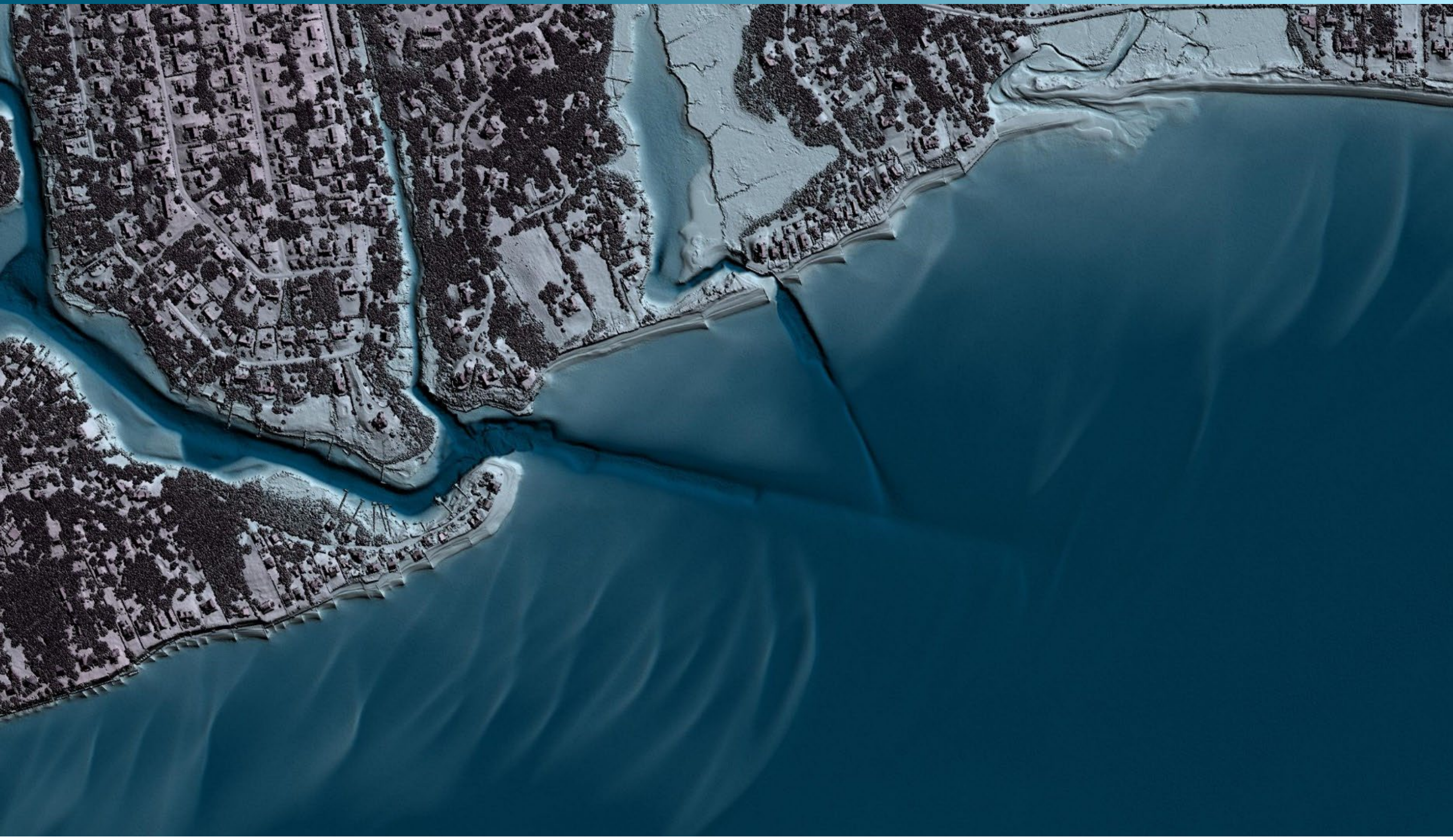
December 19, 2024



NOAA Long Island Sound

Shoreline Mapping Projects: NY2205-TB-C and NY2303-TB-C

Technical Data Report, NOAA Contract 1305M220DNCNL0064, Task Order 1305M223FNCNL0219

Prepared For:

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Cover Photo: A nadir view of Deep Hole Creek. The image was created from the lidar bare earth model colored by elevation.

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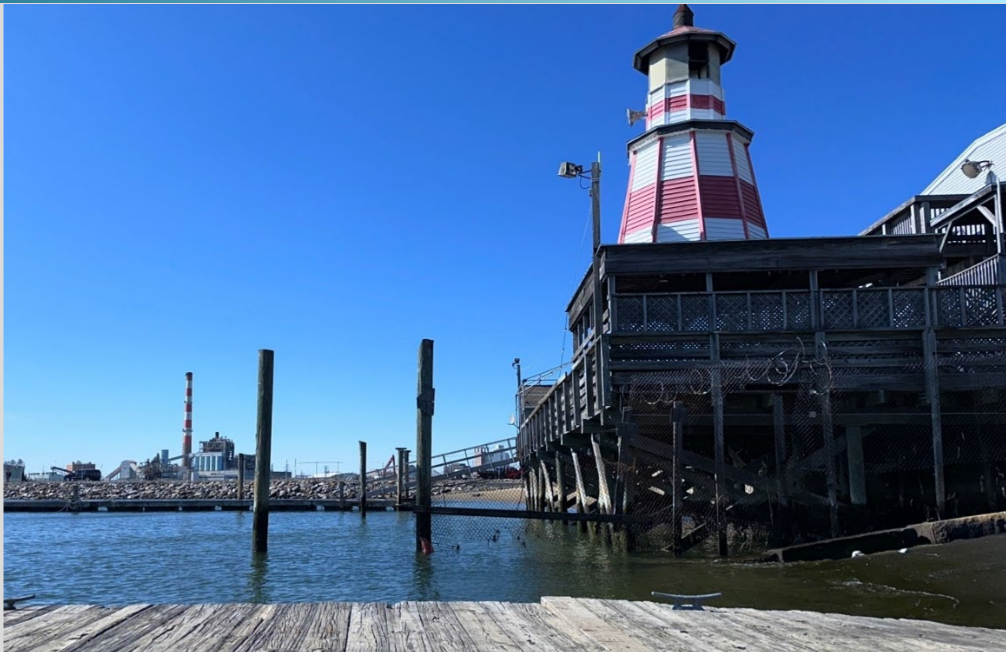
INTRODUCTION

This photo, taken by NV5 acquisition staff, shows a view of the Dolphin's Cove Marina in the NOAA Long Island Sound site.



In December 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 March to June 2023 for the NOAA Long Island Sound site. The NOAA Long Island Sound area of interest encompasses the southeastern coast of New York, Connecticut, and Rhode Island as well as the northern coast of Long Island. In total, the base project area (NY2205-TB-C) of the NOAA Long Island Sound project encompasses approximately 712 square statute miles and 992 miles of shoreline along the northern side of Long Island sound wrapping around where Long Island is connected to the rest of the southeastern United States of America and along the coast surrounding the Long Island Sound. This area of interest (AOI) begins in Rhode Island near Westerly, extends across Connecticut and into New York around Wards Island near Astoria, and ends slightly east of Mt. Sinai Harbor on the western side of Miller Place. Option (NY2303-TB-C) extends east from the base project area along the northern coast of Long Island from east of Miller Place and Mt. Sinai Harbor out to Montauk. 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 Long Island Sound site

Project Site	Contracted Acres	Buffered Acres	Aerial Acquisition Dates	Data Type
NOAA Long Island Sound	736,089	752,147	*3/5/2023 – 10/28/2023	Topobathymetric - Lidar
NOAA Long Island Sound	736,089	752,147	3/26/2023 – 3/29/2023, 4/2/2023 – 4/4/2023, 4/7/2023, 5/14/2023	4-band Imagery

*See Figure 8 for more detailed flight dates for lidar 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 Long Island Sound site

Product Type	File Type	Product Details
Points	LAS v.1.4 (*.las), Point Format 6	• 500m x 500m tiled All Classified Returns with normalized seabed intensity
Rasters	1.0-meter Cloud Optimized GeoTIFFs (*.tif)	• 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
Vectors	Shapefiles (*.shp)	• 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)	• Chiroptera 4X • HawkEye 4X • Chiroptera 5 • HawkEye 5

Product Type	File Type	Product Details
TPU Products	1.0-meter GeoTIFFs (*.tif)	• 2-band Total Propagated Uncertainty (TPU) Raster Model GeoTIFFs (*.tif) ○ Band 1 Total Horizontal Uncertainty (THU) at 95% Confidence ○ Band 2 Total Vertical Uncertainty (TVU) at 95% Confidence
Digital Imagery	GeoTIFFs (*.tif)	• 3000m x 3000m tiled Imagery Mosaics
Metadata	Extensible Markup Language (*.xml)	• 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)	• Imagery Reports • Field Data Collection Sheets • Ground Survey Report • Lidar Technical Data Report

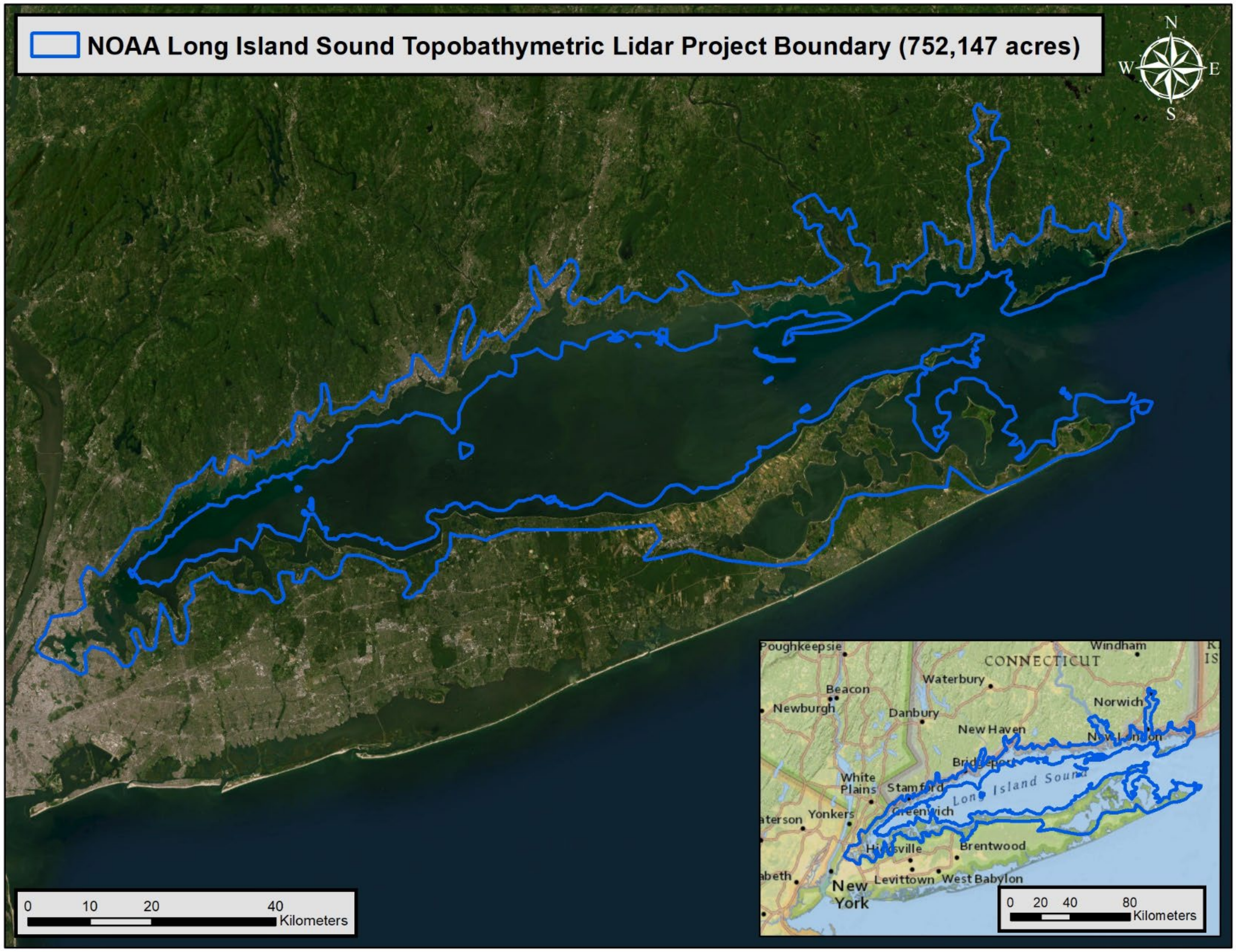


Figure 1: Location map of the NOAA Long Island Sound site in New York

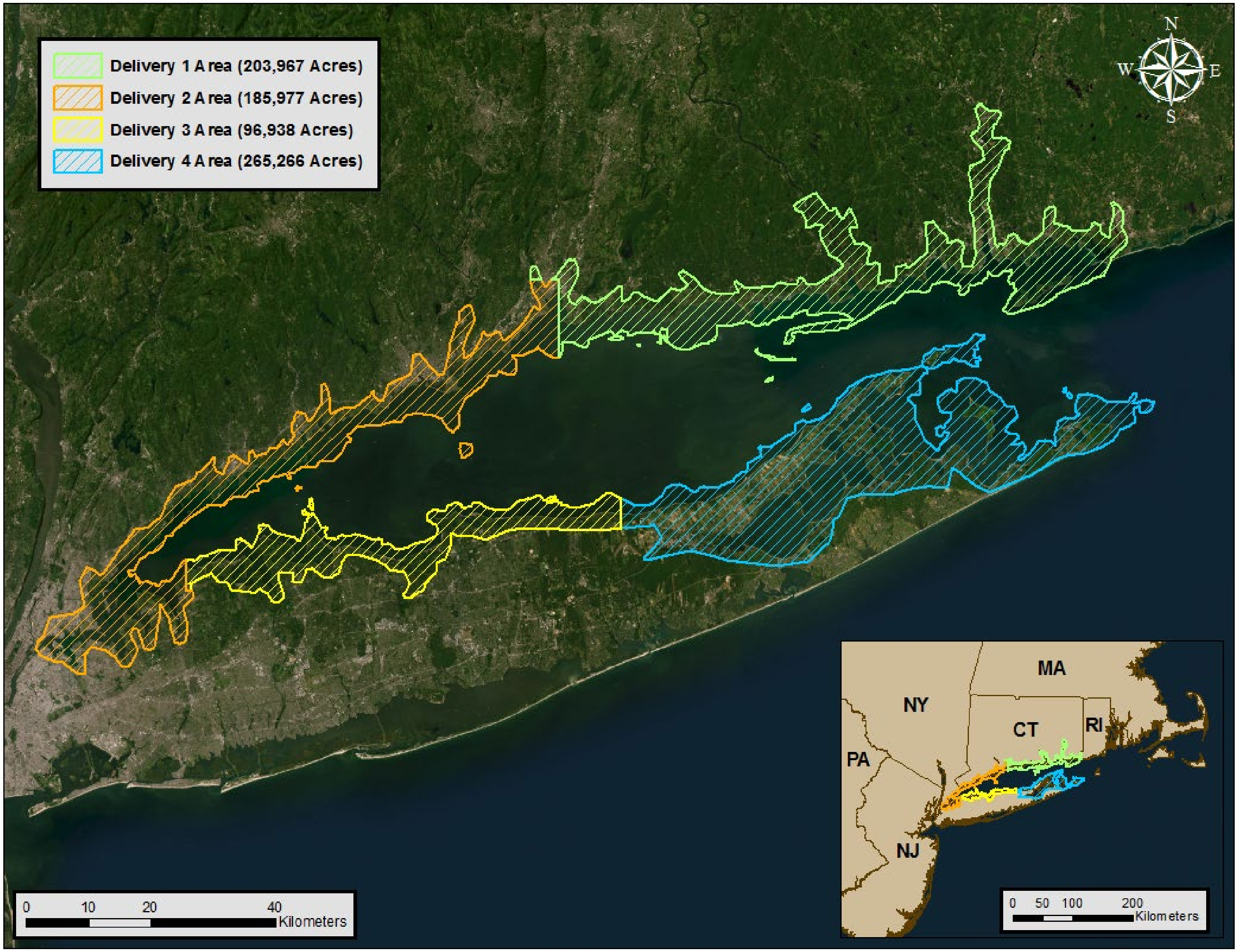


Figure 2: Delivery Area Location map of the NOAA Island Long Island Sound Project

NV5's ground acquisition equipment set up in the NOAA Long Island Sound Lidar study area.

Sensor Selection

Leica Chiroptera/HawkEye 4X and 5

NV5 Geospatial selected the Leica Chiroptera/HawkEye 4X (CH4X/HE4X) and Leica Chiroptera/HawkEye 5 (CH5/HE5) for the NOAA Long Island Sound project (Figure 1). The CH4X shallow green sensor allows for a depth penetration of K*Dmax=2.7/k and the CH5 allows for a depth penetration of K*Dmax=3.2/k at 15% seabed reflectance. Both the HE4XCH4X/CH5 and the HE5 deep green sensors allow for a depth penetration of K*Dmax=4/k at 15% seabed reflectance. The Chiroptera sensors automatically correct for water refraction, making it useful in collecting shallow coastal and shoreline data. It can capture images, NIR, and bathymetric data at the same time. Sensor specifications and settings for the NOAA Long Island Sound acquisitions are displayed in Table 5.

Figure 3: Leica Chiroptera CH4X Sensor

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 Long Island Sound Lidar study area at the target combined point density of ≥3 points/m^2 for bathymetric areas and ≥4 points/m^2 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 8 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 4 through Figure 7), 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 102 locations throughout the project site between March 7th and April 14th, 2023. Turbidity observations were recorded three times to confirm measurements. Table 4 below provides turbidity and Secchi depth results per site on each day of data collection. 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 too shallow or inaccessible for Secchi and/or turbidity measurements.

