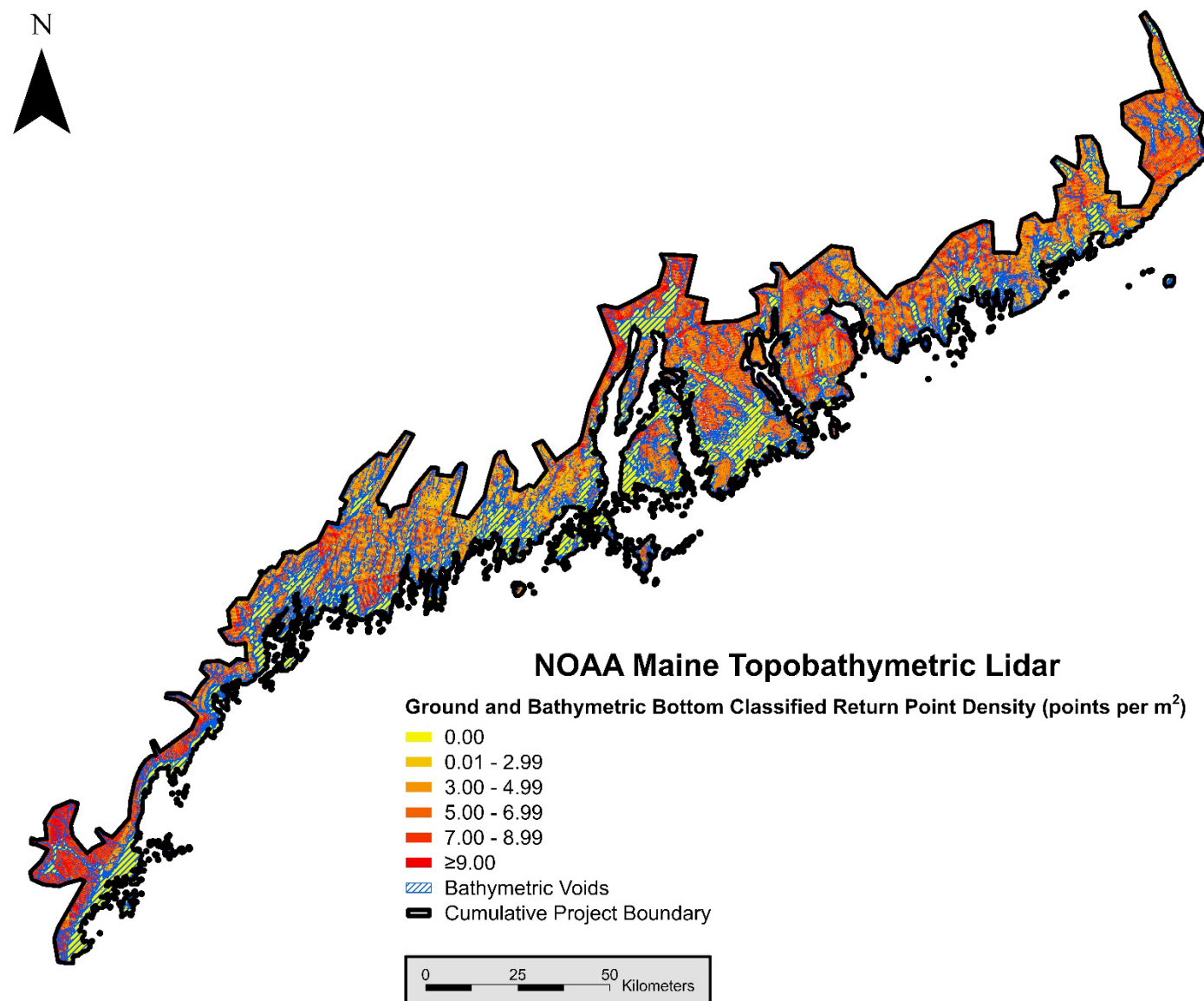


Figure 22: Ground and bathymetric bottom density map for the NOAA Maine site (100 m x 100 m cells)

Lidar Accuracy Assessments

The accuracy of the lidar data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

Lidar Non-Vegetated Vertical Accuracy

Absolute accuracy was assessed using Non-vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy.⁴ NVA compares known ground check point data that were withheld from the calibration and post-processing of the lidar point cloud to the triangulated surface generated by the classified lidar point cloud as well as the derived gridded bare earth DEM. NVA is a measure of the accuracy of lidar point data in open areas where the lidar system has a high probability of measuring the ground surface. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a 19.6 (cm) RMSE_v Vertical Accuracy Class (Table 12 and Table 13).

The mean and standard deviation (σ) of divergence of the ground surface model from ground check point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y, and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the NOAA Maine survey, 80 ground checkpoints were withheld from the calibration and post-processing of the lidar point cloud. The Non-Vegetated Vertical Accuracy (NVA) was found to be RMSE_v = 0.027 m as compared to classified LAS, and RMSE_v = 0.029 m as compared to the bare earth DEM (Figure 23 and Figure 24).

NV5 also assessed absolute accuracy using a total of 216 ground control points. Although these points were used in the calibration and post-processing of the lidar point cloud, they still provide a good indication of the overall accuracy of the lidar dataset and have therefore been provided in Table 14 and Figure 25.

⁴ Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA Edition 2, Version 2, 2024. <https://publicdocuments.asprs.org/PositionalAccuracyStd-Ed2-V2>

Table 12: NVA, as compared to Classified LAS

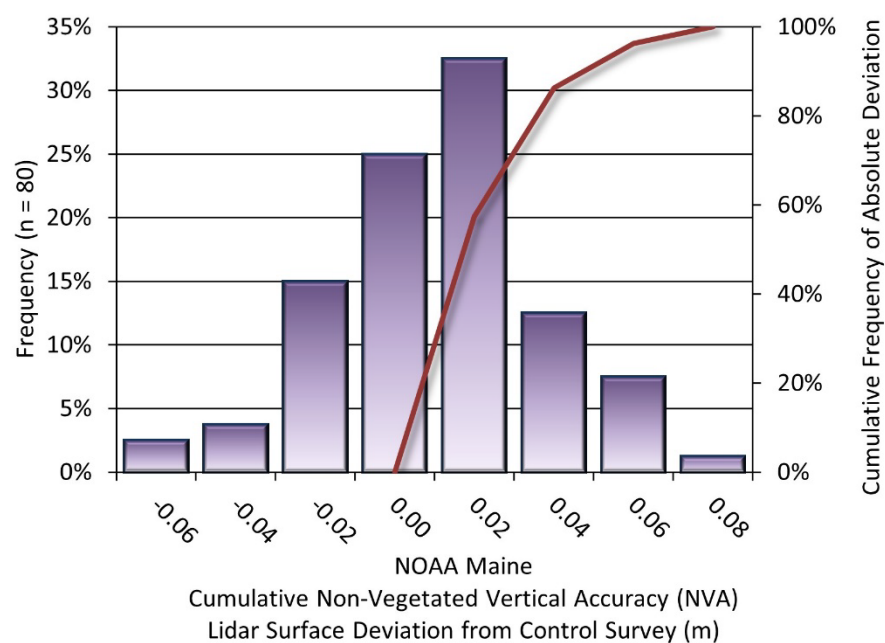
Delivery	Block	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	A	5	0.069 m	0.011 m	0.002 m	0.035 m	0.037 m
D1	B	7	0.069 m	-0.009 m	-0.010 m	0.035 m	0.037 m
D2	C	6	0.057 m	0.015 m	0.010 m	0.029 m	0.028 m
D2	D	9	0.041 m	0.003 m	0.011 m	0.021 m	0.022 m
D2	E	6	0.032 m	0.000 m	0.006 m	0.016 m	0.018 m
D3	F	15	0.040 m	-0.012 m	-0.006 m	0.020 m	0.017 m
D3	G	9	0.069 m	0.011 m	0.016 m	0.035 m	0.036 m
D4	H	8	0.053 m	-0.016 m	-0.008 m	0.027 m	0.024 m
D4	I	11	0.059 m	0.020 m	0.026 m	0.030 m	0.024
D4	J	4	0.017 m	0.005 m	0.002 m	0.009 m	0.008 m
Cumulative	A-J	80	0.053 m	0.002 m	0.003 m	0.027 m	0.027 m

Table 13: NVA, as compared to Bare Earth DEM

Delivery	Block	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	A	5	0.066 m	0.009 m	-0.008 m	0.034 m	0.036 m
D1	B	7	0.071 m	-0.004 m	0.010 m	0.036 m	0.039 m
D2	C	6	0.043 m	0.005 m	0.000 m	0.022 m	0.024 m
D2	D	9	0.067 m	0.007 m	0.006 m	0.034 m	0.036 m
D2	E	6	0.057 m	0.008 m	0.013 m	0.029 m	0.031 m
D3	F	15	0.045 m	-0.011 m	-0.016 m	0.023 m	0.021 m
D3	G	9	0.064 m	0.007 m	0.011 m	0.033 m	0.034 m
D4	H	8	0.053 m	-0.017 m	-0.022 m	0.027 m	0.023 m
D4	I	11	0.057 m	0.022 m	0.020 m	0.029 m	0.021 m
D4	J	4	0.022 m	0.008 m	0.007 m	0.011 m	0.009 m
Cumulative	A-J	80	0.056 m	0.002 m	0.003 m	0.029 m	0.029 m

