Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Maritime Heritage in America's Inland Seas: A Multi-tiered Autonomous Vehicle-based Survey of Two Proposed Great Lakes National Marine Sanctuaries

Rawley Point Lighthouse, Two Rivers, Wisconsin. Image: John Cline, University of Miami.

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February 2022

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Sincerely,
Madeline Roth and Russ Green, NOAA Office of National Marine Sanctuaries

Executive Summary

The Great Lakes provide a natural water highway extending well into the heart of North America and have long been a critical economic growth engine for the United States. There are an estimated 6,000 shipwrecks across the five Great Lakes: tangible reminders of the men and women whose ingenuity, innovation, entrepreneurial spirit, and hard work helped build the nation. Through the use of autonomous survey technology this proposal aimed to: 1) discover and conduct initial characterization of underwater cultural heritage in proposed NOAA national marine sanctuaries in Lakes Michigan and Ontario; 2) expand the breadth of knowledge of America's past maritime-based economic activities in our nation's Great Lakes; 3) generate new data products of value to federal and state resource managers; and 4) create technology-centered educational opportunities for educators, students, and the general public. These goals were met, though several challenges impacted the volume of data collected. On the other hand, the project was highly experimental. In hindsight, a stated goal should have been to *test* new technologies, platforms and methods and *refine* their uses in real-time. In this area, as reported below, the project was highly successful.

Comprised of NOAA, state, academic, and commercial partners, the team surveyed diverse underwater environments using three coordinated autonomous mapping platforms with a small, cost-effective operational footprint. An Uncrewed Aerial Vehicle (UAV), Autonomous Surface Vehicle (ASV), and Autonomous Underwater Vehicle (AUV) equipped varyingly with magnetometers, side-scan and multibeam sonars, and cameras produced magnetic, bathymetric, backscatter and side-scan coverage of historically significant areas within the proposed sanctuaries. Education and outreach events were woven into the project throughout the expedition.

Field operations occurred between 28 July and 20 August 2021, taking place within pre-determined study areas in Lake Michigan and Lake Ontario. Project field activities focused on new and novel methods for autonomous platform-based remote sensing surveys. These methods were tailored for detection of submerged cultural resource materials located in difficult to reach nearshore areas. Each remote sensing instrument was integrated into an autonomous platform selected to work in specific coastal environments. These included an uncrewed aerial vehicle (UAV) for mapping above the surf zone, autonomous surface vehicles (ASVs) for shallow water mapping, and an autonomous underwater vehicle (AUV) for deeper water mapping.

Numerous remote sensing instruments were integrated into an array of platforms and deployed in the two study areas. The diversity of sensors, as well as complexities associated with operating autonomous platforms within a challenging environment and diffused network of partner organizations made for a range of variables to manage during the project expedition. The ongoing pandemic further complicated project efforts. Field operations, preliminary results, as well as a summary of technical and operational challenges experienced are outlined herein.

An initial summary report of these activities was issued on 20 October 2021. This document, the ***2021 Cruise Report***, contained sections for cruise information, operational activities, educational and outreach event descriptions, preliminary results, data management considerations, and presentation of challenges experienced by the field party.

This final report includes those earlier materials, added results, and supersedes the ***2021 Cruise Report.***

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Acronyms

ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
BAM	BOB Analytic Module (Marine Magnetics software)
CORS	Continuously Operating Reference Stations (NOAA service)
CRP	Common Reference Point
GAMS	GNSS Azimuth Measurement Subsystem
GLERL	Great Lakes Environmental Research Laboratory
GLMHC	Great Lakes Maritime Heritage Center (NOAA facility)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HRG	High Resolution Geophysical
IGLD85	International Great Lakes Datum, 1985
ITRF	International Terrestrial Reference Frame
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LONMS	Proposed Lake Ontario National Marine Sanctuary
LWD	Low Water Datum
MAG	Magnetometer
MARIS	Maritime Archaeological Resource Inventory System
MBES	Multibeam Echosounder
MHP	Maritime Heritage Program (NOAA ONMS office)
NAVD88	North American Vertical Datum, 1988
NCEI	National Centers for Environmental Information
NCCOS	National Centers for Coastal Ocean Science
NOAA	National Oceanic and Atmospheric Administration
NY	New York
OER	Office of Ocean Exploration and Research
ONMS	Office of National Marine Sanctuaries (NOAA agency)
ROV	Remotely Operated Vehicle
RTK	Real Time Kinematic
SBAS	Satellite Based Augmentation System
SSS	Side-scan Sonar
SV	Sound Velocity
SVP	Sound Velocity Profiler
SVS	Sound Velocity Sensor
TBNMS	Thunder Bay National Marine Sanctuary
UAV	Uncrewed Aerial Vehicle
UDP	User Datagram Protocol
USV	Uncrewed Surface Vehicle

UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VRS	Virtual Reference Station
WAA	Wide-Area Assessment
WGS84	World Geodetic System, 1984
WI	Wisconsin
WSCNMS	Wisconsin Shipwreck Coast National Marine Sanctuary

Introduction

This project was developed to identify and evaluate maritime heritage resources located within two Great Lakes areas; the Lake Michigan based Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS) and the proposed Lake Ontario National Marine Sanctuary (LONMS) (Figure 1). Over 27 million Americans live in the Great Lakes watershed, with 15 million people in the Lake Michigan and Lake Ontario watersheds alone. The Great Lakes support enormous economic drivers such as shipping, recreation, and tourism. For coastal communities, the Lakes are central to their cultural and economic well-being. Conserving the Great Lakes is a national and state priority, as demonstrated by congressionally directed funding and decades of work by federal and state agencies and nonprofit organizations. But where the water meets the land are the lakeshore communities that depend on these waters and care deeply about preserving—and promoting—their historical and cultural ties to the Great Lakes.

Figure 1. Map of the Wisconsin Shipwreck Coast National Marine Sanctuary and proposed Lake Ontario National Marine Sanctuary located in Lakes Michigan and Ontario, respectively. Image: NOAA.

In 2014 and 2017, local communities and the States of Wisconsin and New York successfully nominated portions of Lakes Michigan and Ontario as National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuaries: the Wisconsin Shipwreck Coast NMS (WSCNMS) and Lake Ontario NMS (LONMS), respectively. Drivers for the nominations centered on conserving nationally significant shipwrecks that possess exceptional historic, archaeological, and recreational value. As envisioned by the nominators, the creation of the WSCNMS (designated 2021) and the on-going designation of the proposed LONMS have expanded opportunities for research, resource protection, educational programming, and community engagement in each state emphasizing the incredible history and heritage of America's inland seas.

In support of the recently designated WSCNMS and the on-going designation of LONMS, an interdisciplinary team of researchers led by NOAA's Office of National Marine Sanctuaries (ONMS) drafted a project to identify and characterize archaeological resources within both areas. The project, funded through the NOAA Office of Ocean Exploration and Research (OER), furthered the ONMS mission of identifying, understanding, and ultimately preserving maritime heritage resources in sanctuary and proposed sanctuary areas.

Between 28 July and 20 August 2021, the research team conducted remote sensing and preliminary documentation of archaeological resources within portions of WSCNMS and the proposed LONMS. The research team, comprised of personnel from ONMS, Marine Magnetics, Ocean Infinity, University of Delaware, and University of Miami utilized a suite of remote sensing instruments integrated across several crewed and uncrewed (autonomous) platforms to conduct reconnaissance-level survey of approximately 1.76 square (sq.) kilometers (km) of WSCNMS and the Two Rivers adjacent areas. The project mapped a further 17.96 sq. km of lakebed within the proposed LONMS. This dataset was processed and reviewed for any indication of cultural materials and historic properties. Additionally, data was collected on several previously discovered sites within each survey area.

All data generated during fieldwork were received from partners and managed by a NOAA ONMS team. At the conclusion of field operations, project personnel conducted data processing and analysis. The result is a full project archive of data spanning raw files, processing projects, results, and reporting materials. Copies of the archive will be made available online through the NOAA National Center for Environmental Information (NCEI) digital atlas[1]. This archive is currently maintained in hard copy at ONMS headquarters in addition to the copies submitted to NCEI.

[1] https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm).

Background

The Great Lakes, St. Lawrence River, and their connecting waterways provide a natural transportation corridor extending over 2,400 miles into the heart of North America. For millennia before European contact, these inland seas and tributaries served as important lines of trade and communication for Indigenous peoples (ONMS 2021). Over the past 300 years, use of these waters expanded to include Europeans, Canadians, and Americans who contributed to the economic growth of North America. Marine transport on the Great Lakes played a central role in the exploration, colonization, economic expansion, and industrialization of the nation (ONMS 2021).

During the 19th century, the Great Lakes evolved from an isolated maritime frontier into one of the world's most significant industrial waterways, where specialized ships and infrastructure moved raw materials and agricultural products in larger quantities and at lower cost than any previous time in history. During this period, entrepreneurs and shipbuilders on the Great Lakes launched tens of thousands of ships, with many featuring distinct designs. Specialized sailing ships, grand palace steamers, revolutionary propeller-driven passenger ships, and industrial bulk carriers transported America's raw goods and products. In the process, they brought hundreds of thousands of new people to the Midwest and made possible the dramatic growth of the region's farms, cities, and industries. The Midwest could not have developed with such speed and vast economic and social consequences without the Great Lakes. Cities such as Chicago, Milwaukee, Detroit, Cleveland, Duluth, Green Bay, and Buffalo achieved economic prominence due to their position on the Great Lakes and a water connection to distant American and world markets. Yet every lakeshore community, regardless of size, has had its economy, culture and history shaped by the Great Lakes.

But with explosive growth comes risk and sometimes tragedy. There are an estimated 6,000 shipwrecks across the five Great Lakes—tangible reminders of the men and women whose ingenuity, innovation, entrepreneurial spirit, and hard work helped build the nation. These historically and culturally important events and people are strongly represented in the archaeological record. Due to their cold fresh water, the Great Lakes possess some of the most extraordinary potential for archaeological investigation of historic shipwrecks and other underwater cultural resources anywhere in the world.

Wisconsin and Lake Michigan Historic Context

The Wisconsin landscape we know today emerged 13,000 years ago when glaciers of the last ice age retreated, leaving the state with 860 miles of Great Lakes coastline between Lake Superior to the north and Lake Michigan to the east. Evidence suggests that Indigenous communities occupied the area as early as 10,000 years ago, using Lakes Michigan and Superior for subsistence, trade, and communication.

In 1634 French explorer Jean Nicolet, arriving by canoe with several native Huron as guides, became the first European to see Lake Michigan and what would later become the State of Wisconsin. By the end of the 17th century, the first fully rigged ship *Le Griffon* had arrived in northern Lake Michigan seeking furs that would be transported to eastern Lake Erie and then on to Europe. By 1778, the schooner *Archange* began supplying fur traders within Lake Michigan, running long north/south routes between Chicago, Mackinaw, and Green Bay. These early events established two enduring patterns of maritime commerce in the region: trade within Lake Michigan, and beyond to other Great Lakes, the eastern United States, and world markets. Archival research indicates that 1,200 shipwrecks may have occurred in Lake Michigan waters (bordered by the states of Indiana, Illinois, Michigan and Wisconsin), with over 500 in Wisconsin waters. One analysis suggests that over 5,000 souls have perished in shipwreck events on Lake Michigan (Creviere pers. com). For centuries, Lake Michigan has been a transportation corridor of national significance.

Natural resources (lumber, grain, minerals, ore, fish) and their proximity to water established and drove Wisconsin's maritime economy. Raw materials were transported east while settlers, manufactured goods, and coal came west in return. As these mainstays of the economy grew, other industries and ventures were made possible such as brewing, paper production, furniture making, tanning and leather manufacturing, carriage, wagon, farm machinery and implement manufacturing, and eventually automobile manufacturing as well as the production of other light industrial products (Lusignan 1986). Thus, a complex economy, made possible by water and shipping, evolved in the 19th century driving tremendous growth. Indeed, becoming a state in 1848, Wisconsin adopted a state seal with unmistakable symbols tying land, water, and labor together: a sailor and iron miner, a plow, pick and shovel, arm and caulking mallet, and an anchor.

New York and Lake Ontario Historic Context

Lake Ontario’s maritime resources and significance as a transportation highway have long been recognized. Ten thousand years before present (BP), the earliest Americans populated the shoreline, engaging in boatbuilding and fishing (Schultz et al. 2011:33). While local communities changed with climatic upheaval, maritime resource utilization and extraction continued to draw people to the lakeshore—a process that continues today. Interactions between European explorers and Indigenous communities from the mid-17th century onward brought new opportunities for commerce and conflict; controlling waterways became synonymous with power, geographic expansion, and enterprise. Between the French, English, and Haudenosaunee, naval battles and skirmishes played out on the Lake’s surface over the course of 200 years to gain natural resources and support westward expansion (ONMS 2021:34-35)

The establishment of the United States in 1776, and later Canada, saw the growth of larger maritime economies. Port cities on Lake Ontario flourished as goods, services, and people moved between the Great Lakes and western frontiers. Following the outbreak of the War of 1812, Sackets Harbor, NY became host to one of the most robust naval shipbuilding yards found anywhere in North America. In a four-year span, the American Navy had constructed eight purpose-built military ships and fifteen armed barges. The ships saw minor action on Lake Ontario, but it was the shipyard at Sackets Harbor that became the focus of two British attacks in 1812 and 1813 (Ford et al. 2013).

Following the war, the waters from Sackets Harbor to Cape Vincent, NY played an active role in 19th century regional trade and commerce (Figure 2). Historic records indicate approximately 29 vessels were lost and never recovered in this corner of Lake Ontario (ONMS 2021). These vessels vary in form and function, beginning with commercial barges and schooners and later transitioning to small pleasure craft and passenger vessels as freight on Lake Ontario declined. For much of the early 20th century, Lake Ontario was dominated by recreational boating instead of the commercial endeavors from the previous century. With the creation of the St. Lawrence Seaway in 1959, however, the lake once again became the gateway to the Great Lakes, linking the Midwest to the Eastern seaboard.

Figure 2. The Duck Galloo Light ca. 1911, pictured here, was one of many aids to navigation placed on the lakeshore to support growing commerce. Despite these safety measures, a handful of shipwrecks occurred off the Galloo Islands. Image: National Archives and Records Administration (Identifier: 45705385).

Wisconsin Lake Michigan Study Area

Within WSCNMS, the team surveyed the near and offshore areas adjacent to Rawley Point at Two Rivers, WI. The survey area consists of a shallow, sandy, dynamic surf zone where many 19th-century vessel losses are known to have occurred (Figure 3). The arcing 11 kilometer (km) long point comprises a series of progradational beach ridges and swales (Dott and Michelson 1995), created from the influx of sediment to the littoral system from nearby Two Rivers. This presents a natural hazard to vessels, with its "quicksands," claimed many vessels stranded by violent fall gales, winter snow storms, and poor navigation. Contemporary newspaper accounts note how quickly ships became embedded in the sand; for example, newspaper reports of the wreck of the *Tubal Cain* (discovered in 2015 and located in the southern end of the survey area), reveal that the wreck stranded in shallow water on a Sunday, and by Tuesday had settled so deep in the sand that its deck was under 3 meters (m) of water.

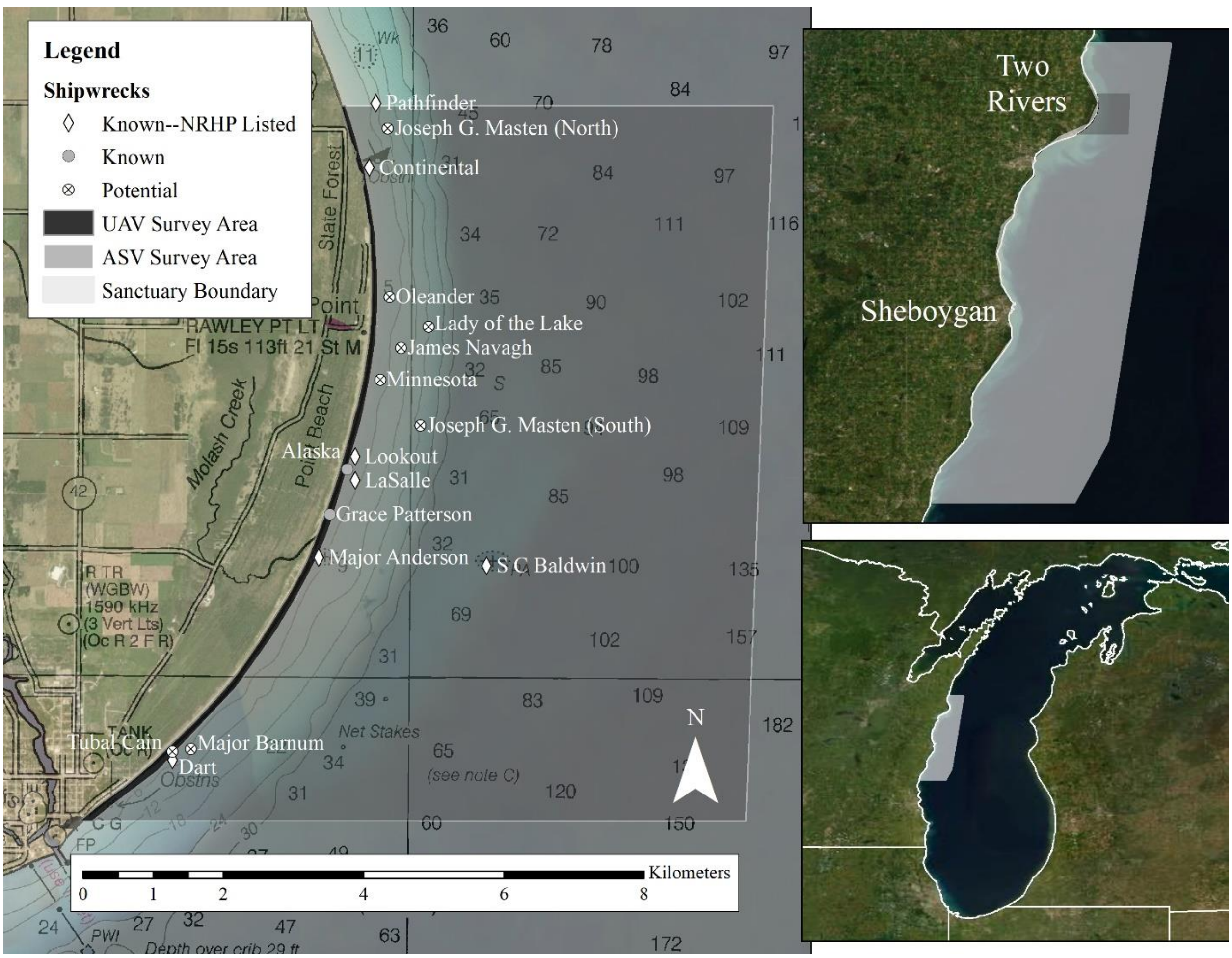

Figure 3. Wisconsin Lake Michigan Area of Interest. Top inset shows area of interest within the Wisconsin Shipwreck Coast National Marine Sanctuary; bottom inset shows the boundary of the Wisconsin Shipwreck Coast National Marine Sanctuary. Image: NOAA.

Prior to this project, there had been no systematic Phase I archaeological survey of the waters adjacent to Rawley Point and Two Rivers, WI. There were, however, seven individual intensive site surveys within the proposed area of operations. In 2006, East Carolina University conducted site documentation of the bulk carrier *Continental*, leading to formal nomination of the site to the National Register of Historic Places in 2008 (Hoyt et al. 2008). From 2013 and 2015, a local ultralight pilot reported several shipwrecks visible in the surf zone that were uncovered following a period of coastal erosion (Wisconsin SHPO 2015). During the summer of 2015, these sites were documented by the Wisconsin State Historical Society leading again to successful National Register nominations. The 2015 field report documenting several sites off Two Rivers and within the OER project location are publicly available online[2]. During the same field season, the Wisconsin State Historical Society also documented the popular shipwreck site *S.C. Baldwin* first located by the recreational fishing community in the 1970s.

Environmental Context

The Two Rivers, Wisconsin nearshore environment consists of dynamic sandy shoals that vary in depth, from 0 to 10 m. The predominant bottom sediment composition is siliceous sand.

The nearshore environmental processes have resulted in repeated burial of archaeological resources. Nearshore archaeological resources are remarkably well preserved and have not experienced colonization from invasive zebra and quagga mussels (*Dreissena polymorpha* and *D. rostriformis bugensis*, respectively). Conversely, the shifting shoals complicate archaeological site investigation as resources are not continually visible and may appear or disappear stochastically. Likewise, the nearshore wrecks around Rawley point are in a shallow high-energy zone which typically results in substantial structural degradation. However, the elements or portions of a ship deeply embedded in sediment may have a higher degree of preservation than portions more directly exposed to waves and ice. A site like *Continental*, for example, is largely disarticulated with much of the wooden hull flattened, creating only low relief above the lakebed. Large features such as engines have more resilience, as is the case with *Continental*. These features have a higher vertical relief due to their materials. Shipwrecks located in the nearshore "quicksands" due east off Rawley Point are remarkedly intact—yet buried in sand.

At the shipwreck sites *S.C. Baldwin* and *Henry Gust*, located off Two Rivers in water approximately 25 m deep, bottom sediment is far less mobile. The team did a short reconnaissance dive at each of these sites. Water temperature was 20 degrees Celsius at the top of the water column, with visibility approximately 12 m at *Henry Gust* and 9 m or less at *S.C. Baldwin*. Both shipwreck sites were well colonized by invasive mussels. The colonization process obscures resource details and, due to weight, can cause structural instability of archaeological resources. Both sites are broken up above the waterline. The site *S.C. Baldwin* does have some larger vertical structures, notably the stempost assemblage that rises high off the

[2] https://www.wisconsinshipwrecks.org/Files/2015%20Field%20Report%20Final.pdf

bottom and a short section of deck stanchions remain upright just aft of the bow. Due to time and site visibility, the dive team did not complete a visual survey of the site in its entirety. The *Henry Gust* hull remains are largely broken up. The steam machinery, located amidships, is the most prominent feature of the site.

New York Lake Ontario Project Area

The Eastern Lake Ontario areas of interest were drawn to best encompass areas of historical significance including the offshore Sackets Harbor area and reported locations of historical significance (Figure 4). In addition, the St. Lawrence River was also identified as an area of interest due to public comments received during initial scoping for the proposed Lake Ontario National Marine Sanctuary.

Situated in the eastern corner of Lake Ontario, Sackets Harbor, NY had one of the most robust naval shipbuilding yards found anywhere in North America during the War of 1812. Over a four-year span, the American Navy constructed 8 purpose-built military ships and 15 armed barges (Ford et al. 2013). The ships saw minor action on Lake Ontario, but it was the shipyard at Sackets Harbor that became the focus of two British attacks in 1812 and 1813. The project survey area at Sackets Harbor was drawn to encompass Horse Island, the site of the British amphibious landing during the Second Battle of Sackets Harbor in May 1813. Prior to this project, terrestrial portions of the battlefield had been archaeologically investigated, including Horse Island. In addition, maritime archaeologist Dr. Ben Ford had conducted a remote sensing survey in the adjacent Black River Bay, although this survey did not extend to the nearshore environment around Horse Island (Ben Ford, personal communication; Ford et al. 2013).

In addition to the Horse Island survey, the project team proposed to survey submerged areas located offshore in deeper water (Figure 4). Historical records indicated approximately 29 vessels were lost and never recovered in the northeastern corner of Lake Ontario (ONMS 2021). These vessels varied in form and function, from small pleasure craft to passenger steamers, commercial barges, and cargo schooners.

Prior to this survey work, no widespread archaeological survey of the offshore areas of eastern Lake Ontario has been published. Within the region, however, several individual projects were undertaken to identify shipwrecks or archaeological sites in nearshore environments. The earliest underwater archaeological site documentation was conducted on the remains of USS *Jefferson* by maritime archaeologists Dr. Kevin Crisman and Dr. Art Cohn in 1985 (Crisman and Cohn 1986). A War of 1812 brig sunk at Sackets Harbor, the archaeological excavation of USS *Jefferson* shed light on American boat building and the war effort at Sackets Harbor. The adjacent Black River Bay area was later investigated by Dr. Ben Ford in 2007 and 2008 for additional War of 1812 remains. While only one potential anomaly was identified, Ford conducted thorough remote sensing of the shallow bay and nearshore areas (Ford 2010, Ford personal communication).

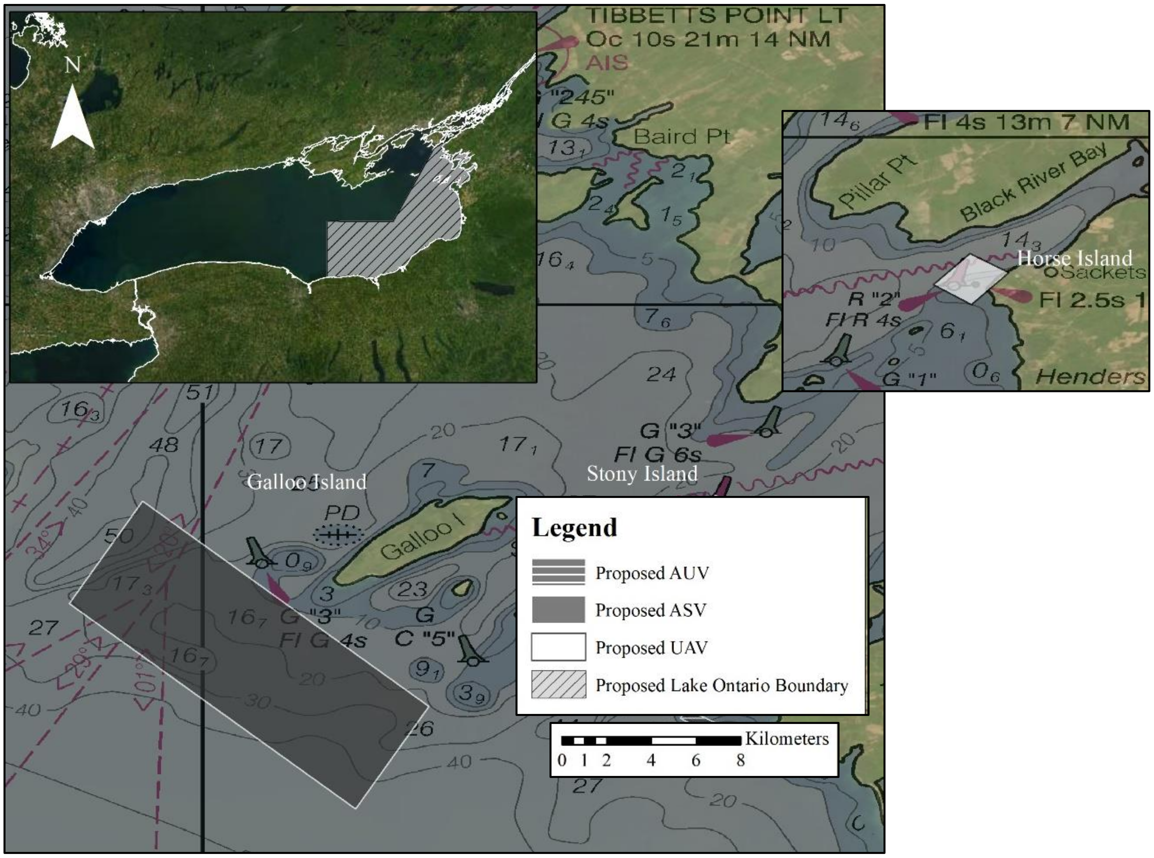

Figure 4. New York Lake Ontario Areas of Interest. Top left inset depicts the proposed Lake Ontario National Marine Sanctuary. Top right inset depicts Horse Island area of interest. Image: NOAA.

The remaining survey areas in eastern Lake Ontario have not been investigated by archaeologists; however, numerous shipwrecks have been previously identified via remote sensing survey conducted by local avocational historians and researchers (Jim Kennard personal communication, Tim Caza personal communication). Additionally, local avocational historian Daniel Gildea provided suggestions on areas to survey. The proposed survey areas for the 2021 work were drawn in consultation with Tim Caza as these represented previously un-surveyed areas with the potential for novel site identification.

Environmental Context

Bottom composition in Lake Ontario varies by location; mud, clays, sand, and exposed bedrock were all found within the study area. Bedrock covered in submerged aquatic vegetation and Dreissenid mussels was the dominant shallow water (0 to 15 m) substrate adjacent to some of the offshore islands. In deeper adjacent areas, the substrate was primarily sand, Dreissenid shells, and submerged aquatic vegetation.

The survey off Horse Island differed in that a thick layer of organic material has accumulated in shallow areas (0 to 7 m) adjacent to the causeway to the island. Nevertheless, a prominent regional magnetic gradient was visible in the associated dataset, indicative of the underlying bedrock. The bottom composition of Black River Bay, too, featured both organic sediments and exposed bedrock features.

Within the St. Lawrence River, the riverbed is largely sand, Dreissenid shells and submerged aquatic vegetation. In some areas near the edge of the channel there are rocky outcroppings and boulders. Because the river system is fed from the surface waters of Lake Ontario, the water temperature is consistent throughout the water column (approximately 23 degrees Celsius) and fluctuates with the surface temperature of the lake. There is high current in the river (approximately 1 knot), though the presence of several islands interspersed throughout the river results in localized eddies and lees that change from site to site. Many fish species were observed in the river including bass, perch and walleye. Notably, the site of the *America* shipwreck held many juvenile walleye.

Research Design

The goal of this project was to conduct a remote sensing archaeological survey in areas of WSCNMS and the proposed LONMS. Proposed methodologies were discussed with the Wisconsin Historical Society and the New York State Historic Preservation Office during the grant proposal writing stage. Key research questions driving the research design included:

1. What is the historical scope of submerged archaeological heritage resources within the proposed survey/sanctuary areas? What is the level of archaeological integrity of these resources? What visible processes are influencing site formation?