Table 4: 2023 Water Clarity Observations for Lidar flights

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/7	10:33 am	Dock and boat ramp in Bridgeport Harbor	41° 10' 08.59137"	-73° 10' 14.67694"	4.13	4.71	4.76	*1.80	10.00
3/7	11:21 am	Dock on upper Bridgeport Bay	41° 11' 25.61474"	-73° 11' 20.52145"	4.46	4.73	5.00	1.70	15.00
3/8	9:17 am	Old Saybrook marina	41° 17' 07.01783"	-72° 20' 58.88253"	5.59	6.97	6.13	1.40	15.00
3/9	2:29 pm	Norwalk Visitor Dock	41° 05' 55.43417"	-73° 24' 47.61285"	3.02	3.56	3.61	1.49	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/11	10:55 am	Dock east of the Connecticut River Museum Essex, CT at USGS stream gauge	41° 21' 05.37085"	-72° 23' 03.69505"	0.00	0.00	0.00	2.00	2.50
3/11	1:15 pm	Secchi recorded off seawall, turbidity collected at lower beach area to the NW of the New London US Coast Guard Station at the Fort Trumball State Park in New London, CT	41° 20' 47.39312"	-72° 05' 42.81551"	2.70	18.71	6.43	*1.50	13.20
3/12	6:45 AM	Secchi 05: Connecticut River Museum Dock in Essex, CT at USGS stream gauging station	41° 21' 05.42833"	-72° 23' 03.55936"	5.10	4.88	6.79	1.50	6.50
3/12	8:43 am	Secchi 07: Connecticut River Museum Dock in Essex, CT at USGS stream gauging station	41° 21' 05.42926"	-72° 23' 03.56023"	0.00	0.00	0.00	2.25	5.40
3/13	6:37 am	Saybrook Point Marina, CT	41° 17' 07.04575"	-72° 20' 58.90100"	20.10	20.40	24.70	1.50	3.80

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/13	7:27 am	Secchi 11: Niantic River Boat Launch in Waterford, CT	41° 19' 35.93069"	-72° 10' 32.80618"	0.00	0.00	0.00	*1.25	3.80
3/13	8:38 am	Veterans Memorial Park Norfolk, CT	41° 05' 54.43059"	-73° 24' 47.35974"	2.95	2.37	3.48	1.39	NA
3/14	7:00 am	Secchi 13: Niantic River Boat Launch in Waterford CT	41° 19' 35.31661"	-72° 10' 32.35254"	6.78	6.58	8.43	*1.50	9.00
3/14	8:15 am	Westport Longshore	41° 06' 30.03487"	-73° 21' 54.77180"	13.90	18.60	10.10	0.85	NA
3/14	10:10 am	Westport Longshore	41° 06' 30.03487"	-73° 21' 54.77180"	6.09	6.64	5.74	0.84	NA
3/14	2:30 pm	Secchi 15: Niantic River Boat Launch in Waterford, CT	41° 19' 35.29289"	-72° 10' 32.40995"	8.03	10.27	9.63	1.25	15.00
3/15	7:20 am	Secchi 17: Niantic River Boat Launch in Waterford, CT	41° 19' 35.28517"	-72° 10' 32.37020"	29.50	30.50	29.70	0.75	20.10
3/16	8:50 am	Village of Mamaroneck dock on NE corner of Harbor Island Park	40° 56' 40.27880"	-73° 43' 44.78923"	5.93	8.90	5.70	1.50	4.50
3/16	8:53 am	North Hempstead Beach Park	40° 49' 35.16467"	-73° 39' 20.06456"	8.16	8.06	9.84	1.06	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/16	10:40 am	Village of Mamaroneck dock on NE corner of Harbor Island Park in Mamaroneck, NY	40° 56' 40.27908"	-73° 43' 44.77588"	8.99	6.39	7.42	1.75	5.80
3/16	12:26 pm	Morgan	40° 51' 46.81909"	-73° 39' 13.40631"	5.32	7.05	5.86	0.98	NA
3/16	1:00 pm	Pryibil Beach	40° 53' 53.24410"	-73° 37' 19.10157"	***NA	***NA	***NA	1.65	NA
3/17	10:31 am	Orchard Beach	40° 52' 11.30823"	-73° 47' 05.84750"	28.90	29.60	26.10	NA	NA
3/17	11:38 am	Clason Point Park Ferry Terminal	40° 48' 18.49149"	-73° 50' 55.86587"	12.89	13.54	10.38	0.97	NA
3/18	9:05 am	Byram Park Boat Ramp in Port Chester, NY	41° 00' 10.11700"	-73° 38' 47.09942"	3.87	3.50	4.37	2.25	2.00
3/18	11:30 am	Port Washington Public Dock	40° 49' 55.63435"	-73° 42' 09.55922"	9.60	10.10	11.70	1.20	NA
3/18	1:38 pm	Byram Park Boat Launch E of Port Chester, NY	41° 00' 10.09623"	-73° 38' 47.10070"	5.75	5.08	5.41	*0.60	0.00
3/18	2:23 pm	Sgt. Paul Tuozzolo Memorial Spray Park	40° 54' 14.76965"	-73° 32' 34.72738"	4.68	3.48	3.58	1.25	NA
3/19	12:38 pm	Fort Totten	40° 47' 26.53005"	-73° 46' 58.41631"	8.79	8.52	9.94	NA	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/19	1:16 pm	Rock outcrop about 300m SE of the Edith Reed Wildlife Sanctuary a visitor Center Rye, NY	40° 57' 56.75042"	-73° 39' 44.22520"	16.30	18.42	17.40	1.00	11.00
3/19	2:40 pm	North end of Orchard Beach in Pelham Bay Park New York, NY	40° 52' 10.90437"	-73° 47' 02.32895"	15.29	13.78	13.94	1.10	11.00
3/19	3:25 pm	Manorhaven Beach	40° 50' 17.35136"	-73° 42' 57.08637"	4.60	4.51	8.72	NA	NA
3/20	12:43 pm	Norwalk Visitor Dock	41° 05' 55.43417"	-73° 24' 47.61285"	4.60	3.72	2.55	1.45	NA
3/20	1:45 pm	Pier next to Hay Harbor Club on Fishers Island, NY	41° 15' 59.36003"	-72° 01' 21.30843"	3.19	3.15	2.65	*2.50	8.00
3/20	3:00 pm	Beach at Barleyfield Cove, SW of Fishers Island Club Fishers Island, NY	41° 16' 45.96249"	-71° 57' 00.46173"	1.71	1.36	3.23	*0.50	8.00
3/21	12:15 pm	Saybrook Point on the east bank of the Connecticut River old Saybrook, CT	41° 17' 07.04575"	-72° 20' 58.90100"	7.89	9.38	9.83	*1.90	5.80

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/21	1:35 pm	Secchi 17: Niantic River Boat Launch in Waterford, CT	41° 19' 35.28517"	-72° 10' 32.37020"	4.74	3.21	3.94	*0.75	4.10
3/21	1:55 pm	Greenwich Point Park Boat Dock	41° 00' 13.35658"	-73° 35' 06.84454"	5.13	9.89	7.25	NA	NA
3/21	2:45 pm	Ocean Beach New London, CT	41° 18' 28.42658"	-72° 05' 55.30383"	2.24	1.43	2.20	*0.80	5.60
3/21	4:14 pm	Greenwich Point Park Boat Dock	41° 00' 13.35658"	-73° 35' 06.84454"	4.54	6.15	5.00	NA	NA
3/22	12:25 pm	Howard T Brown Memorial Park Norwich, CT	41° 31' 23.18440"	-72° 04' 43.73730"	2.51	1.10	1.15	2.50	7.50
3/22	2:40 pm	N end of Bodwich St at Fort Trumball State Park and Museum New London, CT	41° 20' 47.40388"	-72° 05' 42.79984"	8.71	10.12	13.15	*1.80	4.70
3/23	6:28 am	Site 02: Long dock	41° 02' 21.70764"	-73° 35' 26.13483"	3.23	4.47	2.79	*2.23	1.00
3/25	6:58 am	Kings Park Bluff boat ramp	40° 54' 17.84327"	-73° 13' 51.30520"	8.48	4.65	5.21	**NA	13.60
3/26	7:25 am	Secchi 047	41° 16' 41.24369"	-72° 24' 18.11479"	5.81	5.34	6.16	*1.60	10.00
3/26	7:34 am	Caumsett state park, beach	40° 55' 43.09458"	-73° 24' 12.56792"	7.42	9.03	9.36	***NA	12.80
3/26	8:04 am	Secchi 049: Boat Dock in Bay	41° 16' 31.56900"	-72° 28' 27.78652"	3.99	3.96	4.29	1.80	10.00

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/27	6:24 am	West Neck Beach, a rocky beach	40° 54' 06.25532"	-73° 28' 50.15986"	3.14	3.17	3.16	***NA	8.60
3/27	7:38 am	Hobart beach park (rocky beach)	40° 55' 43.09458"	-73° 24' 12.56792"	2.50	2.37	2.05	*1.45	14.80
3/27	8:36 am	Crab Meadow Beach	40° 55' 49.82408"	-73° 19' 22.56718"	4.49	5.18	4.76	***NA	9.30
3/27	8:50 am	Secchi 051, firm sandy bottom	41° 16' 04.66052"	-72° 31' 12.87746"	9.25	8.33	8.54	**NA	3.00
3/28	7:30 am	Schuberts Beach. Long Beach Rd Nissequogue, NY 11780	40° 55' 14.32259"	-73° 10' 36.73802"	2.17	2.19	2.72	*1.32	7.20
3/28	8:19 am	Secchi 055	41° 16' 12.43653"	-72° 36' 28.89958"	5.75	6.06	5.77	*0.80	1.00
3/28	8:53 am	Harborfront park. 101 E Broadway Port Jefferson, NY 11777 United States	40° 57' 00.81050"	-73° 04' 03.50392"	1.36	1.67	1.43	2.38	8.60
3/28	9:00 am	Secchi 057	41° 15' 30.09893"	-72° 41' 04.28211"	22.00	22.10	20.30	**NA	0.00
3/28	9:30 am	Secchi 059	41° 15' 57.09982"	-72° 45' 07.97462"	9.96	9.93	10.87	**NA	5.00
3/28	10:07 am	Secchi 061	41° 15' 42.11687"	-72° 49' 17.74932"	12.33	11.46	12.69	1.50	3.00

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/28	12:43 pm	Cedar beach. 244 Harbor Beach Rd Mount Sinai, NY 11766 United States	40° 57' 55.86153"	-73° 01' 49.59305"	4.72	4.62	4.74	*1.32	9.20
3/29	8:12 am	244–298 Broadway Rocky Point, NY 11778 United States. Broadway Beach	40° 57' 47.00494"	-72° 55' 29.40214"	4.95	4.80	4.21	*1.32	NA
3/29	9:05 am	Secchi 063	41° 09' 00.31611"	-73° 08' 26.28524"	11.26	10.69	13.19	***NA	7.00
3/29	9:09 am	230 Creek Rd Wading River, NY 11792 United States. Public rocky beach	40° 58' 01.82506"	-72° 51' 12.26787"	2.91	2.47	2.55	*1.32	NA
3/29	9:33 am	Secchi 065	41° 11' 43.75200"	-73° 04' 38.01020"	16.70	17.28	18.65	**NA	8.00
3/29	10:08 am	Secchi 067	41° 15' 20.70080"	-72° 57' 03.63235"	124.00	113.00	106.00	0.20	10.00
3/29	10:12 am	404 Oakleigh Ave Calverton, NY 11933 United States. Rocky beach	40° 58' 04.72415"	-72° 45' 15.25426"	2.53	2.64	3.63	*1.32	NA
3/29	10:51 am	Secchi 069	41° 14' 49.19166"	-72° 54' 02.36996"	20.70	19.72	20.50	0.90	11.00
3/29	11:12 am	320 Pier Ave Riverhead, NY 11901 United States. Iron pier beach	40° 59' 18.06915"	-72° 36' 55.17605"	3.88	3.28	2.79	*1.32	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/30	9:09 am	1505 Naugles Dr Mattituck, NY 11952. Boat ramp	41° 00' 49.12122"	-72° 33' 09.35384"	4.17	5.29	5.52	*0.82	NA
3/30	10:25 am	180 Sound Ave Peconic, NY 11958. Goldsmiths' inlet	41° 03' 11.87211"	-72° 28' 16.62601"	2.95	3.39	2.80	*1.32	NA
3/30	10:33 am	Secchi 073	41° 04' 42.29490"	-71° 56' 11.78212"	22.60	22.00	21.30	***NA	15.00
3/30	11:36 am	1920 Minnehaha Blvd Southold, NY 11971. Boat ramp	41° 02' 06.45275"	-72° 25' 43.88543"	5.13	4.49	4.97	*1.32	NA
3/31	9:04 am	Secchi 075	40° 53' 42.10934"	-72° 29' 59.28630"	17.77	12.78	19.36	***NA	5.00
3/31	9:37 am	Secchi 077	40° 56' 19.95047"	-72° 24' 29.11475"	10.88	8.71	8.81	***NA	3.00
3/31	10:02 am	Secchi 079	40° 59' 49.53806"	-72° 21' 01.01897"	0.89	1.32	1.08	*1.70	8.00
3/31	10:06 am	53005 North Rd Southold, NY 11971. Town beach Southold	41° 05' 19.93063"	-72° 24' 54.49008"	3.83	2.61	3.45	*1.32	NA
3/31	10:28 am	Secchi 081	41° 00' 11.39609"	-72° 17' 45.31750"	3.00	3.21	3.84	*1.40	5.00
3/31	10:42 am	Greenpoint Marina: 115 Front St Greenport, NY 11944.	41° 06' 01.94795"	-72° 21' 38.99150"	2.31	2.27	2.12	2.34	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
3/31	11:06 am	Secchi 083	41° 01' 58.42054"	-72° 11' 06.84675"	3.54	3.74	3.82	***NA	9.00
3/31	11:30 am	16827–16979 Main Rd East Marion, NY 11939. Truman's Beach	41° 08' 30.89396"	-72° 19' 06.49884"	2.23	1.83	2.83	*1.32	NA
3/31	12:46 pm	2–198 Narrow River Rd Orient, NY 11957. Beach	41° 07' 50.45383"	-72° 17' 42.25892"	5.04	4.92	4.33	*1.32	NA
3/31	12:50 pm	Site 70: 500–946 Point Rd Orient, NY 11957. Orient ferry beach	41° 09' 19.22120"	-72° 14' 21.13084"	4.38	3.47	4.52	*1.32	NA
4/2	10:45 am	1 Club Dr Shelter Island Heights, NY 11965. Town beach	41° 04' 25.61614"	-72° 16' 41.52565"	4.37	4.89	3.62	*1.32	NA
4/2	11:06 am	Site 085	41° 01' 09.54277"	-72° 07' 56.03578"	11.48	8.31	8.94	***NA	9.00
4/2	11:38 am	Secchi 087	41° 00' 46.82775"	-72° 03' 30.92728"	10.31	9.19	9.76	1.50	10.00
4/2	11:44 am	31–35 Shore Rd Shelter Island Heights, NY 11965. Crescent Beach	41° 04' 29.48816"	-72° 21' 54.58956"	3.56	3.22	2.77	*1.32	NA
4/2	12:20 pm	Secchi 089	41° 02' 30.95275"	-71° 57' 56.02231"	28.40	28.10	27.60	***NA	13.00

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
4/2	12:41 pm	Protected bay near Montauk Point	41° 02' 57.60410"	-71° 54' 38.23888"	11.34	11.99	12.75	***NA	11.00
4/2	12:55 pm	375 First St New Suffolk, NY 11956. New Suffolk beach	40° 59' 24.23439"	-72° 28' 18.30966"	3.30	3.79	3.03	*1.32	NA
4/2	1:48 pm	S Jamesport Ave South Jamesport, NY 11968. Beach	40° 56' 00.42058"	-72° 34' 33.86166"	2.61	2.69	3.43	*1.32	NA
4/3	3:06 pm	Sunken Meadows State Park beach	40° 54' 22.25766"	-73° 13' 57.26577"	3.06	3.39	3.64	*1.32	NA
4/4	12:53 pm	Cordwood Park. Harbor Road Smithtown, NY 11787	40° 53' 42.00000"	-73° 10' 26.40000"	2.42	2.36	2.58	*1.32	NA
4/4	5:12 pm	66 Shore Rd East Setauket, NY 11733. Beach with floating dock	40° 56' 53.6136"	-73° 06' 6.2532"	5.01	4.42	4.95	*0.81	NA
4/8	6:09 am	Woodmont Beach	41° 13' 45.34112"	-72° 59' 18.97289"	6.86	3.99	3.24	***NA	NA
4/9	6:50 am	Cedar Beach	40° 57' 52.36393"	-73° 02' 26.74057"	7.88	7.11	9.71	2.43	NA
4/9	4:29 pm	West Meadow Beach	40° 56' 40.06424"	-73° 08' 41.34282"	2.19	2.42	2.39	***NA	NA
4/10	7:30 am	SITE_096	40° 57' 48.83085"	-72° 52' 45.26021"	2.91	2.30	2.28	***NA	NA

Date	Time (UTC - 4)	Location	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	Secchi Depth (m)	Wind Speed (mph)
4/10	4:52 pm	SITE_098	40° 57' 58.03647"	-72° 59' 05.81784"	1.35	1.45	1.28	***NA	NA
4/11	7:24 am	Reeves Beach	40° 58' 34.13580"	-72° 42' 45.81947"	1.78	1.45	2.87	***NA	NA
4/11	9:24 am	Indian Point Beach	40° 55' 31.71747"	-72° 37' 06.27949"	2.04	2.54	2.86	***NA	NA
4/12	7:57 am	Breakers Beach	41° 00' 53.64615"	-72° 33' 40.69255"	4.39	4.37	4.76	1.87	NA
4/12	10:42 am	Veterans Beach	40° 58' 38.28753"	-72° 31' 53.08465"	1.96	1.26	1.72	***NA	NA
4/13	10:43 am	Jamesport Beach	40° 56' 28.67160"	-72° 34' 08.41102"	2.00	2.50	2.14	2.39	NA
4/13	11:50 am	375 First St New Suffolk, NY 11956. New Suffolk beach	40° 59' 24.23439"	-72° 28' 18.30966"	1.77	2.07	2.05	2.37	NA
4/14	10:21 am	Orient Point near Ferry Terminal	41° 09' 22.20641"	-72° 14' 18.50047"	1.41	1.48	2.25	***NA	NA