Table 14: Ground Control Points

Delivery	Block	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	A	12	0.049 m	-0.006 m	-0.005 m	0.025 m	0.026 m
D1	B	14	0.049 m	-0.013 m	-0.009 m	0.025 m	0.022 m
D2	C	17	0.061 m	0.001 m	0.007 m	0.031 m	0.032 m
D2	D	31	0.062 m	-0.007 m	-0.007 m	0.031 m	0.031 m
D2	E	20	0.045 m	-0.009 m	-0.013 m	0.023 m	0.022 m
D3	F	28	0.042 m	0.000 m	0.002 m	0.021 m	0.022 m
D3	G	31	0.056 m	-0.002 m	-0.009 m	0.028 m	0.029 m
D4	H	19	0.078 m	-0.003 m	0.002 m	0.040 m	0.041 m
D4	I	27	0.046 m	0.006 m	0.005 m	0.023 m	0.023 m
D4	J	17	0.038 m	0.001 m	-0.007 m	0.019 m	0.020 m
Cumulative	A-J	216	0.054 m	-0.003 m	-0.004 m	0.027 m	0.027 m

**Figure 23: Frequency histogram for classified LAS deviation from ground check point values**

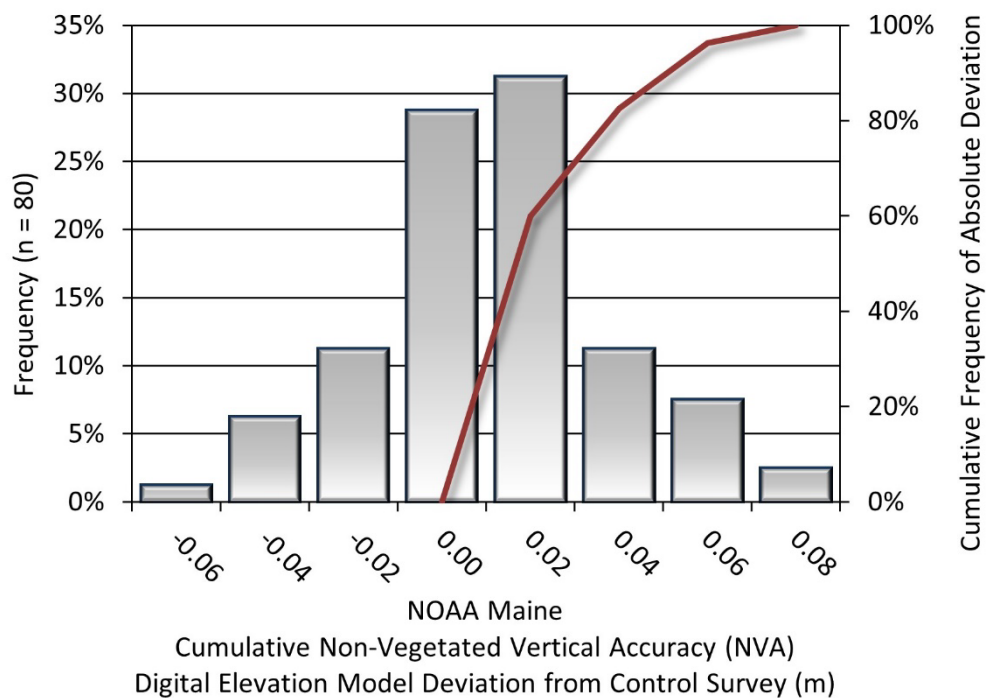


Figure 24: Frequency histogram for lidar bare earth DEM deviation from ground check point values

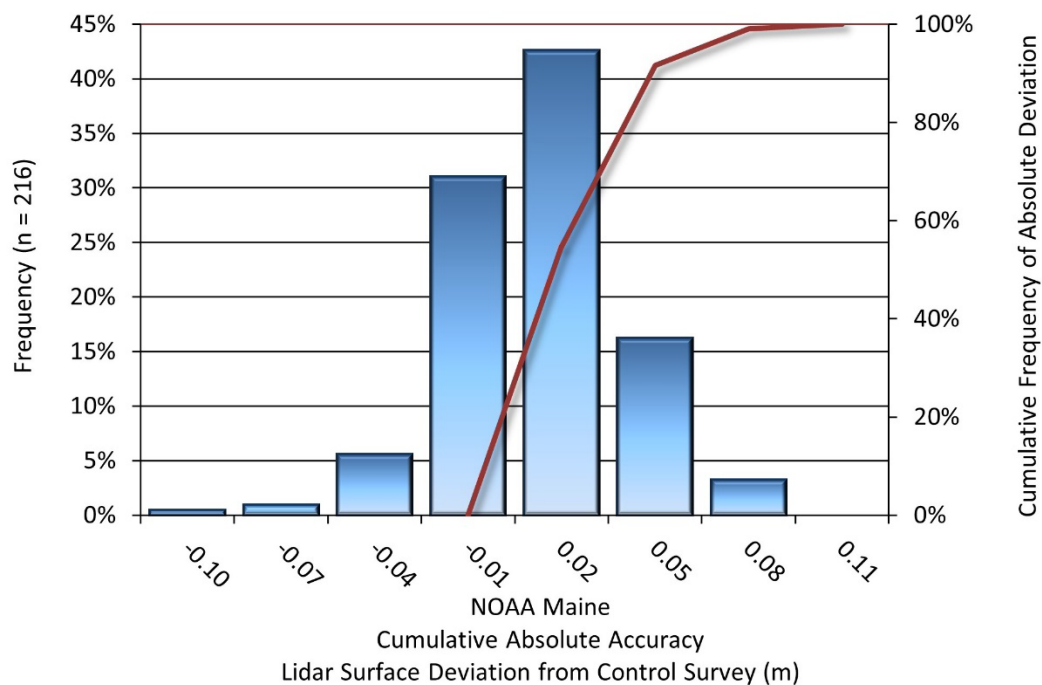


Figure 25: Frequency histogram for lidar surface deviation ground control point values

Lidar Vegetated Vertical Accuracies

NV5 also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground check point data collected over vegetated surfaces using land class descriptions to the triangulated ground surface generated by the ground classified lidar points. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a 29.4 (cm) RMSE_v Vertical Accuracy Class. The Vegetated Vertical Accuracy (VVA) was found to be RMSE_v = 0.120 m as compared to the classified LAS, and RMSE_v = 0.129 m as compared to the bare earth DEM (Table 15, Table 16, Figure 26, and Figure 27).

Table 15: VVA, as compared to Classified LAS

Delivery	Block	Sample	95 th Percentile	Average	Median	RMSE	Standard Deviation (1σ)
D1	A	2	0.326 m	0.308 m	0.308 m	0.309 m	0.028 m
D1	B	6	0.165 m	0.097 m	0.123 m	0.118 m	0.073 m
D2	C	5	0.109 m	0.056 m	0.086 m	0.076 m	0.058 m
D2	D	8	0.196 m	0.085 m	0.062 m	0.116 m	0.084 m
D2	E	3	0.101 m	0.076 m	0.064 m	0.078 m	0.026 m
D3	F	12	0.272 m	0.063 m	0.026 m	0.126 m	0.114 m
D3	G	9	0.241 m	0.105 m	0.095 m	0.131 m	0.084 m
D4	H	5	0.125 m	0.073 m	0.075 m	0.085 m	0.047 m
D4	I	8	0.100 m	0.060 m	0.078 m	0.079 m	0.056 m
D4	J	4	0.162 m	0.066 m	0.070 m	0.105 m	0.095 m
Cumulative	A-J	62	0.284 m	0.084 m	0.075 m	0.120 m	0.088 m

Table 16: VVA, as compared to Bare Earth DEM

Delivery	Block	Sample	95 th Percentile	Average	Median	RMSE	Standard Deviation (1 σ)
D1	A	2	0.353 m	0.308 m	0.308 m	0.312 m	0.071 m
D1	B	6	0.124 m	0.059 m	0.073 m	0.083 m	0.065 m
D2	C	5	0.147 m	0.072 m	0.102 m	0.098 m	0.074 m
D2	D	8	0.218 m	0.088 m	0.061 m	0.118 m	0.084 m
D2	E	3	0.141 m	0.109 m	0.115 m	0.113 m	0.038 m
D3	F	12	0.298 m	0.061 m	0.026 m	0.144 m	0.136 m
D3	G	9	0.251 m	0.104 m	0.090 m	0.137 m	0.095 m
D4	H	5	0.148 m	0.079 m	0.075 m	0.098 m	0.065 m
D4	I	8	0.169 m	0.087 m	0.093 m	0.112 m	0.075 m
D4	J	4	0.177 m	0.068 m	0.060 m	0.110 m	0.099 m
Cumulative	A-J	62	0.257 m	0.087 m	0.076 m	0.129 m	0.098 m