2. Can the archaeological resources located in the Western Lake Michigan and Eastern Lake Ontario proposed sanctuary areas be identified using the archaeological and historical records? Can resources identified during this survey be correlated with historical events or records?

Additionally, this project had four objectives related to the initial award of grant funds from NOAA OER. As outlined in the cruise plan (submitted 01 June 2021), these objectives were to:

1. Conduct multi-vehicle autonomous survey of unexplored nearshore areas of one proposed and one nominated [now designated] Great Lakes national marine sanctuary.

2. Characterize the submerged archaeological resources located within portions of one proposed and one nominated Great Lakes national marine sanctuary.

3. Produce maps and data useful to a variety of stakeholders.

4. Host unique educational opportunities for the public centered around the project's marine technology focus.

Field Methods

Field operations within the Wisconsin/Lake Michigan and New York/Lake Ontario study areas occurred between 28 July and 20 August 2021. A summary report of these activities was issued on 20 October 2021. This document, the ***2021 Cruise Report***, contained sections for cruise information, operations activities, education and outreach event descriptions, preliminary results, data management considerations, and presentation of challenges experienced by the field party. All the results presented in the cruise report are consolidated into the sections of this chapter. At the time of cruise report issuance, however, data processing and interpretation tasks were still underway. As a result, this earlier reporting document lacked results with detailed maps and figures. This final report includes those earlier materials, added results, and supersedes the ***2021 Cruise Report.***

As outlined in the cruise plan, field operations implemented opportunistic scientific diving in addition to the main exploratory and research-focused geophysical surveys. Deployment of autonomous platforms for geophysical surveys was the primary objective of the project and occupied most of the effort during operations. Both field efforts are presented here, with a greater emphasis on autonomous platforms.

Reconnaissance-level remote sensing and survey methodologies were employed in both Lake Michigan and Lake Ontario field components. These operations were aimed at locating and characterizing new archaeological resources and sites. Geodetic parameters for horizontal and vertical reference were established during project planning and implemented during operations to ensure uniformity across data acquisition systems. The geographic coordinate systems utilized in project data are outlined in Table 1. The projected coordinates system used in WI is presented in Table 2, while the NY parameters are shown in Table 3. Vertical reference parameters implemented for the multibeam sonar (MBES) survey are presented in Table 4. Project partners who were responsible for data acquisition and autonomous system operation were advised to incorporate all geodetic parameters in their system settings, setup, and downstream file management.

Four project partners supplied remote sensing equipment and platforms:

University of Delaware: Academic Partner. Provided: Autonomous underwater vehicle (AUV), assorted portable autonomous surface vehicles (ASV), remotely operated vehicle (ROV), research vessel (RV *Dogfish*), and field operations team to operate all platforms, instruments, and ancillary sensors. Team provided acquisition and processing support.

University of Miami: Academic Partner. Provided: Uncrewed aerial vehicle (UAV) equipped with an aerial magnetometer (provided by GEM Systems), and a field operations team to operate their platform, instruments, and ancillary sensors. Team provided acquisition and processing support.

Ocean Infinity: Industry Partner. Provided offshore autonomous surface vehicle (ASV), multibeam sonar, and field operations team to operate platform.

Marine Magnetics: Industry Partner. Provided marine magnetometer and base station magnetometer, field operations team to operate instruments and ancillary sensors, as well as an additional survey vessel. Team provided acquisition and processing support.

Table 1. General geodetic parameters implemented at all project locations.

Horizontal datum: ITRF2014 (EPSG: 7789)	
Datum	International Terrestrial Reference Frame 2014 (ITRF2014)
Ellipsoid	Geodetic Reference System 1980 (GRS 1980)
Prime Meridian	Greenwich (EPSG:8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314 m
Inverse Flattening (1/f)	298.257222101
Unit	meter
Horizontal datum: WGS 84 (EPSG:4326)	
Datum	World Geodetic System 1984 (EPSG:6326)
Ellipsoid	World Geodetic System 1984 (EPSG:7030)
Prime Meridian	Greenwich (EPSG:8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314 m
Inverse Flattening (1/f)	298.257222101
Unit	meter

Table 2. Projection parameters for WGS 84 based UTM projection in zone 16N.

Projection Parameters: WGS84 UTM Zone 16N (EPSG: 32616)	
Projection	UTM
Zone	16 N
Central Meridian	87° 00’ 00’’ W
Latitude origin	00° 00’ 00’’ N
False Northing	0 m
False Easting	500 000 m
Central Scale Factor	0.9996
Units	Meter

Table 3. Projection parameters for WGS 84 based UTM projection in zone 18N.

Projection Parameters: WGS84 UTM Zone 18N (EPSG: 32618)	
Projection	UTM
Zone	18 N
Central Meridian	75° 00’ 00’’ W
Latitude origin	00° 00’ 00’’ N
False Northing	0 m
False Easting	500 000 m
Central Scale Factor	0.9996
Units	Meter

Table 4. Project vertical reference parameters, implemented at all locations.

Vertical Reference Parameters	
Vertical Datum	North American Vertical Datum of 1988 (NAVD 88)
Vertical Reference	IGLD 85, low water datum (LWD)

All project participants are listed in Table 5, which included an intra-agency NOAA team to support field operations, data processing, and reporting as follows:

NOAA Office of National Marine Sanctuaries (ONMS): Provided project management and field personnel; NOAA Scientific Divers. Team provided acquisition, processing, and reporting support. Project personnel included staff from the Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS), Thunder Bay National Marine Sanctuary (TBNMS), and the ONMS Maritime Heritage Program (MHP).

NOAA Great Lakes Environmental Research Laboratory (GLERL): Provided NOAA small boat R*3012* and operators.

NOAA National Centers for Coastal and Ocean Science (NCCOS): Provided data visualization, interpretation, and public dissemination of results support.

Table 5. All project participants. *NOTE, participants also assisted field office personnel with data processing after project demobilization.

Name	Affiliation	Role
Field Operations		
Madeline Roth	NOAA MHP	Project Co-PI; field operations manager; report coordinator
Russ Green	NOAA ONMS	Project PI; Project coordinator, NOAA Diver
Joe Hoyt	NOAA MHP	Project administration, NOAA Diver
Dennis Donahue	NOAA GLERL	Vessel operations, R3012
Beau Braymer	NOAA GLERL	Vessel operations, R3012
Dr. Fritz Hanselmann	University of Miami	Co-PI, Technical advisor, UAV operations.
Ryan Fochs*	University of Miami	UAV Operations, Aerial MAG acquisition, file management
John Cline	University of Miami	UAV Operations, Aerial MAG acquisition
Doug Hrvoic	Marine Magnetics	Technical advisor, Aerial and Marine MAG systems
Ilya Inozemtsev*	Marine Magnetics	MAG data field processing, post processing
Dr. Art Trembanis*	University of Delaware	Co-PI, Party Chief, Technical Advisor for University of Delaware
Hunter Tipton*	University of Delaware	Portable ASV operator
Andy Wood	University of Delaware	Portable ASV operator
Mark Lundine	University of Delaware	Portable ASV operator
Matthew Gossett	Ocean Infinity	Offshore ASV Operation, online MBES acquisition
Regis Reddinger	Ocean Infinity	Offshore ASV Operation, online MBES acquisition
Titus Seilheimer	Wisconsin Sea Grant	Education and Outreach manager, Wisconsin operations
Abbie Diaz	Wisconsin Maritime Museum	Education and Outreach manager, Wisconsin operations
Field Office		
John Bright	NOAA TBNMS	Technical advisor, data management, MBES, MAG, GIS data processing
Avery Paxton	NOAA NCCOS	Data visualization and interpretation
Chris Taylor	NOAA NCCOS	Data visualization and interpretation
Charles Menza	NOAA NCCOS	Data visualization and interpretation
Ed Sweeney	NOAA NCCOS	Data visualization and interpretation

The team utilized three primary survey platforms for beach, nearshore, and offshore survey operations:

> **UAV | Beach and Nearshore**. DJI Matrice 600 Pro. Integrated sensor: GEM Systems DRONEmag GSMP-35U Ultra Light-Weight Potassium Magnetometer. Operated by University of Miami with support from Marine Magnetics, GEM Systems, and NOAA.
> **AUV | Nearshore and Offshore**. L3Harris Iver3 system integrated with an EdgeTech 2205 phase measuring bathymetric side-scan sonar and integrated color camera. Operated by the University of Delaware with support from NOAA small boat.
> **ASV | Offshore**. C-Worker 8 outfitted with R2Sonics 2026 multibeam echosounder. Operated by Ocean Infinity with support from NOAA small boat.

Additional platforms were supplied by the University of Delaware for opportunistic deployment and support, including three portable ASV units, ROV, and a pontoon boat equipped with an EdgeTech 6205 phase measuring bathymetric sonar:

> **ASV | Beach and Nearshore**. Hydronalix Sonar E.M.I.L.Y. integrated with Humminbird Helix 10 side-scan sonar.
> **ASV | Beach and Nearshore**. Seafloor Systems EchoBoat 160 integrated with Humminbird Solix 10 side-scan sonar.
> **ASV | Beach and Nearshore**. Seafloor Systems EchoBoat 240 integrated with RESON T50 MBES. Unit removed from service 4 August due to thruster failure and subsequently repaired and brought to NY. The vessel was not utilized in NY operations.
> **Crewed Boat | Nearshore**. RV *Dogfish* integrated with a Humminbird Solix 10 side-scan sonar and EdgeTech 6205 bathymetric side-scan sonar.
> **Crewed Boat | Nearshore**. MV *Troublemaker* (provided by Marine Magnetics) integrated with a Raymarine bathymetric side-scan sonar and a towed Marine Magnetics Explorer magnetometer. Side-scan data could not be exported for field operations but was used in developing deployment locales.

A summary table of survey platforms and instruments, including relevant operating parameters, is presented in Table 6.

Field tasks were distinguished between geophysical survey data acquisition and scientific diving operations. An additional task—geophysical data processing—began while field teams were mobilized onsite but continued in an offline field office beyond the demobilization of onsite activities. These three tasks—geophysical data acquisition, scientific diving operations, and geophysical data processing—are individually outlined below, though they occurred in a near-simultaneous nature while in the field with data processing continuing thereafter.

Table 6. Geophysical survey instruments and platforms utilized during project operations.

Platform	Primary Survey Instrument	Max Depth (m)	Sample Rate	Survey Speed (m/s)	Range Scale (m)	Line Spacing (m)
UAV						
DJI Matrice Pro 600	GEM GSMP-35U Drone Mag	5	10 Hz	5.00	2 m altitude	5
Base station magnetometer	Marine Magnetics Sentinel	15	1 Hz	N/A	N/A	N/A
ASV						
SONAR E.M.I.L.Y.	Humminbird Helix 10	6.5	1200 kHz	2-2.5	20	15
EchoBoat 160	Humminbird Solix 10	6.5	455/1200 kHz	2-2.5	30	40
EchoBoat 240	RESON T50	6.5	500 kHz	1.5-2	Varies	30
C-Worker 8	R2Sonic 2026	55	170-450 kHz	2.2-3.8	120° sector	30
AUV						
Iver3	EdgeTech 2205	90	600/1600 kHz	2.05	45	30
Crewed Boat						
RV *Dogfish*	EdgeTech 6205	40	230/540 kHz	2-2.5	75-100	75-100
RV *Dogfish*	Explorer MAG, Humminbird Solix 10	40	2-4 Hz (mag) 455/1200 kHz (sonar)	2-2.5	45	45
MV *Troublemaker*	Explorer MAG, Raymarine Sonar	40	2-4 Hz (mag)	2-2.5	75-100	10-75

Geophysical Survey Data Acquisition

Methods employed for each platform and sensor type are summarized in individual sections outlined and organized for quick reference through the Table of Contents.

Uncrewed Aerial Vehicle (UAV) Operations

University of Miami staff were responsible for daily operation of the UAV system. Typical survey routine involved pre-flight mission planning, deployment of an onshore base station magnetometer (the same location was used every day), establishment of an onshore flight control station at the flight site, automated data acquisition flights, and post-flight data recovery. Marine Magnetics personnel assisted with UAV operations and magnetometer troubleshooting, as well as post-flight data recovery, data management, and preliminary processing via the Marine Magnetics BOB and BAM software interface.

Pre-flight Mission Planning

The field team delineated paths within established survey blocks to provide the geographic extent of each planned UAV operation. Once the daily survey area was established, the Pilot-in-

Command (PIC) ensured compliance of flight operations within the National Airspace System and obtained necessary authorizations via the Federal Aviation Administration (FAA).

To ensure the legal operation of the aircraft, the PIC confirmed the airspace designation via Visual Flight Rules Sectional Aeronautical Chart, confirmed the airspace designation via the FAA's Low-Altitude Authorization and Notification Capability system if airspace authorization was needed, and verbally communicated with the closest regional airport's Air Traffic Control (ATC) as a courtesy notification for on-going low-altitude flights in the vicinity of the lakeshore. In both survey areas, the airspace was designated Class "G" which did not require additional flight authorization from the FAA.

Similarly, verbal communication with ATC noted that the flight plans would not require a Notice to Airmen and the flights could proceed as planned. In addition to authorization verification, weather checks occurred throughout daily operations to ensure safe and legal flight parameters as follows: twice daily using forecasted weather maps via NOAA's National Weather Service, every three hours using regional Meteorological Aerodrome Reports, and as needed on site using both visual observation and a handheld anemometer for instantaneous wind velocity readings.

Base station magnetometer deployment

University of Miami personnel determined a suitable location for the daily deployment of the base station magnetometer, removed from all sources of unwanted interference.
Although Marine Magnetics Sentinel base station magnetometer could be deployed either on land or underwater, it proved more practical to deploy it at a secure location on land, within several km of the flight sites. The Sentinel base station was configured to collect background magnetic field readings at a rate of 1 Hz, which was more than sufficient for effective data correction. At the end of each survey day base station data was downloaded and backed up for use during processing. The internal battery was recharged and magnetometer re-deployed at the same exact location the next day.

Control Station Establishment

University of Miami personnel established a control station daily during UAV operations. The control station was sited proximate to the planned flight area to ensure the aircraft would not exceed 1 km distance from the PIC but staggered so the magnetometer would not detect the onshore equipment.

Visual inspection of the planned operation area was conducted to ensure a constant visual line of sight was possible throughout the entirety of flight operations. The control station included a 3 x 3 m sunshade which housed a 2000kWh portable generator, two UAV battery charging bays, a radio-link antenna that provided a real-time data feed from the DRONEmag, as well as a laptop computer that simultaneously ran the autopilot software and the magnetometer digital interface. A 2 x 2 m takeoff and landing pad was laid on semi-level ground 10 m from the control station, followed by 1 x 1 m landing pad 4.5 m from the aircraft landing pad to act as resting place for the tethered sensor. The PIC, the person manipulating the controls, and the visual observer(s), were all based at the onshore control station throughout the UAV operations.

The aerial survey was conducted using a DJI Matrice™ 600 Pro UAV platform (registration Certificate Number: FA374CFEA7); an industrial UAV that included six brushless motors fitted with six sets of propellers, and six lithium-ion batteries to provide power. This aircraft was chosen for its safety redundancy features, high payload lifting capacity, and compliance with Title 14 Code of Federal Regulations part 107 rules and regulations for operation of small uncrewed aerial systems. The Matrice 600 Pro utilized a proprietary A3 Pro flight control system, including utilities for the flight controller, GPS-Compass Pro, power management unit, and two additional IMU Pro and GPS-Compass Pro modules. This triple-modular redundancy improved the system's anti-risk performance. Electric power for the aircraft was derived from six intelligent batteries, located in six individual battery bays. Three sets of batteries were utilized during the operations; twelve TB47s batteries which held a 4500 mAh capacity at a voltage of 22.2 V, and six TB48s batteries which held a 5700 mAh capacity at a voltage of 22.8 V.

Flight Planning

Prior to each mission, autonomous flight paths were generated using Universal Ground Control Software (UgCS) v3.6.248, a software package from SPH Engineering who have entered an educational partnership with the University of Miami.

This software package was chosen for its ability to aid the flight operations of a UAV with a sling payload, providing user-defined transect overshoots at differing flight speeds and adaptive banking procedures to assist the turn radius. UgCS also allows for altitude tolerance to be user defined which is a necessary parameter to control for low-altitude flights. Once the automated flight path was generated, the flight path was uploaded to an android tablet via network hotspot. The android tablet was wired to the UAV's radio control, which then transmitted the desired waypoints to the aircraft via radio signals.

The remote sensing instrument utilized was a GEM DRONEmag GSMP-35U. The DRONEmag is an optically pumped potassium magnetometer consisting of a lightweight high-sensitivity and high-resolution sensor specifically designed for UAV operations, magnetometer electronics module, dedicated battery, and GPS. The magnetometer was mounted to the UAV platform, but not integrated into the aircraft; both systems operated independently. The magnetometer power unit, data logger, and radio link were affixed to the underside of the aircraft chassis utilizing carbon fiber mounting brackets. Attachments were positioned to maintain the stable flight characteristics between the aircraft and payload. An independent GPS receiver connected to the DRONEmag was mounted on an aft propeller arm along the aircraft centerline. Test flights to check magnetic sensor noise determined that the sensor itself should be tethered 5 m below the aircraft to avoid magnetic interference from the UAV. In addition to the sensor's tether data cable, a safety line was affixed to the tether to ensure the weight and momentum stress of the sensor in flight would not create stress on the cable connections themselves, rather placing the stress on the safety line secured to the aircraft frame.

Established project geodetic parameters were implemented such that the aerial magnetometer recorded data in both WGS84 and UTM regional zones. The survey dimensional control utilized both the three onboard GPS-Compass receivers and the GEM systems independent GPS receiver (X = 0 m, Y = 0 m, Z= 0 m). During flight, a 0.5 m layback (i.e. lag correction) was added to sensor position to account for the tilt of the aircraft and drag of the sensor while towed. Transect line spacing was 5 m, with line lengths of up to 500 m.

Flight speeds of the survey varied between 2 and 5 meters per second (m/s). When appropriate, the survey was flown at a speed of 5 m/s, given open transects without obstructions. An overrun of 30 m at a speed of 2 m/s was implemented along each run line for controlled adaptive banking of the aircraft. The 30 m overshoot provided the time and distance to arrest the pendulum swinging of the sensor. It should be noted however, that wind played a significant role in the movement of the sensor while in flight, especially during turns. In the case of the Lake Ontario survey blocks, flights that attempted to survey near the tree line of Horse Island required that the entire survey speed be slowed to 2 m/s, without an overshoot. To accomplish this, the turning procedure was changed to a stop-pivot turn in which the aircraft would stop directly over the end of the survey line, pivot to the next line, and begin again at a constant speed of 2 m/s. These combined flight strategies allowed for efficient coverage of open transects, while allowing for tight maneuvers along coastline obstructions.

Low-altitude flights require a low tolerance for altitude variance. The aim of the aerial surveys was to bring the sensor as close to the surface of the water as possible without endangering the system. UgCS allowed for a 1 m tolerance, indicating that throughout the flight path only a 1 m deviation from the predetermined altitude is allowable. Considering both the 1 m tolerance and air-surface interactions, a 9 m Above Ground Level (AGL) altitude was prescribed, yielding a raw altitude of the aircraft of 6.4 m AGL. Given the 5 m tether of the sensor, this allowed the sensor to collect data at 1.4 m AGL +/- 1 m.

The DRONEmag utilized GEMLink software as the magnetometer command interface and was set to a cycle rate of 10 hertz (Hz). GEMLink also enables the users to define the Gregorian date format, time in UTC, and magnetic field sweep ranges in nano-Tesla (nT) used for auto-tuning the sensor during flight.

Pre-flight Inspection

The pre-flight inspection involved assessment of the functionality of all onboard systems and the airworthiness of the aircraft. The takeoff and landing area were cleared of non-essential personnel, and a pre-flight safety briefing occurred among the flight team.

A checklist-based procedure was implemented to ensure proper configuration and function of the aircraft, sensor payload, control station, and control interface prior to the initiation of flight operations. Safety briefings were held prior to each flight; debriefings followed each. Overwater operations posed specific risks to deployed equipment as items were not waterproof. Emergency procedures for overland operations could result in loss of systems. As a result, all necessary precautions were taken to ensure safe flight operations.

Flight Control

All takeoff and landing procedures were flown manually; once the aircraft was airborne and in the vicinity of the survey block, autopilot was engaged for improved survey line following.

UAV flight times averaged 20 minutes in duration, while the number of flights per day varied due to unfavorable weather, yielding right-of-way to recreational watercraft activity, and technical troubleshooting. Summary statistics for project flights are provided in Table 7.

Table 7. Summary flight statistics for each study area.

Study Site	No. of Flights	Mean Flights /day	Flight Time (mm:ss)	Area Covered (km^2)	Line Distance (km)
Lake Michigan	47	11	09:36:50	0.6579	162.3
Lake Ontario	33	5	06:07:04	32.2	76.1

Data Recovery

Following the completion of an individual flight or survey block, raw magnetic field data were downloaded directly from the magnetometer via a serial port (RS232) connection to GEMLink and saved as a comma-separated value (CSV) plain text file. Once raw data files were copied in duplicate (backed up), the internal memory of the magnetometer device was erased to leave memory space for future flights.

Ryan Fochs (University of Miami) served as the Pilot-in-Command and remote sensing specialist for all flight operations. Ryan holds a commercial FAA certificate for Remote Pilot operations of small Unmanned Aircraft Systems (#4111797) as well as a UAS Safety TRUST certificate (#IAMA23152163105). John Cline (University of Miami) served as primary visual observer and secondary person manipulating the controls for all daily flight operations (see Figure 5). Daily equipment launch and retrieval were supported on-site by NOAA personnel. Small boat transport support was provided by University of Delaware to aid in access of remote beach (WI) and Horse Island (NY) locations. Staff from Marine Magnetics were also present during survey operations and assisted with magnetometer configuration and equipment set-up.

Figure 5. Operation of the UAV system by University of Miami Personnel. Image: John Cline.

Base Station Technical Notes

The base station magnetometer proved invaluable in helping bring data from separate flights, collected at different times of the day, to a common level that enabled subsequent data processing and interpretation. Although the base station was deployed at a secure and remote location, away from sources of potential interference, the data did show signs of noise or external interference on a handful of occasions. Such noise was easy to identify and filter out during data pre-processing. It did not present any obstacles to the overall workflow.

An interesting observation was made during data analysis, where base station correction proved more significant in the case of Wisconsin survey (magnetic background from local geology was very low) than it did in New York where the geology was significantly more magnetic.

Autonomous Underwater Vehicle (AUV) Operations

University of Delaware staff conducted survey operations using the Iver3 AUV and its integrated EdgeTech 2205 bathymetric side-scan sonar and color camera. This system was deployed in nearshore and offshore environments, generally over known shipwreck sites to assist with site characterization, to provide additional physical information on site context and extents, and to assess the technology for use in long term site monitoring. The unit required launch and recovery from a crewed vessel platform which remained on station to provide support during all operations. Tending the AUV offshore was the primary task of NOAA vessel R*3012*, operated by NOAA's Great Lakes Environmental Research Laboratory (GLERL). Nearshore missions around Rawley Point, WI were conducted from RV *Dogfish.* Transit configuration of the AUV onboard R*3012* is shown in Figure 6.

Figure 6. The University of Delaware Iver3 AUV onboard NOAA vessel R3012, ready to transit to a survey location. Image: NOAA.

Survey Planning

During each deployment day, the team transited to the survey area and conducted a survey or series of surveys with each one lasting between thirty minutes and several hours. Surveys were planned at 45 m sonar range scale and 2-30 m line spacing (depending on the application) using VectorMap software by L3 Ocean Server. Frequently, two surveys were conducted over previously identified shipwreck sites; the first survey consisted of a wide area assessment (WAA) utilizing a high altitude (23 m)/low frequency (600 kHz) run line pattern to locate and position the site. Once this data was reviewed onsite by the AUV operations team to determine clearance around a given site, a second, high resolution geophysical (HRG) assessment was performed using a low altitude (8 to 10 m)/high frequency (1600 kHz) run line plan conducted to obtain higher resolution sonar data files and capture photos with the onboard integrated camera.

Survey Operations

Given the University of Delaware team was also operating ASV platforms as well as surface vessels, AUV operations were performed as permitted by offshore weather and available surface vessels in both Lake Michigan and Lake Ontario. In the former area, AUV surveys occurred on 2 and 3 August. Within the New York/Lake Ontario study area, they occurred on 15, 16, and 18 August. These operations are summarized in Table 8.

Table 8. Summary of AUV operations performed in the project areas. *NOTE, planned magnetometer operations from the Iver3 AUV not possible due to unknown power supply interface short that occurred during the pre-mission testing in Delaware with UD and Marine Magnetics between AUV and towed magnetometer device. The issue was troubleshooted onsite in WI and was confirmed to be a non-field reparable issue requiring return to the Iver3 factory for repair. The UD magnetometer remained operational and with assistance from Marine Magnetics Staff was integrated into use as a towed survey instrument.

Date	Activity	Study Area	Site Name	Mission Type
31 July	Transit			
1 August	Arrival-WI			
2 August	Operations	WI/Lake Michigan	Henry Gust	WAA
			Henry Gust	HRG
			Vernon	WAA
			SC Baldwin	WAA
3 August	Operations	WI/Lake Michigan	Vernon	HRG
			Home	WAA
			Gallinipper	WAA
			Gallinipper	HRG
5 August	Operations	Onshore	Mag integration*	
10 August	Transit			
11 August	Arrival-NY			
15 August	Operations	NY/Lake Ontario	Nearshore Area	HRG
			Nearshore Area	Exploratory
			Nearshore Area	HRG
			Nearshore Area	Exploratory
			Offshore Area	Exploratory
16 August	Operations	NY/Lake Ontario	Offshore Area	Exploratory
18 August	Operations	NY/Lake Ontario	Offshore Area	Exploratory
18 August	Operations	NY/Lake Ontario	Offshore Area	HRG
19 August	Demobilization			
20 August	Departure			

Autonomous Surface Vehicle (ASV) Operations

Two teams deployed ASV systems during the project. Ocean Infinity (OI) operated the offshore ASV, a C-Worker 8 unit with MBES onboard. Meanwhile, the University of Delaware handled an array of portable ASV systems engaged in side-scan sonar surveys of nearshore areas. Small ASV operations occurred throughout all project operations. While in Wisconsin, however, technical issues prevented the C-Worker 8 system from acquiring expected data. The unit did not become fully operational until 12 August, while working in the New York/Lake Ontario area.

University of Delaware's approach to the small ASV utilization was based on opportunistic intervals between the offshore AUV surveys, making on-site determinations about where to deploy, usually when weather conditions in open water prevented all but nearshore surveys. As such, their portable systems proved especially versatile in this role. These units were easily deployable from a beach, boat ramp, or RV *Dogfish* and supported COTS marine electronics like the Humminbird side and down imaging sonar payloads. While these units were highly portable, they were also vulnerable to foul weather given their small hull sizes. On a couple of occasions water-ingress into the vehicles required termination of operations.

Of the units in use, the EchoBoat 160 utilized a shore operations station for launch and recovery. Like UAVs, all ASVs require a PIC for mission planning and operational control. Operational control is accomplished from a fixed or mobile operations station. Once this station was established, surveys were conducted using Project11, an open-source ASV survey planner. Sonar range was set to 30 m with 40 m line spacing; surveys lasted between one and three hours in length.

The EMILY ASV was launched either from shore or a small boat (RV *Dogfish* and MV *Troublemaker*). The EMILY did not use a survey line planning software and was instead operated from one of the small boats. Range scale averaged 20 m and lines were overlapped at 15 m or less.

Meanwhile, the offshore ASV conducted a semi-autonomous transit from Sackets Harbor to the offshore survey area, approximately 1.5 hours of transit time each way. OI personnel trailed the system onboard NOAA small boat R*3012* and commenced survey operations with the onboard MBES system. Planned survey lines were spaced 30 m apart and the multibeam operated with an equidistant beam pattern over a 110° to 120° swath sector. Daily offshore on-station ASV survey operations lasted between two and six hours, depending on weather.

Combined ASV operations are summarized in Table 9.

Table 9. Summary of ASV operations performed in the project areas. *NOTE, flooding occurred onboard EchoBoat 240 owing to onsite integration of a towed magnetometer and rough conditions. The EchoBoat 240 was removed from service on 4 August. Following repairs, the unit was returned to service in NY where it was used for outreach and a mapping demonstration for local US Army Corps of Engineers personnel. **NOTE, On 12 August, flooding occurred onboard EMILY ASV due to rough lake conditions. Daily operations were terminated. On 13 August, EMILY ASV was deployed twice and entered a communications failure mode which resulted in termination of both missions.

Date	Activity	Study Area	Platform	Mission Type
31 July	Transit			
1 August	Arrival-WI			
2 August	Testing	Inshore	EchoBoat 160	Testing
			EchoBoat 240	Testing
3 August	Testing	Inshore	EchoBoat 240	Testing
			EMILY ASV	Testing
4 August	Operations	WI/Lake Michigan	EchoBoat 160	Exploratory
			EchoBoat 240*	Exploratory/Testing
5 August	Operations	WI/Lake Michigan	EchoBoat 160	Exploratory
6 August	Operations	Inshore/Riverine	EMILY ASV	Exploratory
	Testing	Inshore	EMILY ASV	Testing
7 August	Outreach	Inshore	EchoBoat 160	Demonstration
9 August	Operations	WI/Lake Michigan	EchoBoat 160	Exploratory
10 August	Transit			
11 August	Arrival-NY			
12 August	Operations	NY/Lake Ontario	EMILY ASV	Exploratory
			C-Worker ASV	Exploratory
13 August	Operations	NY/Lake Ontario	EMILY ASV	HRG**
			C-Worker ASV	Exploratory
14 August	Operations	NY/Lake Ontario	C-Worker ASV	Exploratory
15 August	Operations	NY/Lake Ontario	C-Worker ASV	Exploratory
16 August	Operations	NY/Lake Ontario	EMILY ASV	HRG**
			C-Worker ASV	Exploratory
19 August	Demobilization			
20 August	Departure			

Crewed Vessel Operations

Throughout all operations, NOAA small boat R*3012* supported on-water tasks. This included diving operations, AUV and ASV deployments, as well as over water transits and attending outreach events. No survey instruments, however, were installed onboard R*3012*. Downtime included conditions when the weather prohibited vessel operations and for several days while propeller repairs were made.