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

*** These locations were too shallow for Secchi depth measurements.*

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

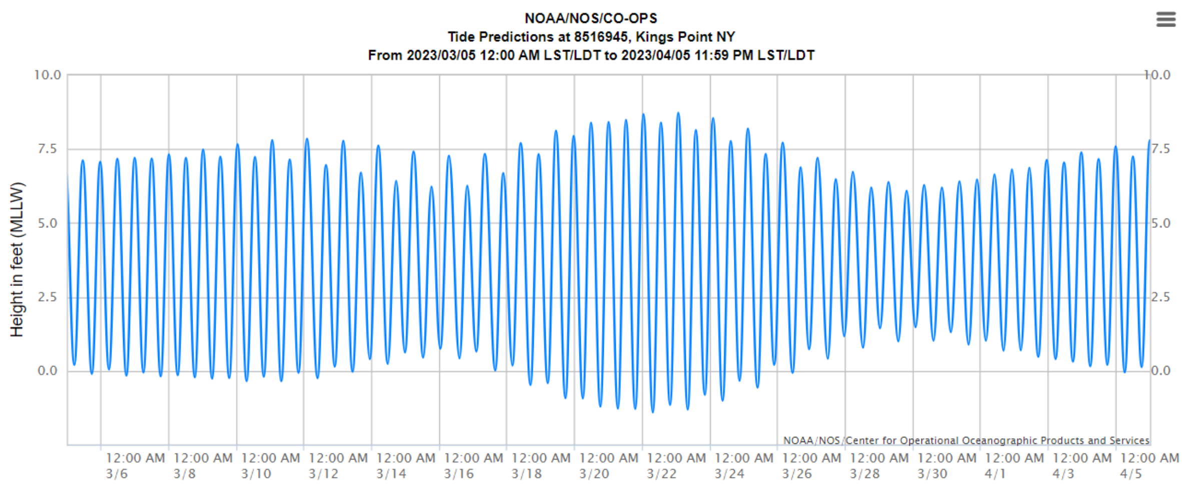


Figure 4: Tide Predictions at 8516945, Kings Point, NY during the time of lidar acquisition (March)

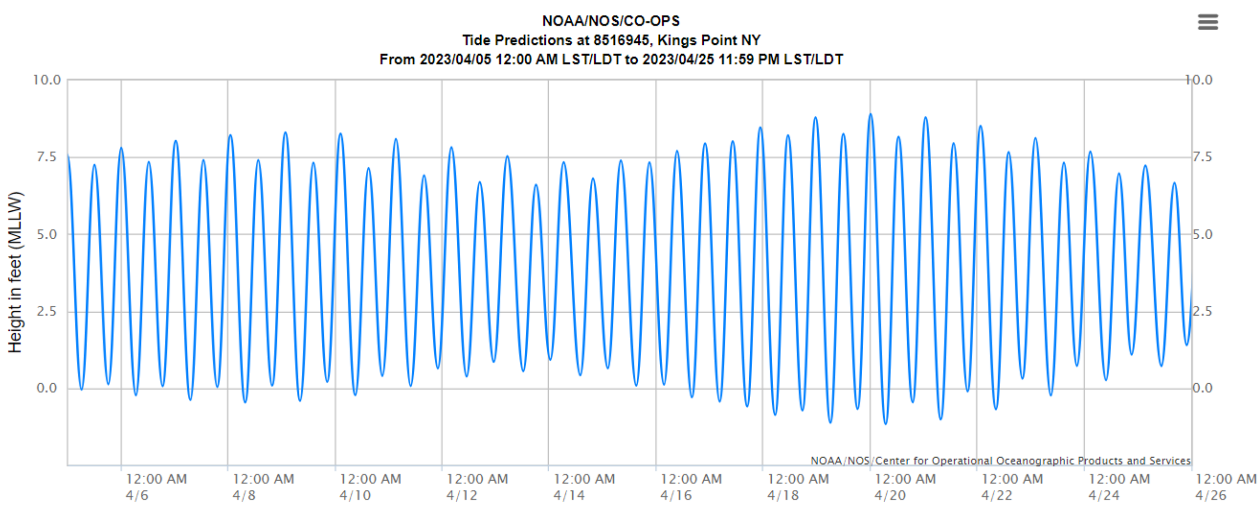


Figure 5: Tide Predictions at 8516945, Kings Point, NY during the time of lidar acquisition (April)

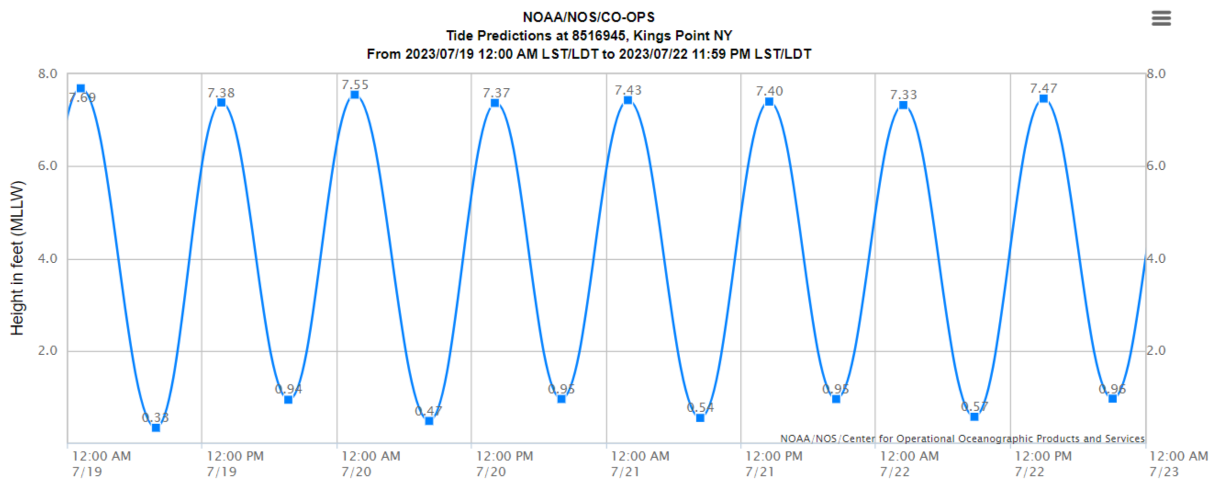


Figure 6: Tide Predictions at 8516945, Kings Point, NY during the time of lidar acquisition (July)

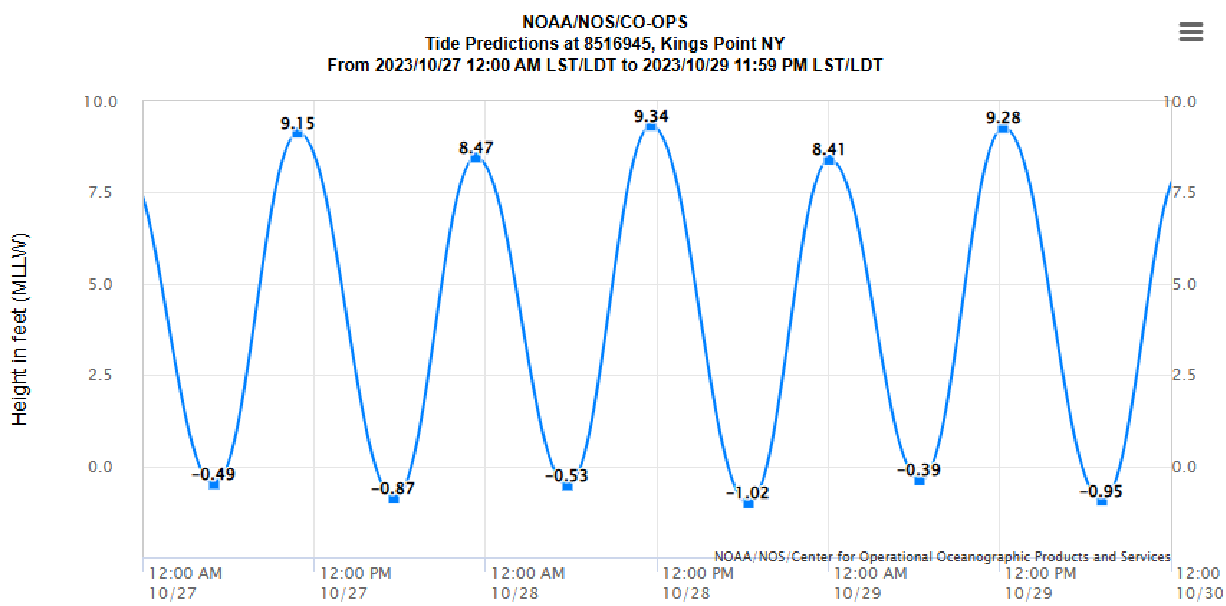


Figure 7: Tide Predictions at 8516945, Kings Point, NY during the time of lidar acquisition (October)

Airborne Survey

Lidar

The lidar survey was accomplished using Chiroptera 4X (CH4X) and Chiroptera 5 (CH5) shallow green laser systems mounted in a Piper Navajo or Cessna Grand Caravan. The CH4X and CH5 sensors allow for a depth penetration of K*Dmax=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.

The CH4X and CH5 laser systems were dually mounted with Leica HawkEye 4X (HE4X) and HawkEye 5 (HE5) 40kHZ deep bathymetric channel sensors, respectively. 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*Dmax=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 +/-14° (front and back) to +/-20° (sides), providing a 40° field of view. This has the benefit of providing multiple look angles on a single pass and helps to eliminate shadowing effects. This can be of particular use 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.

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/m^2 for bathymetric and NIR returns, respectively, over the NOAA Long Island Sound project area. Figure 8 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	3/5/2023 – 10/28/2023	3/5/2023 – 10/28/2023	3/5/2023 – 10/28/2023
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	15	6	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 – 500 m	400 – 500 m	400 – 500 m
Survey speed	140 - 145 knots	140 - 145 knots	140 - 145 knots
Field of View	40º	40º	40º
Mirror Scan Rate	4200 RPM	3430 RPM	1833 RPM
Target Pulse Rate	250 kHz	35, 50 kHz	10 kHz
Pulse Length	2.5 ns	2.5 ns	2.5 ns
Laser Pulse Footprint Diameter	10 – 25 cm	160 – 237.5 cm	288 – 375 cm
Central Wavelength	1064 nm	515 nm	515 nm
Beam Divergence	0.25 mrad, 0.5 mrad	4, 4.75 mrad	7.2, 7.5 mrad
Swath Width	291 – 364 m	291 – 364 m	291 – 364 m
Swath Overlap	25%	25%	25%
Intensity	16-bit	16-bit	16-bit

All areas were surveyed with an opposing flight line side-lap of ≥25% (≥50% 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 ADS 100 orthoimagery sensor mounted in a Cessna Grand Caravan (Table 5). The ADS 100 is a large format digital aerial camera manufactured by Vexel. 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	UltraCam Eagle 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 Long Island Sound 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 Long Island Sound project are in Table 6.

Table 6: Project-specific orthophoto specifications

Parameter	Digital Orthophotography Specification
Ground Sampling Distance (GSD)	≤25 cm
Along Track Overlap	≥60%
Cross Track Overlap	≥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.

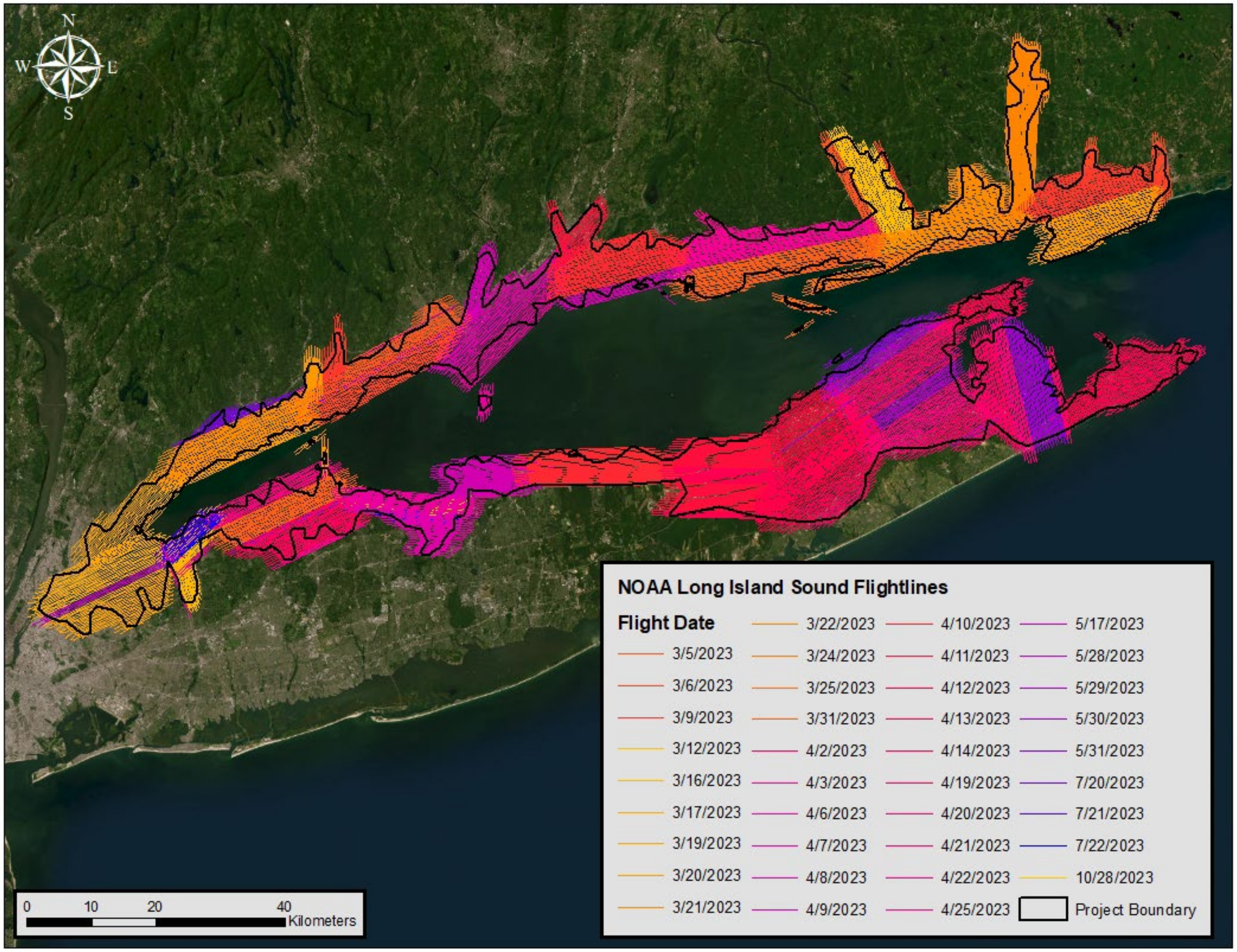


Figure 8: Flightlines map

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 collection of ground survey points using real time kinematic (RTK) survey techniques.

Base station locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NV5 utilized 20 permanent real-time network (RTN) base stations, 13 from the Hexagon SmartNet[1] and 7 from the KeyNet networks for the NOAA Long Island Sound Lidar project (Table 6, Figure 10). NV5's professional land surveyor, Steven J. Hyde (NYPLS#051123-01), oversaw and certified the ground survey. No physical monuments were utilized for this project.

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

Monument ID	Latitude	Longitude	Ellipsoid (meters)	Owner
BGI1	41° 39' 21.67733"	-72° 43' 55.66462"	6.147	KEYNET
CTBP	41° 10' 30.83874"	-73° 11' 45.03575"	-14.304	SMARTNET
CTCL	41° 16' 24.87994"	-72° 29' 23.81486"	-21.379	SMARTNET
CTMN	41° 34' 39.61230"	-72° 40' 18.49655"	-11.604	SMARTNET
CTNH	41° 17' 51.59987"	-72° 54' 43.99584"	37.834	SMARTNET
CTPL	41° 38' 15.91935"	-71° 57' 02.90922"	26.751	SMARTNET
CTSF	41° 04' 28.10765"	-73° 31' 03.75747"	-7.775	SMARTNET
CTWF	41° 20' 08.88112"	-72° 06' 55.96052"	-4.921	SMARTNET
KP18	41° 24' 54.19002"	-71° 38' 49.97505"	23.733	KEYNET
MTG1	41° 28' 59.94786"	-72° 05' 04.22188"	65.714	KEYNET
NJHT	40° 43' 52.04822"	-74° 02' 15.25871"	-11.763	SMARTNET
NYBR	40° 41' 19.14474"	-74° 00' 04.57839"	-19.040	SMARTNET

[1] https://hxgnsmartnet.com/0000000

Monument ID	Latitude	Longitude	Ellipsoid (meters)	Owner
NYCI	40° 45' 38.23688"	-73° 11' 51.78727"	-13.860	KEYNET
NYDP	40° 48' 22.66753"	-73° 13' 06.40352"	11.310	SMARTNET
NYEL	40° 42' 23.08258"	-73° 39' 58.42149"	-2.665	SMARTNET
NYGC	40° 44' 04.76038"	-73° 36' 00.97478"	4.798	KEYNET
NYRH	40° 55' 24.08885"	-72° 42' 50.56089"	-7.951	KEYNET
NYVH	41° 04' 56.22099"	-73° 49' 04.12573"	63.297	KEYNET
NYYO	40° 55' 34.49007"	-73° 52' 08.83781"	56.441	SMARTNET
RIBR	41° 24' 14.38162"	-71° 44' 57.83687"	-8.794	SMARTNET

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 (OPUS[2]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Network Accuracy

Base station coordinates were established or evaluated according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[3] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 7.

Table 7: FGDC monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.020 m
1.96 * St Dev $_{z}$:	0.020 m

[2] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions: OPUS website

[3] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic (RTK) 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 8 for NV5 ground survey equipment information.

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 10).

Table 8: NV5 ground survey equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R10	Integrated Antenna	TRMR10	Rover
Trimble R12	Integrated Antenna	TRMR12	Rover

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 9). 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 9: Example of an aerial target

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 9, see Lidar Accuracy Assessments, page 50).