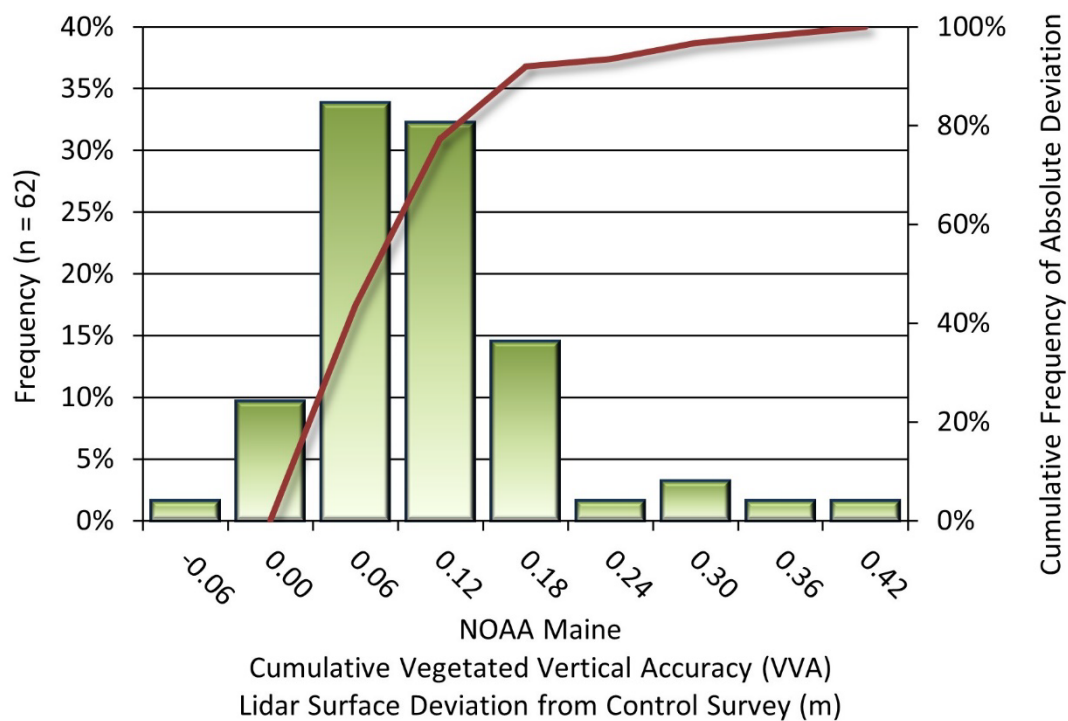


Figure 26: Frequency histogram for lidar surface deviation from all land cover class point values (VVA)

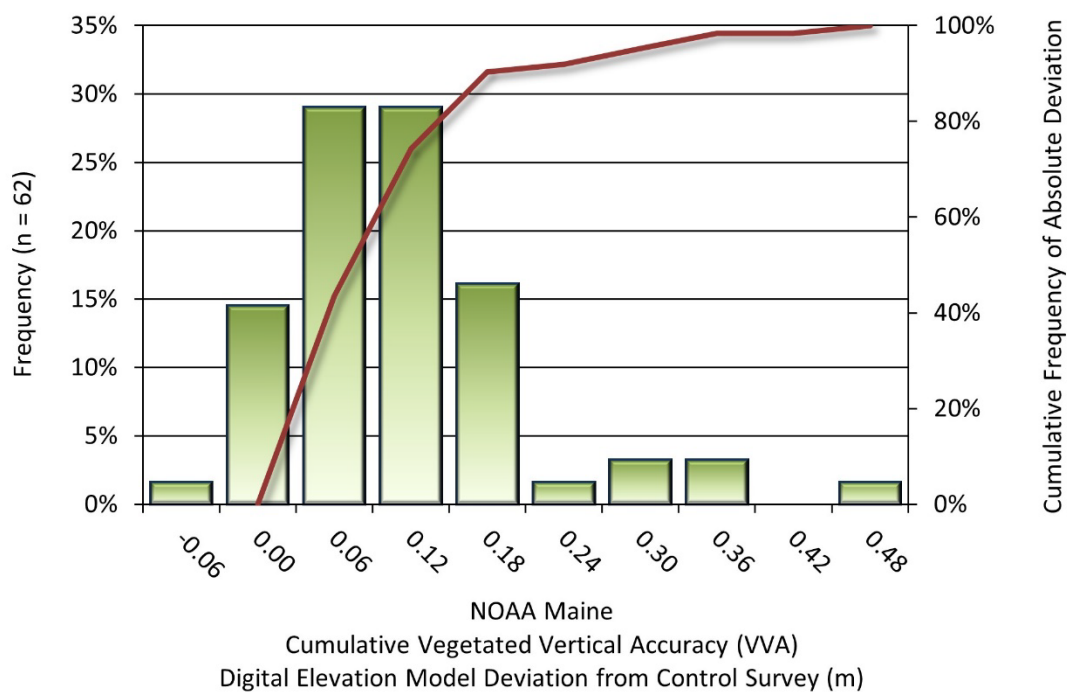


Figure 27: Frequency histogram for the lidar bare earth DEM deviation from vegetated check point values (VVA)

Lidar Bathymetric Vertical Accuracies

Bathymetric (submerged) checkpoints were also collected to assess the submerged surface vertical accuracy. In accessing a total of 1,245 submerged points, the Bathymetric Vertical Accuracy (BVA) was found to be $RMSE_v = 0.068$ m.

Table 17: Bathymetric accuracy

Delivery	Block	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1 σ)
D1	A	108	0.106 m	0.024 m	0.018 m	0.054 m	0.049 m
D1	B	90	0.169 m	0.064 m	0.061 m	0.086 m	0.058 m
D2	C	142	0.122 m	0.031 m	0.029 m	0.062 m	0.054 m
D2	D	123	0.146 m	0.044 m	0.053 m	0.074 m	0.060 m
D2	E	49	0.060 m	0.021 m	0.022 m	0.031 m	0.023 m
D3	F	160	0.141 m	0.040 m	0.037 m	0.072 m	0.060 m
D3	G	273	0.125 m	0.007 m	-0.001 m	0.064 m	0.063 m
D4	H	145	0.142 m	0.006 m	0.017 m	0.073 m	0.073 m
D4	I	62	0.103 m	0.014 m	0.023 m	0.053 m	0.051 m \leq
D4	J	93	0.154 m	0.019 m	0.028 m	0.079 m	0.077 m
Cumulative	A-J	1245	0.133 m	0.025 m	0.023 m	0.068 m	0.063 m

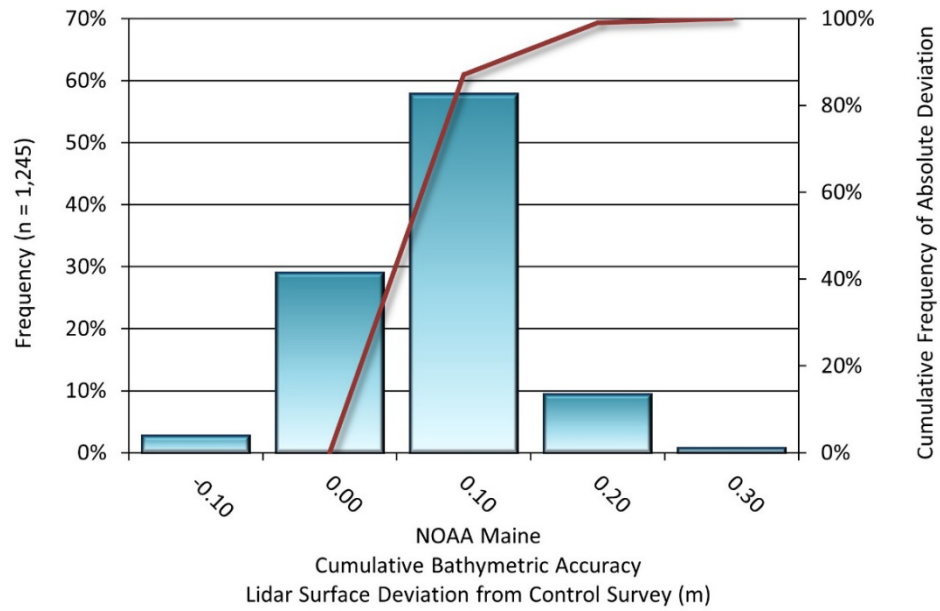


Figure 28: Frequency histogram for lidar surface deviation from submerged check point values

Lidar Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the NOAA Maine Lidar project was 0.044 meters (Table 18, Figure 29).