The University of Delaware provided the surface vessel RV *Dogfish* (18 ft. pontoon boat) to support and supplement geophysical survey operations from the autonomous systems. The RV *Dogfish* was particularly useful in very nearshore mapping and for providing transit to the UM UAV team. Additionally, when conditions were too rough for surveys in the lakes, the RV *Dogfish* was able to conduct survey in protected areas such as the Two Rivers (WI) and Black River (NY). Specifically, RV *Dogfish* deployed a transom-mounted Humminbird Solix side-scan sonar from 3 August until 13 August, when this instrument was replaced by a bow-mounted EdgeTech 6205 bathymetry side-scan sonar coupled with the Coda F190R GNSS/INS.

In addition to supporting AUV and ASV deployments, sonars onboard RV *Dogfish* were used in exploratory and HRG modes to acquire data files.

On 14 August, a second crewed vessel was deployed and worked within the New York/Lake Ontario study area. MV *Troublemaker* featured an integrated Raymarine bathymetric side-scan sonar used for site reconnaissance. Both RV *Dogfish* and MV *Troublemaker* deployed a portable Marine Magnetics Explorer magnetometer for site-focused exploratory surveys.

A summary of vessel-based geophysical surveys is provided in Table 10.

Table 10. Summary of crewed-vessel based geophysical survey operations performed within both project areas.

Date	Activity	Study Area	Platform	Mission Type
31 July	Transit			
1 August	Arrival-WI			
3 August	Operations	WI/Lake Michigan	RV *Dogfish*	Reconnaissance
6 August	Inshore	Riverine	RV *Dogfish*	Testing
7 August	Operations	WI/Lake Michigan	RV *Dogfish*	HRG
10 August	Transit			
11 August	Arrival-NY			
12 August	Operations	NY/Lake Ontario	RV *Dogfish*	Exploratory
13 August	Operations	NY/Lake Ontario	RV *Dogfish*	HRG
14 August	Operations	NY/Lake Ontario	MV *Troublemaker*	Exploratory
16 August	Operations	NY/Lake Ontario	RV *Dogfish*	Exploratory
17 August	Operations	Riverine	RV *Dogfish*	Exploratory/HRG
18 August	Operations	NY/Lake Ontario	RV *Dogfish*	Exploratory
			MV *Troublemaker*	Reconnaissance
19 August	Demobilization			
20 August	Departure			

NOAA Scientific Diving Operations and Photogrammetric Modeling

NOAA divers Hoyt and Green conducted dive operations on previously identified shipwrecks for the purposes of assessing resource condition and obtaining data useful to ongoing monitoring. Photographs were taken during each dive and are logged in Appendix A. Underwater Photography Log. Two dives were conducted in Wisconsin, and six dives were conducted in New York. All dives were conducted within no-decompression dive limits (less than 40 m) and followed protocols set by the NOAA Diving Program relevant to conducting scientific diving tasks via open circuit diving modes. Results are summarized in Table 11.

Photogrammetry was done at three sites during this survey. All images were captured utilizing a Nikon D4 camera system configured with a 15 mm Sigma fisheye lens. This system was encased in an Aquatica housing and 9.25’’ dome port. External lighting was achieved through two Inon

Z4 strobes connected via hot shoe (direct camera connection). All images were recorded using the Nikon native RAW file format which generates a .NEF file. Raw files were converted via Adobe's Camera RAW converter which generates an associated .XMP file that serves as metadata for the edits made to the .NEF before they are exported into a final modified .JPG format.

Table 11. Summary statistics and notes from scientific diving operations performed in WI and NY study areas. Depth of the site is listed as feet of fresh water (ffw) following standard dive terminology.

Date	Site	Divers	Dive Sup	Depth	Notes
8/2/21	*Henry Gust*	RG/JH	BB	80 ffw	Broken up shipwreck site. The vessel is lying on its port side, the starboard hull has collapsed. The fantail stern and steering mechanism are intact; amidships machinery and stem assemblage are somewhat intact. Completed full photogrammetric model of the site. Limited visibility.
8/2/21	*S.C. Baldwin*	RG/JH	BB	75 ffw	Little structure observed. Stempost rises approximately 20 feet off bottom, aft of stem a section of upright stanchions is evident. Little structure remains above the lakebed. Due to visibility a complete survey of the site was not done, more remains likely exist but were not observed. Completed partial photogrammetric model.
8/12/21	*A.E. Vickery*	RG/JH	MR	120 ffw	Intact schooner lying on channel edge. Intact up to deck level, rigging and masts lay on riverbed sloping down from main wreck site. Open cargo hold. High current.
8/12/21	*Iroquoise*	RG/JH	MR	75 ffw	Remains of site are predominantly hull frames. No planking observed, frames extend approximately 0.7 m above riverbed in most places, save for one section which rises approximately 2 m. Sand is predominant between the framing. The keelson protrudes just above the riverbed. Completed full photogrammetric model of the site.
8/13/21	*Maggie L*	RG/JH	KK	65 ffw	Somewhat intact remains of schooner. Bow missing and broken apart. Stern and rudder are intact. Structure up to deck level, however sheared off masts appear cut.
8/13/21	Steam Launch	RG/JH	KK	70 ffw	Attempted dive to locate steam launch. Divers were unable to locate site.
8/16/21	*Keystorm*	RG/JH	KK	40-115 ffw	Intact steel freighter laying in edge of channel. Almost entirely intact with pilot house attached.
8/16/21	*America*	RG/JH	KK	85 ffw	Drill barge site, intact. Site is inverted but access to the top deck and interior is possible as it rises slightly off the riverbed.

Photogrammetry processing was done using Agisoft Metashape Standard version 1.5.5. General workflow included importing images, aligning them, generating a dense point cloud, editing the noise from the dense cloud, generating a mesh, and applying texture. A sample of the typical processing parameters is presented in Table 12.

Table 12. Processing parameters for photogrammetric modeling. This example was taken from the final model of *Henry Gust*.

General	
Cameras	165
Aligned cameras	165
Point Cloud	
Points	169,315 of 179,042
RMS reprojection error	0.150421 (0.688598 pix)
Max reprojection error	0.452258 (25.9703 pix)
Mean key point size	4.21427 pix
Point colors	3 bands, uint8
Key points	No
Average tie point multiplicity	3.75836
Alignment parameters	
Accuracy	High
Generic preselection	Yes
Key point limit	40,000
Tie point limit	4,000
Adaptive camera model fitting	No
Matching time	6 minutes 22 seconds
Alignment time	50 seconds
Software version	1.5.5.9097
Depth Maps	
Count	165
Depth maps generation parameters	
Quality	High
Filtering mode	Disabled
Processing time	6 hours 43 minutes
Software version	1.5.5.9097
Dense Point Cloud	
Points	85,571,995
Point colors	3 bands, uint8
Depth maps generation parameters	
Quality	High
Filtering mode	Disabled
Processing time	6 hours 43 minutes
Dense cloud generation parameters	
Processing time	6 hours 20 minutes
Software version	1.5.5.9097

Model	
Faces	1,310,711
Vertices	658,650
Model, Continued	
Vertex colors	3 bands, uint8
Texture	4,096 x 4,096, 4 bands, uint8
Depth maps generation parameters	
Quality	High
Filtering mode	Disabled
Processing time	6 hours 43 minutes
Reconstruction parameters	
Surface type	Arbitrary
Source data	Dense cloud
Interpolation	Enabled
Strict volumetric masks	No
Processing time	5 days 20 hours
Texturing parameters	
Mapping mode	Generic
Blending mode	Mosaic
Texture size	4,096
Enable hole filling	Yes
Enable ghosting filter	Yes
UV mapping time	4 minutes 1 seconds
Blending time	10 minutes 38 seconds
Software version	1.5.5.9097
Platform	Mac OS 64

Geophysical Data Processing

All recorded geophysical information from navigation equipment and remote sensing instruments required post-processing to render a continuous, corrected result. These data products formed the basis for interpretation and analysis of lakebed areas to determine the presence and location of historical properties or other cultural materials. From these results, acoustic targets were picked from sonar data and magnetic anomalies were picked from the processed marine and aerial magnetometer data. In instances where survey operations were conducted over known historic properties, data products were generated to enhance the interpretation of site features and better understand location, orientation, and disposition on the lakebed.

Each instrument type—magnetometer, multibeam sonar, and side-scan sonar—required a separate processing workflow to achieve a final result. Each workflow consisted of a series of steps to refine or improve sensor navigation data (or navigation and motion for the MBES), apply corrections to raw data, merge files, and export data products. Each workflow took place within dedicated software interfaces specialized for rendering products from their respective survey instruments. Results derived from these processes are outlined in a later section; the stepwise processing workflow for each survey instrument is detailed here as a basis for understanding technical specifications of outputs from each instrument, methods applied to correct and render results, and quality assurance/quality control (QA/QC) criteria applied.

Magnetometer Data Processing

The airborne magnetometer survey data was collected using the GEM DRONEmag unit integrated onboard the DJI Matrice 600 UAV platform. Small, opportunistic surveys were also conducted with a boat-deployed marine magnetometer (a Marine Magnetics Explorer unit operated by the University of Delaware) conducted aboard the RV *Dogfish* (WI) and MV *Troublemaker* (NY). All raw magnetometer data, however, were processed using the same workflow.

This workflow required four general tasks as follows:

1. **Pre-processing** of individual flight log files exported directly from the DRONEmag interface. These files were recorded as comma delimited ASCII (i.e. plain text) files. Pre-processing was necessary to manually remove incomplete sample records (caused by write speed and buffer issues with the remote telemetry system), introduce a run-line identifier field into the flight log file, and to verify proper format of all other fields. This workflow step was performed by personnel at the University of Miami and applied only to the aerial magnetometer system. Resulting flight log files were free of data formatting issues and included a file field for survey run line.

2. **Preliminary processing** using Marine Magnetics BOB and BOB Analysis Module (BAM) software. Pre-processed raw flight log files were combined into survey blocks and received the following standard processing corrections:

    a. Lag correction: position offset corrections for the magnetometer sensor, relative to the position of the DJI vehicle's GNSS antenna as recorded in raw flight logs
    b. Base station correction: to compensate for the continuous diurnal variation in the ambient magnetic field, attributed to solar and atmospheric activity. This was required in order to bring individual flight data collected during different times over multiple days to a common level. Raw data from the base station required smoothing for select days where nearby interference occurred before it could be used.
    c. Heading bias correction, where necessary.

Heading correction was not necessary except for select circumstances where the physical orientation of the suspended magnetometer sensor was temporarily outside the optimal direction range relative to magnetic North. Such changes in sensor orientation were attributed to swinging and rotation of the sensor payload, caused by excessive wind or aircraft maneuvers, and occurred mainly during transitions between survey lines and immediately following turns. In these circumstances the total magnetic field reading would sometimes become offset (by a known constant offset amount) from the true magnetic field value. Such effects were transient, and mainly disappeared within a few seconds of the start of each survey line as the payload stabilized. These jumps in reading value required manual leveling correction by applying a bulk shift offset (usually 86-88 nT) to the affected reading.

Results from the preliminary processing were updated data files (in ASCII text format) containing data that was ready to be visualized using industry-standard data gridding (i.e. surface interpolation) methods. Marine Magnetics BAM software was used to create preliminary raster surface plots of total magnetic field and total magnetic gradient (i.e. analytic signal derived from total field), which were used for data quality control and preliminary survey analysis.

This portion of the workflow was performed by personnel at Marine Magnetics and applied to the aerial magnetometer data (collected using Marine Magnetics BOB software).

3. **Final processing** using the industry-standard Seequent (Geosoft) Oasis Montaj software consisting of Oasis Montaj Essential, Geophysical Leveling, and UXO Marine Extensions. Here, results from BOB/BAM steps were imported into an Oasis Montaj Project (one for WI survey and another for NY survey since each had separate geodetic parameters) and further refined. These steps included
    a. Geophysical leveling as needed to support bulk shift corrections outlined above (task performed by Marine Magnetics personnel in Oasis Montaj)
    b. Smoothing sensor navigation channels to render processed track lines and improved sensor positions; processed track lines mapped in projected coordinate system for QA/QC.
    c. Automated review of signal strength and altitude channels to flag any erroneous readings, another level of QA/QC.
    d. Magnetic data processing to despike and smooth the corrected magnetic field record, compute a background total field signal, compute a residual anomaly signal by differencing the smoothed corrected field with the

background field, and generate background geology field by processing long wavelength signals in the corrected total field record.

Results from these steps provided processed track lines for the UAV and marine magnetometer (exported as GIS shapefiles), filtered raster grids for identifying and describing magnetic anomalies, and processed database exports. Final processing was conducted by personnel at NOAA.

4. **Confidence modeling** consisted of geospatial analysis completed in ArcGIS Pro utilizing a US Department of the Interior (DOI) magnetic data modeling procedure (see Bright et al. 2012). At this step, processed data points were imported into an ArcGIS Pro map where a series of python scripts were used to
    a. Import and convert processed ASCII text files to feature classes in a user-defined geodatabase.
    b. Generate a coverage boundary based on a 15 m buffer distance.
    c. Run additional visualization to grid and contour the total field record and perform a spatial-based signal processing; this was not used for anomaly identification.
    d. Execute spatially-based confidence model to determine thresholds of detection for ferromagnetic materials of a user-defined (theoretical) mass based on the spatial distribution of actual sample points within the coverage area.

   Results from this step were a series of feature classes and raster datasets within a file geodatabase, viewed and assessed via ArcGIS Pro. Confidence modeling was completed by personnel at NOAA.

As noted, final magnetometer data processing took place within Geosoft Oasis Montaj (Version 9.8) with the Geophysical Leveling and UXO Marine extensions enabled. Access to this software was provided free of charge to the NOAA team via North American distributor Seequent via a 1-month trial license. This opportunity was brokered by project partner Marine Magnetics, with Marine Magnetics also providing support and assistance with processing tasks in Oasis Montaj.

Files exported from BOB/BAM during preliminary processing were saved in a comma-delimited ASCII format. These were considered the “raw” files as they contained all the data fields logged during the survey as well as additional data fields created when base station magnetometer and basic corrections were applied. Likewise, these files were imported into Oasis Montaj and ArcGIS. Processed results were produced and exported from both the Oasis Montaj projects and ArcGIS Pro programs. An Oasis Montaj project directory was saved for archival purposes, and a user-friendly interface project was also built within Seequent’s free Geosoft Viewer program.

This allows users to review (but not manipulate or change) the database information created by the Oasis Montaj processing workflow and applied scripts.

Additionally, selected results were exported from Oasis Montaj as GIS-compatible raster and vector data formats. Exported files were migrated to a GIS-project directory and managed with the GIS outputs of the confidence modeling program.
Combined data results from these four workflow tasks included:

1. Raw and processed ASCII text files in comma-delimited format.
2. Processed navigation track lines for the UAV and boat platforms in Shapefile format.
3. Coverage polygons of processed data based on a 15 m dissolved buffer of processed sample locations.
4. Gridded surfaces in FTL and GeoTiff formats representing:
    a. Corrected magnetic total field data record, based on the corrected field generated in BOB/BAM, gridded and viewed in Oasis Montaj.
    b. Processed analytic signal record directly exported from BOB/BAM.
    c. Processed residual anomaly grid computed in Oasis Montaj.
5. File Geodatabase containing results from the US DOI magnetic modeling scripts including raster surfaces containing the confidence modeling results.
6. Point features representing identified magnetic anomalies picked from the residual magnetic anomaly grid in Oasis Montaj.
7. Interactive Geosoft Viewer project to review data products.
8. ArcGIS Pro project to review GIS data products.

Detailed descriptions of workflow task 3, **Final Processing**, and workflow task 4, **Confidence Modeling**, are included in Appendix B. as dedicated subsections to more thoroughly detail steps involved as these impacted how magnetic anomalies were identified and described. Appendix B. also details how magnetic survey coverage results were characterized in terms of theoretical detection levels within the surveyed area geography.

Magnetic Anomaly Identification

Magnetic anomalies of interest were picked from the residual grid surface produced from the *nT_Residual* channel (i.e. data column in a database) results generated in Oasis Montaj. This channel was created by differencing the computed background signal from the cleaned total field signal. This generated a simplified output where signals from spatially localized, high amplitude magnetic density shifts remained visible above the background value which was set to zero. Induced magnetic fields of (likely anthropogenic) ferromagnetic objects appeared as these localized signals and could be distinguished from background values, sensor, environmental, and geological noise. Their locations were marked for further investigation.

Interpretation of the magnetic signal alone only indicates the approximate relative size, position, and orientation of the object based on its magnetic properties that are in contrast with the background. As such, the locations of each magnetic anomaly source identified in this report still require physical visitation, identification, and evaluation of each object generating an anomaly. Possible sources creating ferromagnetic anomalies may include geological features, accumulation of naturally magnetic material such as igneous rock boulders, modern anthropogenic objects such as a pipelines or subsea cables, and historical objects such as the remains of a ship or other structure. In some cases, visible magnetic anomalies may be caused by data processing artifacts or signal noise, though much effort was employed to eliminate all such occurrences from the survey data via the standard analysis methods.

Figure 7 shows an Oasis Montaj processing window with a map displaying the residual grid of a prominent magnetic anomaly. The anomaly is depicted as a 'hotspot' relative to background magnetic field values. The Oasis Montaj map viewer features a data linking tool enabling the user to click on the grid result and see corresponding database values linked to that portion of the grid surface. As this anomaly occupied space along four survey track lines, individual line data can be seen in profile view within the database. The maximum and minimum *nT_Residual* values can be measured, together forming the anomaly amplitude, and the measuring tool within the map interface allows quantification of its horizontal spatial extent, reported as spatial wavelength.

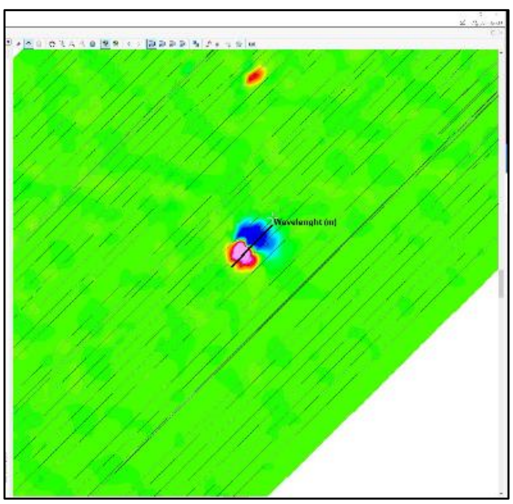

Figure 7. View of an anomaly as seen in the Oasis Montaj Map viewer. Image: NOAA.

Following review of the database and profiles generated by the *Single_Mag_nT-Process* script, the cleaned total field record, which was copied from the raw *Magnetic_Field_CORR* channel, was smoothed, despiked, and interpolated. It was then processed via a series of nonlinear filters to compute the background signal value. Where the total field signal had a high amplitude shift that remained within the bounding parameters of the nonlinear background filters, it was 'skipped' in the resulting computation. Thus, the divergence of the background result from the total field produced a net shift captured in the *nT_Residual* channel while longer duration noise in the total field channel was reduced to a near-zero residual value.

While derivation, visualization, and mensuration of anomaly signals within the *nT_Residual* channel took place entirely within Oasis Montaj, inventory and description of each study area's magnetic anomalies were built as a point feature class in ArcGIS Pro. Specifically, the FLT grid files generated in Oasis Montaj were imported into ArcGIS Pro. Next, an empty point feature class was created where attribute table fields shown in Table 13 were added. Magnetic anomalies were then co-located in both programs, with details contained in the Oasis Montaj GDB manually transcribed into the ArcGIS attribute table. Feature locations were computed using automated geoprocessing tools in ArcGIS Pro. In addition to ascribing geospatial details, each anomaly was assigned a unique identifier. This identifier was formatted to incorporate the project number, location, and an iterative number, as shown in the Anomaly_ID row of Table 13.

Table 13. Attribute table fields added to ArcGIS shapefile feature class marking magnetic anomalies.

Item	Format	Units	Description
Anomaly_ID	Text	Text	202103_NN_OER_###; NN = WI or NY; ### = iterative number to add unique identification
Location	WGS84 Latitude	dd.dddddd	Geographic position
	WGS84 Longitude	dd.dddddd	Geographic position
Location	WGS84 UTM Easting	meters	Projected position, UTM Zone 16N or 18N
	WGS84 UTM Northing	meters	Projected position, UTM Zone 16N or 18N
Wavelength	Integer	meters	Horizontal duration of anomaly signal
Amplitude	Integer	nT	Combined positive/negative density flux magnitude
Type	Text	Text	Types include monopole, dipole, asymmetric dipole, complex

Four types of anomalies are typically identified within a magnetic dataset. They include monopoles containing either positive or negative only shifts, as well as dipoles, asymmetric dipoles, and complex signatures of multiple positive and/or negative shifts occurring within sequence. Maximum values for positive and/or negative *nT_Residual* peaks were used to determine total amplitude assigned to each anomaly. The maximum horizontal extent of each anomaly footprint, as measured in the Oasis Montaj map interface, was used to quantify spatial wavelength. Examples of these anomaly types are shown in Figure 8 through Figure 11. Locations for anomaly center are picked at the point of greatest magnetic density flux, usually in the center of monopole and complex targets and between the positive and negative lobes of dipole and asymmetric dipole signals.

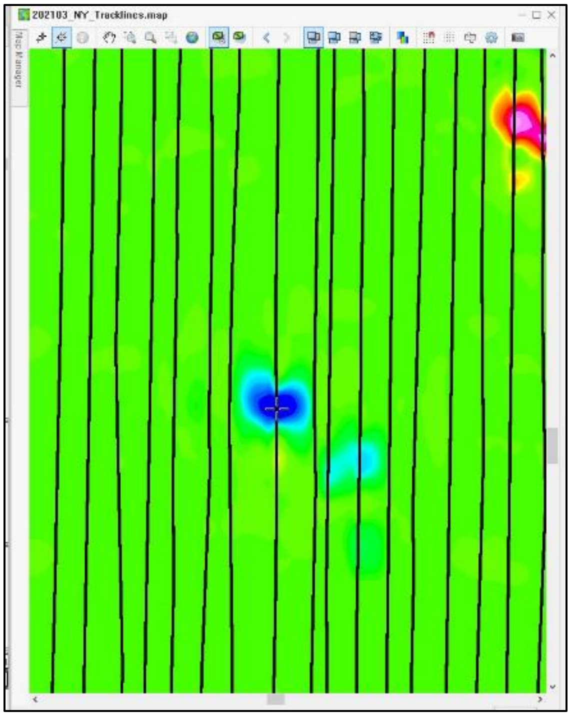

Figure 8. Example of a negative monopole presenting as a single negative shift on the map. Image: NOAA.

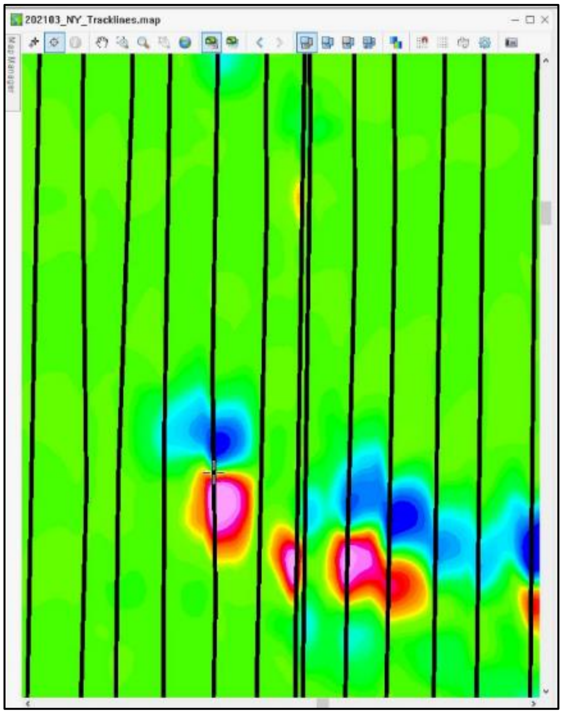

Figure 9. Example of a dipole anomaly where negative and positive shifts occur in nearly equal magnitude and appear as two distinct lobes on the gridded map view. Image: NOAA.

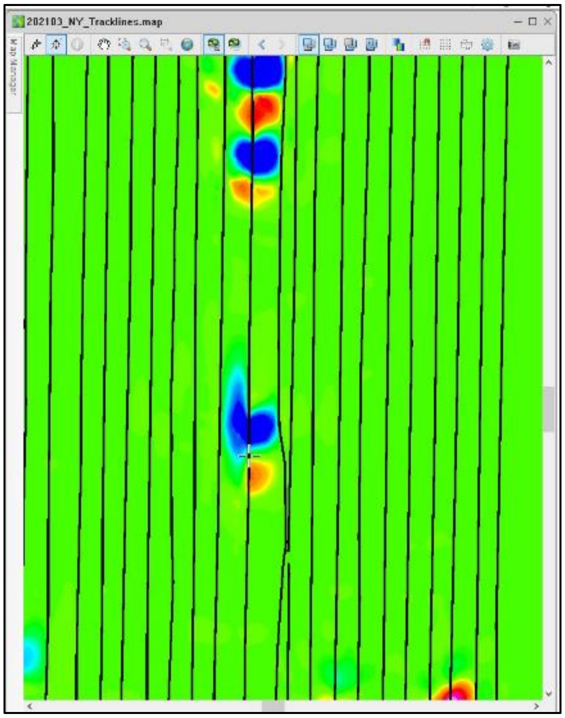

Figure 10. Example of an asymmetric dipole anomaly consisting of a slight shift in one direction followed by a substantially higher shift in the opposite direction. In the above example, a 1.5 nT positive shift is followed by a greater -24.5 nT negative shift. Like a dipole, these appear as two distinct lobes on the gridded map view with one lobe being larger and more prominent. Image: NOAA.

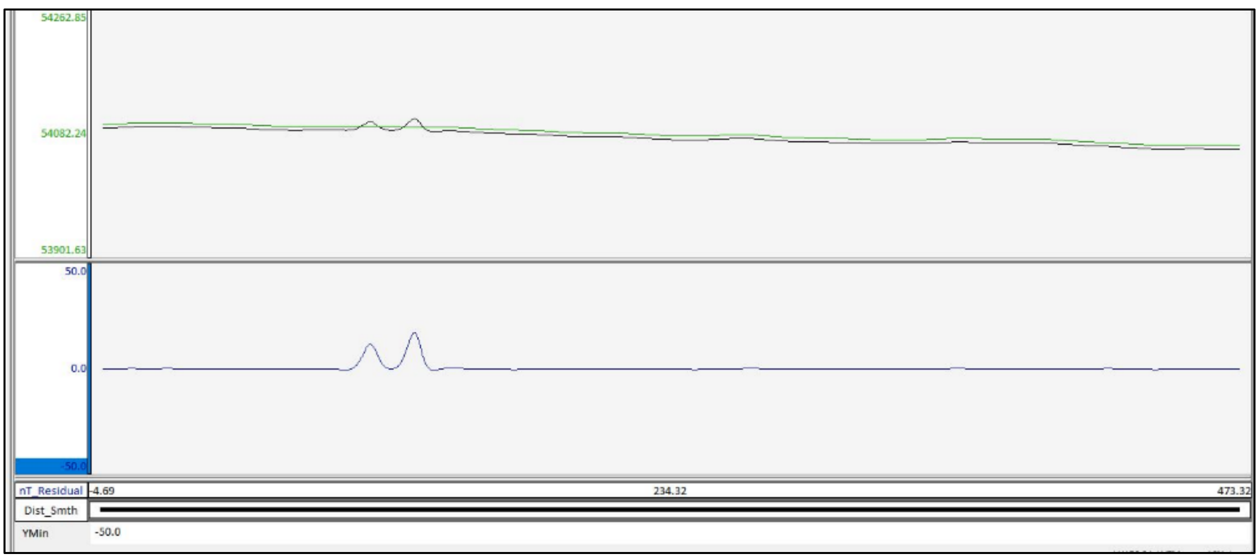

Figure 11. Example of a complex anomaly, seen as two positive shifts occurring in sequence. Image: NOAA.

ArcGIS Confidence Modeling

A final analysis involving the aerial and marine magnetometer data occurred once all the corrections, filtering, gridding, visualization, and anomaly identification were complete. This assessment used the processed sample point locations as the basis for mapping theoretical coverage levels within the study area. Unlike sonar data, where coverage can be quantified and confirmed by overlapping imagery files of known resolution, magnetometer data must report coverage based on the potential mass of objects missed as a function of the spatial distribution of recorded measurements.

Theoretically, no magnetic survey is ever completed in the sense that it could have detected all extant ferromagnetic objects within a given area. There is always a hypothetically undetectable mass either because it was too small or too far away from the sensor (e.g. between survey lines). This is true even in high-resolution survey designs with extremely narrow line spacing, such as the 5 m line spacing employed during the aerial magnetometer survey*. However, with such small line spacing, the theoretical mass evading detection would be extremely small, only a few kilograms. Furthermore, it falls within the threshold considered acceptable for the purposes of cultural resource management. Nevertheless, these thresholds must be explicitly stated such that current survey operations are properly characterized and future efforts scoped accordingly. In the present study, magnetic survey coverage was assessed using a 100 kg ferromagnetic object as the reference point for determining coverage levels in each project area.