Table 9: 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

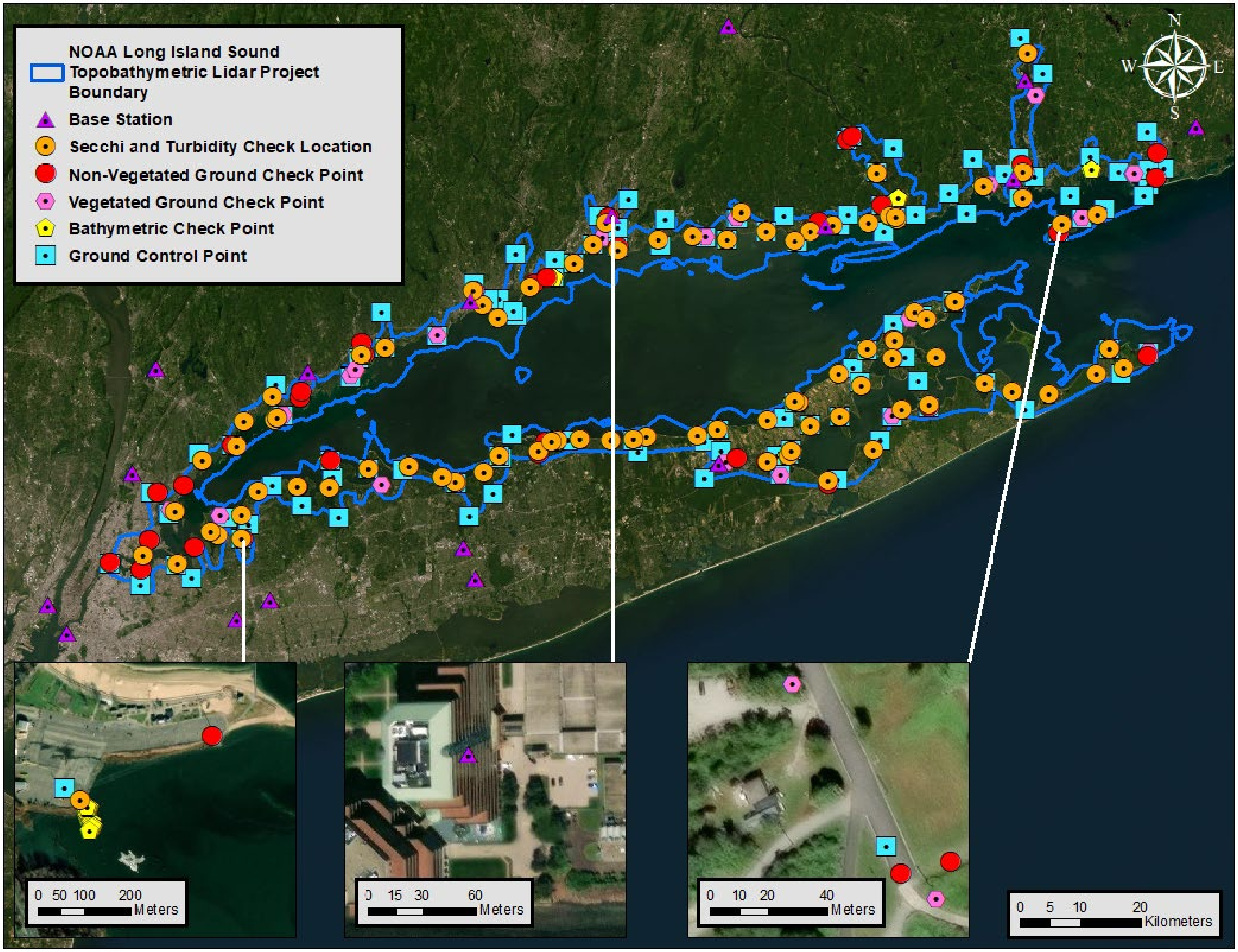
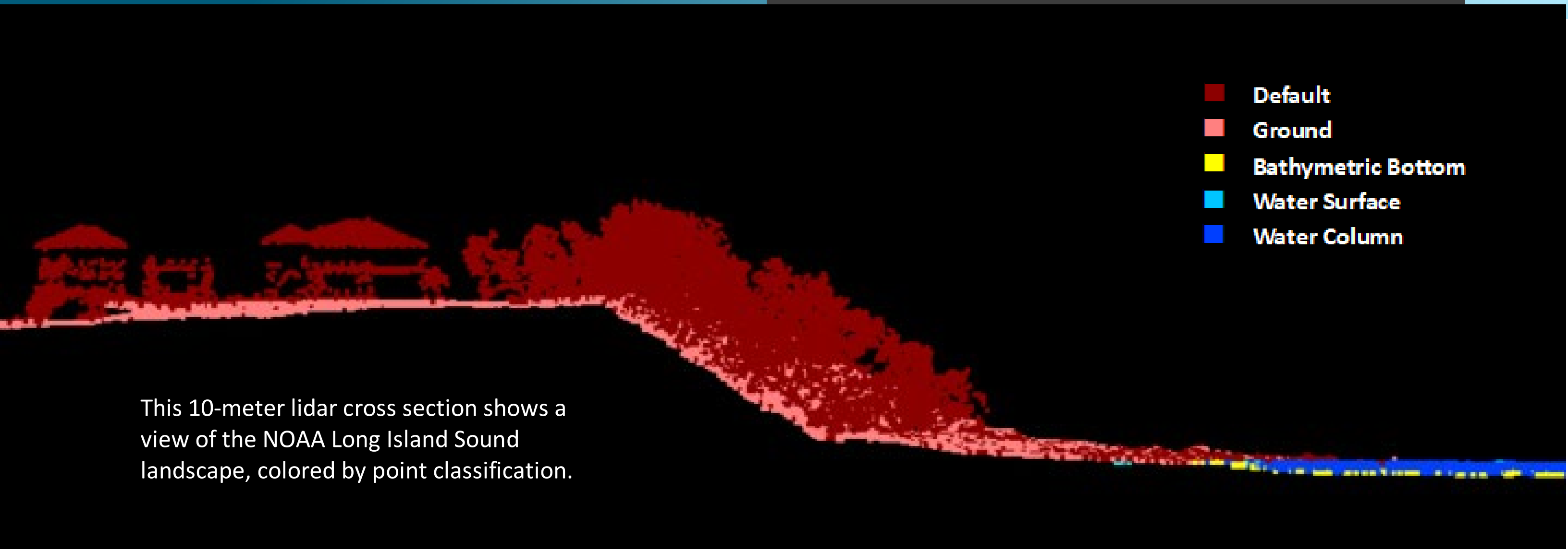


Figure 10: Ground survey location map



This 10-meter lidar cross section shows a view of the NOAA Long Island Sound landscape, colored by point classification.

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 Long Island Sound landscape. Brief descriptions of these tasks are shown in Table 11, and example raster layers for processing and review can be visualized in Figure 11.

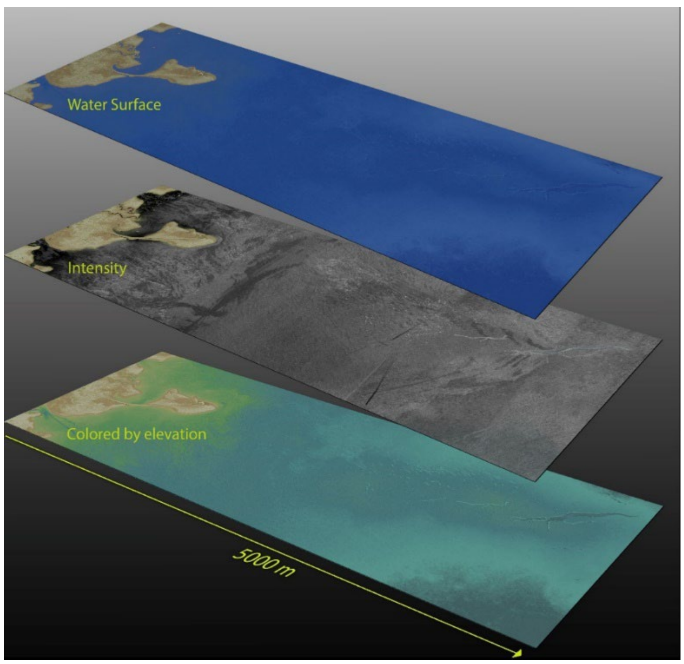


Figure 11: Example processing data layers

Table 10: ASPRS LAS classification standards applied to the NOAA Long Island Sound 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 11: 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 10). 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 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 can 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 atmospherics, 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 12, Figure 13); 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 14). Please note intensity values are still subject to localized changes of water properties within the water column across a water body.

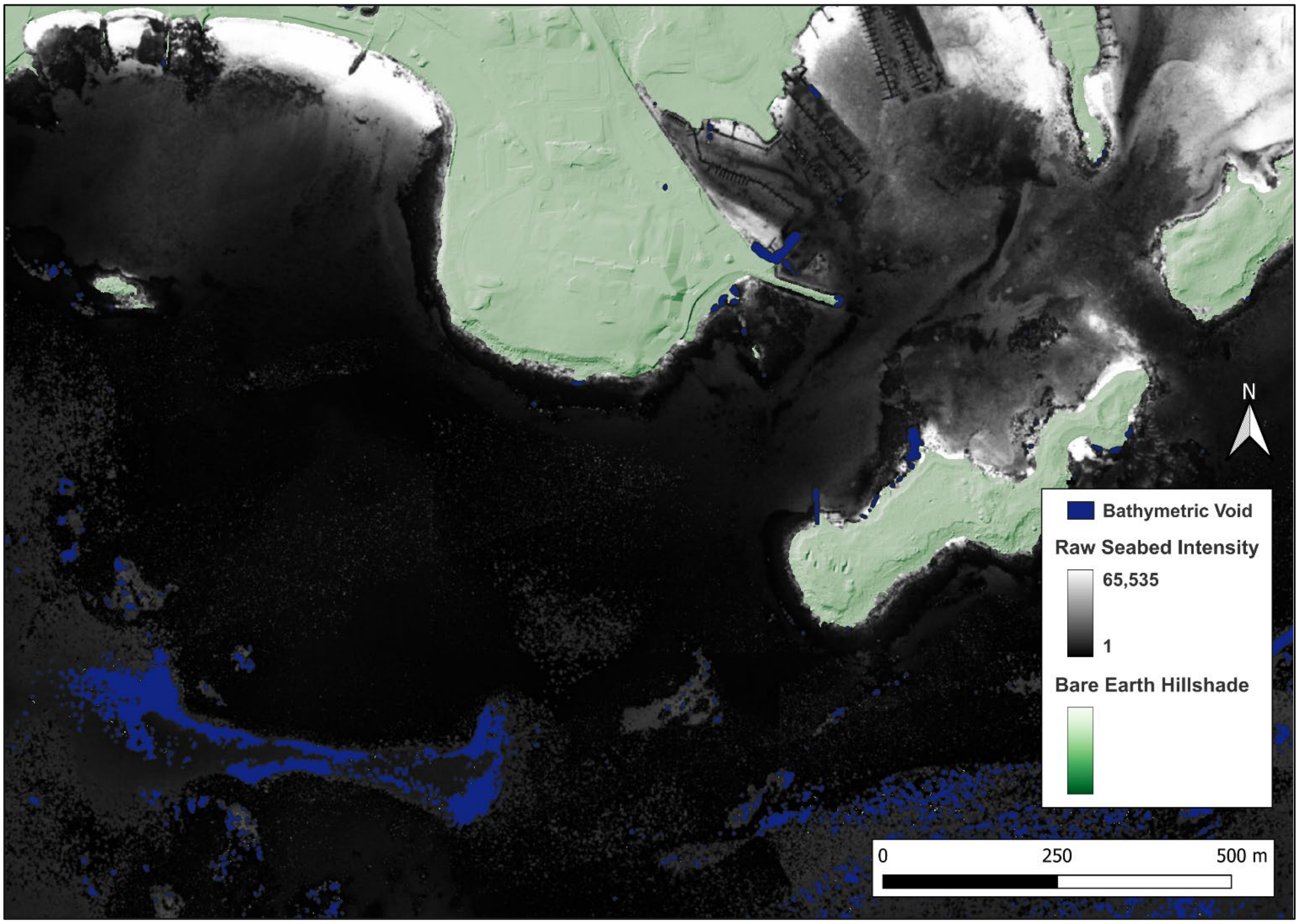


Figure 12: Raw Seabed Intensity values

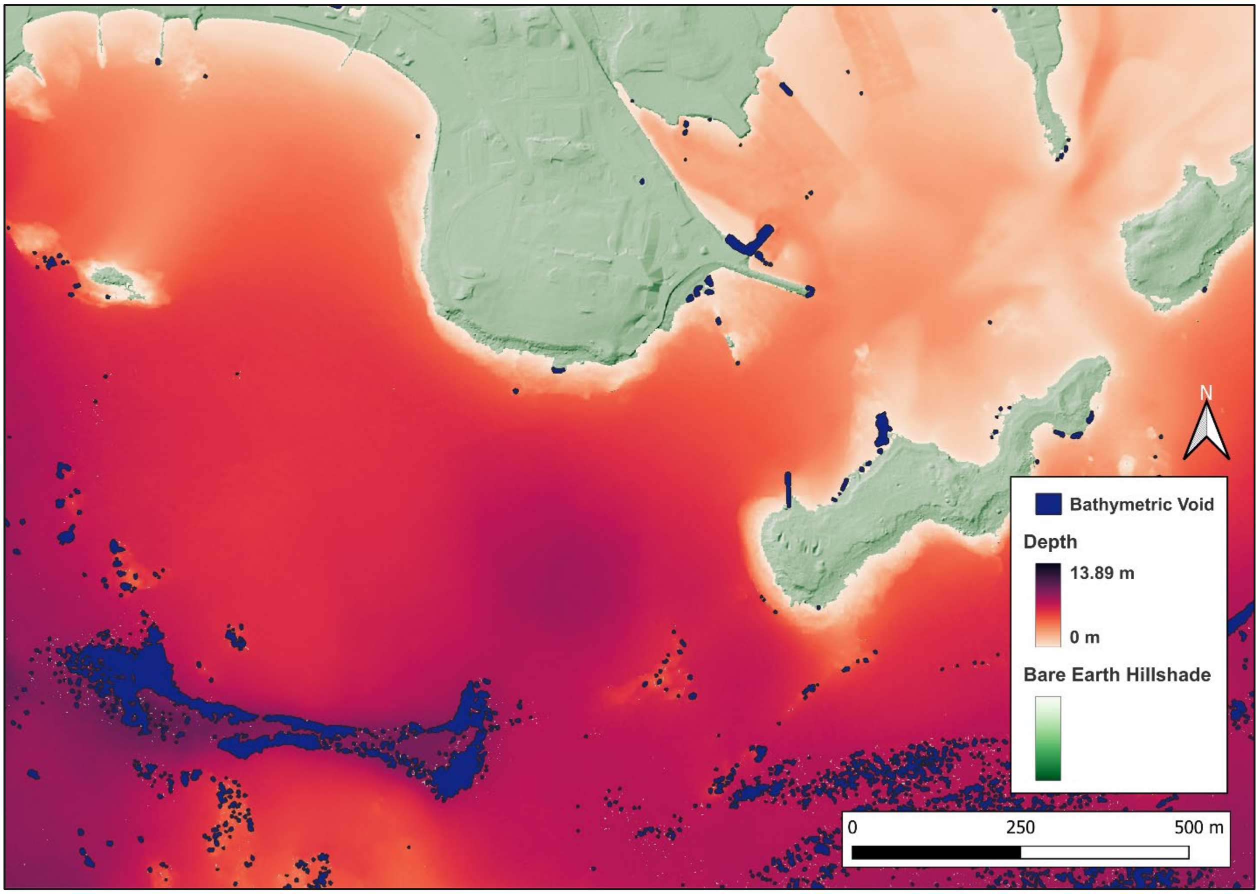


Figure 13: Depth raster shows areas of deeper bathymetry which correlated to diminished seabed intensity values.

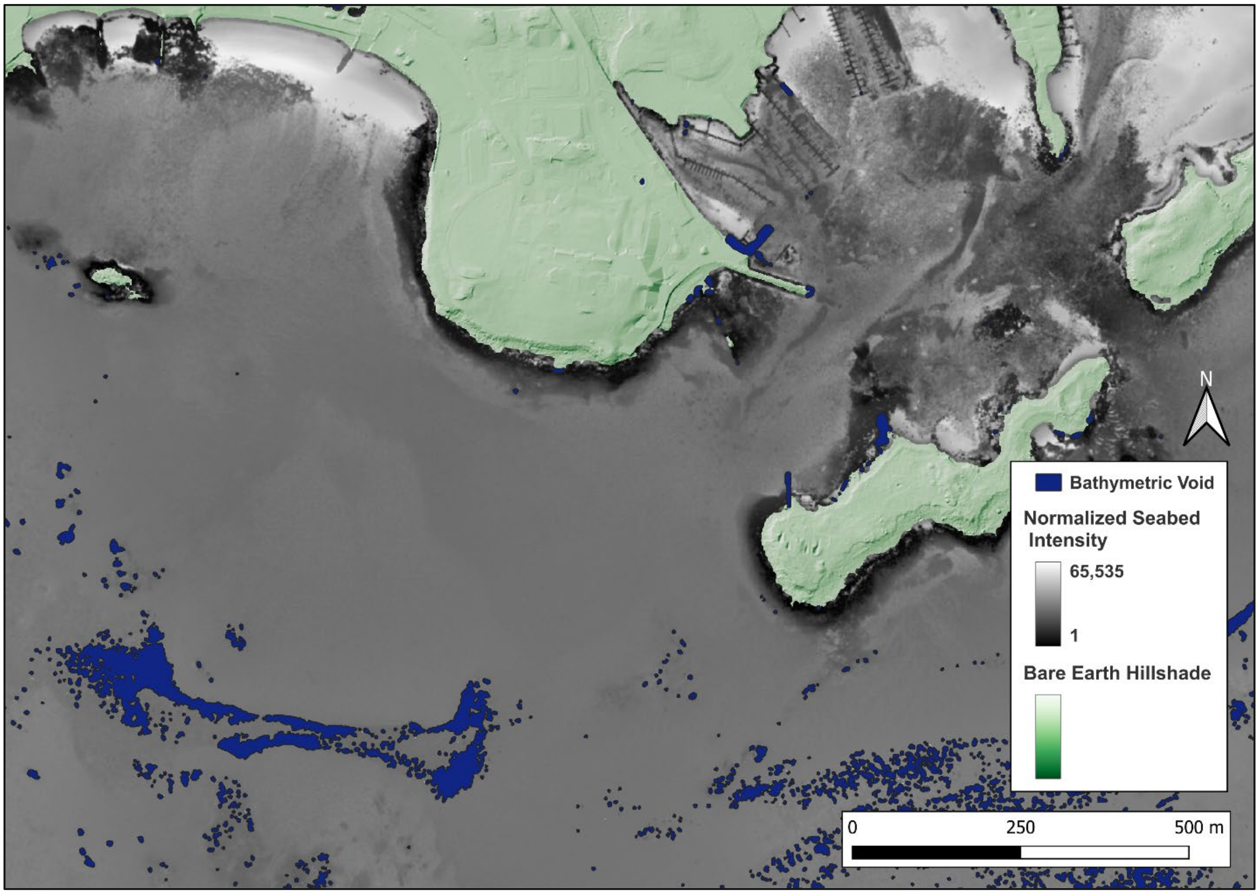


Figure 14: Seabed Intensity values were normalized for depth, angle of incidence, and absolute flying altitude.

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 Long Island 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[4]. The cBlue tool computes subaerial components of the laser pulse's travel path utilizing information from associated smooth 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 sucha 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 vertival 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.