Table 18: Relative accuracy

Delivery	Block	Sample	Average	Median	RMSE	Standard Deviation (1σ)	95% Confidence (1.96*RMSE)
D1	A	490	0.048 m	0.057 m	0.082 m	0.041 m	0.081 m
D1	B	792	0.052 m	0.063 m	0.086 m	0.042 m	0.082 m
D2	C	742	0.040 m	0.046 m	0.062 m	0.025 m	0.049 m
D2	D	741	0.039 m	0.045 m	0.060 m	0.026 m	0.051 m
D2	E	1290	0.073 m	0.054 m	0.071 m	0.031 m	0.060 m
D3	F	1130	0.031 m	0.036 m	0.082 m	0.053 m	0.104 m
D3	G	1137	0.044 m	0.048 m	0.065 m	0.027 m	0.053 m
D4	H	943	0.048 m	0.051 m	0.084 m	0.048 m	0.093 m
D4	I	1325	0.042 m	0.047 m	0.087 m	0.052 m	0.101 m
D4	J	1212	0.053 m	0.055 m	0.082 m	0.042 m	0.082 m
Cumulative	A-J	7,382	0.044 m	0.051 m	0.079 m	0.042 m	0.083 m

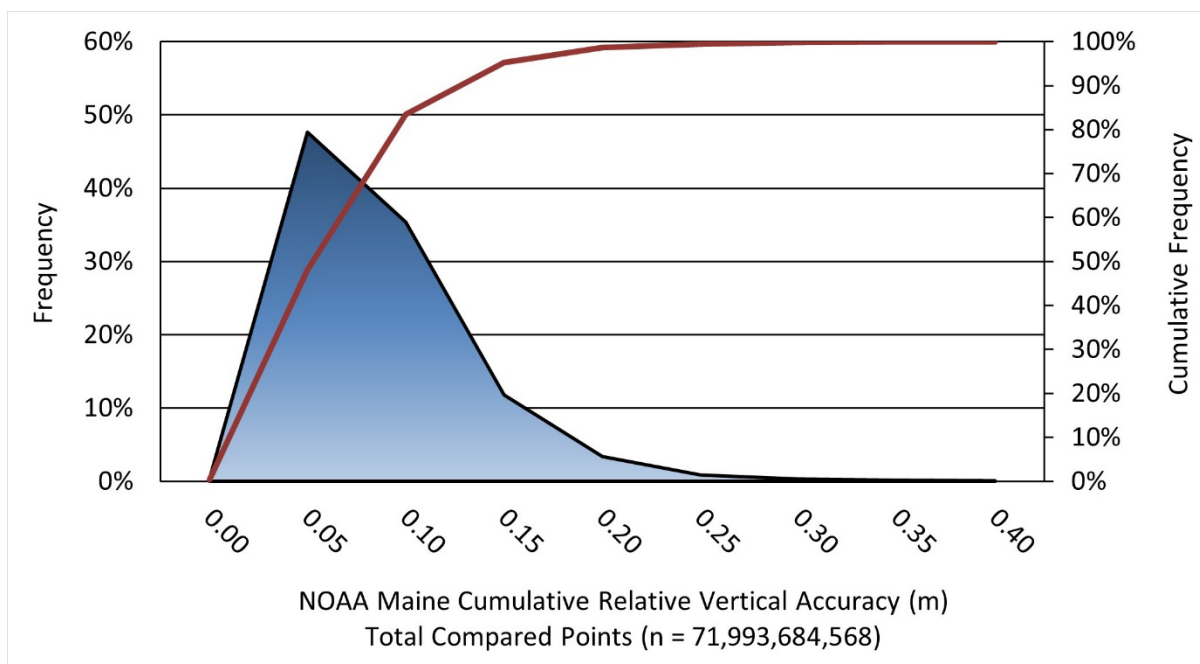


Figure 29: Frequency plot for relative vertical accuracy between flight lines

Lidar Horizontal Accuracy

Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and inertial navigation system (INS) derived attitude error. The obtained RMSE_r value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95 percent of the time. Based on the parameters described in Table 19, summarized by sensor and flying altitude, this project was produced to meet between 0.095 meters and 0.242 meters horizontal accuracy at the 95% confidence level.

Table 19: Cumulative horizontal accuracy

Parameter	Chiroptera 400 m	HawkEye 400 m
IMU Error	0.004 degrees	0.125 degrees
GNSS Error	0.023 m	0.005 m
RMSEr	0.055 m	0.140 m
ACCr	0.095 m	0.242 m

Imagery Accuracy Assessments

To see how the accuracy assessments were conducted and the results, please refer to the “Aerotriangulation Report” in Appendix B: Imagery Reports.

CERTIFICATIONS

NV5 provided lidar services for the NOAA Maine project as described in this report.

I, Alex McManus, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Alex McManus 5/30/2025 | 9:41 AM PDT

Alex McManus
Project Manager
NV5

I, Steven J. Hyde, PLS, being duly registered as a Professional Land Surveyor in and by the state of Maine hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between October 6, 2022 and December 15, 2023.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

Steven J. Hyde

5/30/2025 | 10:14 AM PDT

Steven J. Hyde, PLS
NV5
Corvallis, OR 97330



GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Non-vegetated Vertical Accuracy (NVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

Absolute Accuracy: The vertical accuracy of lidar data is described as the mean and standard deviation (sigma σ) of divergence of lidar point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Relative Accuracy: Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the lidar system is well calibrated, the line-to-line divergence is low (<10 cm).

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the lidar points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of lidar resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echoes) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native Lidar Density: The number of pulses emitted by the lidar system, commonly expressed as pulses per square meter.

APPENDIX A - ACCURACY CONTROLS

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data was tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

Lidar accuracy error sources and solutions:

Source	Type	Post Processing Solution
Long Base Lines	GPS	None
Poor Satellite Constellation	GPS	None
Poor Antenna Visibility	GPS	Reduce Visibility Mask
Poor System Calibration	System	Recalibrate IMU and sensor offsets/settings
Inaccurate System	System	None
Poor Laser Timing	Laser Noise	None
Poor Laser Reception	Laser Noise	None
Poor Laser Power	Laser Noise	None
Irregular Laser Shape	Laser Noise	None

Operational measures taken to improve relative accuracy:

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 20^\circ$ to $\pm 21^\circ$ for the green and NIR lasers, respectively, from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

APPENDIX B: IMAGERY REPORTS

See the Attached Imagery Reports Starting on the Next Page

**Project ME2201-TB-C
State of Maine Shoreline Mapping
2022 Limited Acquisition and 2023
Final Project Acquisition.**

Data Acquisition Summary

**Prepared by: Shane Good
NV5 Geospatial
523 Wellington Way, Suite 225
Lexington, KY 40503
859-277-8700**



I. Project Overview:

Project Number:	ME2201-TB-C
Project Title:	State of Maine Shoreline Mapping
Number of Flight Lines:	70
Emulsion:	RGB/NIR
Tide Coordination:	Multispectral / Non- Tide Coordinated
Instrument:	Leica ADS100
Altitude:	10000 feet
Leica ADS100 RGB GSD:	0.8 feet (0.25 meters)
Leica ADS100 NIR GSD:	0.8 feet (0.25 meters)
End Lap and Side Lap:	N/A, 30% Side

Note: The project was collected to support the Coastal Mapping Program (CMP). Further project information and instruction can be obtained from the IJJA Maine Project_Instructions_v3.15.pdf dated June 6, 2022.

II. Data Acquisition Summary:

Flight Date	Folder Name	Lines Acquired	Patches/ Refls Required ?	Patches/ Refls Flown?	Project Complete?	Camera RGB/NIR	Lens sn RGB (62.5m m)	RGB Camera Calibration	Lens sn NIR (62.5m m)	NIR Digital Back	NIR Camera Calibration	RGB/NIR Boresight
10/22/2022	41065 Maine	925055 925057 925059 925060 925069 925070	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
10/23/2022	41065 Maine	925054 925062 925063 925064	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
10/31/2022	41065 Maine	925047 925056 925058 925061 925068	N	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
11/02/2022	41065 Maine	925065 925066 925067 925069 925064 925063 925062 925060 925046 925045 905044 925043 925042	Y	Y	N	ADS100, 10541	0023	08/05/2020	0053	N/A	08/05/2020	08/05/2020
11/03/2022	41065 Maine	925054 925041 925040 925039 925038 925037 925036 925035 925034 925070	Y	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020

11/04/2022	41065 Maine	925033 925032 925048 925049 925050 925051 925052 925053	N	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
11/15/2022	41065 Maine	925054 925042 925043 925044	N	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
05/18/2023	41065 Maine	925009 925010 925011 925012 925013 925014 925001 925002 925003 925004 925005 925006 925007 925008	N	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
05/22/2023	41065 Maine	925025 925026 925027 925028 925029 925030 925031 925020 925021 925022 925023 925024	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
05/23/2023	41065 Maine	925015 925016 925017 925018 925019	N	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
05/28/2023	41065 Maine	925020 925030 925031	N	Y	Y	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020

***Note: Leica ADS100 sensor calibrations generally only need to be done after their manufacture or after an IMU is re-positioned or replaced. The reason for this is that the lens, IMU and sensor are rigidly mounted together within the sensor-head (SH) unit. Leica recommends that a calibration is performed directly after delivery, once installed in an aircraft and the GNSS lever-arms are measured. The calibration guidelines consist of varying altitudes with perpendicular and bi-directional tracks. The data is then sent to Leica for an Aerotriangulation (AT) which will produce an updated IMU-misalignment (roll/pitch/heading and standard deviations) - the precise angular offset between the IMU and the reference-point of the SH. The resulting misalignment values for a Leica ADS100 sensor can last for years due to the rigid structure of the SH and its lack of moving parts. This is unlike the operation of traditional frame cameras or lidar sensors that need continual maintenance, calibration and/or boresight. Additionally, providing the removal and installation of an SH from one aircraft to another is done carefully, the integrity of the IMU-misalignment should not be disturbed. Furthermore, if the IMU were affected somehow in the process or re-installation, the IMU's angular residuals would be present in the AT results and a new misalignment measurement would be necessitated. NV5 is confident that the calibrations used on the Hurricane Ida project for all sensors and aircraft are acceptable.