* A common approach used in UXO surveys is to conduct survey over a known set of ferrous targets (referred to as an instrument verification strip, or IVS) to confirm the instrument signal noise throughout the day (Carton et al. 2017, 2019).

A series of scripted ArcGIS tools developed by the US Department of the Interior (shown in Figure 12) were run in an ArcGIS Pro project using the raw ASCII data files. These tools included an Input Tool feature to import the data table and convert to feature classes, a Generate Survey Boundary tool to create masking geometries which delineated remaining processes, a Visualization tool, and the Confidence Model process (see Bright et al. 2012).

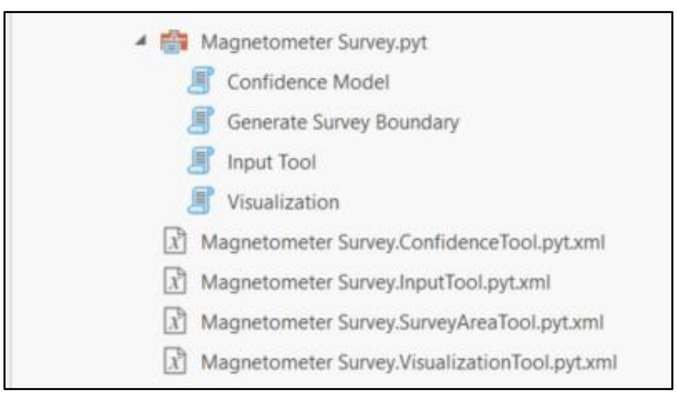

Figure 12. Scripted ArcGIS tools used to conduct spatially-based confidence modeling on processed magnetometer datasets in WI and NY. Image: NOAA.

To complete the confidence modeling, a point feature class of all processed data points in each project area were defined as the Input Survey Points Feature Class. Next, a boundary area was defined to delineate the extent of processing; this was the boundary based on a 15 m blanking distance set in Oasis Montaj and buffered in the Generate Survey Boundary utility. A Magnetic Moment value of 50 was chosen to determine the strength of each hypothetical object's magnetic field. Sensor noise was set at 5 nT based on the amplitude used to pick anomalies, and the mass threshold was set at a 100 kg object. These parameters are shown in Figure 13.

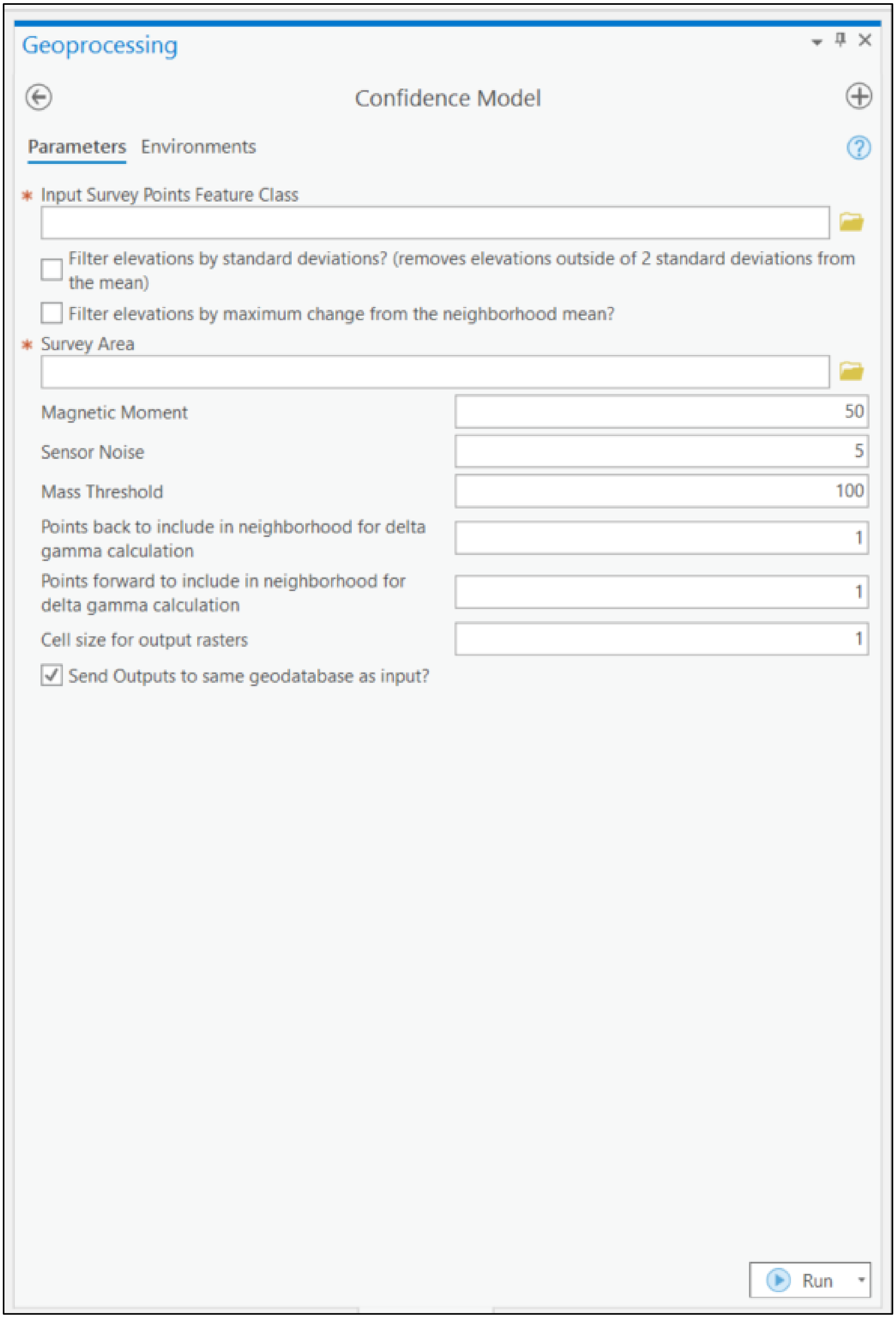

Figure 13. Interface and parameters used in the spatially-based confidence modeling of magnetic data collected in WI and NY. Image: NOAA.

When completed, the process populated a user-defined file geodatabase with features including a raster surface where each cell computed the potential mass missed at that location based on proximity to sampling points (both horizontally and vertically) and the defined object's magnetic moment. As distance from recording sampling points (i.e. the magnetometer sensor) increased, the computed potential mass of missed values likewise increased. Within the generated raster surface, an attribute table saved each result which was synthesized into the coverage statistics presented in Table 14 for the WI dataset and Table 15 for the NY dataset.

Table 14. Confidence modeling results for the WI magnetometer survey area based on the reported modeling parameters. Note that the largest potentially undetected object in the entire survey area was computed at 131 kg. Any ferromagnetic object of greater mass laying exposed on the surface would have been detected at the stated parameters.

Potential Mass Missed (kg)	Area Encompassed (m^2)	Percent of Total
5.0	110,245	16.26
25.0	54,392	8.02
50.0	33,855	4.99
75.0	19,117	2.82
100.0	9,187	1.35
200.0	0.00	0.00

Table 15 Confidence modeling results for the NY magnetometer surveys where the aerial and marine magnetometer survey occurred in separate locations. This analysis used the same modeling parameters applied to the WI dataset. Note that the largest potentially undetected object in the UAV survey area was computed at 107 kg. The largest potentially undetected object in the marine magnetometer survey area was computed at 477 kg. Any ferromagnetic objects of greater mass laying exposed on the surface would have been detected at the stated parameters.

Aerial Mag		
Potential Mass Missed (kg)	**Area Encompassed (m^2)**	**Percent of Total**
5.0	64,682	15.04
25.0	39,470	9.18
50.0	23,830	5.54
75.0	13,237	3.07
100.0	381	0.08
200.0	0.00	0.00
Marine Mag		
5.0	67,153	65.34
25.0	34,171	33.24
50.0	19,729	19.19
75.0	10,810	10.51
100.0	5,865	5.70
200.0	2,709	2.64

The narrow line spacing utilized in the aerial magnetometer survey (5 m) resulted in theoretical coverage levels that would identify objects larger than 100 kg in a majority (99.2%) of the areas surveyed. This value equates to a high level of confidence in the potential discovery of large anthropogenic ferromagnetic materials on the scale of anchors, cannon, engines, or deck machinery. Maps of each raster result are presented in Figure 14 and Figure 15. Note that the larger missed mass estimates for the UAV data occur only at the edge of the buffered polygon. Within the survey area, detection levels were much lower, falling into the under 75 kg category. This example demonstrates the value of narrow line spacing and close to the surface altitudes as well as the need for study area boundaries to extend beyond the geographical area of interest to ensure adequate object detection. Comparing the aerial survey map to the boat-towed magnetometer map, it is clear that the aerial platform excelled at maintaining consistently straight, parallel, and equally spaced track lines, which in turn resulted in a more uniform dispersal of missed mass areas.

For operational considerations, it is important to note the well-known trade-off between detection and coverage area that are attendant with the magnetometer surveys, which these results confirm. Approaches recommended in marine survey applications involve combining orthogonal sets of magnetometer survey lines and to combine sensor modalities utilizing both magnetometer and side-scan sonar (Carlton et al. 2019).

A standalone marine magnetometer survey was performed to the northeast of the aerial magnetometer study area in NY. This survey used wider line spacing set by WAA side-scan swath coverage and navigated by human pilots. As such the survey exhibited larger interstitial spaces between collected data points. Consequently, greater potentially undetected masses resided in these interstitial spaces, as noted by the yellow and red portions of the associated raster surface in Figure 15. An important qualifying consideration is that the vessel-based magnetometer survey was conducted within approximately 1.5 hours of survey whereas the tighter spaced UAV surveys required several days of operation, again emphasizing the trade-off between resolution and coverage for different platform modalities. The comparison also clearly demonstrates the superior line following that a well-tuned autonomous system can achieve compared to even the best human navigator.

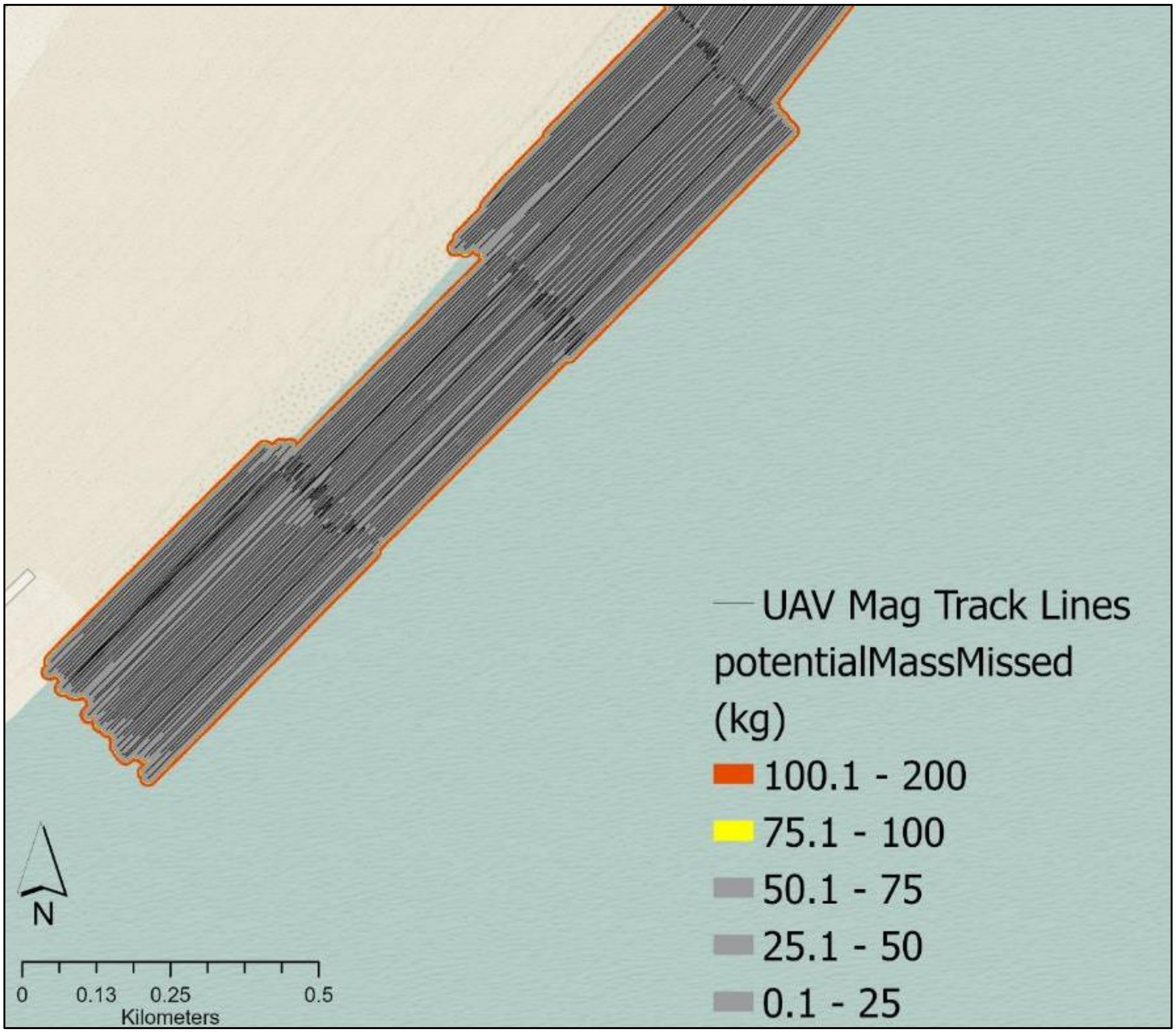

Figure 14. Example of aerial magnetometer track lines overlaid on raster surface depicting potential mass missed estimates in the WI survey area. Image: NOAA.

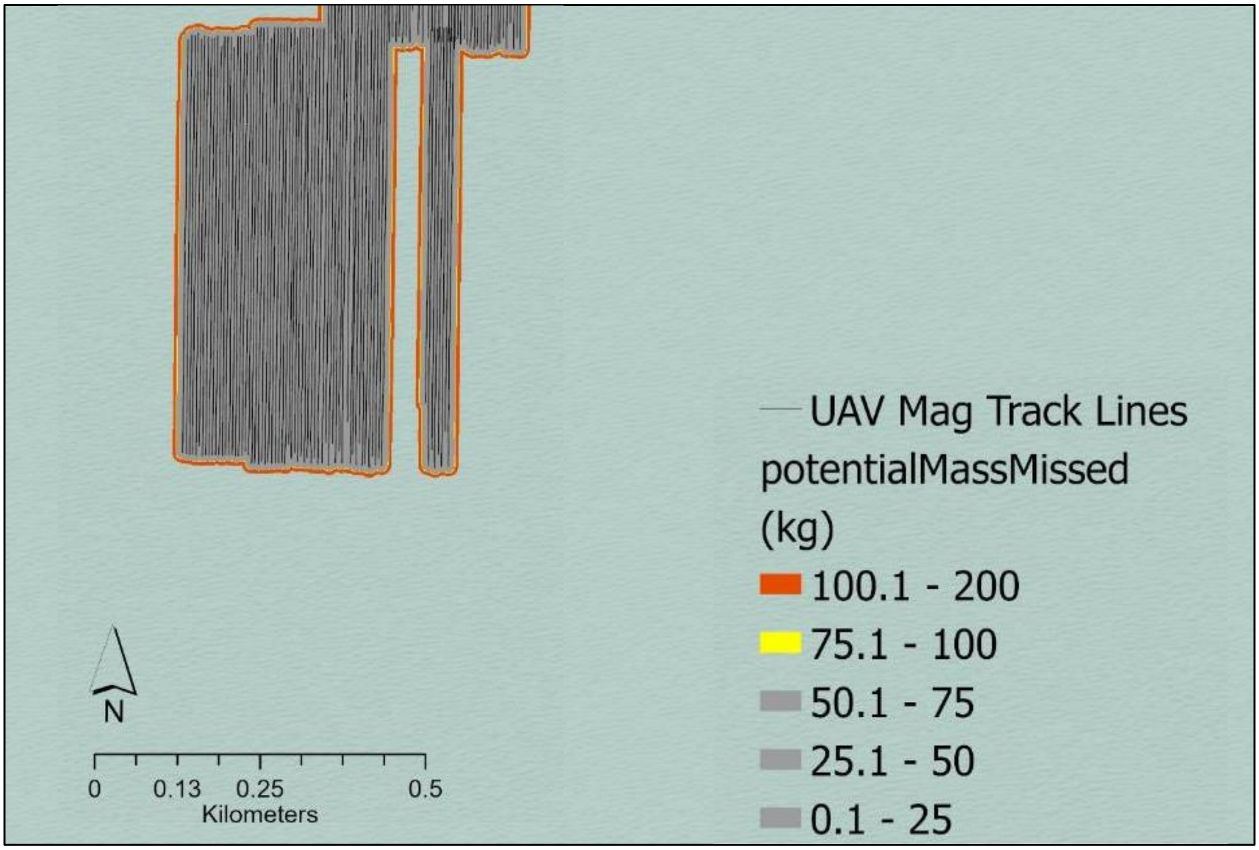

Figure 15. Detail of aerial magnetometer track lines overlaid on raster surfaces depicting potential mass missed estimates in the NY survey area. Image: NOAA.

Multibeam Sonar Data Processing

Multibeam sonar operations onboard the C-Worker 8 ASV occurred in earnest between 12 and 16 August within the Lake Ontario study area. Prior operations in Lake Michigan only involved testing and calibration of the vehicle system and survey instruments. As a result, no exploratory survey was performed by the C-Worker 8 ASV while in Lake Michigan. Thus, all acquired MBES data which was processed to a final result occurred within the Lake Ontario study area.

The MBES onboard survey team recorded raw sonar files and INS navigation files to data acquisition computers (DAC) on the ASV. These files were transferred daily to a portable hard drive where they were organized and managed in day folders corresponding to instrument type. At the conclusion of ASV operations, a copy of this drive was provided to NOAA project personnel, along with the ASV offset diagram provided in Figure 16. Data from the provided portable drive was then uploaded to a shared Google Drive location.

	SYSTEM	X	Y	Z		SYSTEM	X	Y	Z
1	CRP	0.000	0.000	0.000					
2	GPS Bow	0.025	3.065	2.930					
3	GPS Stern	0.025	0.675	3.130					
4	Hemisphere GPS	0.025	-1.515	4.590					
5	MBES FF	0.035	0.125	-0.370					
6	MBES AC	0.035	0.305	-0.690					
7	IMU	0.000	0.000	0.000					

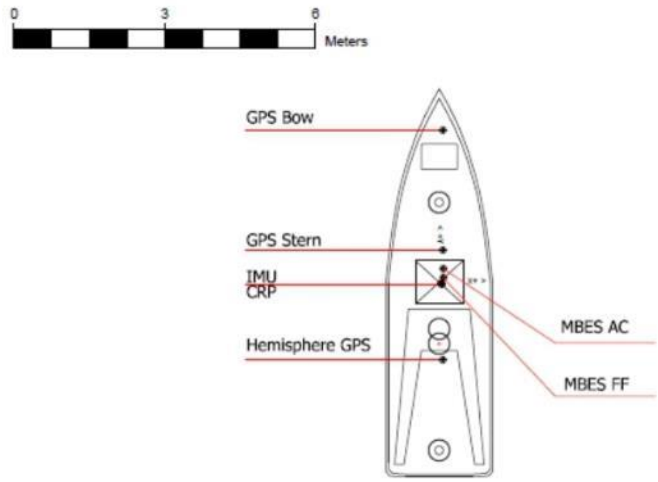

Figure 16. Instrument offsets for the C-Worker 8 ASV operated by Ocean Infinity to conduct MBES operations in Lake Michigan and Lake Huron. Image: Ocean Infinity.

Once available on Google Drive, field data was shared to an offline processing office at NOAA's Great Lakes Maritime Heritage Center (GLMHC) in Alpena, MI. Files were copied down from Google Drive onto a local 40TB NAS and integrated into a computer workgroup for post-processing in a series of software programs. MBES processing workflow started with file management to organize the raw files in a project-based directory which would assist in co-locating raw and processed files in a standardized directory schema. Next, raw INS navigation files were post-processed. These data produced updated position, heading, and motion outputs used to improve referencing of sonar data. Once completed, sonar data processing took place which included application of the processed navigation files in addition to correction and cleaning of the MBES point cloud results.

It is important to note that field data transfer to NOAA personnel took place following the demobilization and departure of the ASV survey team and MBES equipment. Consequently, NOAA did not preview the data or conduct QA/QC of MBES files during the field survey. Likewise, the MBES team performed minimal review of acquired data during operations and did not provide any online logs, handover documents, or procedures to the NOAA team. Such minimal QA/QC activity, therefore, accounts for technical issues discovered by the data processing team while working through the MBES data as outlined in the ensuing section.

File Management

Prior to data processing efforts an offline project archive was created to organize field data based on the directory schema outlined in several tables below. The project archive was named

202103_MHP_OER_Benthic_Survey

and this nomenclature was carried through as a derivative for files names, folder names, project names, and data backups in downstream processing. This naming system aligned with a project-based nomenclature implemented at NOAA's Thunder Bay National Marine Sanctuary (TBNMS) to establish a unique naming code for operations based on an iterative, annual project numbering schema as follows:

yyyyNN_[Partner]_{Survey_Type},

where yyyy = calendar year;
NN = project number in iterative, ascending sequence;
[Lead agency] are abbreviated organization names;
{Survey_Type} is a generalized classification of work type performed per the technical scope.

Within this archive were three sub-folders pertaining to project MBES data which included:

1-MAC: DIRECTORY EMPTY. No mobilization or calibration (MAC) procedures were performed prior to the initiation of MBES operations. Upon arrival, MBES system setup and testing incorporated saved parameters based upon prior settings utilized onboard the ASV's computers and devices.

2-Raw_Data: All raw files recorded during exploration activities. Within this directory is a folder for raw data produced by the C-Worker ASV. Its contents are shown in Table 16 which were sorted to group similar raw file formats from the sonar instrument, INS position and motion system, as well as SVP data. Note that SVP files were not collected by the online MBES team. Instead, files collected by the AUV team were converted from their native format into a file type used by the CARIS HIPS and SIPS processing program to correct raw MBES data. Applied SVP files were not co-located with the MBES survey area and they were not collected at the same time as raw sonar file recording. Sound velocity corrections, however, were required for referencing processing bathymetric soundings, thus the AUV-related files constituted the only available set of local water column sound velocity information. They were copied into this directory for use during MBES data processing.

Table 16. Directory schema for storage of project raw survey data. *NOTE: No SVP files were recorded by the MBES online team. Those saved in the raw data directory were instead collected by the University of Delaware team operating an AUV in nearby areas.

2-Raw_Data	3_OI_C-Worker_ASV	MBES_R2S	*No files recorded in this format*		
		MBES_XTF	*No files recorded or converted to this format*		
		MBES_SBD	YYYY_MM_DD_[Lake_Name]	*yymmddhhmmss.sbd*	
		Positioning_and_INS	POSMV_Raw	YYYY_MM_DD_GNSS1	*Log.000*
		SVP*	Access_MAT	*CC1618007_yyyymmdd_hhmmss.mat*	
			CARIS_SVP	*CC1618007_yyyymmdd_hhmmss.svp*	
			CastAway_CSV	*CC1618007_yyyymmdd_hhmmss.csv*	
			HYPACK_VEL	*CC1618007_yyyymmdd_hhmmss.vel*	

3-Process: All processed files were organized into the appropriate sub-directories encompassing software-specific folder structures, as shown in Table 17. Main folders in use were the ArcGIS, CARIS, and POSPac processing projects. Since MBES acquisition occurred through the EIVA online software interface, blank directories were created in the event NaviEdit and NaviModel programs were utilized. Some raw file preview did occur in NaviModel Viewer, however, none of the rendered results were saved. A blank directory was also maintained for a SonarWiz project intended to assist with visualizing bathymetry and backscatter data. All this processing, however, took place in CARIS with visualization in ArcGIS.

Table 17. Directory schema for storage of project processed data. Each of the sub-folders within this directory tree encompass processing projects that, in turn, implement software-specific directories.

3-Process	3_OI_C-Worker_ASV	2-Data	ArcGIS	202103_MHP_OER_Benthic_Survey	*GIS files and databases*
			CARIS	202103_MHP_OER_Benthic_Survey	*CARIS project files*
			NaviEdit	*No files*	
			NaviModel	*No files*	
			POSPac	Projects	*CWorker_yyyymmdd_[SOL-EOL]*
				SBET	*SBET_CWorker_yyyymmdd_[SOL-EOL]_smartbase.out*
					SMRMSG_CWorker_yyyymmdd_[SOL-EOL]_smartbase.out
			SonarWiz	*No files*	
			z_screengrabs	*Assorted JPEG image files*	

Each of these processing projects were iterative and updated as more files were added to the workflow. Until finalized, their contents were frequently overwritten to include expanding results. As a result, the 3-Process folder was necessary to partition raw files from the active workspaces where copies of these files were converted, manipulated, exported, overwritten, etc.

Navigation data from the ASV’s onboard Applanix INS system was post-processed to incorporate correction data distributed as publicly available files from the NOAA Continuously Operating References Station (CORS) network. Outputs from the processed Applanix files were uploaded into the CARIS HIPS and SIPS multibeam sonar processing interface where the raw MBES files were loaded and organized by acquisition day. Here, they were paired with the Applanix outputs, and georeferenced to include SV corrections. Much of the MBES post processing, therefore, took place within the CARIS project. It was organized according to the project directory shown in Table 18, and was maintained as standalone deliverable with copies of raw MBES and SVP files included. Resulting bathymetry surfaces and navigation files were then exported for use in ArcGIS projects to determine area coverage, and assessment alongside other data types.

Table 18. CARIS processing project directory schema. This was built to represent a stand-alone processing project which could be shared among project partners or archived for later review.

202103_MHP_OER_Benthic_Survey	HIPS Directories	YYYY_MM_DD		*Tracklines_YYYY_MM_DD*
				YYYY_MM_DD.hips
	Export	ASCII		*202103_MHP_OER_CWorker_MBES_Processed.csv*
		BAG		*202103_MHP_OER_Benthic_Survey_Processed.bag*
				202103_MHP_OER_Benthic_Survey_TRANSIT_LINES_Processed.bag
		GeoTiff		*202103_MHP_OER_Benthic_Survey_Processed.tiff*
				202103_MHP_OER_Benthic_Survey_TRANSIT_LINES_Processed.tiff
		GSF		*yymmddhhssmm.gsf*
		Tracklines	01_RAW	*n/a raw file referencing erroneous and replaced*
			02_PROC	*202103_MHP_OER_CWorkerASV_PROCESSED.shp*
	Height Model			*202103_NY_SEP_Boundary_WGS84-LWD_IGLD85*
	QA_QC_Surfaces			*202103_MHP_OER_Benthic_Survey_QAQC.csar*
				202103_MHP_OER_Benthic_Survey_transitlines_QAQC.csar
	QC_Stats	1_Main_Lines		*.TXT and .PDF exports for Deep (mean), Depth (mean), Sounding Density, Standard Deviation, and Uncertainty*
		2_Transit_Lines		*.TXT and .PDF exports for Deep (mean), Depth (mean), Sounding Density, Standard Deviation, and Uncertainty*
	Raw_Files	yyyy_mm_dd_raw		*Yymmddhhssmm.sbd*
	SBET			*SBET_CWorker_yyyymmdd_[SOL-EOL].Smarbase.out*
				SMRMSG_CWorker_yyyymmdd_[SOL-EOL].Smarbase.out
	SVP			*CC1618007_yyymmdd_hhmmss.svp*
	Vessel_File			*2021_C-Worker_ASV_R2Sonic2026.hvf*
				202103_MHP_OER_Benthic_Survey.project

As previously mentioned, all file transfers from the field to the offline processing office occurred via Google Drive folder. Total directory size for MBES raw data archive (Table 16), was 10.8 GB encompassing 128 files in 23 folders. Upon receipt at the offline processing office, they were loaded onto a NAS system and managed through a processing workstation, NAS directories, and independent backup drives. Once processing was complete, the processed data archive (Table 17) was 155 GB encompassing 2,957 files in 104 folders.

Navigation Data Processing

Navigation files were recorded onboard the C-Worker ASV platform in the Applanix POSMV POSPac file format separately from real time navigation information written into raw MBES files. Specifically, the same navigation datagrams sent to the MBES computer via UDP broadcast over the integrated vessel computer network were simultaneously written to files in a separate directory. These datagrams included position, heading, speed, motion, and time as received from the satellite navigation hardware and measured by the Applanix's GNSS antennae and IMU. As a result, this information arrived in an ITRF/WGS coordinate system with UTC as the time datum. Motion values were computed relative to the established reference frame in the Applanix programming, as were position offsets. Recording of these raw values, therefore, proceeded independently of settings governing the MBES hardware and vessel navigation in EIVA. Applanix instrumentation provided raw navigation and motion data to the ASV's network and independently recorded the same.

When previewing raw MBES files after the completion of field operations, it was discovered that an incorrect project geodesy had been implemented in the ASV's survey and MBES control interface. Namely, by accepting prior EIVA software settings during mobilization, a coordinate system outside of the continental United States was erroneously selected for use during the WI and NY operations. While the Applanix instrument broadcasted correct ITRF/WGS84 based position datagrams over the network, these positions were then transformed by EIVA to a location beyond the US Great Lakes and then written into the raw MBES files. As mentioned previously, lack of real time QA/QC allowed this condition to persist throughout the entirety of WI and NY survey operations. Raw Applanix POSPac files, therefore, were integral to properly referencing all acquired MBES data and replacing incorrect real-time navigation.

Likewise, since real time position corrections (such as VRS-based RTK or SBAS) were not implemented during MBES survey operations, the planned bathymetric processing workflow already included steps for generating post-processed smoothed best estimate of trajectory (SBET) files to improve position and motion reference information and thus improve sonar data quality. Inclusion of these files is generally regarded as a means of improving MBES survey results. Given issues with real time navigation, however, this step became essential to properly referencing those files with the benefit of adding improved horizontal and vertical accuracy.