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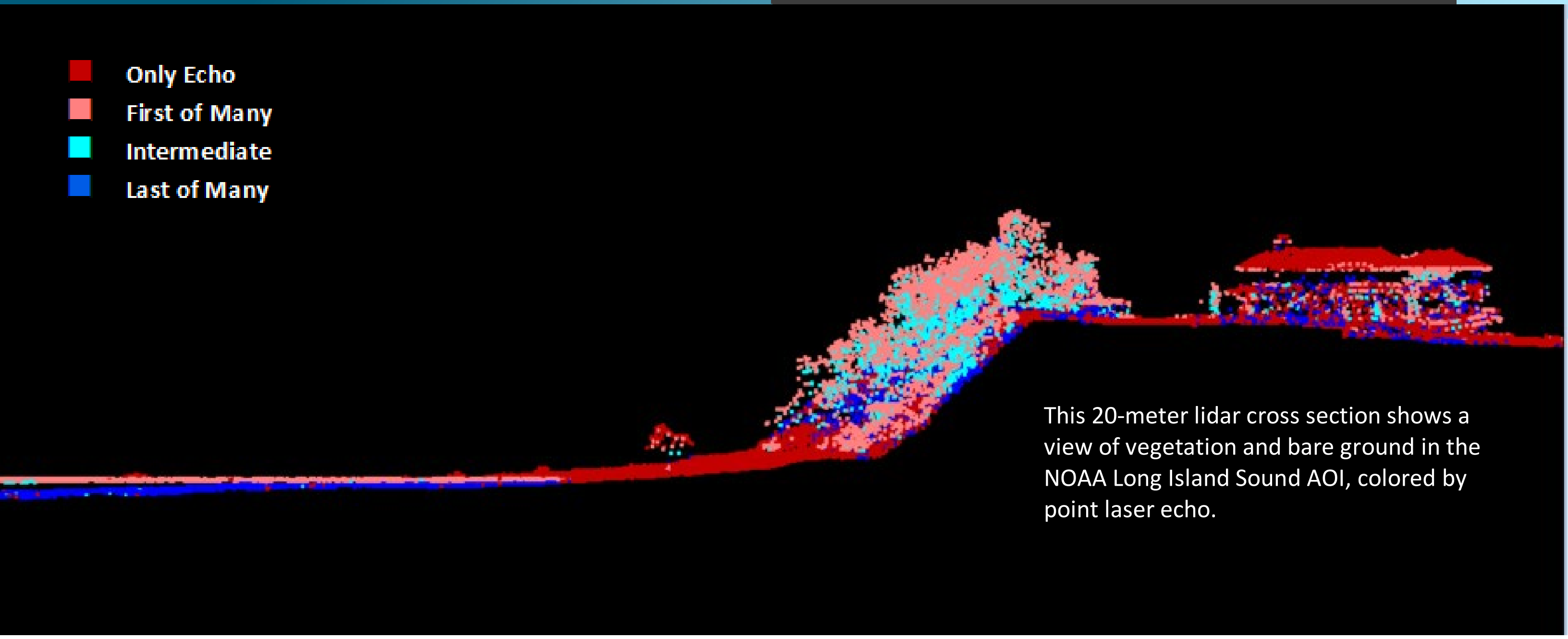
[4] NOAA cBlue: https://noaa-rsd.github.io/cBLUE.github.io/index.html



This 20-meter lidar cross section shows a view of vegetation and bare ground in the NOAA Long Island Sound AOI, colored by point laser echo.

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 and Depth Penetration

Under optimal conditions, the specified depth penetration range of the CH4x is about 1.5 Secchi depths, CH5 about 1.8 Secchi depths, and both HawkEyes are about 3 Secchi depths; therefore, bathymetry data below these depths at the time of acquisition are not to be expected. Since the HawkEyes 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 m^2), were identified as data voids. NV5 also analyzed the depth of the project area with the maximum recorded depth for the NOAA Long Island Sound topobathymetric dataset being 15.93-meters (Figure 15).

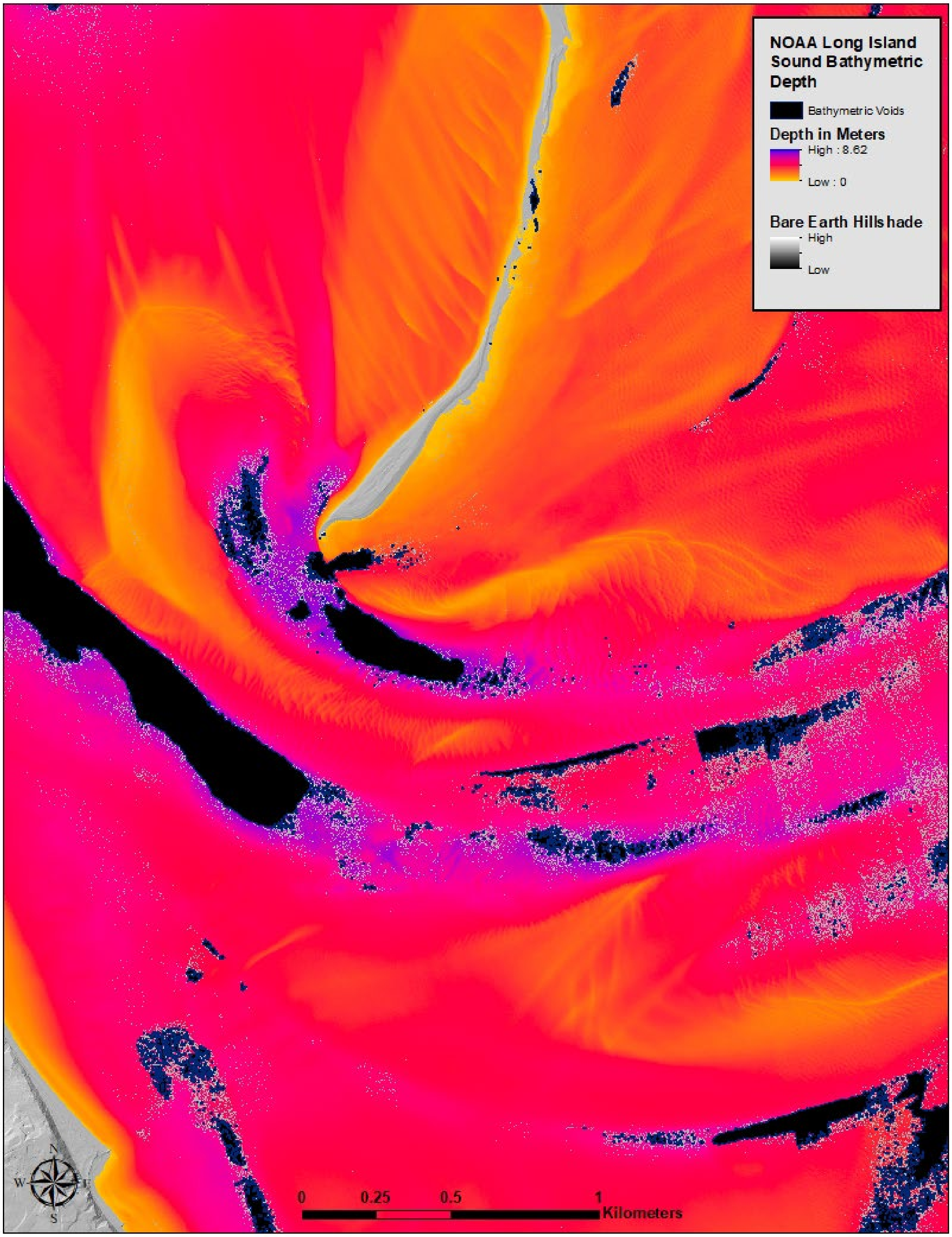


Figure 15: Depth model of the Long Island Sound

Lidar Point Density

First Return Point Density

The acquisition parameters were designed to acquire an average first-return density of 4 points/m^2 in terrestrial areas and 3 4 points/m^2 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 of the NOAA Long Island Sound Lidar project was 11.76 points/m^2 (Table 12). The statistical and spatial distributions of all first return densities per 100 m x 100 m cell are portrayed in Figure 16 through Figure 18 and Figure 20.

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 Long Island Sound project was 5.56 points/m^2. The return density for each delivery is shown in Table 12. 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 19 and Figure 21.

Additionally, for the NOAA Long Island Sound 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 2.50 points/m^2 was achieved.

Table 12: Average Lidar point densities

Delivery	NIR First Returns	Green First Returns	Combined First Returns	Ground and Bathymetric Bottom Classified Returns	Bathymetric Bottom Classified Returns
D1	8.76 points/m^2	3.03 points/m^2	11.70 points/m^2	5.76 points/m^2	4.30 points/m^2
D2	7.46 points/m^2	3.09 points/m^2	10.55 points/m^2	4.65 points/m^2	1.17 points/m^2
D3	8.89 points/m^2	4.07 points/m^2	12.96 points/m^2	6.46 points/m^2	5.53 points/m^2
D4	7.45 points/m^2	4.76 points/m^2	12.21 points/m^2	5.71 points/m^2	2.57 points/m^2
Cumulative	7.97 points/m^2	3.79 points/m^2	11.76 points/m^2	5.56 points/m^2	2.50 points/m^2

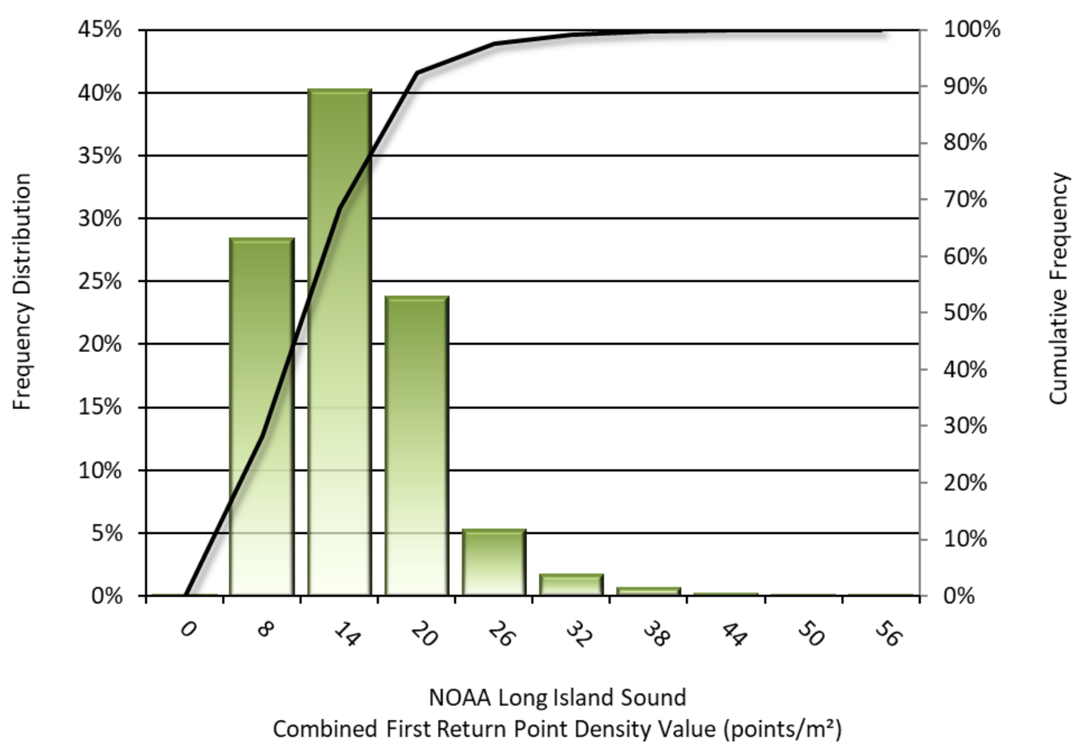


Figure 16: Frequency distribution of first return densities per 100 x 100 m cell

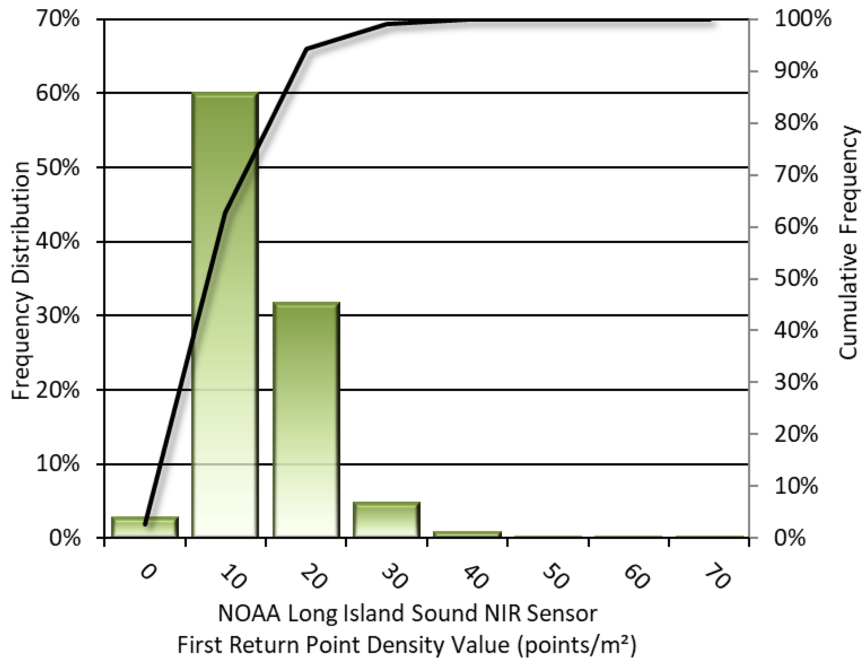


Figure 17: Frequency distribution of NIR sensor first return densities per 100 x 100 m cell

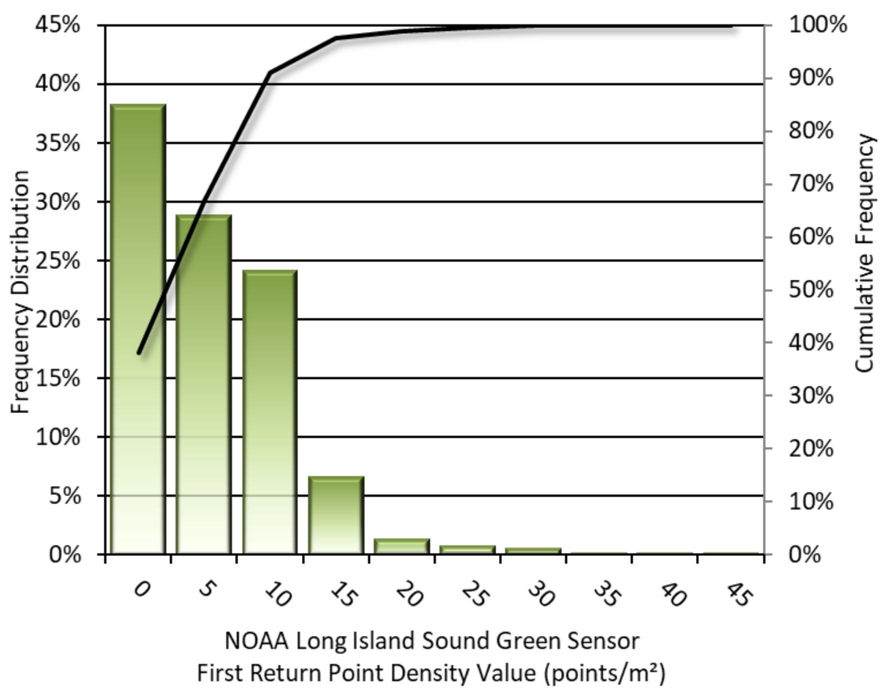


Figure 18: Frequency distribution of Green sensor first return densities per 100 x 100 m cell

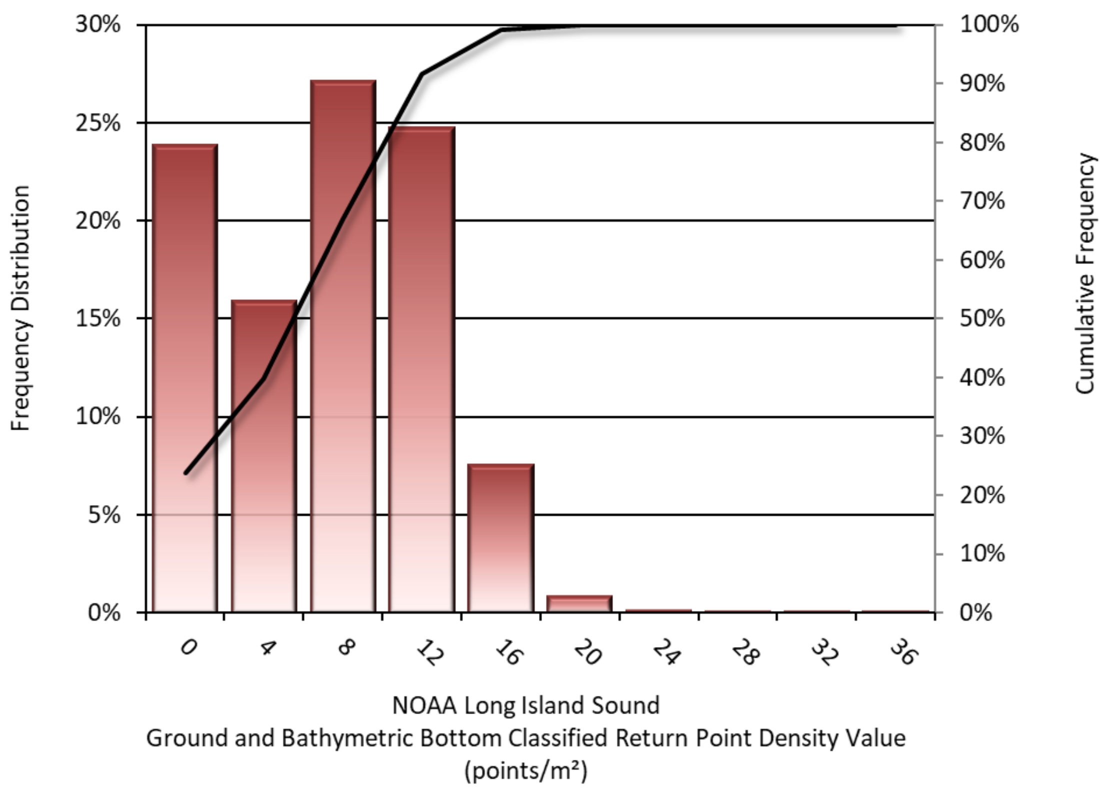


Figure 19: Frequency distribution of ground and bathymetric bottom classified return densities per 100 x 100 m cell