Data Acquisition: 10/22/2022 (2952022)

Acquisition	
Date:	10/22/2022
Project:	ME2201-TB-C
Flight Lines:	925055, 925057, 025059, 925060, 925069, 925070
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	10/25/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
	Image QC
Imagery Flagged:	925060 reflly miles 0 thru 28, 925069 reflly all. 925070 reflly miles 0 thru 3.5. Reflights for smears and clouds.

Data Acquisition: 10/23/2022 (2962022)

Acquisition	
Date:	10/23/2022
Project:	ME2201-TB-C
Flight Lines:	925054, 925062, 025063, 925064
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	10/25/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	925062 refly miles 0-21. 925063 refly miles 0-20. 925064 refly miles 0-23. Refly for Clouds. 925054 partial flight need miles 7 to EOL needed.

Data Acquisition: 10/31/2022 (3042022)

Acquisition	
Date:	10/31/2022
Project:	ME2201-TB-C
Flight Lines:	925047, 925056, 025058, 925061, 925068
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	11/04/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 11/02/2022 (3062022)

Acquisition	
Date:	11/02/2022
Project:	ME2201-TB-C
Flight Lines:	925065, 925066, 025067, 925069, 925064, 925063, 925062, 925060, 925046, 025045, 925044, 925043, 925042
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Refls Required:	Yes
Patches/Refls Flown:	Yes
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	11/04/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	925044 reflly miles 0-10. 925043 reflly miles 0-24. 925042 reflly miles 0-31. Overcast-dark imagery.

Data Acquisition: 11/03/2022 (3072022)

Acquisition	
Date:	11/03/2022
Project:	ME2201-TB-C
Flight Lines:	925054, 925041, 025040, 925039, 925038, 925037, 925036, 925035, 925034, 925070
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys Flown:	Yes
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	11/07/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	925054 partial flight refly.

Data Acquisition: 11/04/2022 (3082022)

Acquisition	
Date:	11/04/2022
Project:	ME2201-TB-C
Flight Lines:	925033, 925032, 025048, 925049, 925050, 925051, 925052, 925053
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	None
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	11/07/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 11/15/2022 (3192022)

Acquisition	
Date:	11/15/2022
Project:	ME2201-TB-C
Flight Lines:	925054, 925042, 025043, 925044
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	None
Patches/Reflys Flown:	Yes
Platform/ Tail:	Cessna Caravan / N704MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	11/17/2022
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 05/18/2023 (1382023)

Acquisition	
Date:	05/18/2023
Project:	ME2201-TB-C
Flight Lines:	925009, 925010, 925011, 925012, 925013, 925014, 925001, 925002, 925003, 925004, 925005, 925006, 925007, 925008
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	No
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N604MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	05/20/2023
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 05/22/2023 (1422023)

Acquisition	
Date:	05/22/2023
Project:	ME2201-TB-C
Flight Lines:	925025, 925026, 925027, 925028, 925029, 925030, 925031, 925020, 925021, 925022, 925023, 925024
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N604MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	05/24/2023
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	925020, 925030, 925031 reply for sun angle

Data Acquisition: 05/23/2023 (1432023)

Acquisition	
Date:	05/23/2023
Project:	ME2201-TB-C
Flight Lines:	925015, 925016, 925017, 925018, 925019
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	No
Patches/Reflys Flown:	None
Platform/ Tail:	Cessna Caravan / N604MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	05/25/2023
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 05/28/2023 (1482023)

Acquisition	
Date:	05/28/2023
Project:	ME2201-TB-C
Flight Lines:	925020, 925030, 925031
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Refls Required:	No
Patches/Refls Flown:	Yes
Platform/ Tail:	Cessna Caravan / N604MD
Emulsion:	RGB / NIR
Camera	Leica ADS100 / SN10541
Lens:	62.5 mm
Terrestrial Calibration:	08/05/2020
Boresight:	08/05/2020
Image Development	
CCD Configuration:	N/A
Photocorr Creation Date:	N/A
Lens Distortion Correction:	N/A
Correction Gamma:	N/A
Dark Images:	N/A
GPS Processing	
EO Creation Date:	05/30/2023
APOR Report Title:	ME2201-TB-C_Maine_Coastal_APOR.pdf
Image QC	
Imagery Flagged:	None All ReFls

Project Status:

Acquisition for ME2201-TB-C State of Maine Shoreline Mapping is 100% Acquired.

Project ME2201-TB-C
State of Maine Shoreline Mapping
2022 Limited Acquisition and 2023 Final
Project Acquisition.

Airborne Positioning and Orientation
Report

Prepared by: Shane Good
NV5 Geospatial
523 Wellington Way, Suite 225
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859-277-8700



1. INTRODUCTION

Maine ME2201-TB-C

The project area referenced as ME2201-TB-C covers one Area of Interest (AOI) along the Southern shoreline of Maine.

The AOI extends from just south of Hampton, New Hampshire, and runs northwest to Johnson Bay covering the entire coast of Maine. The AOI covers several bays and islands including Machias-Seal Island Lighthouse.

The AOI covers approximately 2821 Sq Miles.

The project is located approximately between 42°49’09” and 45°12’35” North Latitude, and 70°48’41” and 67°10’53” West Longitude.

Dataset ID:	ME2201-TB-C
Dates of Acquisition:	10-22-22 through 11-15-22 and 5-18-23 through 5-28-23
Project Name:	State of Maine Shoreline Mapping
Flight Lines:	70

This report is reflective of the partial 2022 delivery and the 2023 final delivery. Flight lines 925032 through 925070 where captured fall of 2022 and flight lines 925001 through 925031 in May of 2023.

2. POSITIONING

Embedded Novatel SPAN GNSS \ IMU with tightly coupled processing is used to get the most accurate positional data possible. The Novatel SPAN technology allows us to maintain GNSS signal tracking even when the aircraft is making sharp turns. The Novatel SPAN technology eliminates the need to be close (under 20km) to reference stations and is ideal for larger flight areas.

The GNSS is processed using Inertial Explorer GNSS \ Tightly coupled workflow. Using Inertial Explorer Precise-Point Positioning (PPP) to compute a set of corrections for the receiver in the airplane. We compute a smoothed final solution (SOL) for the flight using the raw inertial, GNSS, and PPP data. We then review the Estimated Position Accuracy results to ensure sub decimeter residuals and that we have a fixed solution throughout.

2.1 Hardware & Software Used

Airborne Kinematic Data #1	
Platform:	Cessna Caravan / N704MD
Camera System:	ADS100 (RGB/NIR)
Camera Manufacturer:	Leica
Camera Serial Number:	10541
POS System:	Novatel SPAN
POS Serial Number:	S/N DFX141330014
Antenna Manufacturer:	AeroAntenna Technology Inc.
Antenna Type:	ACCG5ANT_42ATI
Antenna Serial Number:	N/A
Reference to Primary GNSS Lever Arms:	X= 0.023
	Y= 0.041
	Z= 1.029

Airborne Kinematic Data #2	
Platform:	Cessna Caravan / N604MD

Camera System:	ADS100 (RGB/NIR)
Camera Manufacturer:	Leica
Camera Serial Number:	10541
POS System:	Novatel SPAN
POS Serial Number:	S/N DFX141330014
Antenna Manufacturer:	AeroAntenna Technology Inc.
Antenna Type:	ACCG5ANT_42ATI
Antenna Serial Number:	N/A
Reference to Primary GNSS Lever Arms:	X= 0.056
	Y= 0.087
	Z= 0.997

GPS\IMU Processing Software	
Software:	Inertial Explorer
Version:	8.9
GNSS-Inertial Processing Mode:	Tightly Coupled

2.2 Flight Data

	Acquisition						
Date:	10/22/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	16:10 – 17:43						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925055	N /A	45.11207	-67.215414	N /A	45.181875	-67.121261	
925057	N /A	45.16254	-67.088242	N /A	45.076596	-67.204723	
925059	N /A	45.035345	-67.201554	N /A	45.135796	-67.065217	
925060	N /A	45.104843	-67.048167	N /A	44.306817	-68.123438	To Patch

925069	N / A	44.468092	-67.280625	N / A	44.585469	-67.079427	To Refly
925070	N / A	44.463379	-67.066212	N / A	44.693362	-67.228654	To Patch

Acquisition							
Date:	10/23/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	17:09 – 18:40						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925054	N / A	44.455010	-68.102840	N / A	44.539288	-67.987089	To Refly
925062	N / A	44.326422	-67.979665	N / A	45.046263	-67.009128	To Patch
925063	N / A	45.017315	-66.987688	N / A	44.308038	-67.944321	To Patch
925064	N / A	44.248396	-67.964148	N / A	44.985376	-66.971894	To Patch

Acquisition							
Date:	10/31/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	15:04 – 16:46						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925047	N / A	44.145022	-69.175811	N / A	44.596130	-68.398344	
925056	N / A	44.413114	-68.099501	N / A	44.696998	-67.718372	
925058	N / A	44.900404	-67.384489	N / A	44.373278	-68.094198	
925061	N / A	44.292049	-68.084189	N / A	45.077108	-67.026829	
925068	N / A	44.864425	-66.895792	N / A	44.555409	-67.312133	