Standard online survey procedures required logging Applanix POSPac files for no less than 20 minutes prior to sonar data recording as well as a minimum of 20 minutes after the cessation of sonar data recording. The interval of POSPac recording needed to include the entire sonar data recording event without interruption. Likewise, an ample POSPac data record before and after the sonar data recording event was needed to allow for forward/reverse processing to be completed within the SBET file. A break in the POSPac record during sonar logging or insufficient data before/after sonar data recording would render portions of the sonar record uncorrectable. Given the stated issues with real time EIVA navigation, any portions of the raw sonar record not coinciding with an SBET file would not align with the remaining data and thus be rejected.

Once recorded, raw INS navigation files were sorted into a raw data directory folder (see Table 17) which was sorted into daily sub-folders. Throughout the survey, POSPac files were named according to the convention shown below in Table 19. They were logged at an unknow rate (most likely 100 Hz) and at a maximum file size of 130 MB.

Table 19. INS raw file naming system uses for logging POSPac files

Date	INS Raw File Base Name
2021-08-12	log.000
2021-08-13	1308.000
2021-08-14	logs.000
2021-08-15	logs.000
2021-08-16	logs.000

Offsets programmed into the Applanix system to reference components to a common point are shown in Figure 17.

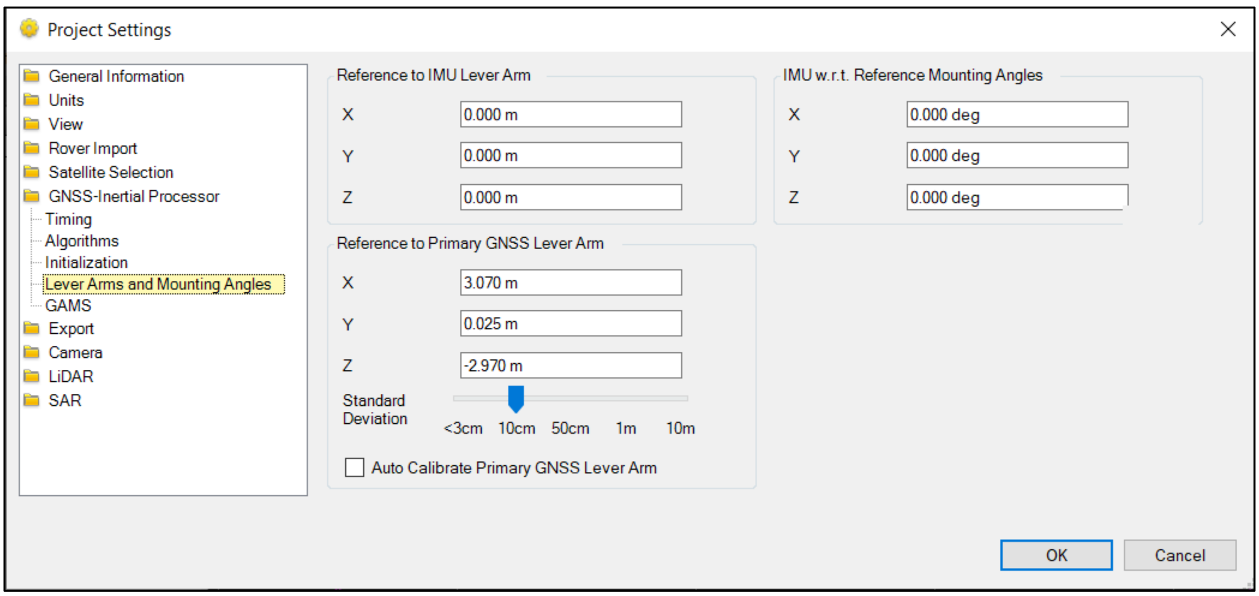

Figure 17. Programmed offsets between the primary GNSS antenna and the CRP onboard the C-Worker 8 ASV platform. Image: NOAA.

The online team utilized the IMU as the common reference point (CRP) to which all broadcast navigation was computed. Offsets between the primary GNSS antenna (GPS Bow) and the IMU are shown, corresponding closely to the values provided in the offset diagram in Figure 16. There is a .005 m delta between the programmed forward (X) offset and that listed in the dimensional control table, as well as .040 m delta between the programmed vertical (Z) offset and that listed in the dimensional control table with respect to the primary GNSS antenna location. Applied GNSS Azimuth Measurement Subsystem (GAMS) parameters, presumably copied from prior settings, are shown in Figure 18.

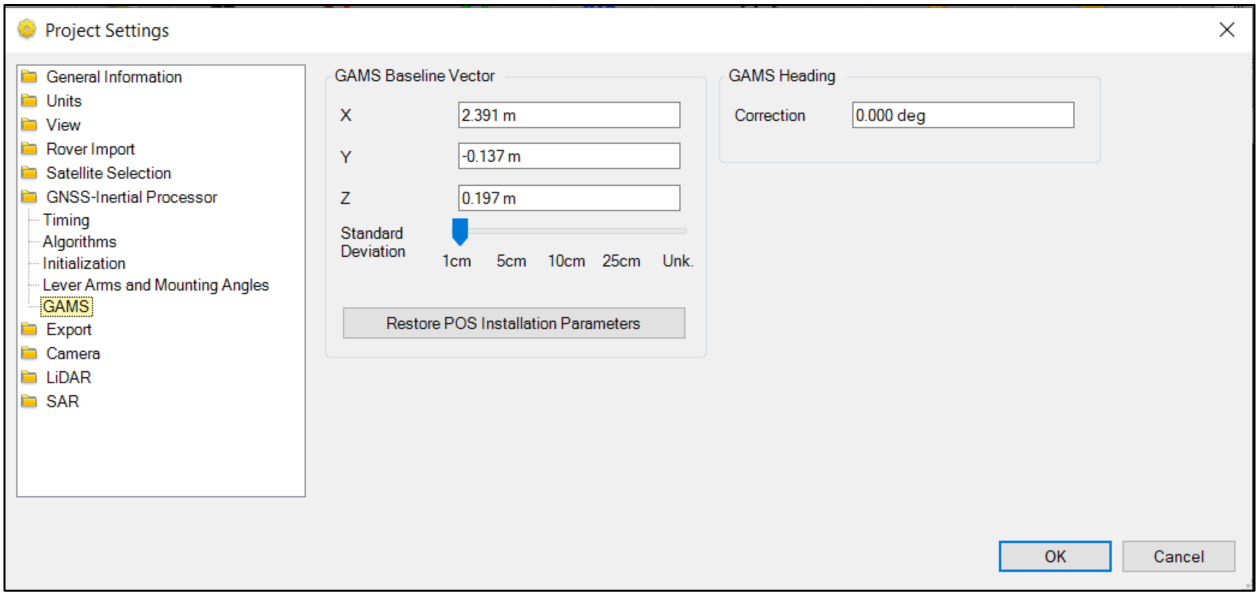

Figure 18. Applied GAMS parameters used onboard the C-Worker 8 ASV. Image: NOAA.

SBET files were generated by processing the recorded raw Applanix POSPac files within the Applanix Mobile Mapping Suite (MMS) program. At the start of data processing, MMS version 8.6 was in use, with version 8.6 SP1 HotFix implemented on 20 August 2021. This Applanix-issued patch was necessary due to changes in NOAA's online CORS data portal. Web-based search and retrieval of the correction information is an automated function within the MMS program. The SP1 HotFix addressed the new pathway to access the CORS correction files. Applanix MMS achieves navigation improvements by first updating the raw POSPac file information with CORS corrections as well as published GNSS ephemeris files specific to the make/model of GNSS antennae in use on the vehicle (Trimble), and the recomputing the trajectory and motion aspects of the vehicle's navigation.

Completion of the navigation data processing workflow resulted in a corrected and improved navigation solution relative to the defined CRP on the vehicle, written to an SBET result file with an associated error statistics file (RMS). This Applanix MMS processing workflow proceeded as follows:

- Open Applanix MMS 8.6, create a New Default Project template
- Import POSPac files for a single survey day
- Define GNSS antenna type (Trimble AT1675-540TS)
- Following file import, verify map extents, raw vehicle track line plot, and file recording start/end times
- Confirm Lever Arm Offsets, GAMS Parameters, and IMU Offsets per Figure 16, Figure 17, and Figure 18
- Download and import base station data utilizing Applanix SmartBase search option

- Set an Applanix SmartBase reference network
- Run GNSS Inertial Processor
- When completed, review map extends for processed vehicle frame
- Review time-series plot of SBET altitude
- Review time-series position error statistics plots (north, east, and down).
- Begin the SBET export process; review sensor frame (use vessel CRP). Review export file type, interval settings, and geodetic parameters.
- Utilize project relevant SBET file name to define export SBET file name; naming as follows
    - SBET_CWorker_yyymmdd_[SOL-EOL]_smartbase.out
- Export SBET
- Copy SMRMSG error statistics file for Applanix project PROC folder to EXPORT folder; overwrite default SMRMSG file name with nomenclature used for SBET file, replacing "SBE" prefix with "SMRMSG."
- Save and close Applanix MMS project; copy entire project to PROCESSED data folder in project archive. Copy SBET and SMRMSG files to CARIS project for use with sonar data correction.

Each of the result files (SBET and SMRMSG) were then imported midway into the sonar data processing workflow. Sonar data processing occurred concurrently in the CARIS HIPS and SIPS program. The SBET import was necessary to replace the real time navigation in all MBES files. Completion of this step resolved the incorrect geodesy used during online acquisition while also improving horizontal and vertical alignment of the sonar data. This correction, however, was limited to sonar files recorded while INS data was also being logged. On 14 August and 16 August there were raw sonar files logged outside the logging interval of the INS system, one file on each day. As a result, these two files could not receive corrected navigation. Instead, they remained projected in an incorrect geodesy and would not align with other files in the post-processing project. Consequently, these two sonar files were rejected as unable to merge with the remaining sonar data.

Sonar Data Processing

Raw MBES sonar files were recorded in the EIVA .SBD file format. These files were imported into a CARIS HIPS and SIPS (version 11.3) project for post processing. This project was established within a dedicated workspace and utilized the directory format outlined in Table 18. This included copying the raw SBD files into the project directory, as well as copying the SVP files. Generated SBET and SMRMSG files saved in their respective Applanix MMS projects but also copied into the CARIS project directory. As the MBES sonar data processing workflow proceeded, all files were likewise saved in the CARIS directory. The objective of this data management approach was to ensure the CARIS project remained a self-contained archive-within-the-archive. As the CARIS program exercises directory links between integrated files, the best way to maintain project function across multiple users and across archives is to build the entire project within a single folder.

To begin import of SBD files into CARIS, default parameters were used to convert the SBD files into a HIPS directory; one HIPS directory per survey day. Having a single HIPS directory per day aligned with the daily logging of MBES files as well as the daily logging of POSPac files. As such, a single HIPS directory would correspond to a single directory of raw files and a single set of SBET and SMRMSG correction files. EIVA settings used online, however, were not reported by the MBES/ASV survey team so it was unknown if EIVA navigation was computing the offset between the ASV's CRP (see Figure 16) and MBES acoustic center when writing the raw files. Given this uncertainty, defaults were accepted to initialize the processing workflow.

A default CARIS vessel file (.HVF) was created for the ASV to include parameters for the R2Sonic 2026 echosounder.

2021_C-Worker_ASV_R2Sonic2026.hvf

Within the vessel file all offsets and mounting angles were set to zero. Again, it was unclear how the sensor frame correlated to the navigation and motion instruments as the online team did not provide any documentation of the platform setup. Likewise, no calibration or testing procedures were performed to use as a basis for establishing project-specific hardware parameters.

Using default SBD to HIPS conversion settings and a generic vessel file, the raw SBD files were imported into the CARIS processing project. It was at this point that online navigation issues became apparent. Imported files appeared distorted and were not located near the study area. The entire archive of raw SBD files was then loaded into EIVA's NaviModel Viewer program. This resulted in similar mis-projection. Subsequent communication with the online survey team revealed the use of saved EIVA parameters on the ASV system; parameters programmed for survey operations outside of the continental United States. Thus, following the initial import of raw SBD files into CARIS, it was confirmed that online navigation was incorrect.

Another detail noticed upon import into CARIS was that raw MBES file logging appeared to run continuously during daily operations. Review of the plotted track lines showed multiple survey run lines, as well as turns, captured within a single EIVA SBD file. Data logged during turns were noisy and required substantial point cleaning to remove erroneous points. Also noted, no SVP files were collected by the online MBES survey team. Files from another team were copied for use in MBES post-processing though they were not directly co-located with the water column SV at the time and location of MBES operations. Subsequently, Marcus Kwasek of QPS performed use of the TUDelft sound speed inversion tool in Qimera and confirmed that the nearby SVP casts collected by the UD team provided reasonable sound speed correction though other vessel motion artifacts remained (Kwasek pers. comm.).

The MBSE sonar data processing workflow for CARIS HIPS and SIPS processing is as follows:

- Create new folder for CARIS project using schema in Table 18.
- Copy raw SBD, SV files, and SBET/SMRMSG files into their respective folders.
- Create default vessel file for C-Worker ASV and R2Sonic 2026 echosounder.
- Convert EIVA SBD file into CARIS HIPS directory; done with files from a single day to maintain a 1:1 parity with SBET files and HIPS directories.
  - Define new HIPS file for acquisition day; save to root CARIS project folder in yyyy_mm_dd format.
  - Select the C-Worker vessel file.
- Upon import verify inclusion of all files into newly created HIPS directory.
- Georeference files with copied SV corrections from AUV team.
  - Import SV files into the CARIS project via the Reference Bathymetry settings interface.
  - Select correction based on Nearest in Distance.
  - Vertical correction was NOT applied at this step.
- Generate fixed resolution 1 m surface for QA/QC of coverage and data quality; update as necessary when additional sonar files are added and referenced. Review surface and output for issues with raw navigation, SVP corrections, etc.

There are numerous ways to vertically reference MBES sonar data and account for changes in water levels (e.g. tides) and the vertical component of vessel motion (heave). These can include GNSS-assisted methods where sounding data is referenced to an ellipsoidal height during online survey and later converted to an orthometric system referenced to a known vertical datum. The US Great Lakes are considered non-tidal and do not require the same types of vertical corrections as those in marine environments (e.g. tide gauge data). GNSS-assisted methods of vertical correction, therefore, work particularly well in the Great Lakes region.

To implement such a method, no vertical transformation is applied during online operations and MBES sounding data is simply referenced to the ellipsoidal height associated with each horizontal position. Relative sounding depth, the distance between the transducer and the lakebed, combined with the ellipsoidal height would result in vertical distance units not adjusted to a known vertical datum, such as the NAVD88 or IGLD85 datum for the Great Lakes. As a result, these units would appear irrational and misaligned with charted depths which are adjusted to vertical datums. A transformation is needed to convert ellipsoidal heights to an orthometric, vertically-based system.

This transformation is performed in post-processing through application of a separation model. A spatially-based conversion occurs to replace the raw ellipsoidal height values with the correct vertical datum heights for the same location. A separation model, therefore, is a gridded surface provided with each grid cell representing the conversion value between defined ellipsoidal and orthometric systems. This, in turn, requires knowledge of the ellipsoidal system implemented in the raw file acquisition, as well as defining the final vertical datum for output, of which two are generally used in the US Great Lakes (IGLD85 and an IGLD85-based Low Water Datum or LWD). When the separation model parameters are defined, the associated grid output is generated and thus applied within the sonar data processing project. All heights are thus adjusted, accounting for the conversion to the orthometric system as well as vertical instrument offsets, and sounding depths updated accordingly. These are characterized as ‘corrected depths.’ Now, measured depths align with those presented on nautical charts are determined in prior surveys.

While geodetic parameters during online survey were incorrect, the replacement of all navigation with the SBET files reverted them all to the ITRF/WGS84 reference system. This allowed specification of the proper transformation parameters and thus generation of a separation model to vertically reference the processed MBES files. That model converted the ellipsoidal heights of the WGS84 reference in the SBET files to orthometric height equivalents in the IGLD85-based LWD, the same vertical datum used on NOAA nautical charts.
Remaining processing steps involve the introduction of the SBET file to correct online navigation errors, re-processing of horizontal and vertical referencing, point cloud cleaning, and data product export:

- Import the Applanix SBET and SMRMSG files. Each SBET/SMRMSG file set is pair with a daily HIPS directory.
- Recompute georeferenced HIPS file from above, now with corrected navigation and improved position/motion added.
    - Define SEP model parameters for vertical referencing to convert GNSS heights (WGS84) to orthometric heights (IGLD 85 LWD).
    - This reprocesses HIPS directories with proper vertical reference, improved position, and improved motion. As a result, TPU should be reduced to improve data alignment.
- Recompute QA/QC fixed resolution surface.
- Complete point cloud cleaning via CARIS Subset Editor; substantial edits were necessary in certain areas, especially in the logged turn data (Figure 19) where up to 25 percent of soundings required removal, as well as fliers logged on run lines (Figure 20).
- Generate backscatter layer via CARIS SIPS Backscatter Mosaic engine.
- Deliverable file export to include:
    - Processed track lines in ESRI Shapefile format.
    - Convert processed soundings from CARIS HIPS directory to GSF file format.
    - Convert fixed resolution grid surface to georeferenced raster formats.

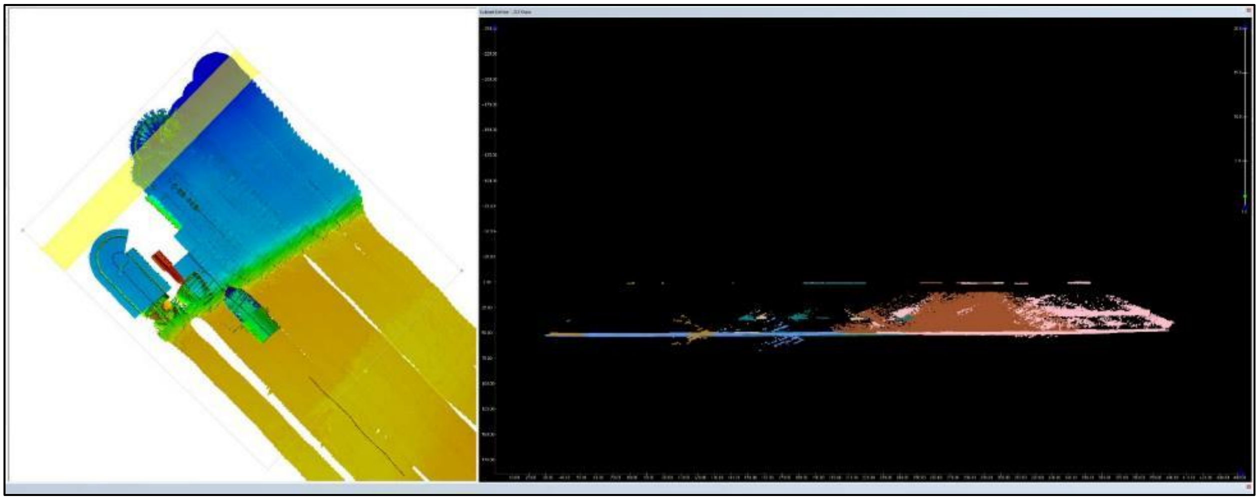

Figure 19. View of CARIS Subset Editor showing cross section point cloud of turn data in the C-Worker 8 ASV files. Sonar data logged during turns required substantial cleaning to remove erroneous soundings. Image: NOAA.

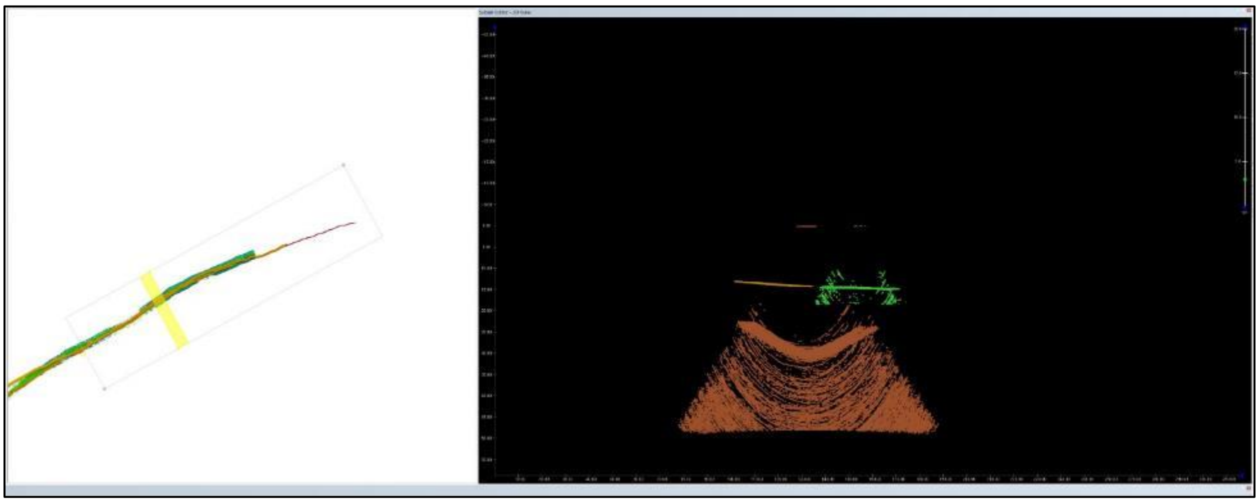

Figure 20. View of CARIS Subset Editor showing across track line fliers due to sensor noise. Image: NOAA.

At the conclusion of the MBES processing workflow it was determined that CARIS could not read the saved acoustic return intensity values within SBD files. As a result, the CARIS SIPS mosaic engine was not able to produce a backscatter grid for any of the provided MBES data. No backscatter data was processed for the MBES datasets or study area.

Of the 13 raw SBD files provided by the online MBES team, only 11 were accepted during post processing. Two were rejected due to misalignment as they were logged outside the interval of INS POSPac file logging. Eleven accepted files spanned five days of online survey occurring between 12 and 16 August in the Lake Ontario study area. Since raw files were continuously recorded, these eleven files encompass numerous run lines. Specifically, the vehicle recorded three lines while in transit to/from the offshore survey area. While on station, the ASV completed thirteen full-length run lines with a fourteenth partial run line that extended most of the survey area's length.

Spatial distribution of data is shown in Figure 21. Three transit lines extend between the main, offshore survey area and the ASV staging area in Sackets Harbor. When vertical referencing was applied near the end of the aforementioned workflow, a portion of the transit line area (highlighted in a box in Figure 21) displayed an incorrect vertical shift. While all the offshore area soundings, as well as most of the transit line data, referenced to the appropriate LWD values, the area between Sackets Harbor and Lime Barrel Shoal displayed negative depth values which abruptly switched to correct values along track per the view in Figure 22. Due to the incorrect referencing, this portion of three transit lines were removed.

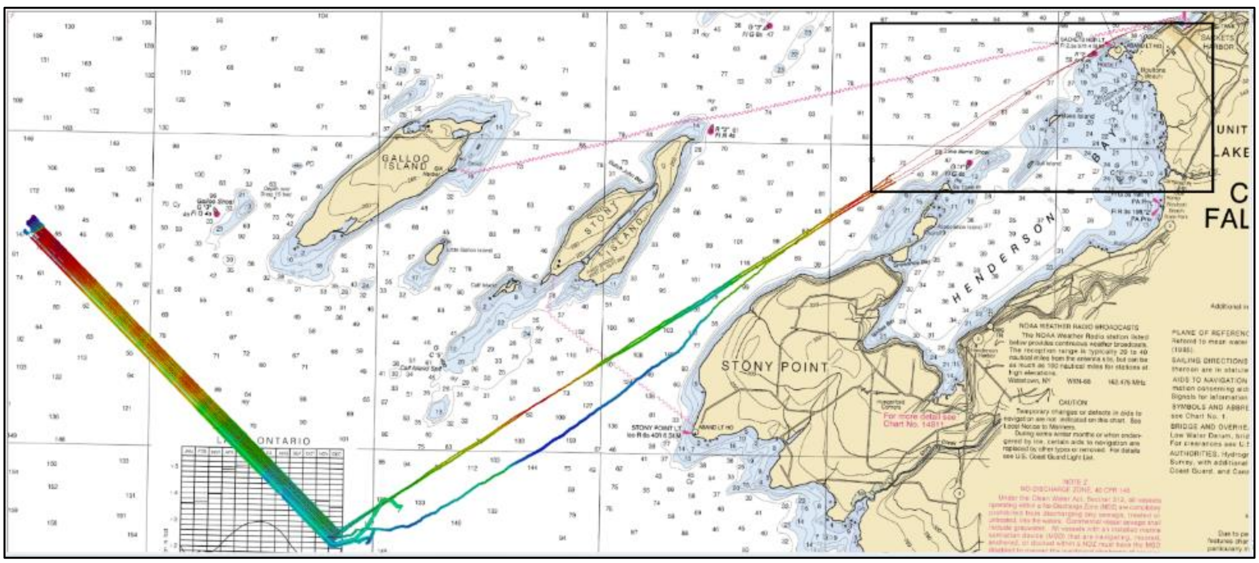

Figure 21. Processed MBES data within the NY project area. Accepted survey lines included 3 transit lines and 14 run lines within the offshore survey block. Image: NOAA.

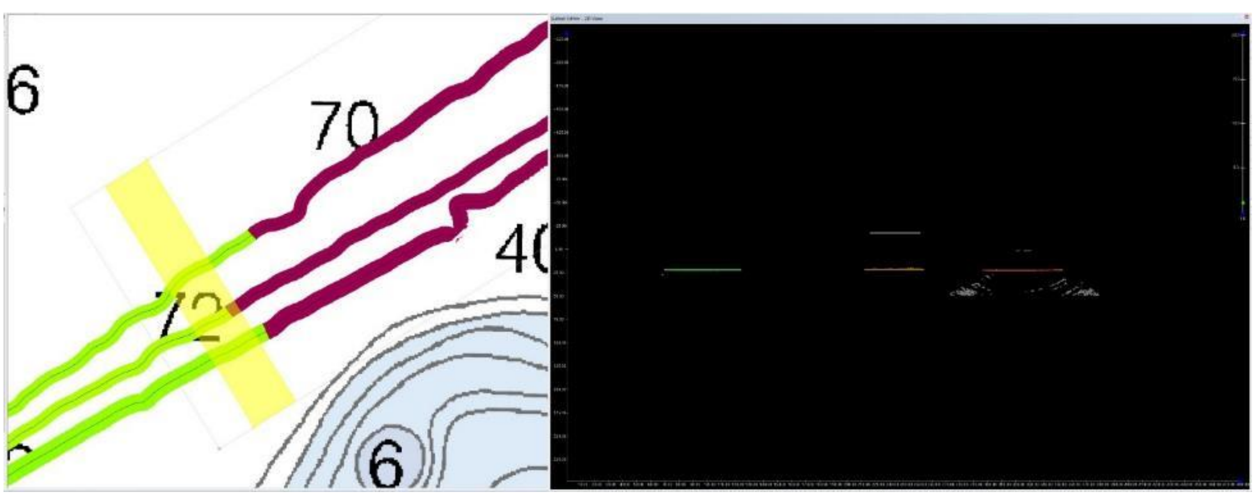

Figure 22. Nearshore area of ASV transit lines showing substantial vertical reference issues. Between port and Lime Barrell Shoals, negative depth values were registered until an abrupt switch along track to correct values. Image: NOAA.

Side-scan Sonar Data Processing

The data collected via EdgeTech side-scan sonar (SSS) instruments was processed by NOAA personnel using SonarWiz 7 by Chesapeake Technologies while data collected via the Humminbird sonar units was processed using ReefMaster 2. University of Delaware staff processed all side-scan sonar data collected from Humminbird units using SAR HAWK. All SSS data was visually checked for anomalies, however only acoustic targets with data collected by EdgeTech instruments are presented in this report due to data processing limitations.

SonarWiz 7 Data Processing

SonarWiz 7 was used by NOAA staff to process acoustic data collected by EdgeTech side-scan sonar instruments. One SonarWiz 7 project was developed for each AUV deployment or day of vessel-conducted survey. The geographic coordinate systems chosen for each project followed the WGS84 project standard. Project nomenclature followed that utilized by personnel in the field.

Initial processing included uploading proprietary EdgeTech .JSF files to the project file and adjusting gains through the post-processing setting. If necessary, individual gains were adjusted manually for each file. An updated color palette was then applied to the display to better visualize targets, and the nadir was removed manually in the bottom tracking function so the resulting mosaic only displayed the lakebed. Finally, the acoustic signal was adjusted with empirical gain normalization to optimize image contrast. As the EdgeTech instruments were not towed, additional layback offsets were not applied.

Following post-processing of the sonar data files, each file was visually checked for acoustic targets or areas of interest. Selected targets were compared across sonar files (if possible) and classified as either identifiable or potential cultural material(s). Measurements of each target (length, width, and height from bottom) were taken and exported with target information and image into a .DOC file.

Final side-scan sonar products exported from SonarWiz include full georectified .TIFF mosaics of each survey, individual .TIFF images of targets as seen in multiple survey lines, target reports in .DOC and .CSV formats, and target shapefiles. The georectified .TIFF images and shapefiles were imported into ArcGIS and displayed as overlays with additional project data. Coverage shapefiles and vessel or instrument track lines were manually created in ArcGIS from the imported files.

SAR HAWK Post Processing

University of Delaware staff utilized SAR HAWK software to visualize the Humminbird sonar files. Detailed processing steps are presented in Appendix C. Instructions on Processing Humminbird Side-scan Sonar Data in SAR HAWK. SAR HAWK offers several data post-processing tools including visual identification of acoustic targets, generation of target reports, and georectified mosaics. Both SAR HAWK and ReefMaster can apply TVG (time varying gain) corrections and remove the nadir (water column) that results from either from an amplitude detection or using the integrated single beam bathymetric from the Humminbird. SAR HAWK includes the ability to incorporate offsets between the sonar transducer and the GPS (internal or external).