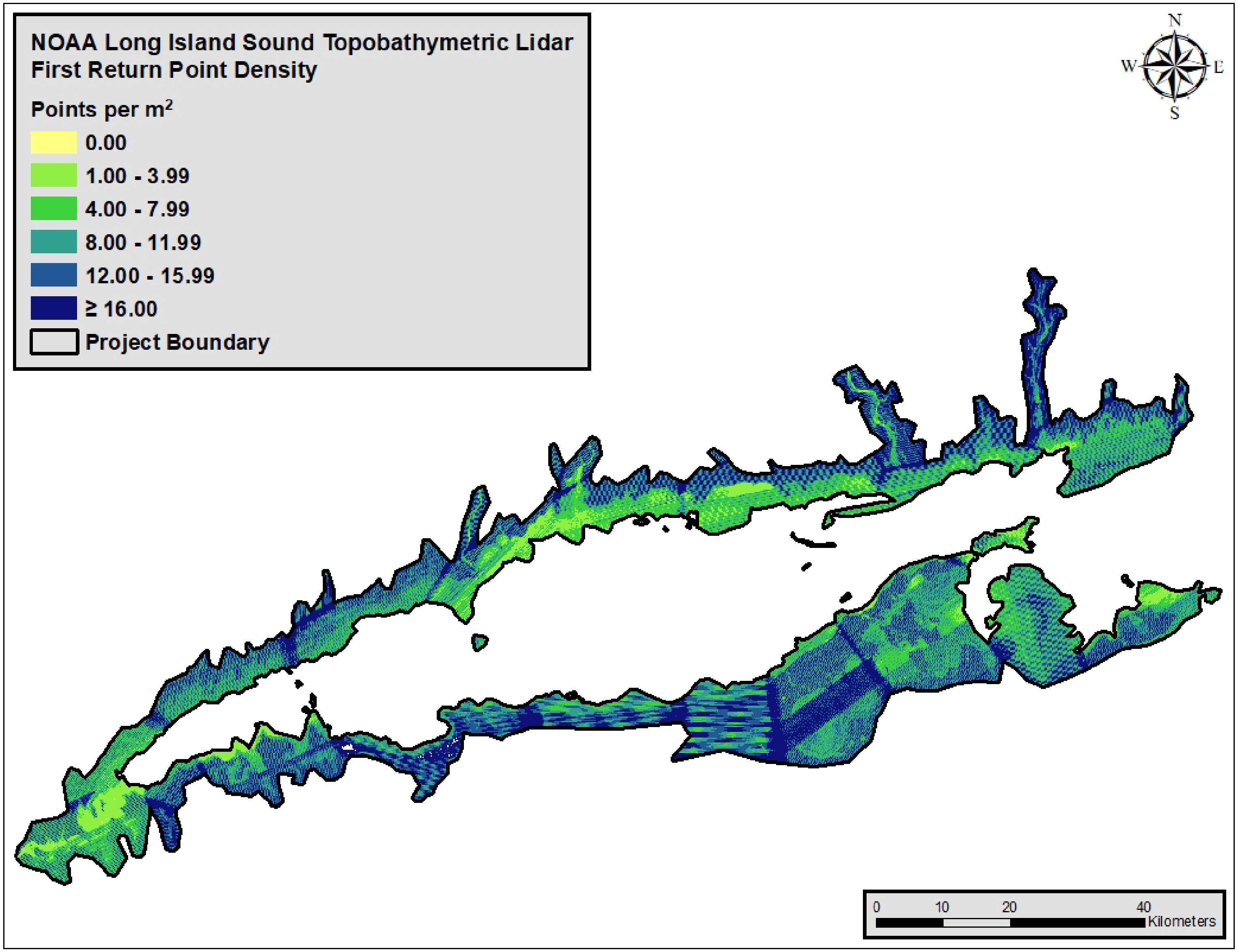


Figure 20: First return density map for the NOAA Long Island Sound site (100 m x 100 m cells)

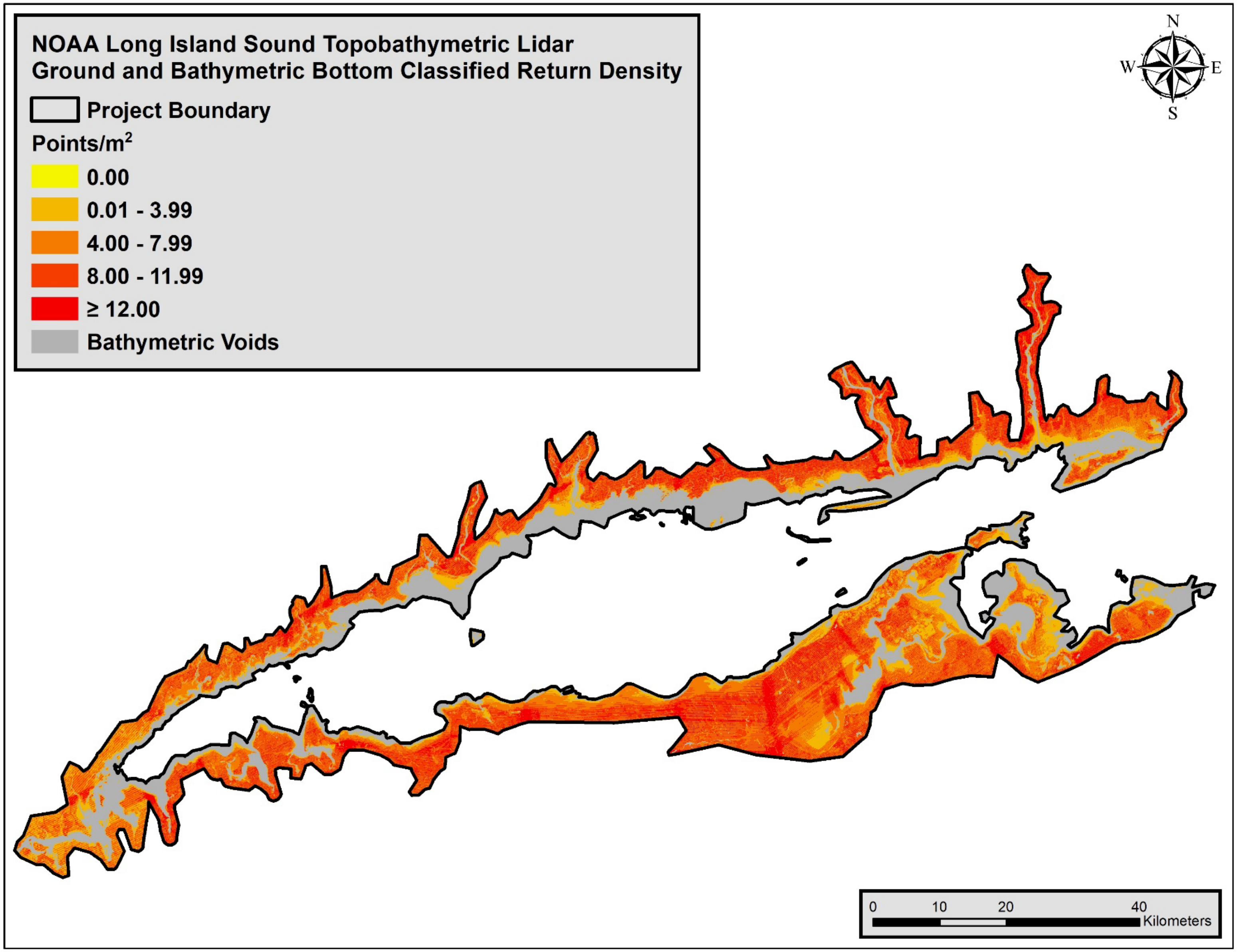


Figure 21: Ground and bathymetric bottom density map for the NOAA Long Island Sound site (100 m x 100 m cells)

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[5]. 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 and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 13 and Table 14.

The mean and standard deviation (sigma 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 Long Island Sound survey ground checkpoints were withheld from the calibration and post-processing of the lidar point cloud, with a resulting non-vegetated vertical accuracy of 0.053 meters as compared to the classified LAS, and 0.057 meters against the bare earth DEM, with 95% confidence (Table 13, Table 14, Figure 22, and Figure 23).

NV5 also assessed absolute accuracy using 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 15and Figure 24.

Table 13: NVA, as compared to Classified LAS

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	13 points	0.055 m	0.011 m	0.008 m	0.028 m	0.027 m
D2	16 points	0.055 m	0.002 m	0.010 m	0.028 m	0.029 m
D3	5 points	0.032 m	0.004 m	0.001 m	0.016 m	0.017 m
D4	10 points	0.056 m	-0.002 m	-0.009 m	0.029 m	0.030 m
Cumulative	44 points	0.053 m	0.004 m	0.004 m	0.027 m	0.027 m

[5] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. https://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf.

Table 14: NVA, as compared to Bare Earth DEM

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	13 points	0.058 m	0.010 m	0.004 m	0.030 m	0.029 m
D2	16 points	0.057 m	0.004 m	0.007 m	0.029 m	0.030 m
D3	5 points	0.049 m	0.012 m	0.002 m	0.025 m	0.024 m
D4	10 points	0.060 m	-0.004 m	-0.018 m	0.031 m	0.032 m
Cumulative	44 points	0.057 m	0.005 m	0.001 m	0.029 m	0.029 m

Table 15: Ground Control Points

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	41 points	0.045 m	0.003 m	0.003 m	0.023 m	0.023 m
D2	29 points	0.053 m	0.005 m	0.000 m	0.027 m	0.027 m
D3	17 points	0.050 m	0.000 m	0.007 m	0.026 m	0.026 m
D4	31 points	0.063 m	0.001 m	0.001 m	0.032 m	0.033 m
Cumulative	118 points	0.053 m	0.003 m	0.003 m	0.027 m	0.027 m

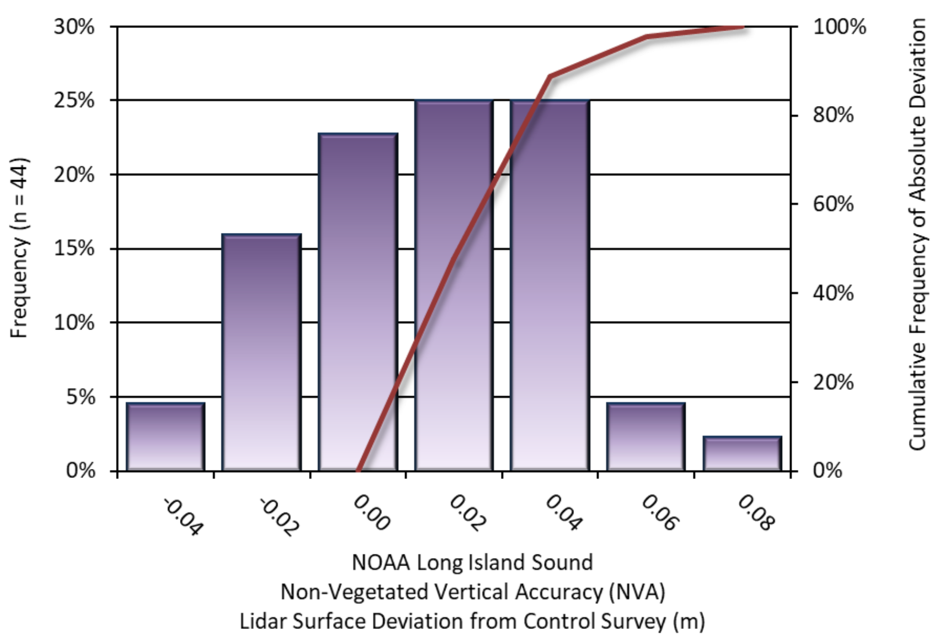


Figure 22: Frequency histogram for classified LAS deviation from ground check point values

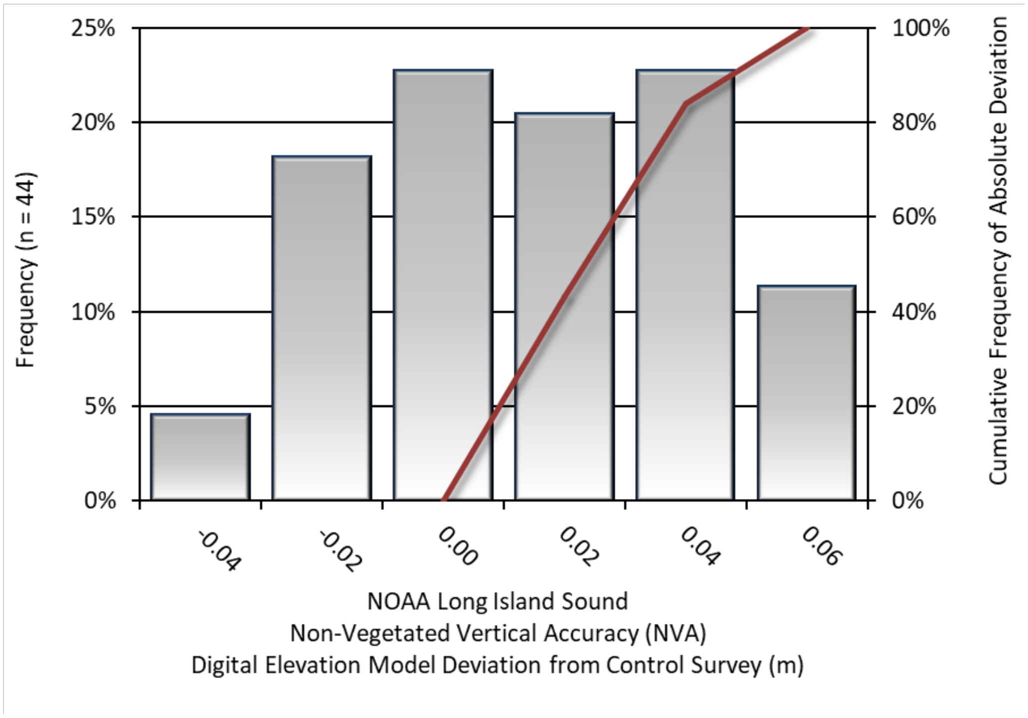


Figure 23: Frequency histogram for lidar bare earth DEM deviation from ground check point values

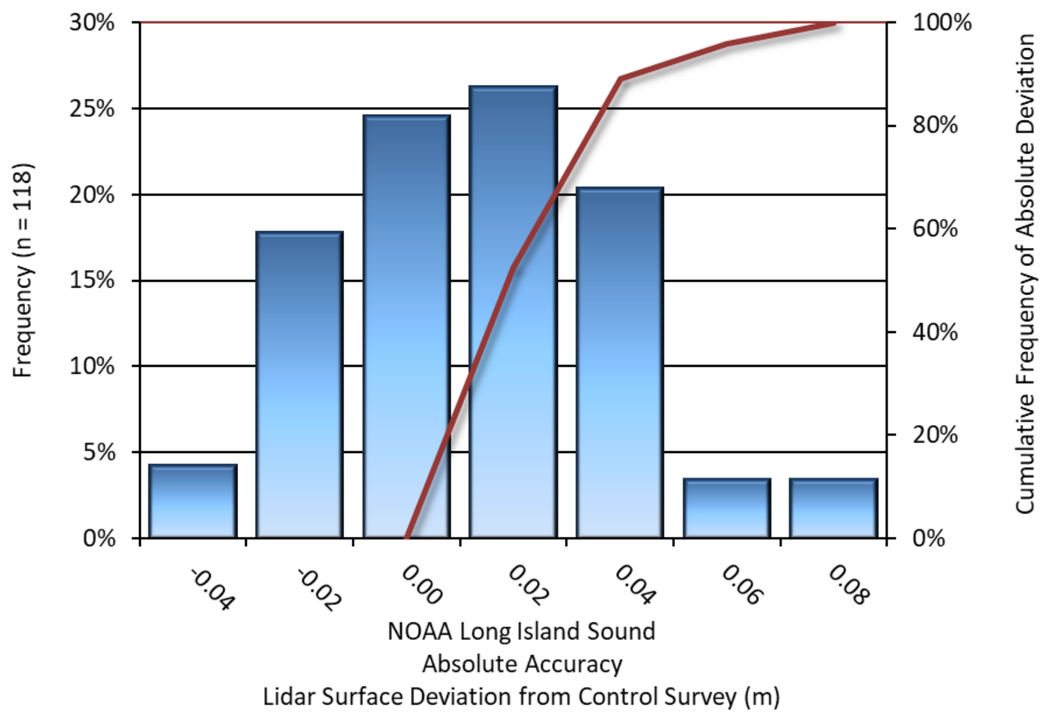


Figure 24: Frequency histogram for lidar surface deviation ground control point values

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. For the NOAA Long Island Sound survey, 32 vegetated checkpoints were collected, with resulting vegetated vertical accuracy of 0.233 meters as compared to the classified LAS, and 0.212 meters as compared to the bare earth DEM evaluated at the 95th percentile (Table 16, Table 17, Figure 25, and Figure 26).