Acquisition							
Date:	11/02/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	13:41 – 17:56						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925065	N / A	44.276987	-67.865876	N / A	44.959489	-66.947232	
925066	N / A	44.934732	-66.920259	N / A	44.391187	-67.652945	
925067	N / A	44.450424	-67.513101	N / A	44.905768	-66.899457	
925069	N / A	44.586836	-67.077024	N / A	44.470076	-67.276755	Refly
925064	N / A	44.528399	-67.588611	N / A	44.250421	-67.961352	Patch
925063	N / A	44.305663	-67.947498	N / A	44.524833	-67.653389	Patch
925062	N / A	44.557763	-67.668932	N / A	44.328112	-67.977381	Patch
925060	N / A	44.305411	-68.126293	N / A	44.602522	-67.727339	Patch
925046	N / A	44.576087	-68.367264	N / A	44.116676	-69.159136	
925045	N / A	44.074943	-69.165954	N / A	44.635687	-68.200301	
925044	N / A	44.625205	-68.151091	N / A	44.042456	-69.155020	To Patch
925043	N / A	44.006401	-69.149335	N / A	44.600105	-68.127731	To Patch
925042	N / A	44.006401	-69.149335	N / A	44.600105	-68.127731	To Patch

Acquisition							
Date:	11/03/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	13:45 – 18:11						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925054	N / A	44.575261	-67.941396	N / A	44.671549	-67.811591	To Refly
925041	N / A	44.552587	-68.077821	N / A	43.941751	-69.129296	
925040	N / A	43.905995	-69.123046	N / A	44.528520	-68.052146	
925039	N / A	44.506858	-68.023869	N / A	43.873819	-69.112031	
925038	N / A	43.842727	-69.102580	N / A	44.466867	-68.030644	

925037	N /A	44.432877	-68.026806	N /A	43.832839	-69.056891	
925036	N /A	43.807387	-69.032782	N /A	44.394081	-68.027165	
925035	N /A	44.311810	-68.100747	N /A	43.789640	-68.995979	
925034	N /A	43.769150	-68.962790	N /A	44.251387	-68.135892	
925070	N /A	44.696275	-67.230797	N /A	44.646308	-67.195388	Patch

Acquisition							
Date:	11/04/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	215:52 – 17:34						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925033	N /A	44.194897	-68.164527	N /A	44.056917	-68.401734	
925032	N /A	43.915440	-68.643949	N /A	43.752328	-68.922619	
925048	N /A	44.203288	-69.139476	N /A	44.494580	-68.637010	
925049	N /A	44.514681	-68.665777	N /A	44.264396	-69.097581	
925050	N /A	44.321298	-69.065081	N /A	44.546723	-68.676048	
925051	N /A	44.591468	-68.665495	N /A	44.363555	-69.059057	
925052	N /A	44.391076	-69.076986	N /A	44.613015	-68.693990	
925053	N /A	44.619967	-68.748312	N /A	44.424437	-69.086437	

Acquisition							
Date:	11/15/22						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	14:33 – 15:54						
Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925054	N /A	44.455264	-68.102440	N /A	44.671314	-67.811817	ReFly
925042	N /A	44.292178	-68.594698	N /A	43.975589	-69.138230	Patch
925043	N /A	44.006506	-69.149447	N /A	44.253863	-68.724717	Patch
925044	N /A	44.178369	-68.921770	N /A	44.042232	-69.155127	Patch

Acquisition							
Date:	05/18/23						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	11:51 – 13:28						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925009	N /A	43.572654	-70.164872	N /A	42.986720	-70.850489	
925010	N /A	42.891480	-70.905327	N /A	43.442360	-70.262582	
925011	N /A	43.302779	-70.370169	N /A	42.851589	-70.895984	
925012	N /A	42.818589	-70.878549	N /A	43.186986	-70.449535	
925013	N /A	43.166858	-70.416837	N /A	42.804162	-70.839330	
925014	N /A	42.917740	-70.651106	N /A	43.158211	-70.371229	

Acquisition							
Date:	05/18/23						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	19:24 – 21:18						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925001	N /A	43.109418	-70.981743	N /A	43.275123	-70.788003	
925002	N /A	43.477351	-70.551177	N /A	43.708526	-70.279293	
925003	N /A	43.266347	-70.743429	N /A	43.079400	-70.961914	
925004	N /A	43.682547	-70.255185	N /A	43.457821	-70.519121	
925005	N /A	43.020920	-70.974978	N /A	43.224459	-70.737851	
925006	N /A	43.350010	-70.590551	N /A	43.653569	-70.234567	
925007	N /A	43.628734	-70.209167	N /A	43.004171	-70.940001	
925008	N /A	42.986759	-70.905447	N /A	43.598917	-70.189498	

Acquisition							
Date:	05/22/23						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	19:41 – 21:47						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925020	N /A	43.967684	-69.020273	N /A	43.615777	-70.312844	ToRefly
925021	N /A	43.642208	-70.337729	N /A	43.997597	-69.031690	
925022	N /A	44.029288	-69.035505	N /A	43.671720	-70.349838	
925023	N /A	43.703092	-70.355510	N /A	44.058506	-69.047527	
925024	N /A	44.090173	-69.051588	N /A	43.748632	-70.308584	

Acquisition	
Date:	05/23/23
Project:	Maine Coastal Mapping
Time of Collection:	11:15 – 12:53

Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925015	N /A	43.504811	-70.229320	N /A	43.542731	-70.090960	
925016	N /A	43.738624	-69.373150	N /A	43.779801	-69.221421	
925017	N /A	43.874343	-68.997390	N /A	43.533606	-70.247274	
925018	N /A	43.560128	-70.273237	N /A	43.904841	-69.007990	
925019	N /A	43.936590	-69.013038	N /A	43.588566	-70.291289	

Acquisition							
Date:	05/28/23						
Project:	State of Maine Shoreline Mapping						
Time of Collection:	11:39 – 12:54						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925020	N /A	43.614855	-70.316343	N /A	43.856464	-69.430685	ReFly
925030	N /A	44.132135	-69.613827	N /A	44.044970	-69.935810	ReFly
925031	N /A	44.100159	-69.851773	N /A	44.159566	-69.632417	ReFly

.3 Static Base Station

Static Base Station	
Receiver:	NA
Receiver Serial Number:	NA
Antenna Manufacturer:	NA
Antenna Code:	NA
Antenna Type:	NA
Antenna Serial Number:	NA
ARP Height (m):	NA
Collection Rate:	NA
Duration:	NA

OPUS Position (Precise Ephemeris)	
Reference Frame:	NA
Latitude:	NA
Longitude:	NA
Ellipsoidal Height (m):	NA

2.4 CORS Data

CORS Station #1	
CORS Station Name:	NA
CORS PID:	NA
Source:	NA
Latitude:	NA
Longitude:	NA
Ellipsoidal Height:	NA
Receiver:	NA
Receiver Serial Number:	NA
Antenna Manufacturer:	NA
Antenna Code:	NA
Antenna Type:	NA
Antenna Serial Number:	NA
ARP Height (m):	NA
Collection Rate:	NA
Duration:	NA

3. EXTERIOR ORIENTATION DATA

Upon receiving the SBET for the ADS100 pushbroom sensor we create support files in SocetSet format in place of the traditional frame sensor EO format. The software can re-project from latitude and longitude to the projection required for the project. In this case that would be in UTM 19 North,

NAD83 (2011) Epoch:2010; Meters; NAVD88(Geoid 18). The final supporting files include: .ads, .odf.adj, .cam and .sup files.

4. FINAL RESULTS

All flown data meets accuracy requirements based on the contract specifications. This report is reflective of the partial 2022 delivery and the 2023 final delivery. Flight lines 925032 through 925070 were captured fall of 2022 and flight lines 925001 through 925031 in May of 2023.



ME2201-TB-C State of Maine Shoreline Mapping 2023 Remaining Acquisition

Aerotriangulation Report

July 2023

Area Covered

The project area referenced as ME2201-TB-C covers one Area of Interest (AOI) along the Southern shoreline of the State of Maine.

The AOI extends from just south of Hampton, New Hampshire and runs Northwest to Frenchman Bay. The AOI covers several bays and islands including Acadia National Park.

The AOI covers approximately 1421 Sq Miles.

The project is located approximately between 42°49'09" and 44°31'39" North Latitude, and 70°48'01" and 67°10'53" West Longitude.

See Annex 1 – Project Coverage Diagram

Imagery

The photography used in this aerotriangulation phase was flown by NV5 Inc and consists of 53 flight lines out of 70. The imagery was acquired at a nominal ground sample distance of 0.25 meters using the Leica ADS100 push broom sensor at an altitude of 10,000 ft. The 4band color photographs were acquired between November 11th, 2022 and May 28th, 2023. All imagery was acquired using >30% side overlap, sun angles >20 or >25 degrees (depending on the date of acquisition). This report will be reflective of a partial delivery. It includes the remainder of the acquisition captured in 2023 and the 2022 acquisition that was not in the initial aerotriangulation. Flight lines 925001 thru 925031 were captured in 2023 out of 70 total lines and lines 925001 thru 925053 were used for this AT block. The layout of the photographs is shown in the Annex 2 ME2201-TB-C Flight Lines Included in AT diagram. Photographic coverage, resolution, overlap, and metric quality were adequate for the performance of the aerotriangulation phase. Additional information can be found in the ME2201-TB-C_Maine_Coastal_Acquisition_Summary_Report.