The general workflow for initial sonar processing in SAR HAWK involved the following:

1. **Mosaic side-scan sonar data in the mosaic view window.** To mosaic Humminbird data:
    a. The data of interest was isolated for review.
    b. Next, a SAR HAWK project was created following unique nomenclature associated with the file management system. Once generated,
    c. Relevant data files were independently uploaded via the Playback function. Playback allowed for tweaking gathered data, trimming of irrelevant turn data, adjustment of gains on individual files, and splitting of acoustic data into smaller files.
    d. With files uploaded, vessel offsets were entered via the configuration menu, notably the sonar head offset (Figure 23).
    e. Once offsets were manually entered, the data files were imported using the quick look function to ensure appropriate file selection. Sonar data files were then manually loaded into the playback menu.
    f. Uploaded sonar files were corrected for brightness, gain, and vertical/horizontal feathering. Files were then run in sequence to obtain a mosaiced data view. Erroneous turn data was removed.
    g. The final mosaic was exported as a .kmz file and georectified image. Area coverages were then calculated for each survey mosaic, including total area and line km of the survey vessel or instrument.

2. **Sonar Contact Identification and Export.** Using the mosaiced acoustic image, contacts of interest were selected as objects of interest. The steps were as follows:
    a. The processor opened the acoustic data stream using ‘waterfall view.’
    b. Once open, the processor selected objects of interest within the sonar data stream. Potential anthropogenic objects were delineated, measured, and marked.
    c. Geographic position of sonar contact marks and subsequent information was exported into a contact report.

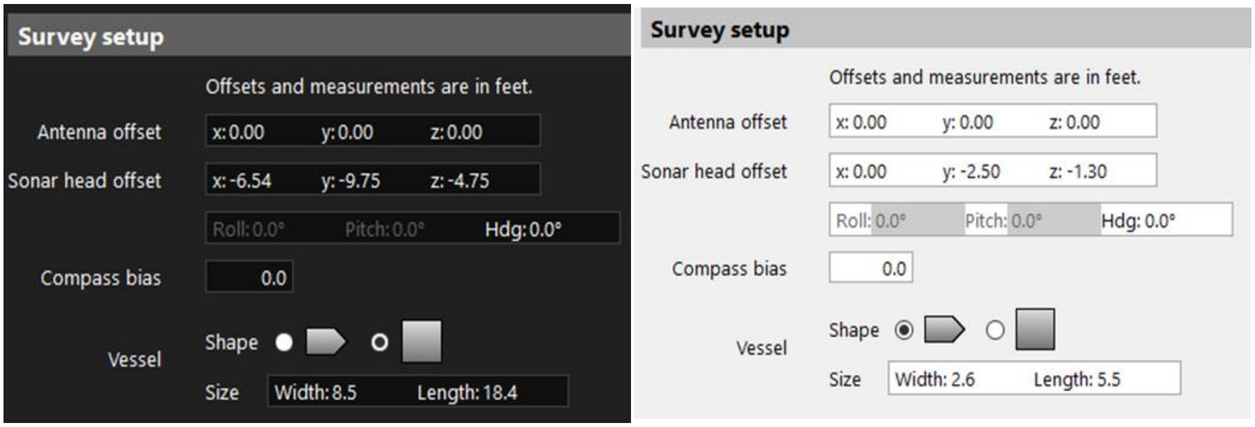

Figure 23. Screen captures of SAR HAWK survey setup. Left image depicts vessel offsets for RV *Dogfish*, right image depicts offsets for the EchoBoat 160. Image: University of Delaware.

ReefMaster Data Visualization

In addition to SAR HAWK, NOAA staff used a trial version of ReefMaster 2 software for the purposes of visually identifying spatial coverage and potential targets of Humminbird sonar data. The software trial does not allow for post-processing, restricting processing to solely observation-based purposes.

Individual projects were created in ReefMaster corresponding to single surveys. All associated sonar files from each survey were uploaded into the ReefMaster file. Each sonar file was visually reviewed for targets and, if located, a screenshot of the target was taken. The coordinates of the target were recorded along with general dimensions (width and length). Height from bottom could not be calculated due to trial limitations.

Mosaiced survey images were taken and imported into ArcGIS. These were georectified using the UTM grid provided by ReefMaster. Coverage shapefiles and vessel or instrument track lines were then manually created in ArcGIS from the georectified mosaics.

Public Outreach

During each leg of the cruise, researchers worked with local museums to host a public engagement event. In Wisconsin, researchers partnered with the University of Wisconsin Sea Grant and the Wisconsin Maritime Museum to host an in-field educator day. Twenty teachers and educators from around the state were invited to see hands-on demonstrations of the technology with the intent of bringing the data products from these technologies into the classroom.

As all the technologies have strong ties to STEM learning, this outreach targeted building connections between educators and local preservation efforts, STEM education, environmental stewardship programs, and the National Marine Sanctuary System. While this outreach day was geared toward educators, local community members also attended the technology demonstrations and were presented with opportunities to discuss the sanctuary with NOAA staff and to meet with and discuss the mapping technologies with team members from UM, OI, and UD. This was the first educator outreach event held by the newly designated WSCNMS. The event nicely conveyed how educators can leverage and partner with the sanctuary to enhance their STEM activities and expose students to career paths in marine technology and oceans and Great Lakes conservation.

In New York, the project team partnered with the Sackets Harbor State Historic Battlefield Site to host an outreach event discussing the project aims and technologies. The project team set up individual stations featuring each platform and instrument where visitors could interact with the technologies, meet the research team members, and learn more about the proposed Lake Ontario National Marine Sanctuary. In attendance were members of the public, the Sanctuary Advisory Council, county officials, and local researchers. The backdrop of the outreach day — the historic battlefield — was the site of the 1813 Battle of Sackets Harbor. As such, technology demonstrations during the outreach event included an aerial magnetometer survey of the nearby Fort Kentucky and replica cannon. Technology demonstrations also included playback of ROV HD video and AUV data collected in the area in the days leading up to the event.

Given the relatively recent nomination of the proposed Lake Ontario National Marine Sanctuary as well as the limited public engagement due to the ongoing Covid-19 pandemic, the outreach day presented the first opportunity for in-person community engagement with local communities potentially impacted by the sanctuary nomination. Moreover, partnering with the Sackets Harbor Battlefield State Historic Site presented project staff with the opportunity to both further ongoing research efforts of the 1813 Battle of Sackets Harbor and to support the incredible preservation efforts of the New York State Parks system. Moreover, this outreach event strengthened the burgeoning relationship with NY State Agencies and their personnel.

Results and Observations

Completion of field operations and post-field data processing tasks resulted in an archive of data products produced by each sensor across the deployed platforms. During the study, UAV operations resulted in processed magnetometer data which, combined with marine magnetometer operations conducted from RV *Dogfish*, allowed identification of numerous magnetic anomalies within the WI and NY project areas. Similarly, side-scan sonar operations onboard the suite of ASV platforms, the IVER3 AUV, and RV *Dogfish* crewed vessel likewise generated sonar mosaics from which targets were identified. Some sonar operations took place in an exploratory mode, some over known cultural resource locations to better resolve their positions and site features, and to test the feasibility of using AUV-based sonar to conduct ongoing site monitoring. Finally, MBES survey data from the largest ASV deployed, the C-Worker 8 ASV, recorded bathymetric information within the NY project area which was assessed for possible cultural features. All these reconnaissance-level surveys produced information requiring additional investigation and ground-truthing to refine known feature locations and description, as well as to investigate features of interest on the lakebed as identified through review of the acoustic and magnetic data records.

Collectively, these operations produced an archive of digital data results organized per geophysical sensor with a corresponding subset of files according to the technical specifications of the instrument as well as data type. These include track lines for the vehicle during acquisition, coverage grids with data (i.e. magnetic field readings, sonar imagery, sonar bathymetry), and polygons representing coverage geometries. Table 20 outlines these data products. Three folders each contain materials generated by the MBES, SSS, and MAG instruments, respectively. A fourth folder provides GIS shapefiles consisting of vehicle track lines and associated attribute information for all platforms and survey systems. A final folder contains a full archival set of data files which organizes all the raw data files collected in the field, the software-specific processing projects and immediacy files used to generate data products organized in the other four folders, as well as copies of project reporting documents. This directory is stored in physical copy at ONMS headquarters and will also be submitted to NOAA NCEI per the grant award data sharing plan.

The two main methodologies applied across the WI and NY study area were geophysical surveys and opportunistic scientific diving operations. Summary notes from scientific diving operations were presented in Table 11 with imagery results collated in Appendix A. Underwater Photography Log. Summary statistics for geophysical survey operations are provided in Table 21. Coverage amounts for each survey sensor are provided for both WI and NY project areas. The coverage termed ‘total area’ includes overlapping datasets, while the ‘total coverage’ reports the spatial footprint of all sensors merged into single geography. The distribution of total area surveyed between crewed and autonomous systems is presented in Table 22.

Table 20. Directory for final deliverables files generated during survey operations.

<table>
<tr><td rowspan="35">01_Full_Delivery_yyyymmdd</td><td rowspan="5" colspan="2">01_MBES</td><td>01_Point_Cloud</td></tr>
<tr><td>02_Average_Grid</td></tr>
<tr><td>03_Sounding_Density</td></tr>
<tr><td>04_Coverage_Polygons</td></tr>
<tr><td>05_SVP</td></tr>
<tr><td rowspan="3" colspan="2">02_SSS</td><td>01_Mosaic</td></tr>
<tr><td>02_Coverage_Polygons</td></tr>
<tr><td>03_Targets</td></tr>
<tr><td rowspan="8" colspan="2">03_MAG</td><td>01_Total_Field_Grid</td></tr>
<tr><td>02_Residual_Anomaly_Grid</td></tr>
<tr><td>03_Analytic_Signal_Grid</td></tr>
<tr><td>04_Anomalies</td></tr>
<tr><td>05_Processed_CSV</td></tr>
<tr><td>06_MAGTOOL_Output</td></tr>
<tr><td>07_Coverage_Polygons</td></tr>
<tr><td>09_Geosoft_Viewer_Project</td></tr>
<tr><td rowspan="6" colspan="2">04_TRACKPLOTS</td><td>01_UAV_MAG</td></tr>
<tr><td>02_BOAT_MAG</td></tr>
<tr><td>03_MBES</td></tr>
<tr><td>04_ASV_SSS</td></tr>
<tr><td>05_AUV_SSS</td></tr>
<tr><td>06_BOAT_SSS</td></tr>
<tr><td rowspan="13">07_ARCHIVE</td><td rowspan="5">01_RAW_DATA</td><td>01_C-Worker_ASV</td></tr>
<tr><td>02_UMiami_UAV</td></tr>
<tr><td>03_UDel_IVER3_AUV</td></tr>
<tr><td>04_UDel_ASV</td></tr>
<tr><td>05_UDel_RVDogfish</td></tr>
<tr><td rowspan="5">02_PROCESSED_DATA</td><td>01_C-Worker_ASV</td></tr>
<tr><td>02_UMiami_UAV</td></tr>
<tr><td>03_UDel_IVER3_AUV</td></tr>
<tr><td>04_UDel_ASV</td></tr>
<tr><td>05_UDel_RVDogfish</td></tr>
<tr><td rowspan="3">03_REPORT</td><td>01_Cruise_Plan</td></tr>
<tr><td>02_Crusie_Report</td></tr>
<tr><td>03_Final_Report</td></tr>
</table>

Table 21. Summary of coverage results per instrument type in each project area. Note that many areas included overlap between sensor systems so total coverage reports geographic coverage including this overlap. Total area coverage is the sum of all sensor types, including geographic areas surveyed by numerous sensors.

	Total Coverage (km^2)	**Total Area (km^2)**	**MAG (km^2)**	**SSS (km^2)**	**MBES (km^2)**
WI	1.76	1.88	0.67	1.21	0.00
NY/LONMS	17.96	18.43	0.53	7.01	10.88

Table 22. Distribution of Total Area surveyed between autonomous and crewed systems in each project area.

	Autonomous Systems (km^2)	**Crewed Systems (km^2)**
WI	1.65	1.04
NY	13.65	4.78

Wisconsin/Lake Michigan Operations

Geophysical survey operations within the Wisconsin/Lake Michigan study area were conducted between 28 July and 9 August 2021. They resulted in multi-instrument data products totaling 1.88 sq. km, encompassing an area of 1.76 sq. km due to overlap between the sonar and magnetic survey boundaries. Total coverage amounts for each sensor, differentiated further between deployment platforms, are reported in Table 23.

Table 23. Area coverage per survey instrument and platform within the Wisconsin/Lake Michigan study area.

Instrument Type	Platform	Coverage (km^2)
SSS	IVER3 AUV	0.15
SSS	EchoBoat ASV	0.51
SSS	RV Dogfish	1.04
Aerial MAG	UAV	0.67
Marine MAG	RV Dogfish	0.08
ALL INSTRUMENTS	ALL PLATFORMS	1.73

Operations grouped within three general locales among the overall study area as necessitated by each platform's technical capabilities:

> **Nearshore**: located adjacent to Point Beach State Park and termed Rawley Point; depth range 0 to 5 m; UAV-based aerial magnetometer survey area, crewed vessel-based marine magnetic survey (within UAV survey area), ASV-based side-scan sonar survey.
> **Open Water**: Open water areas where known shipwreck sites were located offshore of Two Rivers and Manitowoc, WI; depth range 3 to 70 m; AUV-based side-scan sonar survey.
> **Riverine**: within the East and West Twin Rivers at Two Rivers, WI; depth range 0 to 7 m. Crewed vessel and ASV-based side-scan sonar survey.

Figure 24 and
Figure 25 show details from coverage areas completed within the Wisconsin/Lake Michigan study area as represented by magnetometer versus side-scan sonar (Figure 24) datasets as well as the distribution of autonomous platform types (
Figure 25). Figure 26 shows a detailed view of the side-scan sonar survey conducted inland due to inclement offshore weather.

Processed, finalized magnetic data provided a residual anomaly used to identify signatures in the survey record likely to represent cultural ferromagnetic materials. This grid is visualized in Figure 27. All residual channel signals of 5 nT or greater were marked as anomalies. Details of each anomaly, including its peak-to-peak amplitude, wavelength distance, location, type, and name designation are presented in Table 24.

The largest magnetic anomaly in the southeastern corner of the survey area was associated with a known shipwreck site. All other anomalies are of unknown origin and will require follow-on visual survey to determine if they represent cultural materials on or within the lakebed.

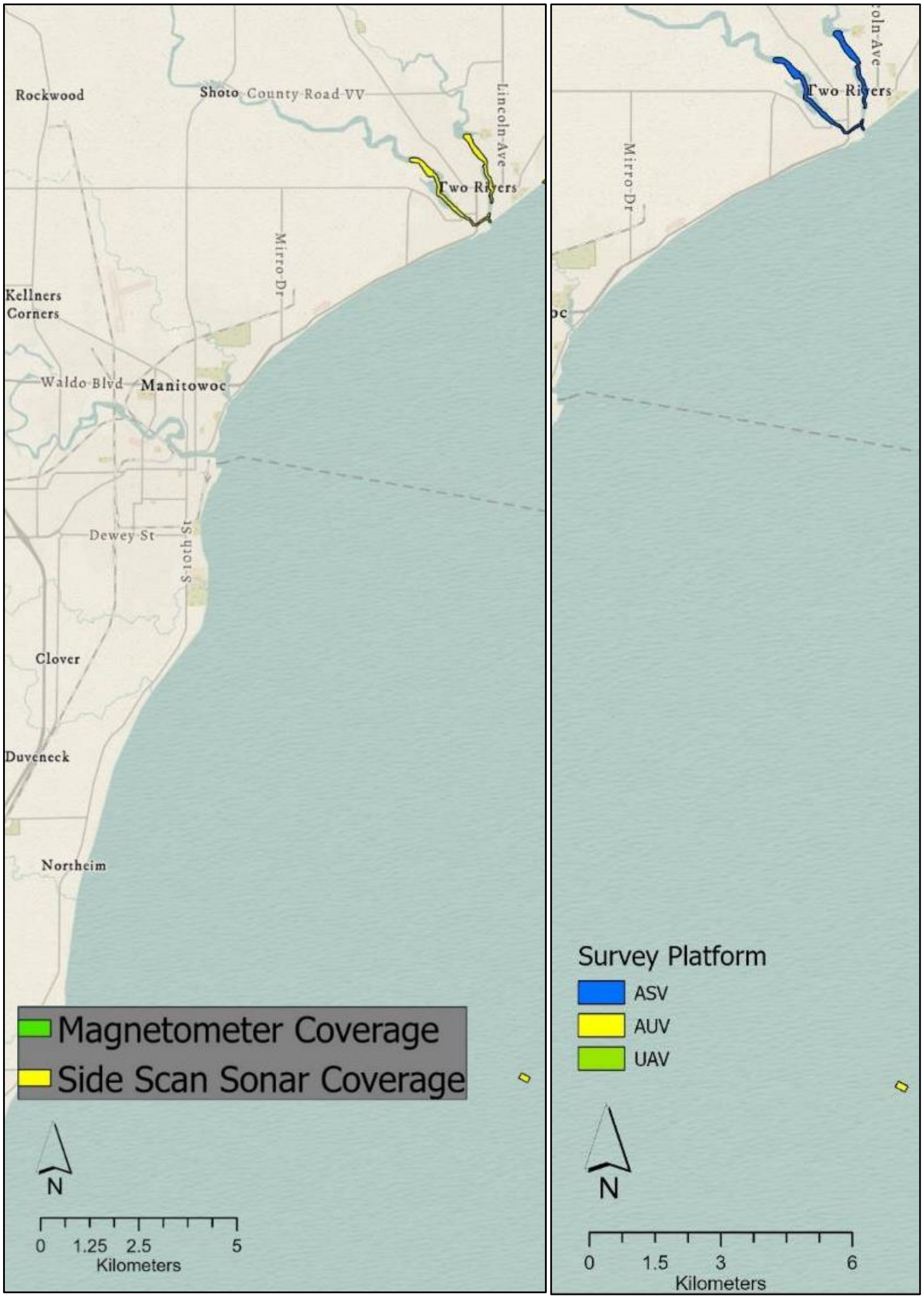

Figure 24 (left). Geophysical coverage per data type in the Wisconsin/Lake Michigan survey areas offshore of Two Rivers, Wisconsin. Note: Entirety of survey areas not pictured due to image scaling. Image: NOAA.

Figure 25 (right). Geophysical coverage per autonomous platform type in the Wisconsin/Lake Michigan survey areas. Note: Entirety of survey areas not pictured due to scaling of image. Image: NOAA.

Figure 26. Side-scan sonar coverage of the East Twin River and West Twin River, Two Rivers, Wisconsin. Opportunistic survey was conducted in the rivers due to inclement offshore weather. Image: NOAA.

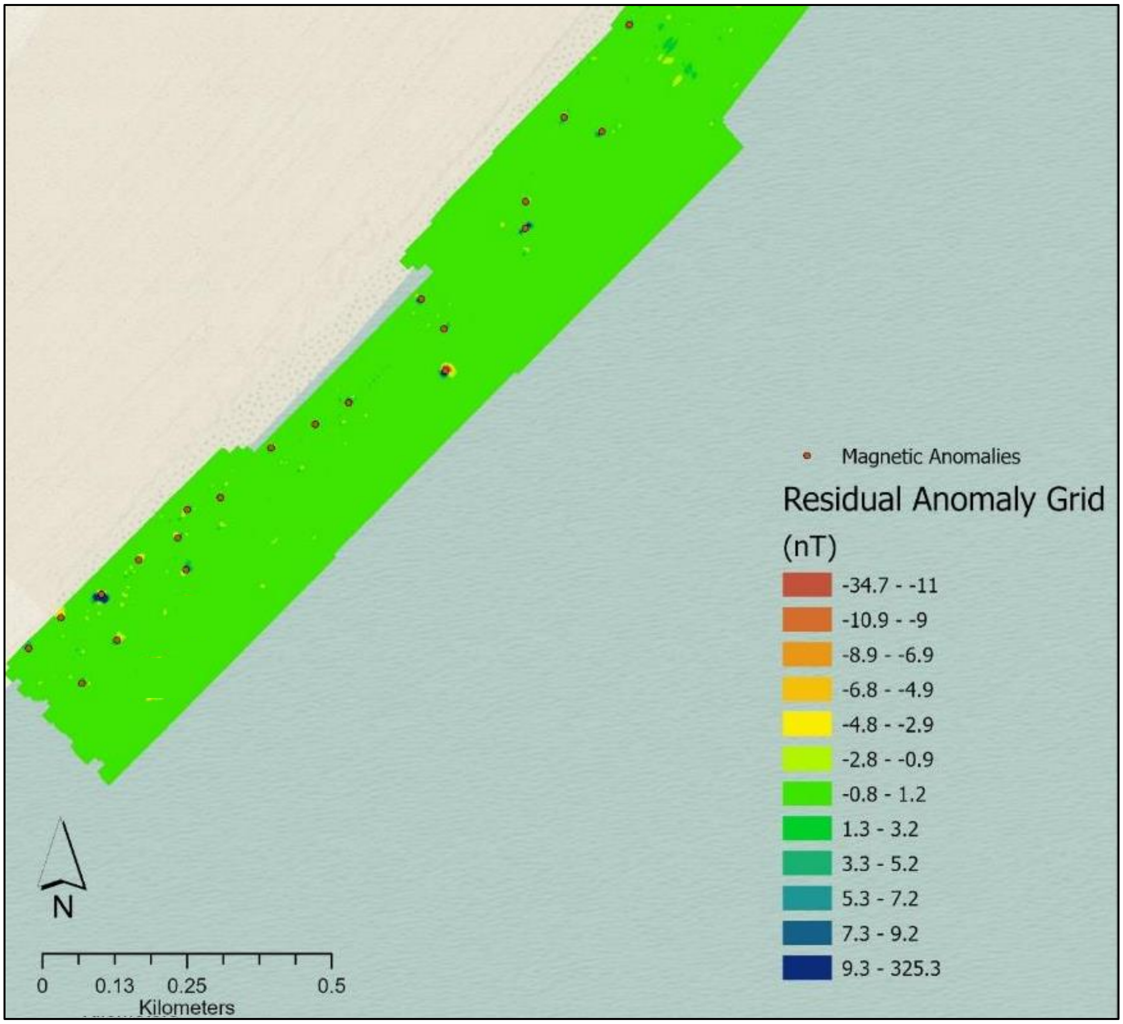

Figure 27. Detail from processed magnetic survey results within the Wisconsin/Lake Michigan study area represented as the residual anomaly grid with picked anomaly points overlaid. Image: NOAA.

Table 24. Magnetic survey anomalies identified in Lake Michigan survey area.

Anomaly ID	λ (m)	Amp. (nT)	Type
202103_WI_OER_001	14.8	10.4	Dipole
202103_WI_OER_002	45.25	346.3	Asymmetric Dipole
202103_WI_OER_003	35.05	122.8	Asymmetric Dipole
202103_WI_OER_004	13.25	16.2	Dipole
202103_WI_OER_005	21.02	14.3	Dipole
202103_WI_OER_006	15.88	11	Monopole
202103_WI_OER_007	17.65	7.8	Dipole
202103_WI_OER_008	15.36	11.7	Dipole
202103_WI_OER_009	9.75	4.9	Monopole
202103_WI_OER_010	10.5	7.1	Monopole
202103_WI_OER_011	13.06	10.6	Monopole

202103_WI_OER_012	23.73	58.8	Asymmetric Dipole
202103_WI_OER_013	11.55	8.9	Monopole
202103_WI_OER_014	10.98	13.8	Dipole
202103_WI_OER_015	12.19	12.9	Monopole
202103_WI_OER_016	13.21	21.6	Asymmetric Dipole
202103_WI_OER_017	11.1	8.3	Monopole
202103_WI_OER_018	26.02	66.3	Dipole
202103_WI_OER_019	3.64	4.6	Monopole
202103_WI_OER_021	30.18	16.5	Complex
202103_WI_OER_022	10.05	7.1	Dipole
202103_WI_OER_023	10.59	7	Monopole
202103_WI_OER_024	12.61	11.5	Monopole
202103_WI_OER_025	16.03	5.5	Monopole
202103_WI_OER_026	7.45	5.5	Monopole
202103_WI_OER_027	34.95	6.8	Dipole
202103_WI_OER_028	25.13	10.1	Monopole
202103_WI_OER_029	14.7	6	Monopole
202103_WI_OER_030	11.92	12.7	Monopole
202103_WI_OER_031	16.55	7.2	Monopole
202103_WI_OER_034	13.12	5.9	Monopole

All side-scan sonar targets were associated with known shipwreck site locations and features. None of the acoustic targets corresponded to magnetic anomalies as only a small portion of the two datasets overlapped. All side-scan sonar targets are reported in Table 25. Example side-scan sonar over known sites (collected with the AUV platform) are provided in Figure 28 through Figure 31. An example of photographs taken during the AUV survey overlaid over the sonar imagery can be seen in Figure 32. Figure 33 shows a comparison between multibeam bathymetry and side-scan sonar imagery collected using the Iver3 AUV. The multibeam sonar on the Iver3 was further refined for New York operations following Wisconsin survey operations.

Table 25. Side-scan sonar targets identified in the Lake Michigan survey area. All targets represent features at known cultural resource locations.

Target Name	Description
S.C._Baldwin_01	Main site location
S.C._Baldwin_02	Main site location
Gallinipper_01	Main site location
Gallinipper_02	Western extent of debris field
Gallinipper_03	Eastern extent of debris field
Gallinipper_04	Northern extent of debris field
Gust_01	Main site location
Gust_02	Main site location
Gust_03	Main site location

Home_01	Main site location
Home _02	Main site location
Home _03	Main site location
Vernon_01	Northeast extent of debris field
Vernon_02	Possible anchor
Vernon_03	Northwestern extent of debris field
Vernon_04	Main site location
Vernon_05	Southern extent of debris field

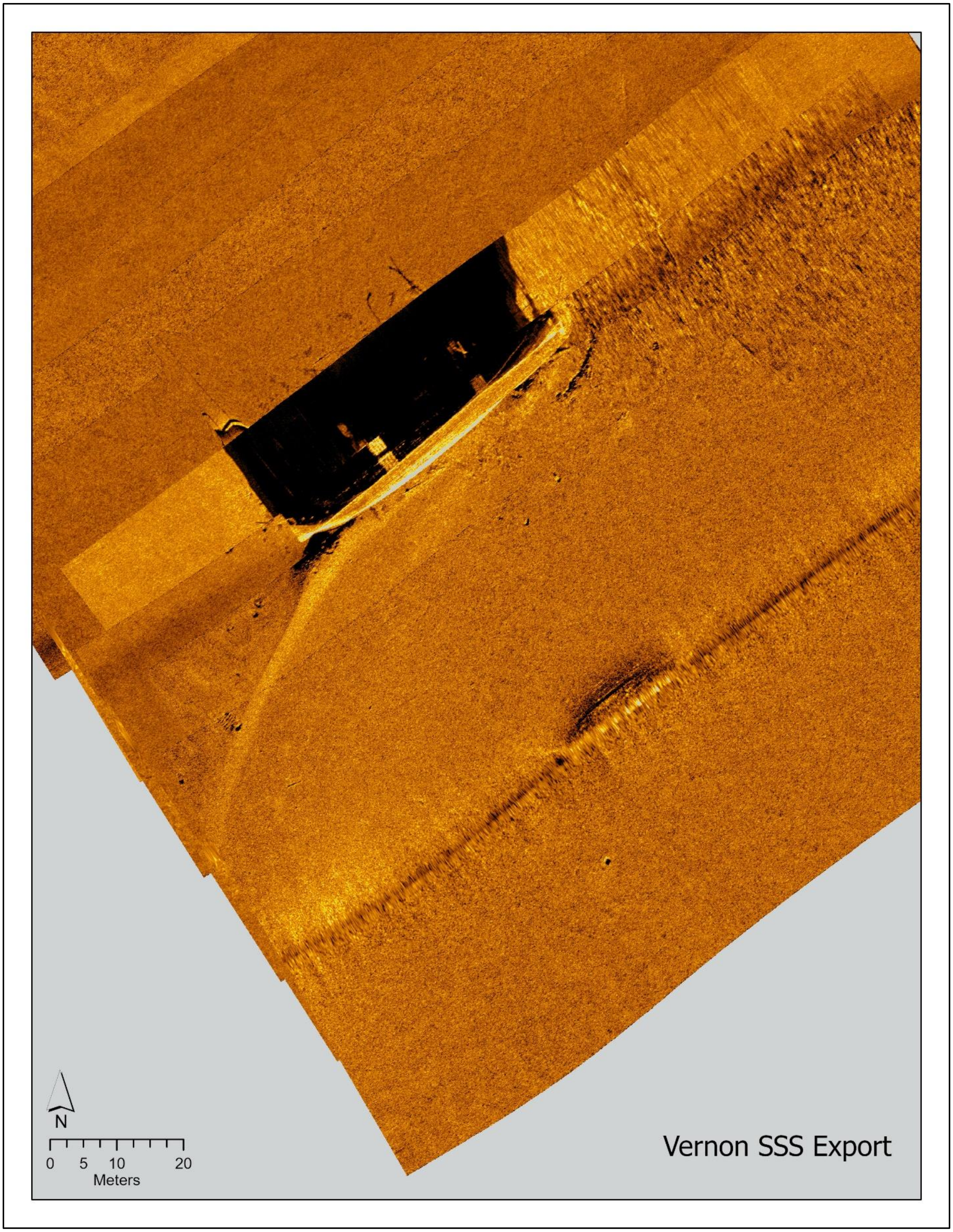

Figure 28. AUV-based side-scan sonar images collected over the site of *Vernon's* historic vessel remains. Map: NOAA; Side-scan sonar processing: University of Delaware.