Table 16: VVA, as compared to Classified LAS

Delivery	Sample	95th Percentile	Average	Median	RMSE	Standard Deviation (1σ)
D1	11 points	0.105 m	0.048 m	0.044 m	0.059 m	0.035 m
D2	10 points	0.115 m	0.046 m	0.041 m	0.063 m	0.045 m
D3	5 points	0.142 m	0.063 m	0.064 m	0.088 m	0.069 m
D4	6 points	0.456 m	0.210 m	0.193 m	0.264 m	0.176 m
Cumulative	32 points	0.233 m	0.080 m	0.057 m	0.129 m	0.103 m

Table 17: VVA, as compared to Bare Earth DEM

Delivery	Sample	95th Percentile	Average	Median	RMSE	Standard Deviation (1σ)
D1	11 points	0.108 m	0.051 m	0.070 m	0.065 m	0.042 m
D2	10 points	0.111 m	0.050 m	0.042 m	0.062 m	0.038 m
D3	5 points	0.158 m	0.075 m	0.065 m	0.094 m	0.064 m
D4	6 points	0.461 m	0.192 m	0.163 m	0.258 m	0.190 m
Cumulative	32 points	0.212 m	0.081 m	0.063 m	0.129 m	0.102 m

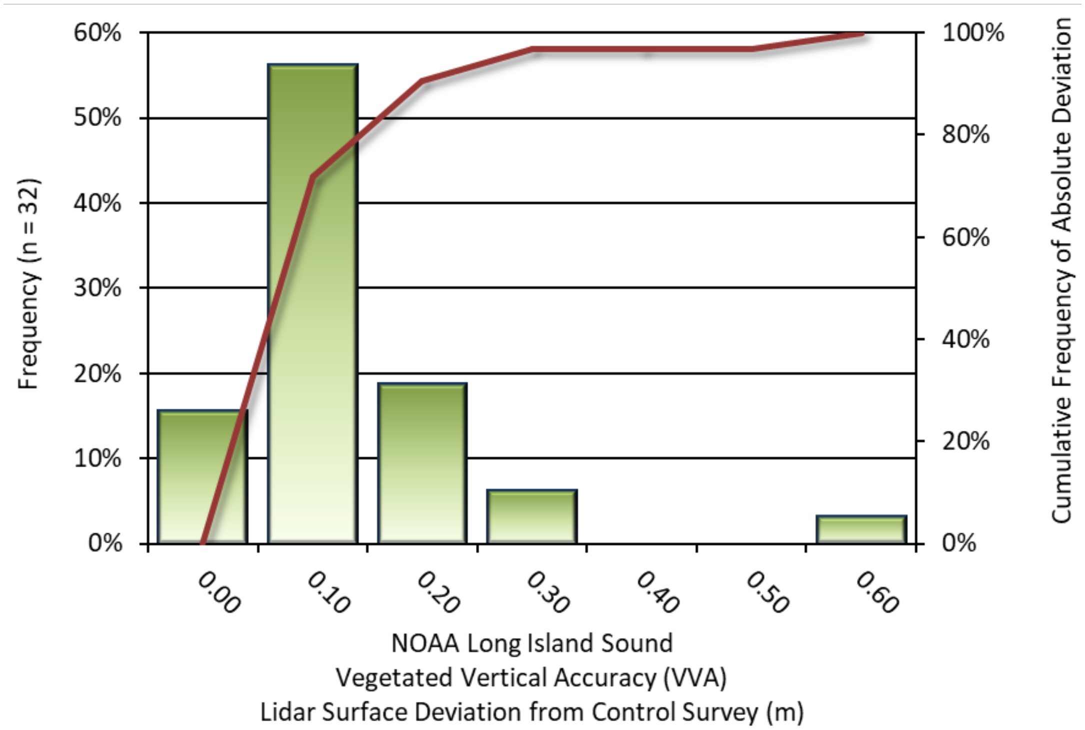


Figure 25: Frequency histogram for lidar surface deviation from all land cover class point values (VVA)

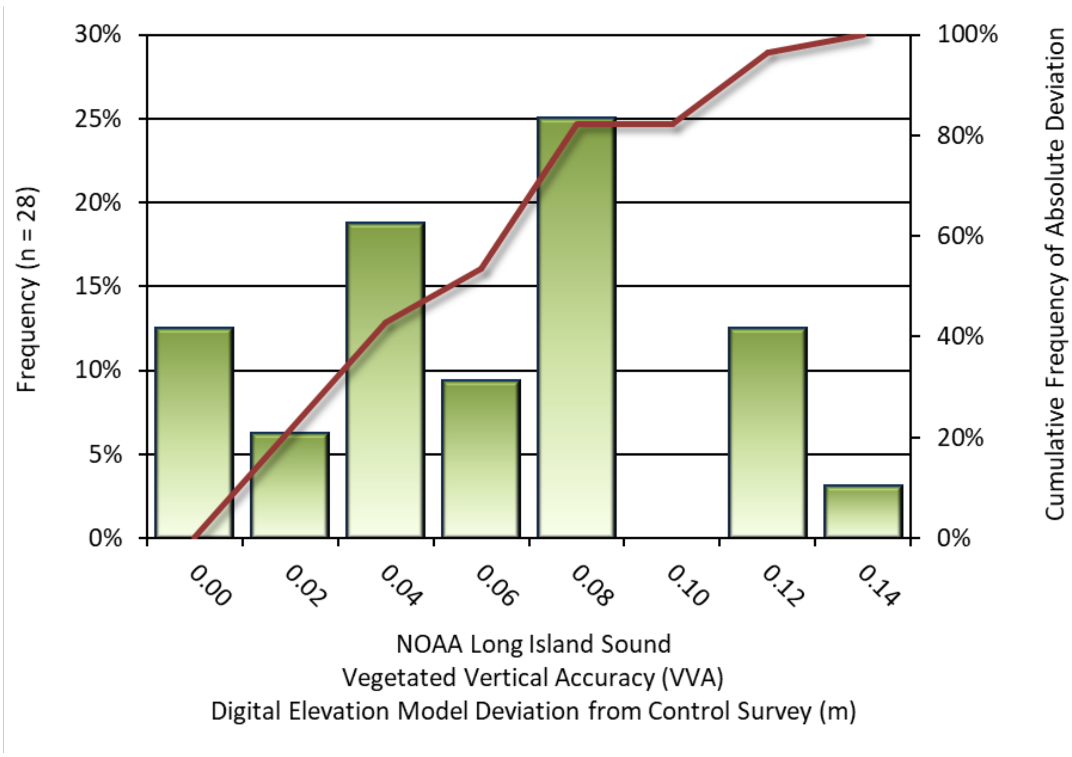


Figure 26: Frequency histogram for the lidar bare earth DEM deviation from vegetated check point values (VVA)

Lidar Bathymetric Vertical Accuracies

Bathymetric (submerged or along the water's edge) checkpoints were also collected to assess the submerged surface vertical accuracy. Assessment of 1,184 submerged bathymetric checkpoints resulted in a vertical accuracy of 0.159 meters, evaluated at 95% confidence interval (Table 18, Figure 27).

Table 18: Bathymetric accuracy

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	**170 points**	0.095 m	0.007 m	0.000 m	0.049 m	0.048 m
D2	**254 points**	0.136 m	0.003 m	0.003 m	0.069 m	0.070 m
D3	**244 points**	0.218 m	0.045 m	0.024 m	0.111 m	0.102 m
D4	**516 points**	0.154 m	-0.015 m	-0.013 m	0.079 m	0.077 m
Cumulative	**1,184 points**	0.159 m	0.004 m	-0.001 m	0.081 m	0.081 m

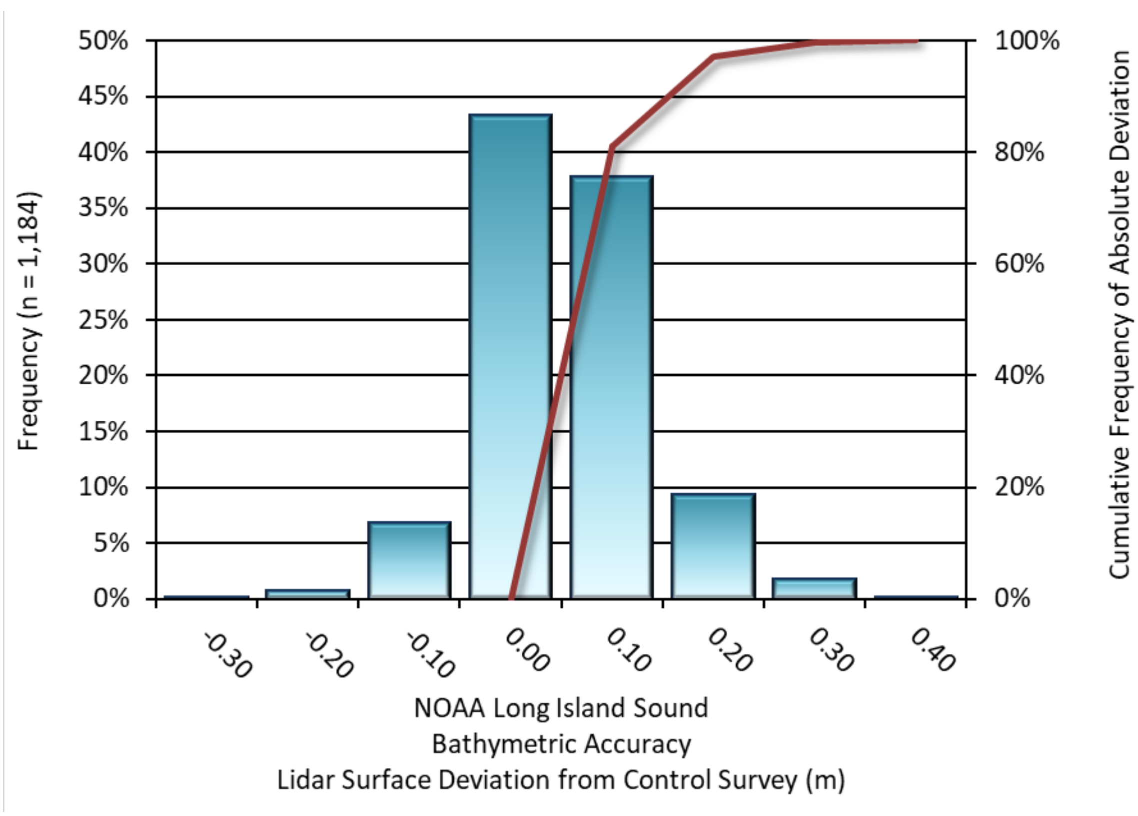


Figure 27: Frequency histogram for lidar surface deviation from submerged check point values

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 Long Island Sound Lidar project was 0.029 meters (Table 19, Figure 28).

Table 19: Relative accuracy

Delivery	Sample	Average	Median	RMSE	Standard Deviation (1σ)	95% Confidence (1.96*RMSE)
D1	972 lines	0.020 m	0.039 m	0.061 m	0.037 m	0.073 m
D2	869 lines	0.022 m	0.045 m	0.094 m	0.066 m	0.130 m
D3	598 lines	0.031 m	0.050 m	0.095 m	0.065 m	0.126 m
D4	1,209 lines	0.029 m	0.041 m	0.071 m	0.045 m	0.089 m
Cumulative	3,086 lines	0.029 m	0.040 m	0.079 m	0.055 m	0.107 m

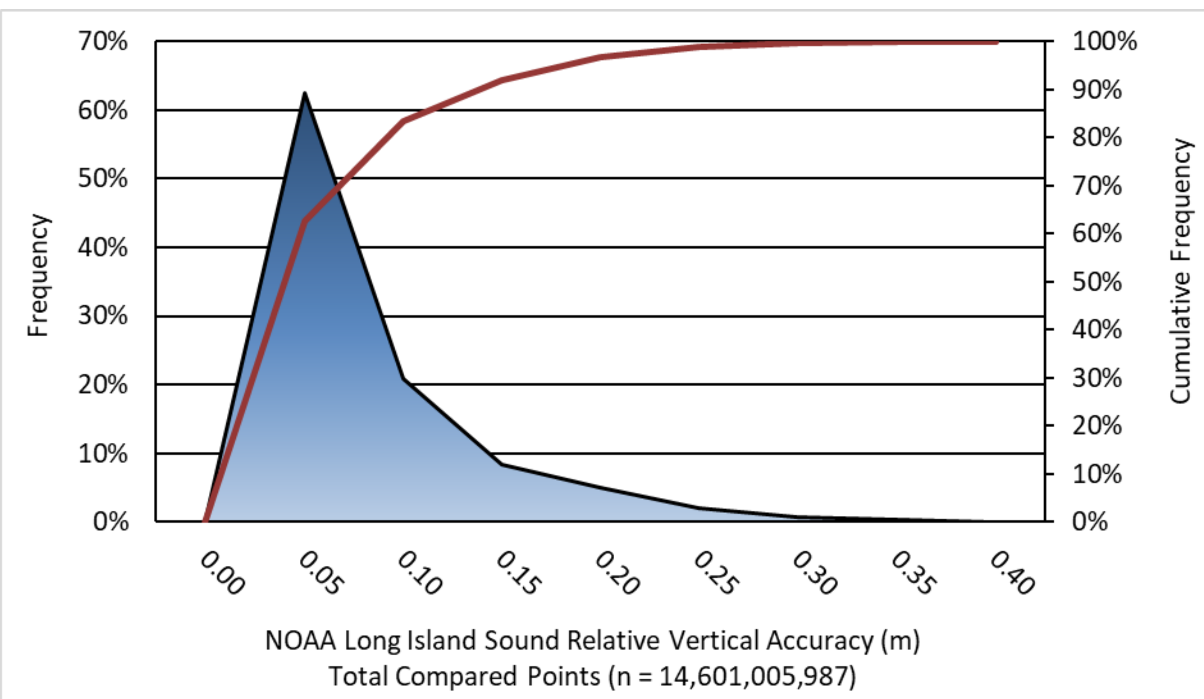


Figure 28: Frequency plot for relative vertical accuracy between flight lines

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 20, summarized by sensor and flying altitude, this project was produced to meet between 0.055 meters and 0.088 meters horizontal accuracy at the 95% confidence level.

Table 20: Cumulative horizontal accuracy

Parameter	Chiroptera 400 m	HawkEye 400 m	Chiroptera 500 m	HawkEye 500 m
IMU Error	0.003 deg	0.004 deg	0.003 deg	0.002 deg
GNSS Error	0.008 m	0.008 m	0.005 m	0.005 m
RMSEr	0.038 m	0.051 m	0.047 m	0.032 m
ACCr	0.066 m	0.088 m	0.082 m	0.055 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 Long Island Sound project as described in this report.

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

____

John English
Project Manager
NV5

I, Steven J. Hyde, PLS, being duly registered as a Professional Land Surveyor in and by the state of New York, Connecticut, and Rhode Island 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 March 5 and October 28, 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, 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.

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 ±20^{o} to ±21o 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 NY2205_NY2303-TB-C

States of New York and Connecticut Shoreline Mapping

Data Acquisition Summary

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

I. Project Overview:

Project Number:	NY2205_NY2303-TB-C
Project Title:	States of New York and Connecticut Shoreline Mapping
Number of Flight Lines:	32
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 NY2205_2303-TB-C_Project_Instructions_v3.27 dated January 13, 2022.

II. Data Acquisition Summary:

Flight Date	Folder Name	Lines Acquired	Patches/ Reflys Required ?	Patchs/ Reflys Flown?	Project Complete?	Camera RGB/NIR	Lens sn RGB (62.5mm)	RGB Camera Calibration	Lens sn NIR (62.5mm)	NIR Digital Back	NIR Camera Calibration	RGB/NIR Boresight
03/26/2023	41054 NY	925021 925022 925023 925024 925025	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
03/26/2023	41054 NY	925011 925012 925013 925014 925016	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
03/27/2023	41054 NY	925001 925002 925009 925010	Y	N	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
03/29/2023	41054 NY	925017 925018 925019 925020 925026 925027 925028 925029 925030 925031 905032	N	N	N	ADS100, 10541	0023	08/05/2020	0053	N/A	08/05/2020	08/05/2020
04/02/2023	41054 NY	925022	N	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
04/03/2023	41054 NY	925001 925002 925003 925004 925009 925010 925015 925022 925023 925024 925025	Y	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020

04/04/2023	41054 NY	925005 925005 925006	Y	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
04/07/2023	41054 NY	925005 925006 925007 925008	Y	Y	N	ADS100, 10541	0023	08/05/2020	0023	N/A	08/05/2020	08/05/2020
05/14/2023	41054 NY	025004 025004 025005 025006 025007 025008	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: 03/26/2023 (852023)

Acquisition	
Date:	03/26/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925011 thru 925014, 925016, 25021 thru 925025
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:	03/28/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	925022 thru 925024 refly

Data Acquisition: 03/27/2023 (862023)

Acquisition	
Date:	03/27/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925001, 925002, 925009, 925010
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:	03/29/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	Refly all strips

Data Acquisition: 03/29/2023 (882023)

Acquisition	
Date:	03/29/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925017 thru 925020, 925026 thru 925032
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:	04/05/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 04/02/2023 (922023)

Acquisition	
Date:	04/02/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925022
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys 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:	04/05/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	Refly

Data Acquisition: 04/03/2023 (932023)

Acquisition	
Date:	04/03/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925001 thru 925010, 925015, 925022 thru 925025
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys 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:	04/06/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	925004 refly

Data Acquisition: 04/04/2023 (942023)

Acquisition	
Date:	04/04/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925005, 925016
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	Yes
Patches/Reflys 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:	04/06/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	Refly all

Data Acquisition: 04/07/2023 (972023)

Acquisition	
Date:	04/07/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925005 thru 925008
Tide Stage:	Multispectral / Non-Tide Coordinated
Tide File Used:	N /A
Patches/Reflys Required:	None
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:	04/09/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	None

Data Acquisition: 05/14/2023 (1342023)

Acquisition	
Date:	05/14/2023
Project:	NY2205_NY2303-TB-C
Flight Lines:	925004 thru 925008
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:	05/16/2023
APOR Report Title:	NY2205_NY2303-TB-C_Coastal_Mapping_APOR.pdf
Image QC	
Imagery Flagged:	None

Project Status:

Acquisition for NY2205_NY2303-TB-C States of New York and Connecticut Shoreline Mapping is 100% Acquired.

Project NY2205_NY2303-TB-C

States of New York and Connecticut Shoreline Mapping

Airborne Positioning and Orientation Report

Prepared by: **Shane Good**
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1. INTRODUCTION

The project area referenced as NY2205_NY2303-TB-C covers one Area of Interest (AOI) along the Northern Coast of Long Island and the Southern Coast of Connecticut.

The AOI extends from just west of Rikers Island and runs northeast to the Connecticut and Rhode Island State lines. The AOI covers several bays and islands including the eastern tip of Long Island to include Hampton Bays Sag Harbor and Montauk..

The AOI covers approximately 1200 Sq Miles.

The project is located approximately between 40°44'22" and 41°33'38" North Latitude, and 73°57'10" and 71°46'59" West Longitude.