Control

A combination of photo identifiable ground control points and Airborne GPS/IMU data were used to control the imagery for aerotriangulation.

- A. Airborne GPS/IMU: Airborne GPS and IMU data was processed by NV5 and was used as control in the aerotriangulation, and inertial measuring unit (IMU) measurements were used to refine these.
- B. Ground Points: NV5 was dispatched to survey Fifty Three (53) photo ID control points (horizontal and vertical), and Twenty one (21) check points. Twenty One surveyed points were used to check the horizontal and vertical accuracy of the survey. The results of the survey will be published in the final ground control report.

Overall, the ground control points were found to be adequate to supplement the airborne GPS control.

Methodology

The imagery was bridged using digital aerotriangulation methods to establish the network of photogrammetric control required for the compilation phase. The imagery was bridged in a bundle adjustment that included 16 4Band color non-tide coordinated flight lines. Measurements were made utilizing a digital photogrammetric workstation running the Windows 10 operating system. Leica's XPRO Aerotriangulation software was used to perform automatic point measurements and interactive point measurements of tie points. The final adjustment of the block was accomplished by using a rigorous simultaneous least squares bundle adjustment, and analysis tools within XPRO were used to refine the aerotriangulation solution and to evaluate the accuracy of the adjustment. The aerotriangulation block was adjusted in UTM Zone 19.

Analysis of Results

The final XPRO results were evaluated for the triangulation adjustment providing a display of the image and point residuals and connections between frames. Weak points and blunders were identified and corrected. The final aerotriangulation solution for the image block was computed in XPRO as a full bundle block adjustment. The RMS of the standard deviations in both X and Y directions were calculated and used to determine the radius of the 95% confidence circle for each image block. The predicted horizontal circular error accuracy (RMSE or 95% CI) is 0.36m for the 4band photos. (see Annex 3 for details of the computations). This accuracy refers to the overall block, but in the bundle adjustments the error was distributed such that the largest errors are associated with points around the edges of the project and areas of vast water where the strength of the solution is weakest, while points down the middle of each block located on areas of extensive land cover have the smallest errors because those points are measured on a greater number of images. In addition, each of the twenty one (21)



ground control check points measured in and the coordinates and elevations of these check points were not constrained at all in any of the block adjustments, but were treated as pass points, and adjusted coordinates were computed and the differences are shown below:

<u>POINT ID</u>		<u>ΔX M</u>	<u>ΔY M</u>	<u>ΔZ M</u>
AT106CHK		-0.4416	0.5413	-0.2117
AT107CHK		0.0701	0.1668	0.2333
AT108CHK		-0.0244	-0.0564	0.4221
AT109CHK		0.073	-0.302	-0.0221
AT110CHK		0.1123	-0.1855	0.302
AT111CHK		0.158	-0.1046	0.2301
AT112CHK		-0.0237	0.1069	0.1931
AT113CHK		0.0935	0.2985	-0.0601
AT114CHK		-0.0657	-0.0591	-0.2426
AT115CHK		0.1199	0.0242	-0.0514
AT116CHK		-0.078	0.0227	-0.208
AT117CHK		-0.2086	-0.3247	-0.0698
AT118CHK		-0.1853	-0.1565	-0.1091
AT119CHK		-0.3704	0.2433	-0.0879
AT120CHK		-0.0882	0.0056	-0.1873
AT121CHK		-0.0481	-0.161	0.5514
AT122CHK		0.1353	0.2532	-0.0109
AT130CHK		N/A	N/A	-0.0246
AT131CHK		-0.0598	0.1882	-0.0091
AT132CHK		-0.1546	-0.174	-0.2432
AT134CHK		0.0815	0.0824	0.1847

As a final check select strips of photography were examined in XPRO QCViewer to ensure the horizontal and vertical integrity of the XPRO solution, and to verify the suitability of the database for use in the compilation phase. The images were checked for proper parallax, ground control tolerance, and check point tolerance. Models covering the check points referenced above were specifically reviewed in this manner, and included the following:



Point ID	Flight Lines	Image Dates
AT106CHK	925040, 925041	11-NOV-2022
AT107CHK	925041	11-NOV-2022
AT108CHK	925045	02-NOV-2022
AT109CHK	925050	04-NOV-2022
AT110CHK	925047	31-OCT-2022
AT111CHK	925046, 925047	02-NOV-2022, 31-OCT-2022
AT112CHK	925025, 925026, 925045, 925046	02-NOV-2022, 22-MAY-2023
AT113CHK	925023	22-MAY-2023
AT114CHK	925026	22-MAY-2023
AT115CHK	925027, 925028	22-MAY-2023
AT116CHK	925021	22-MAY-2023
AT117CHK	925024, 925025	22-MAY-2023
AT118CHK	925022, 925023	22-MAY-2023
AT119CHK	925008, 925009	18-MAY-2023
AT120CHK	925008	18-MAY-2023
AT121CHK	925045	02-NOV-2022
AT122CHK	925050	04-NOV-2022
AT130CHK	925036	03-NOV-2022
AT131CHK	925036, 925037	03-NOV-2022
AT132CHK	925036	03-NOV-2022
AT134CHK	925042	15-NOV-2022

To conclude, the aerotriangulation block meets the horizontal standards set forth by NOAA in Chapter I of the Version 14A Statement of Work for Shoreline Mapping.

Project Database

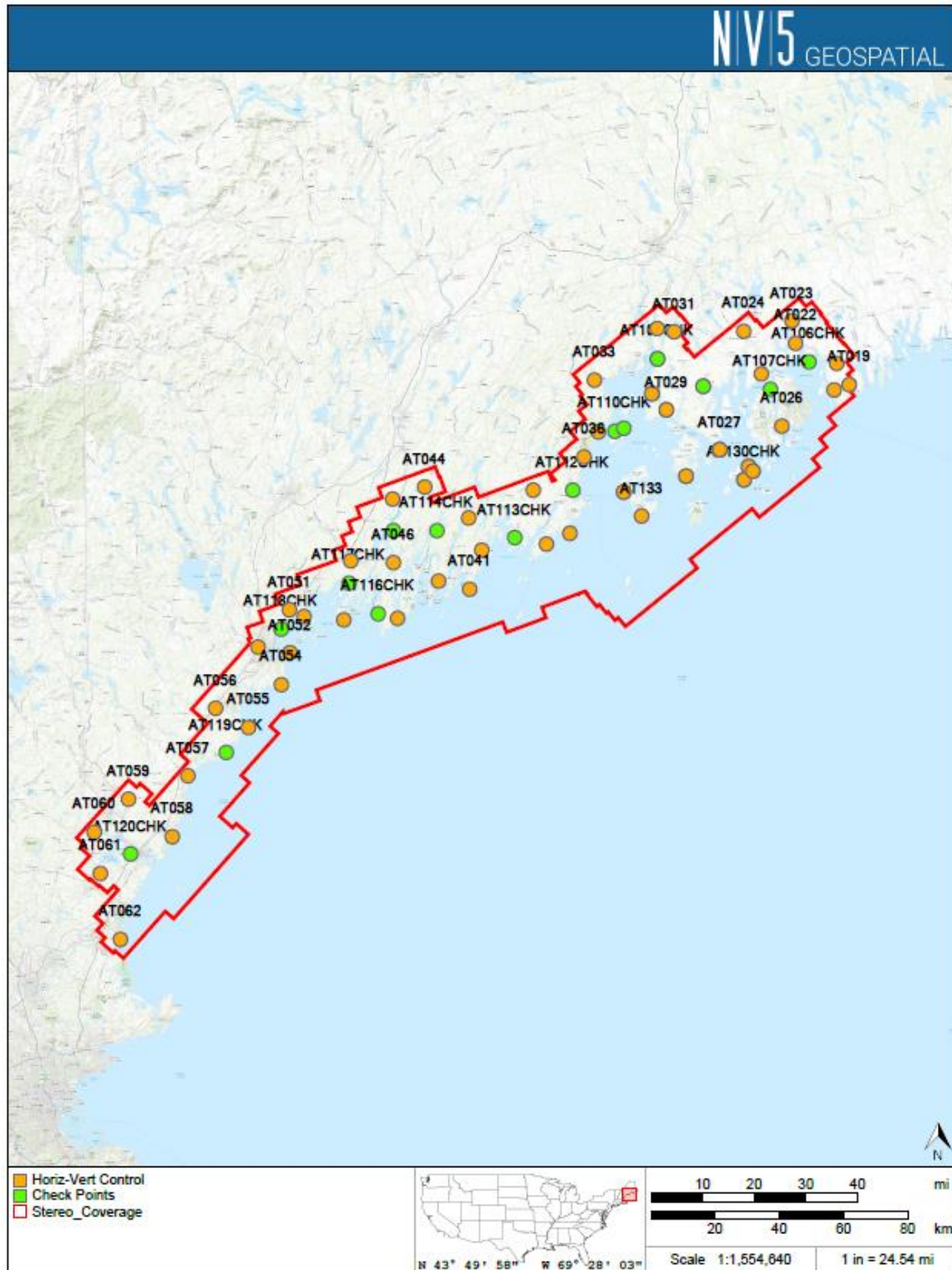
A project database containing the following files has been included in this submittal.