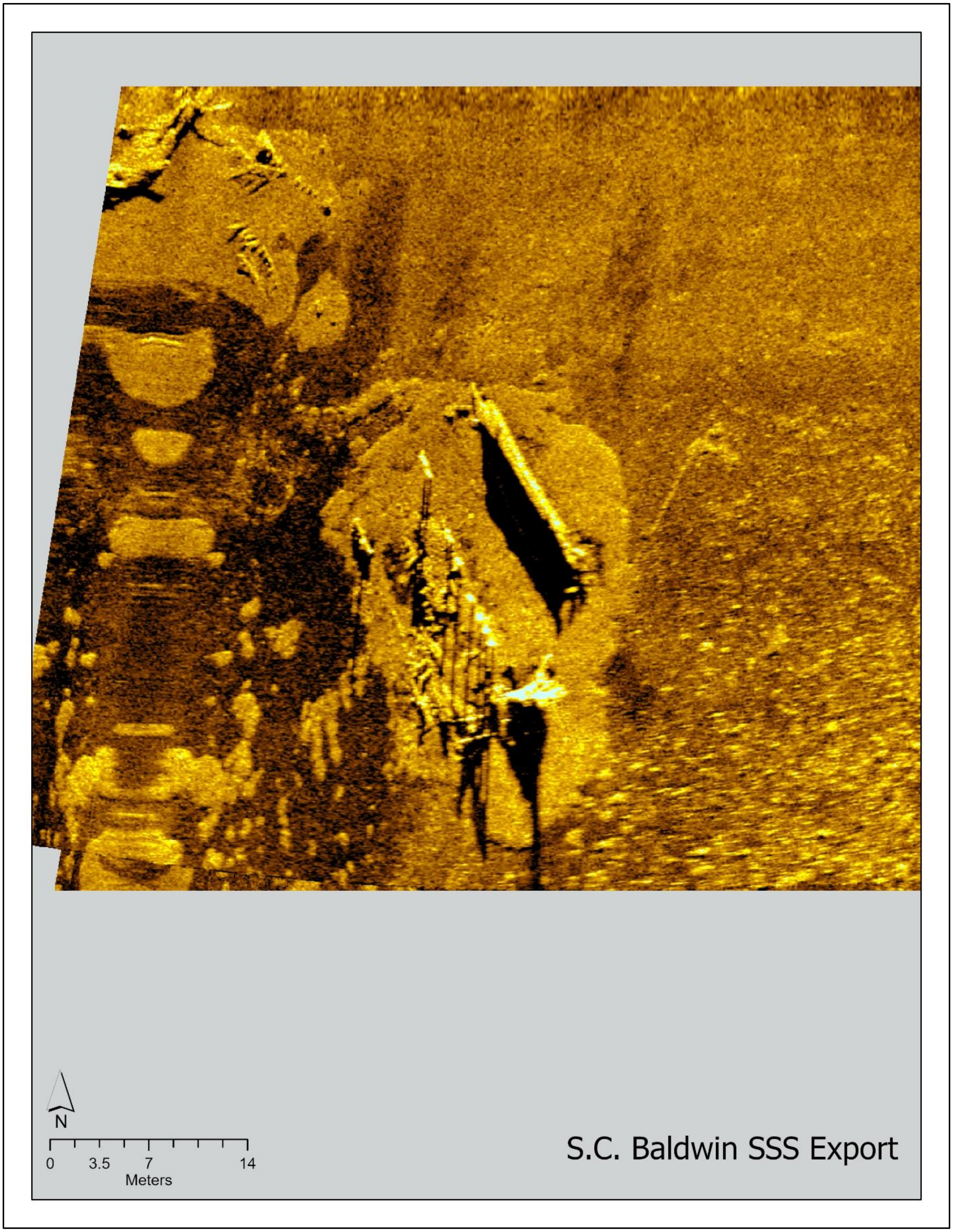

Figure 29. AUV-based side-scan sonar images collected over the site of *S.C. Baldwin's* historic vessel remains. Map: NOAA; Side-scan sonar processing: University of Delaware.

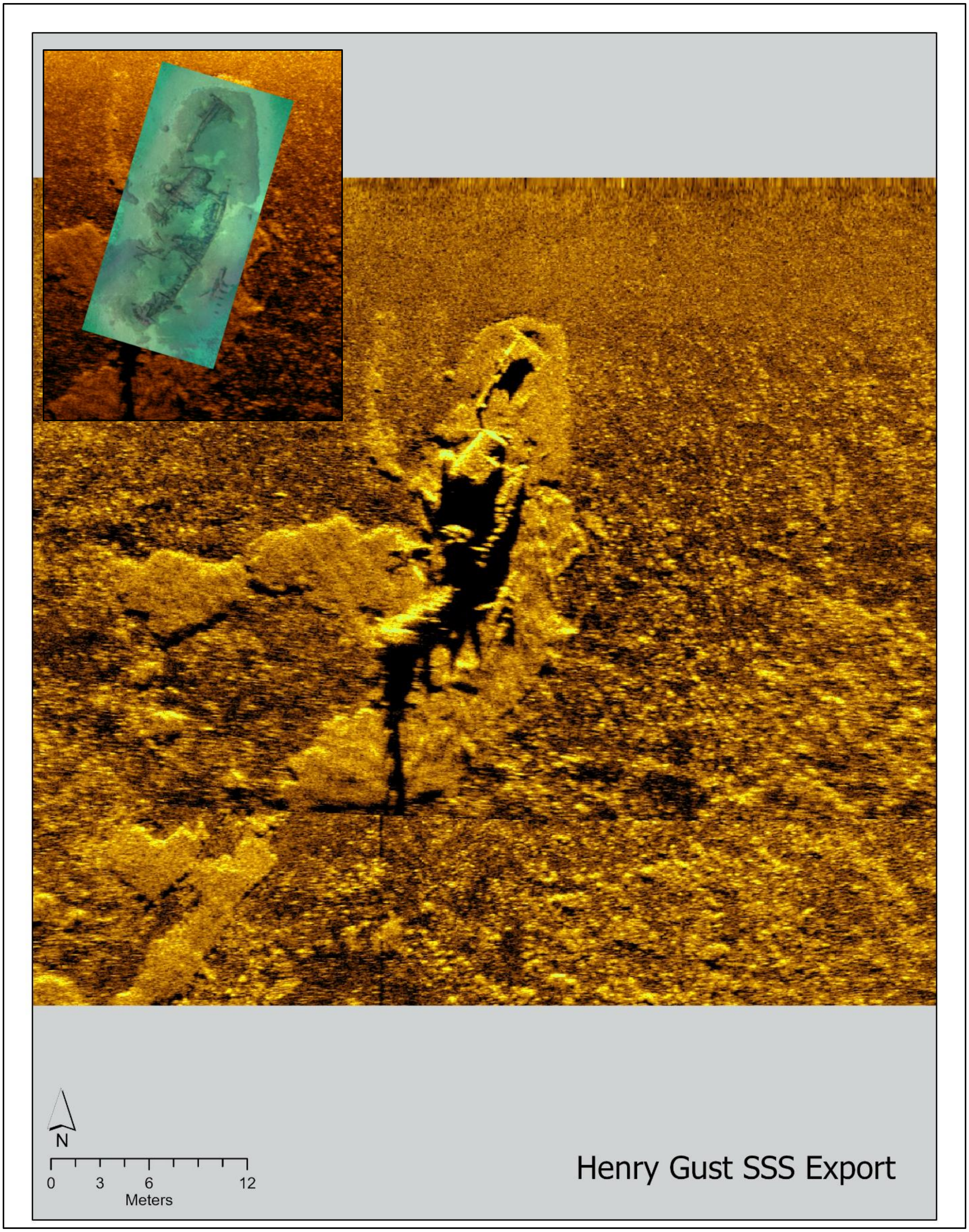

Figure 30. AUV-based side-scan sonar images collected over the site of *Henry Gust's* historic vessel remains. Top left inset shows a photogrammetric model overlaid with the shipwreck site (no scale). Map: NOAA; Side-scan sonar processing: University of Delaware.

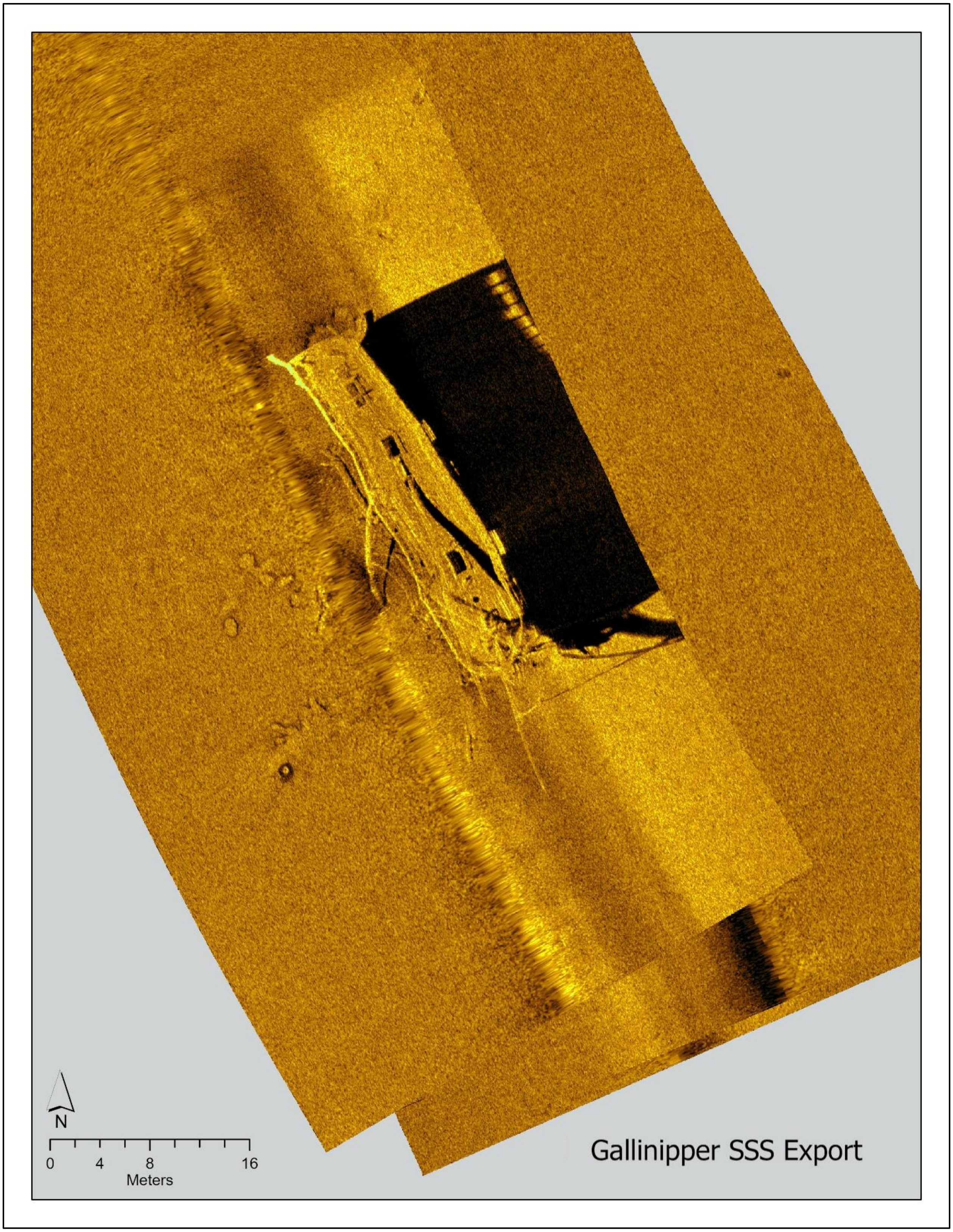

Figure 31. AUV-based side-scan sonar images collected over the site of *Gallinipper's* historic vessel remains. Map: NOAA; Side-scan sonar processing: University of Delaware.

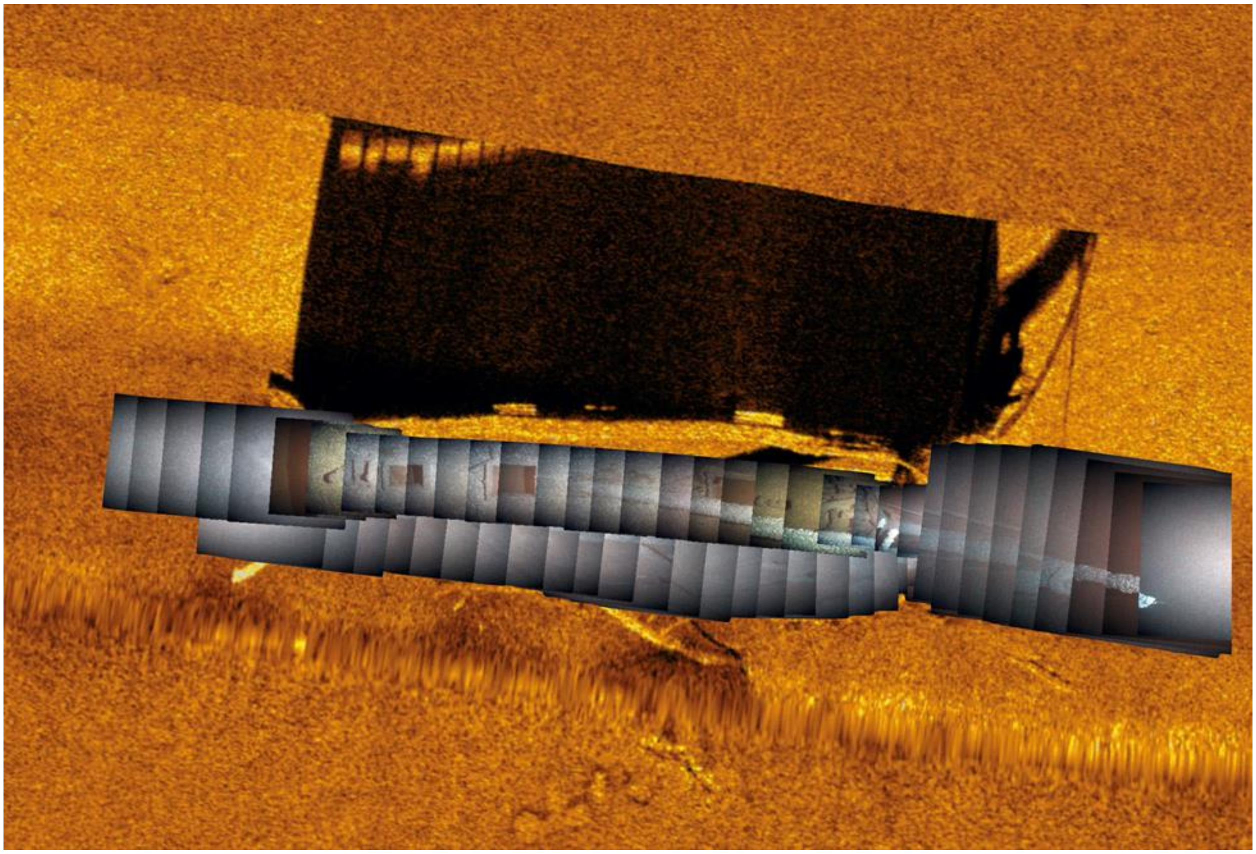

Figure 32. *Gallinipper* AUV based side-scan sonar mosaic with AUV photo overlay. Overlapping AUV photos were also stitched into seamless image mosaics using Agisoft Metashape photogrammetric software. Image: University of Delaware.

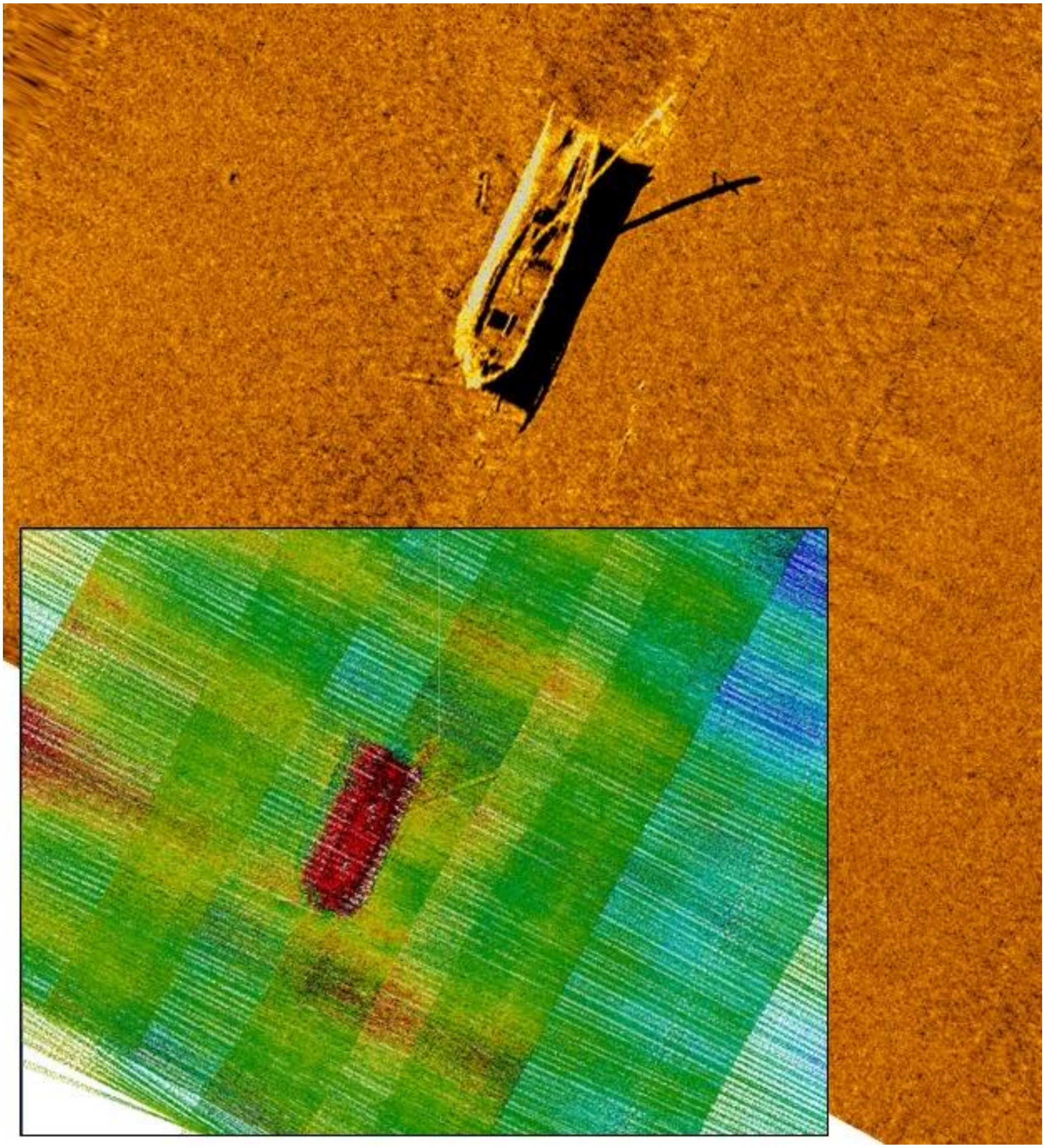

Figure 33. Side-scan sonar acoustic image of the shipwreck *Home*. Bathymetric acoustic imagery of *Home* collected via the Iver3 AUV can be seen in the bottom left. Side-scan sonar and multibeam sonar processing: University of Delaware.

Significant Archaeological Findings

All of the magnetic anomalies identified in the survey should be investigated for their archaeological potential (Figure 34). As no side-scan survey targets were identified, only magnetic anomalies are recommended for further investigation.

In addition to conducting AUV survey over known shipwreck sites, project staff also snorkeled out to the *Tubal Cain* shipwreck site. No evidence of the site was found, suggesting the remains are currently buried under the sediment. Periodic targeted survey and visual observation is recommended to determine the rate at which the site is covered or uncovered.

Additionally, diving operations were conducted on two previously identified sites in WSCNMS to generate photogrammetric models and a baseline understanding of site processes. A single dive was conducted at both the *Henry Gust* and the *S.C. Baldwin*. Despite poor visibility, conditions permitted a complete photogrammetry survey of the *Henry Gust* and a partial model *of S.C. Baldwin* (Figure 35 and Figure 36, respectively).

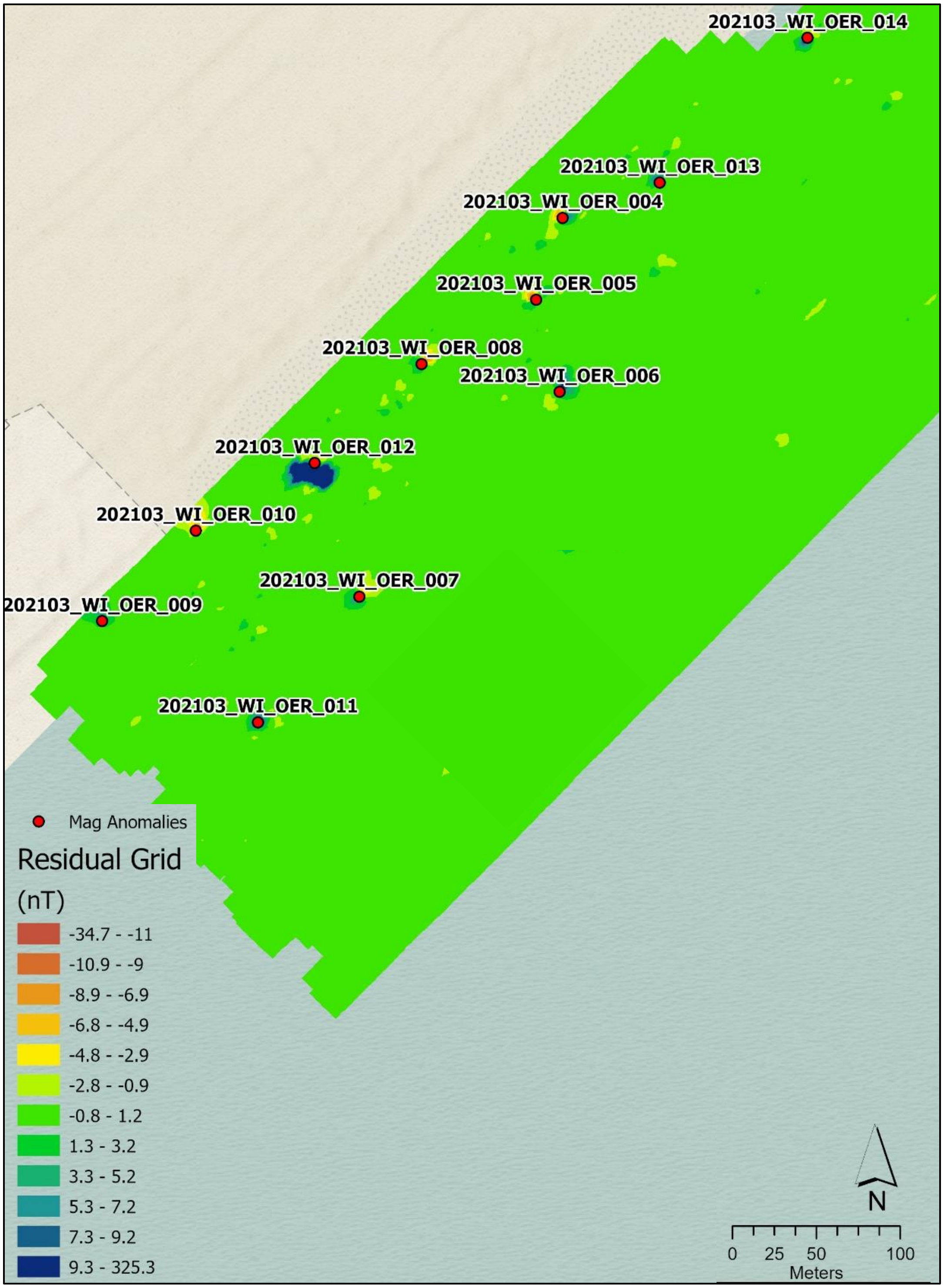

Figure 34. Detail of several magnetometer anomalies within the Wisconsin/Lake Michigan study area. Individual anomalies represented as the residual anomaly grid with picked anomaly points overlaid. Image: NOAA.

Figure 35. Photogrammetric Model of the *Henry Gust* wreck site. As the model is scaled, it can be overlaid with additional remote sensing data. Image: NOAA.

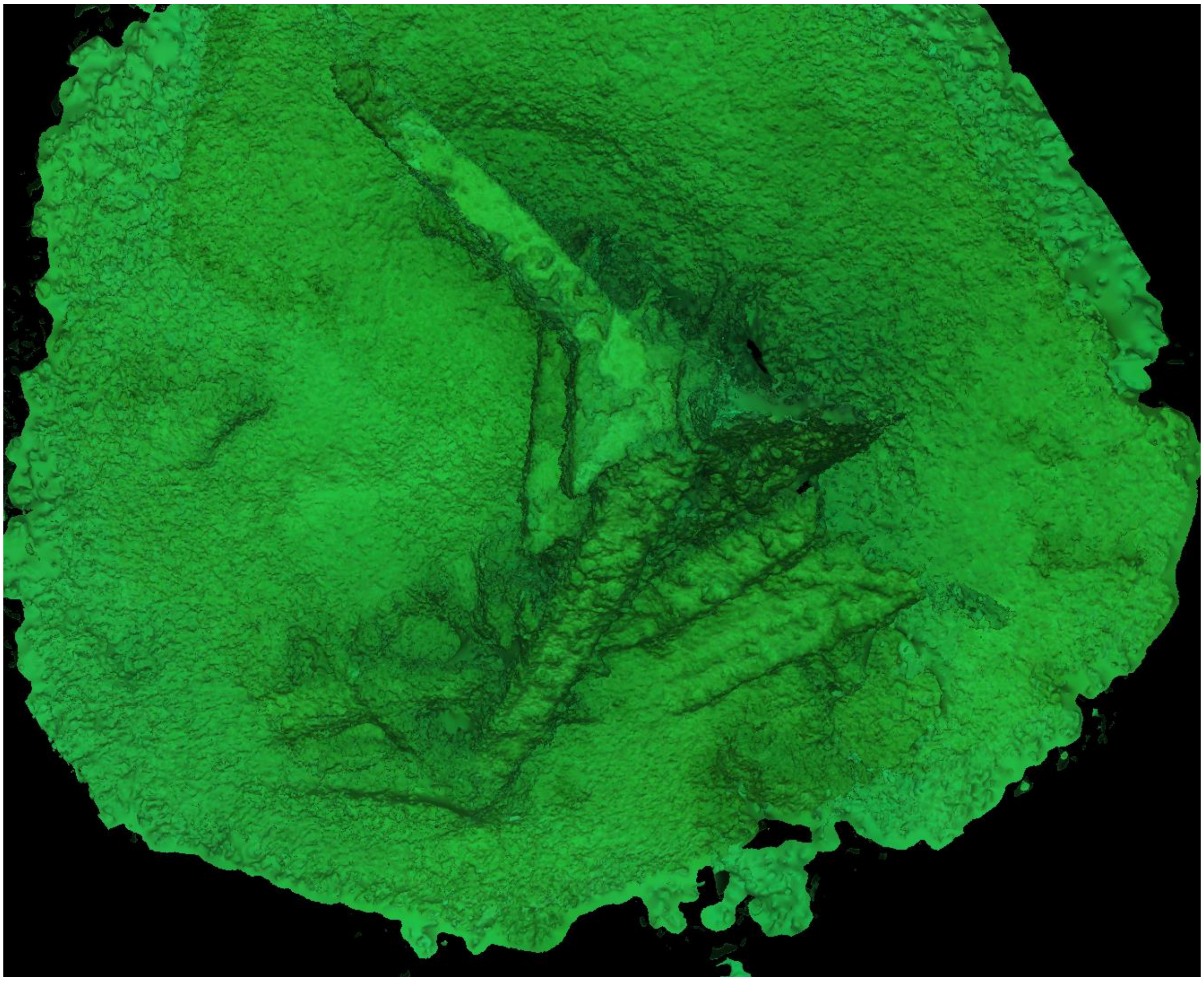

Figure 36. Partial Photogrammetric Model of *S.C. Baldwin*, focusing on the stem post. Image brightened to show contrast. Image: NOAA.

New York/Lake Ontario Operations

Immediately following geophysical survey operations within the Wisconsin/Lake Michigan study area, the team re-mobilized and continued working within the New York/Lake Ontario study area. These operations occurred between 12-19 August 2021 and resulted in multi-instrument data products covering an area of 17.96 sq. km. Total coverage amounts for each sensor, differentiated further between deployment platforms, are reported Table 26.

Table 26. Area coverage per survey instrument and platform within the New York/Lake Ontario study area

Instrument Type	Platform	Coverage (km^2)
SSS	IVER3 AUV	1.24
SSS	EchoBoat ASV	1.09
SSS	EMILY ASV	0.01
SSS	RV *Dogfish*	4.68
Aerial MAG	UAV	0.43
Marine MAG	RV *Dogfish*	0.10
MBES	C-Worker 8 ASV	10.88
ALL INSTRUMENTS	ALL PLATFORMS	18.43

Operations within the New York/Lake Ontario study area grouped within three geographical areas as follows, presented in their north-to-south distribution:

> **Clayton, NY, St Lawrence River:** located adjacent to coastal areas between Clayton and Fishers Landing; depth range 0 to 70 m; crewed vessel-based bathymetric side-scan sonar surveys of three known site locations and exploratory survey between Clayton and Round Island.
>
> **Sackets Harbor, NY, Nearshore:** located inland along Black River Bay to State Rt. 180 bridge; depth range 0 to 70 m; UAV-based aerial magnetometer surveys, crewed vessel-based marine magnetometer and side-scan surveys, ASV-based side-scan sonar survey, and AUV-based side-scan sonar survey.
>
> **Henderson, NY, Nearshore to Open Water:** located in open water in Lake Ontario; depth range 0 to 55 m; ASV-based multibeam sonar survey, ASV-based side-scan sonar survey.