Dataset ID:	NY2205_NY2303-TB-C
Dates of Acquisition:	03-26-23 through 05-14-23
Project Name:	States of New York and Connecticut Shoreline Mapping
Flight Lines:	32

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 / N22TE
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= 0.030
	Y= -0.076
	Z= 0.961

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:	03/26/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	13:15 – 14:14						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925021	N /A	41.526794	-72.161456	N /A	41.537979	-72.007514	
925022	N /A	41.508282	-71.990830	N /A	41.496372	-72.153259	To ReFly
925023	N /A	41.477855	-71.987096	N /A	41.440422	-72.489992	To Refly
925024	N /A	41.409166	-72.502906	N /A	41.446634	-72.000748	To Patch
925025	N /A	41.422762	-71.909507	N /A	41.401505	-72.201121	To ReFly

Acquisition			
Date:	03/26/23		
Project:	States of New York and Connecticut Shoreline Mapping		
Time of Collection:	16:04 – 18:09		
Platform:	Cessna Caravan / N604MD		
FLIGHT LINE #	START	END	NOTES

	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925011	N /A	40.977890	-72.966448	N /A	40.804380	-73.976450	
925012	N /A	40.773597	-73.972649	N /A	40.947509	-72.960159	
925013	N /A	40.896153	-73.081069	N /A	40.745563	-73.954517	
925014	N /A	40.720312	-73.923372	N /A	40.858462	-73.119861	
925016	N /A	41.280258	-73.034169	N /A	41.004793	-73.729159	ToReFly

	Acquisition						
Date:	03/27/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	13:00 – 14:26						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925001	N /A	40.957915	-73.060632	N /A	41.213191	-72.051953	To ReFly
925002	N /A	41.180165	-72.053898	N /A	40.929606	-73.043513	To ReFly
925009	N /A	40.893541	-73.832319	N /A	41.022690	-73.078690	To ReFly
925010	N /A	41.008110	-72.974971	N /A	40.840128	-73.953939	To ReFly

Acquisition							
Date:	03/29/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	16:40 – 10:35						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925017	N /A	40.903246	-73.894764	N /A	41.288182	-72.925285	

925018	N /A	41.261681	-72.903795	N /A	40.869808	-73.890871	
925019	N /A	40.839109	-73.879523	N /A	41.232400	-72.889344	
925020	N /A	41.205276	-72.868447	N /A	40.813253	-73.855779	
925026	N /A	41.401968	-71.776460	N /A	41.308294	-73.010071	
925027	N /A	41.277516	-73.009858	N /A	41.371290	-71.775626	
925028	N /A	41.340911	-71.768173	N /A	41.247137	-73.002330	
925029	N /A	41.216576	-72.991557	N /A	41.309209	-71.771724	
925030	N /A	41.275166	-71.806133	N /A	41.186699	-72.969245	
925031	N /A	41.173638	-72.735728	N /A	41.235854	-71.912627	
925032	N /A	41.170950	-72.411804	N /A	41.158866	-72.568338	

Acquisition							
Date:	04/02/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	17:33 – 18:44						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925022	N /A	41.508338	-71.990569	N /A	41.496405	-72.153541	ReFly

	Acquisition						
Date:	04/03/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	15:36 – 19:45						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925001	N /A	40.957828	-73.059653	N /A	41.213049	-72.051930	ReFly
925002	N /A	40.928693	-73.047129	N /A	41.179692	-72.056404	ReFly
925003	N /A	41.152214	-72.035610	N /A	40.908731	-72.998892	
925004	N /A	41.159347	-71.875011	N /A	40.904938	-72.883939	To ReFly
925009	N /A	41.023033	-73.076024	N /A	40.894487	-73.827940	ReFly
925010	N /A	40.839324	-73.958090	N /A	41.007921	-72.977264	ReFly
925015	N /A	41.156902	-73.145374	N /A	41.014626	-73.071890	

925022	N /A	41.508301	-71.990412	N /A	41.496908	-72.153336	Refly
925023	N /A	41.477817	-71.987064	N /A	41.440430	-72.490387	ReFly
925024	N /A	41.423633	-72.311157	N /A	41.446486	-72.001052	Patch
925025	N /A	41.422841	-71.909596	N /A	41.338337	-73.012116	ReFly

Acquisition							
Date:	04/04/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	17:59 – 18:50						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925005	N /A	40.891187	-72.805926	N /A	41.011251	-72.350120	To ReFly
925005	N /A	40.891187	-72.805926	N /A	41.011251	-72.350120	ReFly
925016	N /A	41.280300	-73.033814	N /A	41.004705	-73.729060	ReFly

Acquisition							
Date:	04/07/23						
Project:	States of New York and Connecticut Shoreline Mapping						
Time of Collection:	16:36 – 18:15						
Platform:	Cessna Caravan / N604MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925005	N /A	41.151256	-71.775177	N /A	40.893645	-72.802279	ReFly
925006	N /A	40.884193	-72.818665	N /A	40.883589	-72.821143	To ReFly
925007	N /A	41.101250	-71.726184	N /A	40.865698	-72.667952	To Patch
925008	N /A	40.851625	-72.595257	N /A	41.060542	-71.759828	To Patch

Acquisition	
Date:	05/14/23
Project:	States of New York and Connecticut Shoreline Mapping
Time of Collection:	13:10 – 15:43

Platform:	Cessna Caravan / N704MD						
FLIGHT LINE #	START			END			NOTES
	FRAME #	LAT	LONG	FRAME #	LAT	LONG	
925004	N /A	41.161500	-71.866487	N /A	40.905549	-72.883903	ReFly
925004	N /A	41.161500	-71.866487	N /A	40.905549	-72.883903	ReFly
925005	N /A	40.892918	-72.805032	N /A	41.150684	-71.777376	Refly
925006	N /A	41.128058	-71.737684	N /A	40.864318	-72.789609	ReFly
925007	N /A	40.864816	-72.671338	N /A	41.100590	-71.728373	Patch
925008	N /A	41.061023	-71.757639	N /A	40.852785	-72.591043	Patch

2.3 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 18 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.

NY2205_NY2303-TB-C Shoreline Mapping

Aerotriangulation Report

October 2023

Area Covered

The project area referenced as NY2205_NY2303-TB-C covers one Area of Interest (AOI) along the Northern Coast of Long Island and the Southern Coast of Connecticut.

The AOI extends from just west of Rikers Island and runs northeast to the Connecticut and Rhode Island State lines. The AOI covers several bays and islands including the eastern tip of Long Island to include Hampton Bays Sag Harbor and Montauk..

The AOI covers approximately 1200 Sq Miles.

The project is located approximately between 40°44’22” and 41°33’38” North Latitude, and 73°57’10” and 71°46’59” West Longitude.

See Annex 1 – Project Coverage Diagram

Imagery

The photography used in this aerotriangulation phase was flown by NV5 Inc and consists of 32 flight lines. 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 March 26th, 2023 through May 14th, 2023. All imagery was acquired using >30% side overlap, sun angles >20 or >25 degrees (depending on the date of acquisition) and was non-tide coordinated. Flight lines 925001 thru 925032 where included in this AT block. The layout of the photographs is shown in the Annex 2 NY2205_NY2303-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 NY2205_NY2303-TBC_Coastal_Mapping_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. For further information please refer to NY2205_NY2303-TB-C_Maine_Coastal_APOR Airborne Positioning and Orientation Report.

B. Ground Points: NV5 was dispatched to survey Sixty Seven (67) photo ID control points (horizontal and vertical), and Twenty (20) check points. Twenty 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

Starting July 5th 2023 and completed on August 14th 2023 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 32 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 18.

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 0.32m 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 (20) 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:

POINT ID		ΔX M	ΔY M	ΔZ M
AT100CHK		-0.074	0.039	0.026
AT101CHK		-0.128	-0.003	0.04
AT102CHK		0.225	0.142	0.201
AT103CHK		-0.19	-0.079	0.002
AT104CHK		-0.149	0.196	0.141
AT105CHK		-0.07	-0.051	0.101
AT106CHK		-0.068	0.063	-0.037
AT107CHK		N/A	N/A	0.284
AT110CHK		0.423	0.028	0.04
AT111CHK		0.139	0.297	-0.112
AT112CHK		-0.169	-0.022	0.055
AT113CHK		-0.112	-0.153	0.117
AT114CHK		0.168	-0.08	0.534
AT115CHK		0.065	-0.062	0.044
AT116CHK		0.148	0.015	0.036
AT117CHK		-0.057	-0.126	0.087
AT118CHK		-0.17	0.428	0.267
AT119CHK		0.204	0.176	-0.253
AT150CHK		0.138	0.007	-0.101
AT151CHK		-0.052	0.057	-0.022

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
AT100CHK	925023	03-APR-2023
AT101CHK	925028	29-MAR-2023
AT102CHK	925028	29-MAR-2023
AT103CHK	925028	29-MAR-2023
AT104CHK	925018	29-MAR-2023
AT105CHK	925017, 925018	29-MAR-2023
AT106CHK	925017, 925016	29-MAR-2023, 04-APR-2023
AT107CHK	925011, 925012, 925020	26-MAR-2023, 29-MAR-2023
AT110CHK	925011, 925012	26-MAR-2023
AT111CHK	925004	14-MAY-2023
AT112CHK	925003	03-APR-2023
AT113CHK	925001	03-APR-2023
AT114CHK	925007	14-MAY-2023
AT115CHK	925024, 925025	26-MAR-2023, 03-APR-2023
AT116CHK	925028	29-MAR-2023
AT117CHK	925009, 925019, 925019	29-MAR-2023, 03-APR-2023
AT118CHK	925027	29-MAR-2023
AT119CHK	925006, 925007	14-MAY-2023, 07-APR-2023
AT150CHK	925028	29-MAR-2023
AT151CHK	925018	29-MAR-2023

To conclude, the aerotriangulation block meets the horizontal standards set forth by NOAA in Chapter I of the Version 15 Statement of Work for Shoreline Mapping.

Project Database

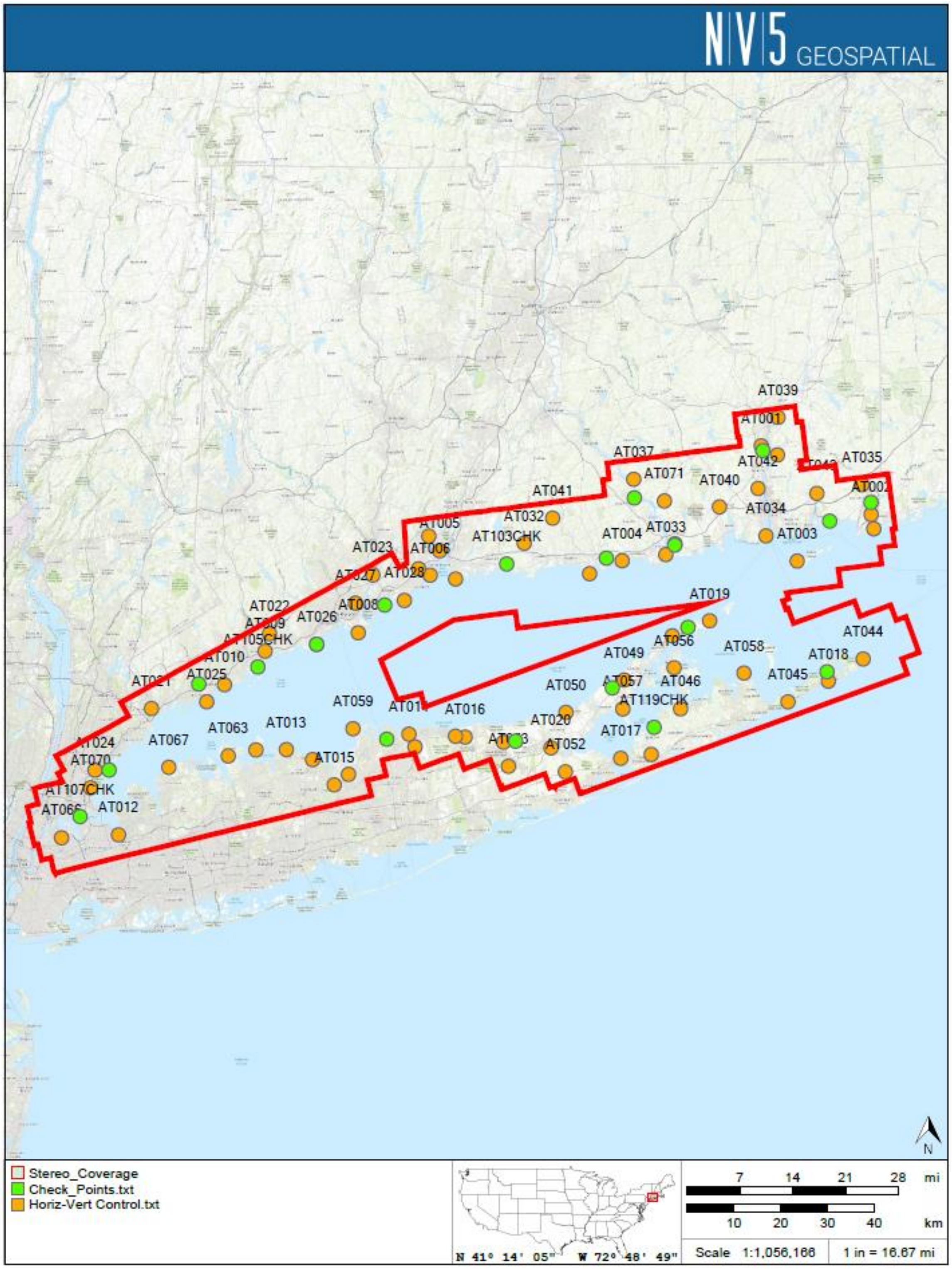
A project database containing the following files has been included in this submittal.

- 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 18 coordinate system.

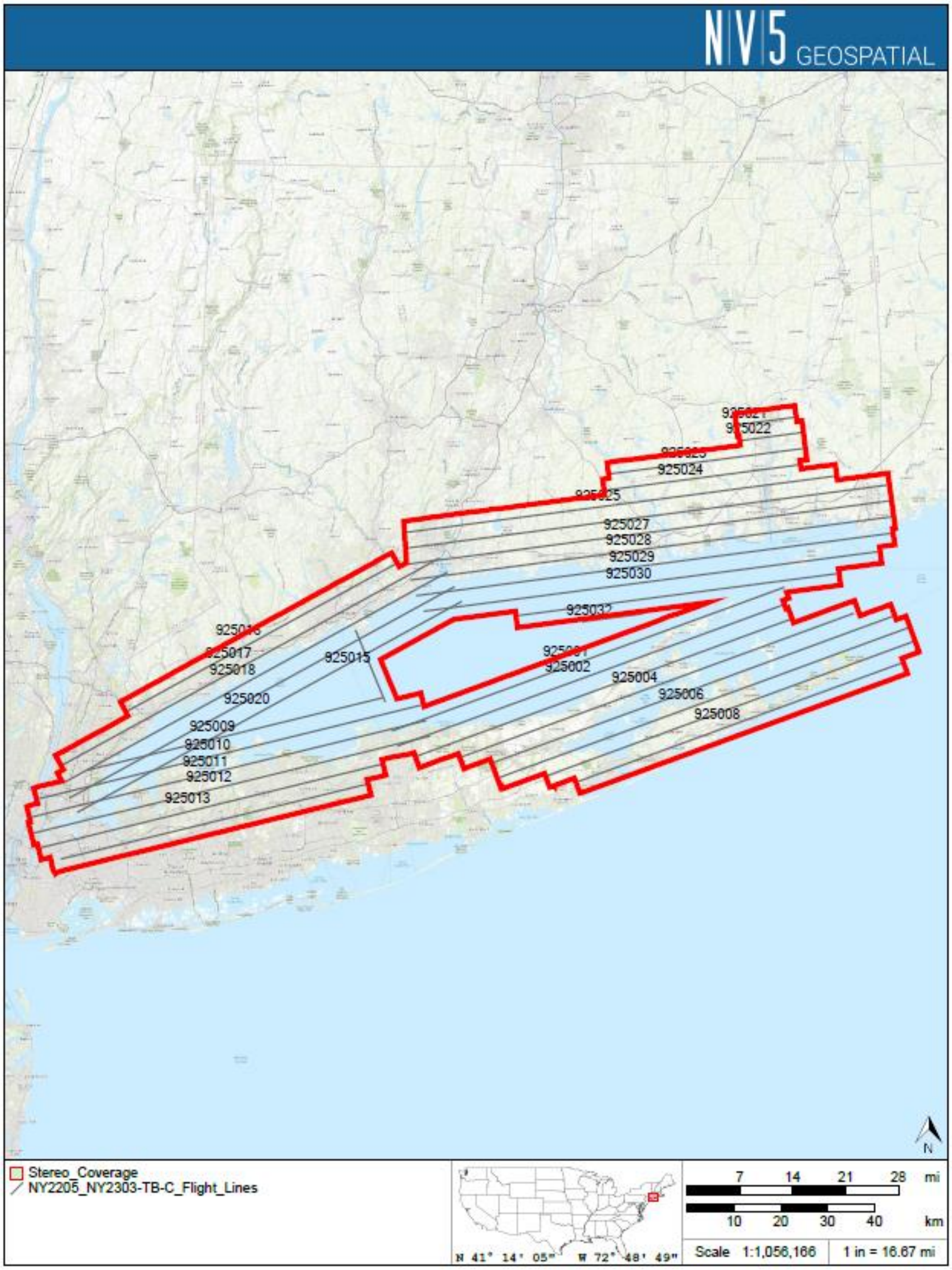
N|V|5 GEOSPATIAL

ANNEX 1 – NY2205_NY2303-TB-C Project Coverage Diagram



NV5 GEOSPATIAL

ANNEX 2 - NY2205_NY2303-TB-C Flight Lines Included in AT



Flight Line	Date	Tide Coordination
925001	3-APR-2023	Non-Tidal
925002	3-APR-2023	Non-Tidal
925003	3-APR-2023	Non-Tidal
925004	14-MAY-2023	Non-Tidal
925005	14-MAY-2023	Non-Tidal
925006	14-MAY-2023	Non-Tidal
925007	14-MAY-2023	Non-Tidal
925008	14-MAY-2023	Non-Tidal
925009	3-APR-2023	Non-Tidal
925010	3-APR-2023	Non-Tidal
925011	26-MAR-2023	Non-Tidal
925012	26-MAR-2023	Non-Tidal
925013	26-MAR-2023	Non-Tidal
925014	26-MAR-2023	Non-Tidal
925015	3-APR-2023	Non-Tidal
925016	4-APR-2023	Non-Tidal
925017	29-MAR-2023	Non-Tidal
925018	29-MAR-2023	Non-Tidal
925019	29-MAR-2023	Non-Tidal
925020	29-MAR-2023	Non-Tidal
925021	26-MAR-2023	Non-Tidal
925022	02-APR-2023	Non-Tidal
925023	3-APR-2023	Non-Tidal
925024	3-APR-2023	Non-Tidal
925025	3-APR-2023	Non-Tidal
925026	29-MAR-2023	Non-Tidal
925027	29-MAR-2023	Non-Tidal
925028	29-MAR-2023	Non-Tidal
925029	29-MAR-2023	Non-Tidal
925030	29-MAR-2023	Non-Tidal
925031	29-MAR-2023	Non-Tidal
925032	29-MAR-2023	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:

RMS(x) = 0.120 meters   RMS(y) = 0.138 meters

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

$$R = K * Sx$$

where Sx 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:

$$C = 0.120 / 0.138 = 0.870$$

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

$$\begin{aligned} K &= 2.23029 + [(0.870 - 0.8) / (0.9 - 0.8) * (2.33180 - 2.23029)] \\ &= 2.23029 + [(0.070 / 0.1) * 0.10151] \\ &= 2.23029 + (0.70 * 0.10151) \\ &= 2.23029 + 0.07062 = 2.30091 \\ K &= 2.301 \\ R &= K * Sx = 2.301 * 0.138 = 0.318 \end{aligned}$$

The Radius of the 95% Confidence Circle = 0.32 meters