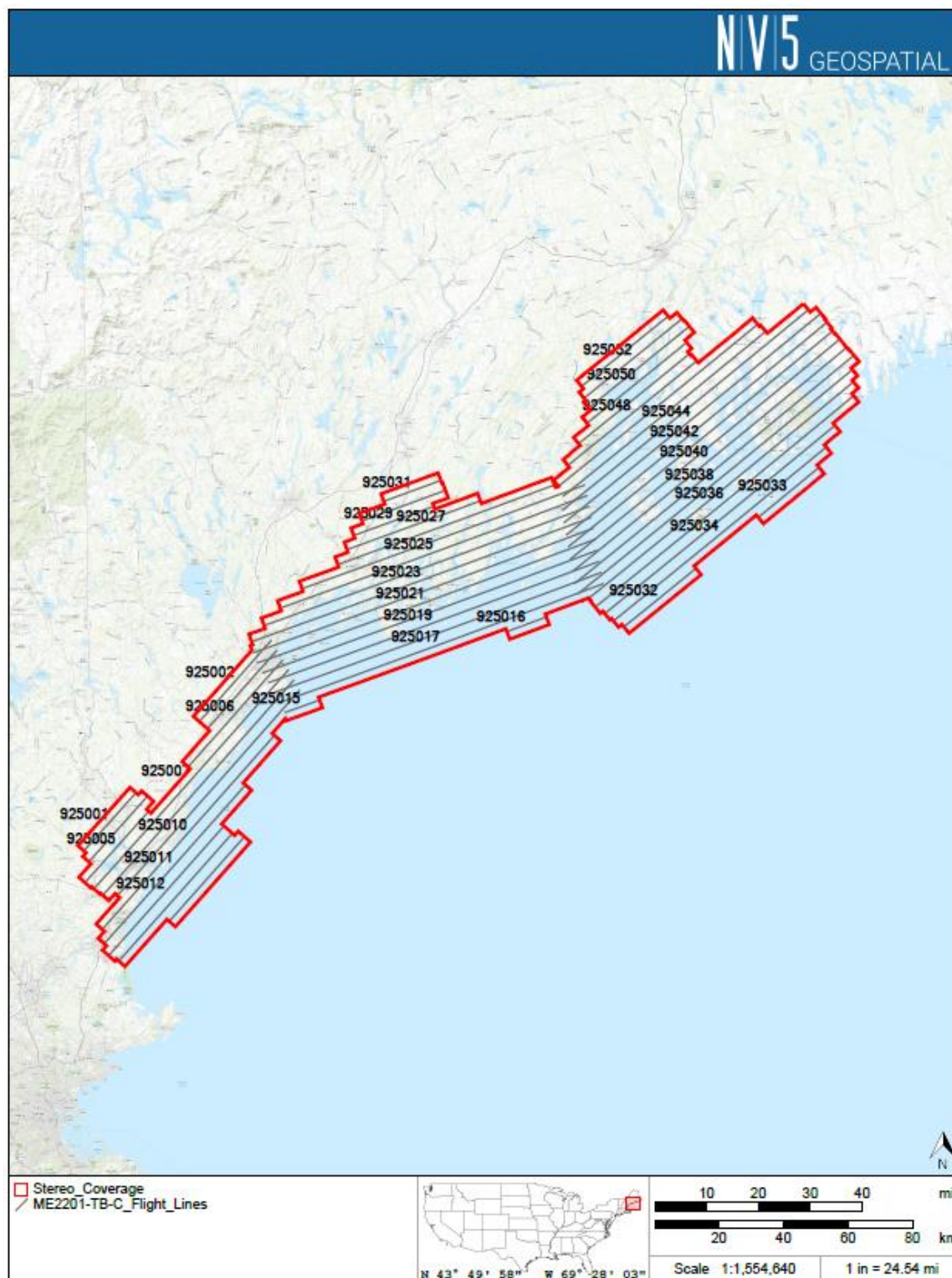
- Exposure Stations
- Electronic Exposure Data (EED)
- Camera calibration data
- Airborne GPS Control File and IMU Orientation Original DG SocetSet format
- RGB/NIR Stereo Imagery
- RGB/NIR Stereo Imagery Metadata
- Flight Line Shapefile
- Airborne Positioning and Orientation Report (APOR)
- Acquisition Summary Report
- AT Report

Positional data is based on the North American Datum of 1983 (NAD83 (2011)) and is referenced to the Universal Transverse Mercator (UTM) Zone 19 coordinate system.

ANNEX 1 – ME2201-TB-C Project Coverage Diagram



ANNEX 2 - ME2201-TB-C Flight Lines Included in AT





Flight Line	Date	Tide Coordination
925001	18-MAY-2023	Non-Tidal
925002	18-MAY-2023	Non-Tidal
925003	18-MAY-2023	Non-Tidal
925004	18-MAY-2023	Non-Tidal
925005	18-MAY-2023	Non-Tidal
925006	18-MAY-2023	Non-Tidal
925007	18-MAY-2023	Non-Tidal
925008	18-MAY-2023	Non-Tidal
925009	18-MAY-2023	Non-Tidal
925010	18-MAY-2023	Non-Tidal
925011	18-MAY-2023	Non-Tidal
925012	18-MAY-2023	Non-Tidal
925013	18-MAY-2023	Non-Tidal
925014	18-MAY-2023	Non-Tidal
925014	31-SEP-2023	Non-Tidal
925015	23-MAY-2023	Non-Tidal
925016	23-MAY-2023	Non-Tidal
925017	23-MAY-2023	Non-Tidal
925018	23-MAY-2023	Non-Tidal
925019	23-MAY-2023	Non-Tidal
925020	28-MAY-2023	Non-Tidal
925021	22-MAY-2023	Non-Tidal
925022	22-MAY-2023	Non-Tidal
925023	22-MAY-2023	Non-Tidal
925024	22-MAY-2023	Non-Tidal
925025	22-MAY-2023	Non-Tidal
925026	22-MAY-2023	Non-Tidal
925027	22-MAY-2023	Non-Tidal
925028	22-MAY-2023	Non-Tidal
925029	22-MAY-2023	Non-Tidal
925030	28-MAY-2023	Non-Tidal
925031	28-MAY-2023	Non-Tidal
925032	28-MAY-2023	Non-Tidal
925033	04-NOV-2022	Non-Tidal
925034	03-NOV-2022	Non-Tidal
925035	03-NOV-2022	Non-Tidal
925036	03-NOV-2022	Non-Tidal
925037	03-NOV-2022	Non-Tidal
925038	03-NOV-2022	Non-Tidal
925039	03-NOV-2022	Non-Tidal



925040	03-NOV-2022	Non-Tidal
925041	03-NOV-2022	Non-Tidal
925042	02-NOV-2022, 15-NOV-2022	Non-Tidal
925043	02-NOV-2022, 15-NOV-2022	Non-Tidal
925044	02-NOV-2022, 15-NOV-2022	Non-Tidal
925045	02-NOV-2022	Non-Tidal
925046	02-NOV-2022	Non-Tidal
925047	31-OCT-2022	Non-Tidal
925048	04-NOV-2022	Non-Tidal
925049	04-NOV-2022	Non-Tidal
925050	04-NOV-2022	Non-Tidal
925051	04-NOV-2022	Non-Tidal
925052	04-NOV-2022	Non-Tidal
925053	04-NOV-2022	Non-Tidal

ANNEX 3 - HORIZONTAL ACCURACY COMPUTATION - The Horizontal Accuracy Statement reported in the Analysis of Results section is based on the predicted circular horizontal accuracy of all adjusted points in the AT solution. This circular accuracy equals the radius of the 95% confidence circle as calculated from the horizontal (X and Y) root-mean-square (RMS) values of the standard deviations for all triangulated points and rounded to the nearest hundredth of a meter. This Annex demonstrates the calculation procedures and explains the computational methods. The 95% confidence circle radius shall be computed and reported for each block, if more than one photo block was adjusted separately.

Example computation:

The root mean square of all standard deviations of triangulated ground points:

$$\text{RMS}(x) = 0.149 \text{ meters} \quad \text{RMS}(y) = 0.144 \text{ meters}$$



The value for the confidence circle radius is given by the following expression:

$$R = K * S_x$$

where S_x is defined as the larger of the two (X and Y) RMS values (0.149 m. in this case), and K is interpolated using the C ratio from the Table of Cumulative Probability.

The C ratio equals the smaller of the RMS values divided by the larger:

$$C = 0.144 / 0.149 = 0.966$$

The following line (95% probability level) from the Table of Cumulative Probability was used to determine the value of K by a simple linear interpolation between the two nearest values of C:

C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
K(95%)	1.95996	1.96253	1.97041	1.98420	2.00514	2.03586	2.08130	2.14598	2.23029	2.33180	2.44775

$$\begin{aligned}
 K &= 2.33180 + [(0.966 - 0.9) / (1.0 - 0.9) * (2.44775 - 2.33180)] \\
 &= 2.33180 + [(0.066 / 0.1) * 0.11595] \\
 &= 2.33180 + (0.66 * 0.11595) \\
 &= 2.33180 + 0.07704 = 2.40884 \\
 K &= 2.409 \\
 R &= K * S_x = 2.409 * 0.149 = 0.359
 \end{aligned}$$

The Radius of the 95% Confidence Circle = 0.36 meters