Figure 37 and Figure 38 show details from the coverage areas completed within the New York/Lake Ontario study area as represented by data types (Figure 37) as well as the distribution of platform types (Figure 38).

Processed, finalized magnetic data from the area around Horse Island provided a residual anomaly grid surface used to identify signatures in the data record likely to represent anthropogenic ferromagnetic materials. This grid is visualized in Figure 39. All residual channel signals of 5 nT or greater were marked as anomalies. In some cases, smaller magnetic signals were picked due to their appearance among an otherwise quiet residual background. A total of 57 anomalies were marked. Details of each anomaly, including its peak-to-peak amplitude, wavelength distance, location, type, and name designation are presented in Table 27.

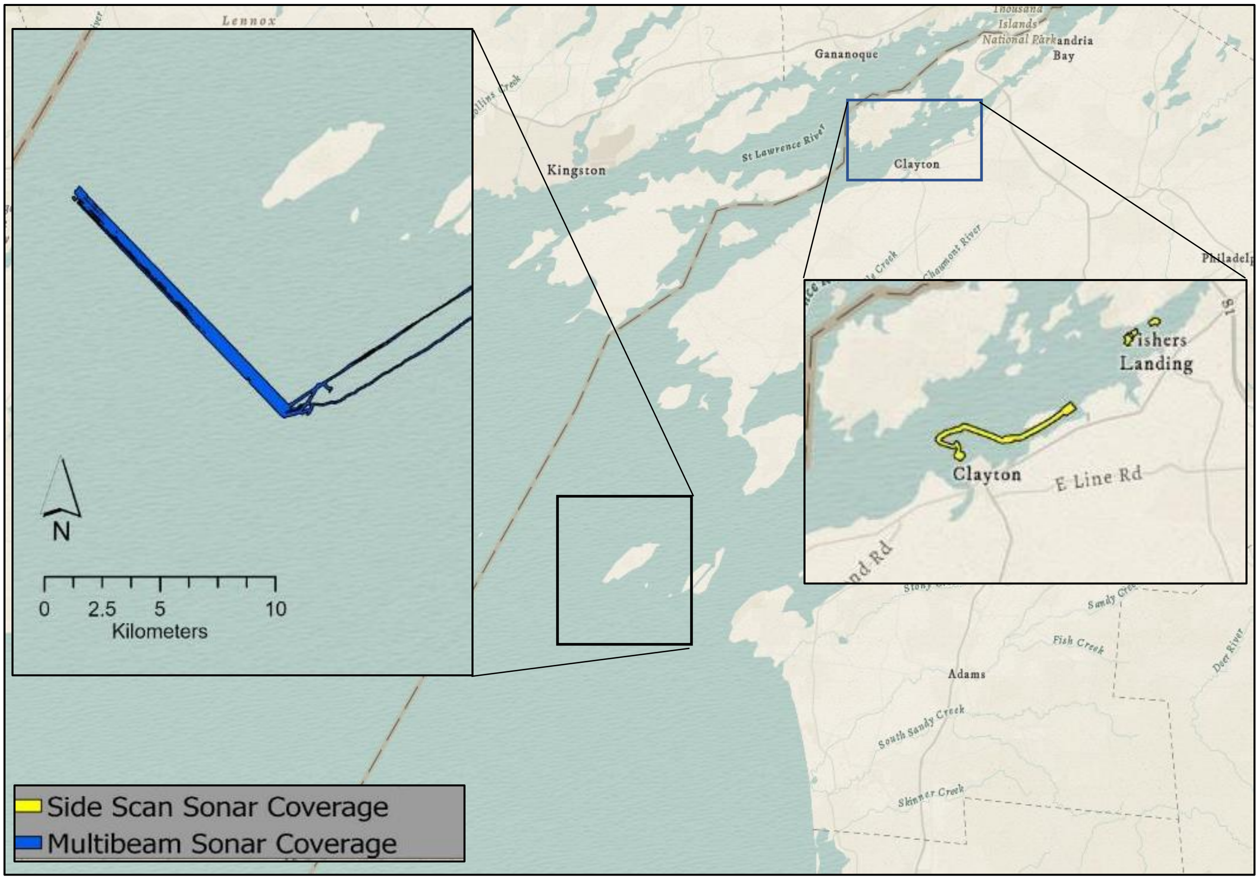

Figure 37. Example of geophysical coverage per data type in the New York/Lake Ontario survey areas offshore off Clayton, NY, and Sackets Harbor, NY. Not all survey coverage depicted due to map scaling. Image: NOAA.

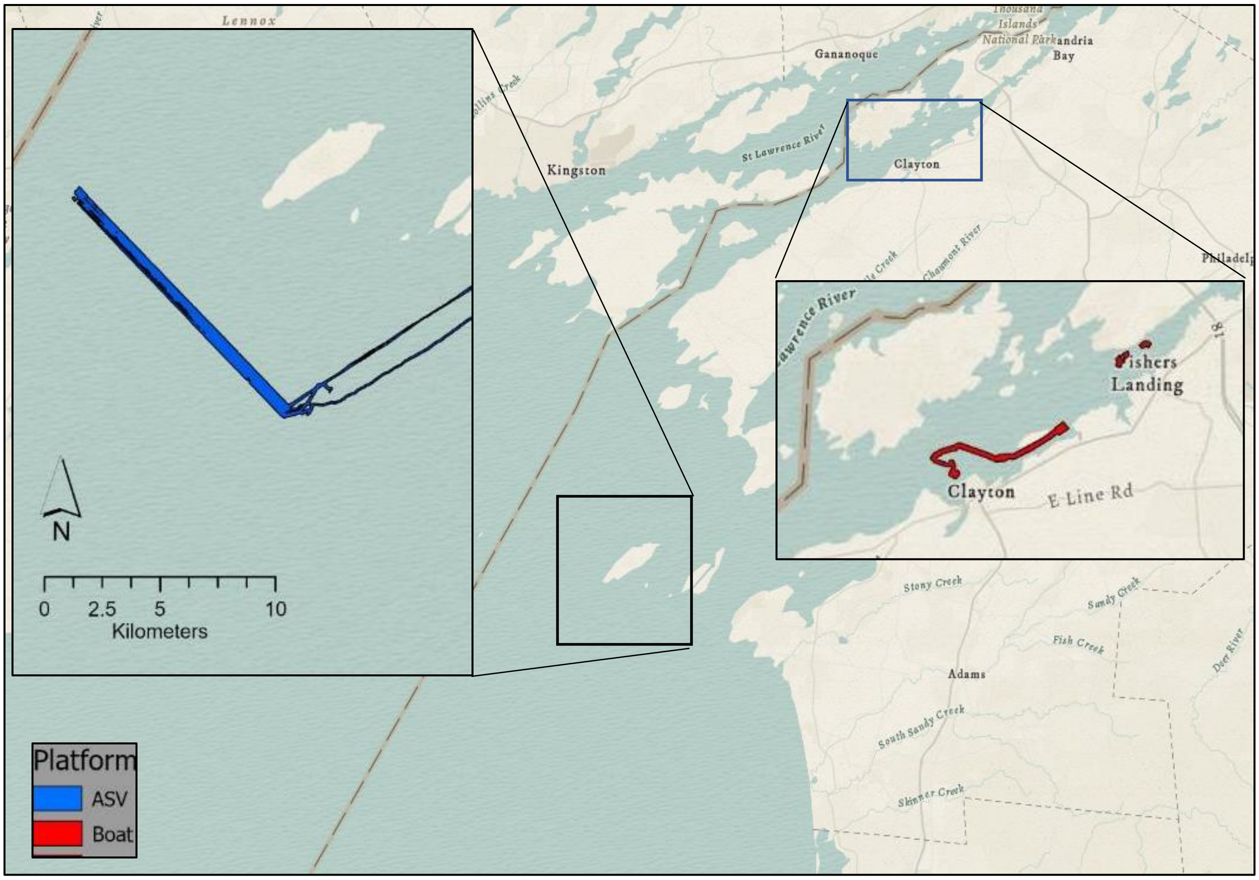

Figure 38. Example of geophysical coverage per platform type in the New York/Lake Ontario survey areas offshore off Clayton, NY, and Sackets Harbor, NY. Not all survey locations depicted due to map scaling. Image: NOAA.

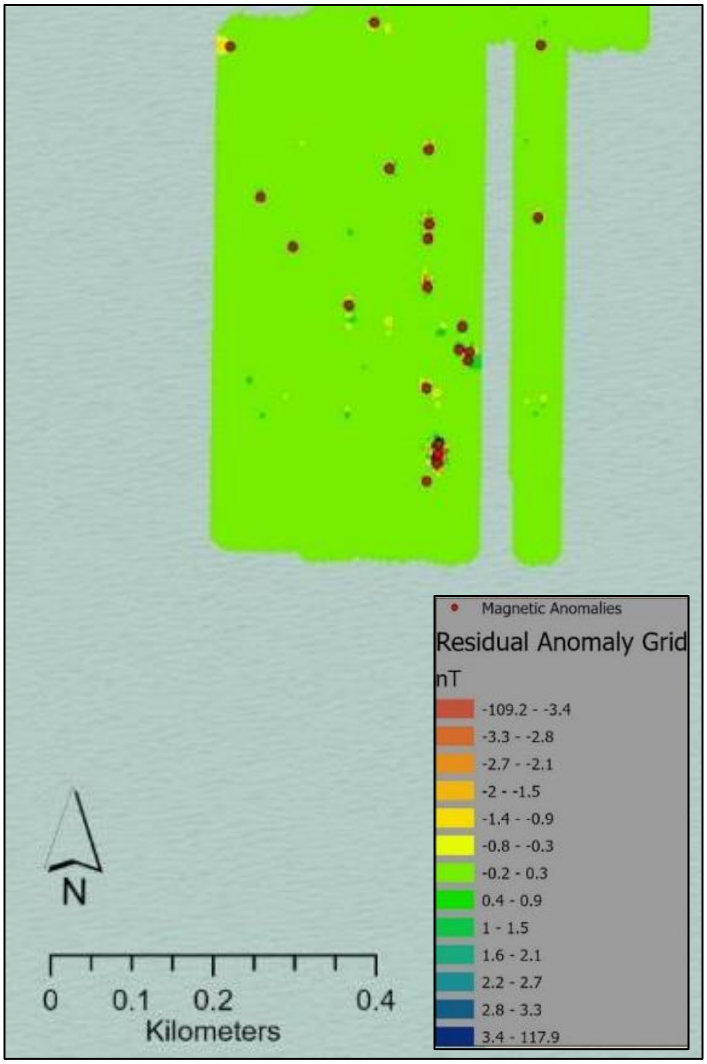

Figure 39. Detail of processed magnetic survey results within the New York/Lake Ontario study area represented as the residual anomaly grid with picked anomaly points overlaid. Image: NOAA.

Table 27. Magnetic survey anomalies identified in Lake Ontario survey area.

Anomaly ID	λ (m)	Amp. (nT)	Type
202103_NY_OER_001	23.18	6.5	Complex
202103_NY_OER_002	25.39	9.3	Complex
202103_NY_OER_003	17.39	6	Complex
202103_NY_OER_004	21.56	22.2	Dipole
202103_NY_OER_005	19.84	6.2	Dipole
202103_NY_OER_006	16.35	10	Complex
202103_NY_OER_007	14.8	5.2	Dipole
202103_NY_OER_008	18.4	21.5	Asymmetric Dipole
202103_NY_OER_009	7.28	3.1	Monopole
202103_NY_OER_010	15.28	3.8	Dipole
202103_NY_OER_011	23.75	7.8	Complex

202103_NY_OER_012	16.35	5.6	Dipole
202103_NY_OER_013	8.25	3.6	Dipole
202103_NY_OER_014	11.88	3.4	Asymmetric Dipole
202103_NY_OER_015	18.62	11.3	Dipole
202103_NY_OER_016	10.82	2.4	Monopole
202103_NY_OER_017	18.9	9.5	Dipole
202103_NY_OER_018	17.96	9.2	Dipole
202103_NY_OER_019	13.27	15.9	Asymmetric Dipole
202103_NY_OER_020	15.15	5.4	Dipole
202103_NY_OER_021	24.52	11	Complex
202103_NY_OER_022	18.26	20.5	Dipole
202103_NY_OER_023	11.6	4.8	Dipole
202103_NY_OER_024	15.17	12.1	Dipole
202103_NY_OER_025	24.14	8.1	Asymmetric Dipole
202103_NY_OER_026	12.08	34.7	Asymmetric Dipole
202103_NY_OER_027	13.77	2.5	Dipole
202103_NY_OER_028	11.6	4.3	Dipole
202103_NY_OER_029	17.86	8.2	Asymmetric Dipole
202103_NY_OER_030	15.4	3.2	Dipole
202103_NY_OER_031	12.39	2.7	Dipole
202103_NY_OER_032	9.29	2.7	Monopole
202103_NY_OER_033	7.67	2.9	Asymmetric Dipole
Anomaly ID	λ (m)	Amp. (nT)	Type
202103_NY_OER_034	6.05	3.4	Monopole
202103_NY_OER_035	9.05	2.1	Monopole
202103_NY_OER_036	18.98	31.4	Asymmetric Dipole
202103_NY_OER_037	13.2	3.2	Dipole
202103_NY_OER_038	14.35	227.9	Dipole
202103_NY_OER_039	8.9	12.2	Monopole
202103_NY_OER_040	16.6	132	Asymmetric Dipole
202103_NY_OER_041	17.55	119	Asymmetric Dipole
202103_NY_OER_042	10.65	12.4	Monopole
202103_NY_OER_043	14.25	5.1	Dipole
202103_NY_OER_044	14.56	14.8	Asymmetric Dipole
202103_NY_OER_045	10.61	4	Monopole
202103_NY_OER_046	13.35	4.2	Asymmetric Dipole
202103_NY_OER_047	26.4	26	Asymmetric Dipole

202103_NY_OER_048	14.25	7	Asymmetric Dipole
202103_NY_OER_049	13.41	3.4	Dipole
202103_NY_OER_050	12.51	2.6	Dipole
202103_NY_OER_051	17.26	13.9	Dipole
202103_NY_OER_052	14.1	31.4	Asymmetric Dipole
202103_NY_OER_053	19.7	32.7	Asymmetric Dipole
202103_NY_OER_054	20.16	2.6	Asymmetric Dipole
202103_NY_OER_055	17.5	1.2	Monopole
202103_NY_OER_056	63.9	34.3	Complex
202103_NY_OER_057	41.6	9.7	Complex

During field operations, personnel conducted a snorkel survey of 5 anomalies that were in shallow water (< 2 m) (Table 28). Personnel utilized a Garmin GPS 64x unit and portable diver-held mag to locate anomalies. A visual identification of the ferrous materials was conducted; all 5 anomalies were identified as modern debris that do not require further investigation. As the diver-held magnetometer is currently under development by Marine Magnetics, the positive location of all anomalies suggested the diver-held magnetometer is an appropriate tool for locating ferromagnetic objects with signatures of approximately 5 nT (the smallest signature of located anomalies being 3.1 nT in strength). The remaining 52 magnetic anomalies identified in New York were not investigated during field operations. As such, all 52 require additional visual surveys to determine if they represent cultural materials on or within the lakebed.

Table 28. Magnetometer anomalies surveyed during NY field operations

Anomaly ID	λ (m)	Amp. (nT)	Result
202103_NY_OER_002	25.39	9.3	Modern Debris
202103_NY_OER_008	18.4	21.5	Modern Debris
202103_NY_OER_009	7.28	3.1	Modern Debris
202103_NY_OER_019	13.27	15.9	Modern Debris
202103_NY_OER_024	15.17	12.1	Modern Debris

From the processed side-scan sonar data, 34 acoustic targets were picked (Figure 40). Only 9 were associated with known archaeological site locations, the remaining 25 represented features on the lakebed not corresponding with any known historic vessel remains. These acoustic targets were noted for exhibiting characteristics of man-made objects, thus distinguishing them from the natural lakebed environment and compelling further review to understand their structure, size, and composition. Some may be undiscovered archaeological sites; some may relate to modern materials lost or otherwise deposited on the lakebed (i.e. trash or debris). Until this additional level of investigation occurs, they are noted as ‘objects of interest’. All side-scan sonar targets are reported in Table 29, including their name and brief description.

Meanwhile, any side-scan sonar targets mentioned above that seemed likely to contain historic material culture, were reported to the New York State Historic Preservation Office. This report occurred via the submission of an archaeological site form. In addition to this administrative action, all new sites listed in Table 29 were entered into the NOAA ONMS Maritime Archaeological Resource Inventory System (MARIS) database used by the ONMS to inventory archaeological resources within sanctuary boundaries.

Of the magnetic anomalies and acoustic targets, only two of each were correlated (Table 30). Both these pairs of magnetic anomalies and side-scan sonar targets are associated with the oil dock adjacent to Sackets Harbor Battlefield State Historic Site. Figure 41 and Figure 42 shows these locations, marked in the residual anomaly grid data from the vessel-based magnetometer and side-scan sonar survey operations around Sackets Harbor.

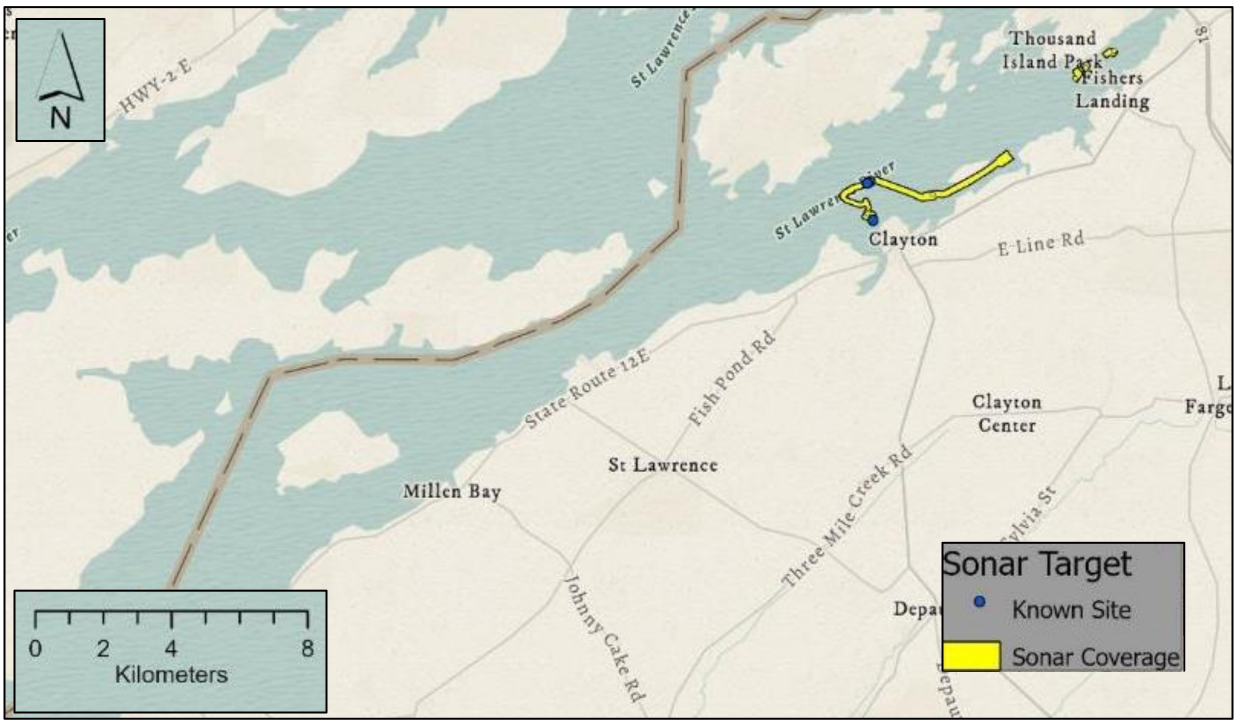

Figure 40. Polygons showing areas of side-scan sonar coverage in New York/Lake Ontario study area with picked target points overlaid. Of 34 targets, 25 were previously unidentified features and 9 corresponded with known historic vessel remains. Not all survey areas shown due to map scaling. Image: NOAA.

Table 29. Side-scan sonar targets identified in Lake Ontario study area. Of 34 marked targets, 25 represent newly identified objects requiring follow-up investigation while the remaining 9 represent features at known cultural resource locations. Note: the target names are derived from colloquial nomenclature used by the regional avocational shipwreck community.

Target Name	Description
Survey Area 1_01	Object of interest, further investigation required
Survey Area 1_02	Object of interest, further investigation required

Survey Area 1_03	Object of interest, further investigation required
Survey Area 1_04	Object of interest, further investigation required
Survey Area 1_05	Object of interest, further investigation required
Survey Area 1_06	Object of interest, further investigation required
Survey Area 2_01	Object of interest, likely modern. Further investigation required
Ellsworth_01	Object marked at known shipwreck location Ellsworth
Ellsworth_02	Object marked at known shipwreck location Ellsworth
Ellsworth_Bow	Mark at bow end of Ellsworth site
Ellsworth_Stern	Mark at stern end of Ellsworth site
Gildea_Site	Mark at known shipwreck location Gildea
Survey Area 3_01	Object of interest, further investigation required
Survey Area 3_02	Object of interest, further investigation required
Survey Area 3_03	Object of interest, further investigation required
Survey Area 3_04	Object of interest, further investigation required
Survey Area 3_05	Object of interest, further investigation required
Survey Area 3_06	Object of interest, further investigation required
Survey Area 3_07	Object of interest, further investigation required
Survey Area 3_08	Object of interest, further investigation required
Survey Area 3_09	Object of interest, further investigation required
Survey Area 3_10_A	Object of interest, further investigation required
Survey Area 3_10_B	Object of interest, further investigation required
Survey Area 3_10_C	Object of interest, further investigation required
Survey Area 4_01	Object of interest, likely modern. Further investigation required
Onondaga_Shipwreck	Mark at known shipwreck location Onondaga
Survey Area 05_01	Object of interest, further investigation required
Dauntless	Mark at known shipwreck location of yacht Dauntless
A.E. Vickery	Mark at known shipwreck location AE Vickery
Survey Area 5_02	Object of interest, further investigation required
Oconto	Mark at known shipwreck location Oconto
Maggie_L	Mark at known shipwreck location Maggie L
L'Iroquoise	Mark at known shipwreck location L'Iroquoise
Work Boat	Mark at known shipwreck location False Squaw/work boat

Table 30. Magnetic anomalies correlated with remote sensing contacts in the New York/Lake Ontario study area.

Mag Anomaly Name	Description
202103_NY_OER_056	34 nT anomaly to SW, aligns with acoustic mark with high shadow indicating significant vertical relief.
202103_NY_OER_057	9.7 nT anomaly to NE, aligns with acoustic mark among a series of linear features with some vertical relief.

Figure 41. Detail of side-scan sonar and magnetometer data recorded around Sackets Harbor Oil Dock. Note grouping of magnetic anomalies and sonar targets. Image: NOAA.

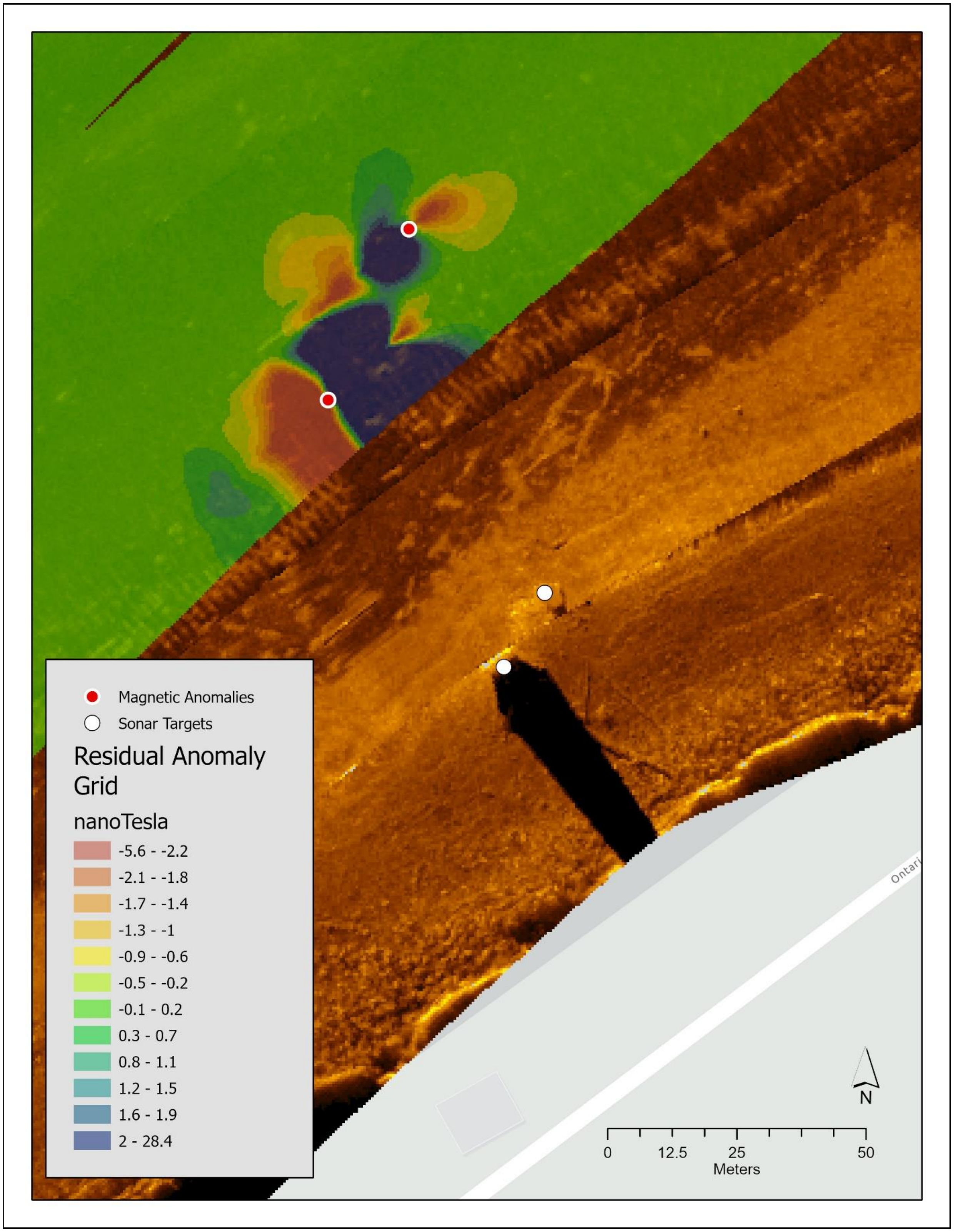

Figure 42. View of adjacent magnetometer and side-scan sonar contacts located in the vicinity of Sackets Harbor Oil Dock. Concurrent targets and anomalies are associated with the derelict oil dock structure adjacent to the Sackets Harbor Battlefield State Historic Site. Map: NOAA; Side-scan sonar processing: NOAA.

Processed MBES bathymetry data collected by the C-Worker 8 ASV are shown in Figure 43. The lack of localized, co-occurring water column sound velocity measurements resulted in prolific sound velocity related errors throughout the entire MBES dataset. An example is seen in Figure 44 where the outer beams of each sonar swath bend upwards. Simultaneously, motion-related errors also permeated the dataset. Despite application of SBET corrections, misalignments and motion-related distortions are seen throughout the entire dataset. Lacking mobilization data (such a patch test results, dimensional control survey, etc.) made troubleshooting motion issues difficult in post processing. Nevertheless, the persistence of these data quality issues did not prevent review of the data for contacts or features which may indicate the presence of large cultural materials such as structures. None, however, were found within the area encompassed by the processed MBES results.

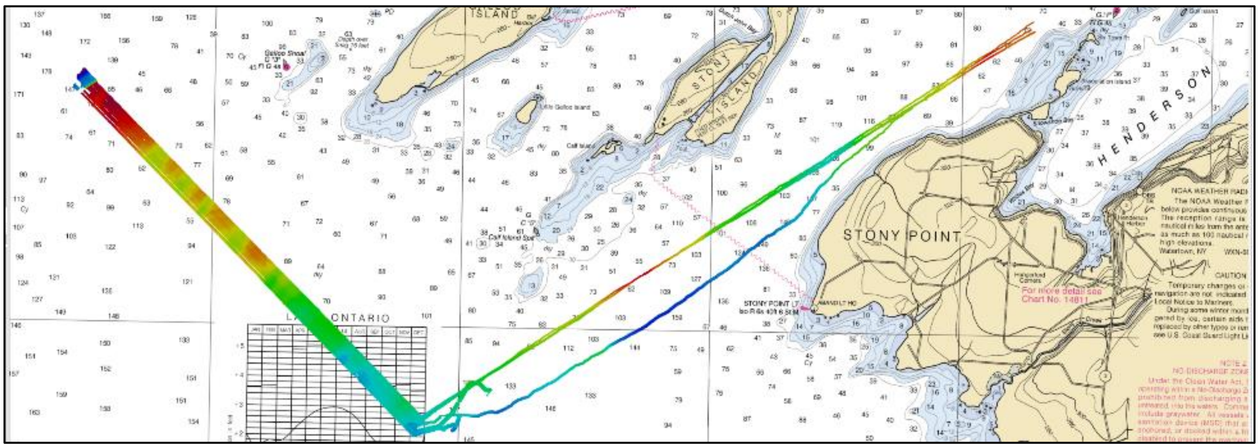

Figure 43. Processed MBES bathymetry gridded at 1 m within the New York/Lake Ontario study area. Image: NOAA.

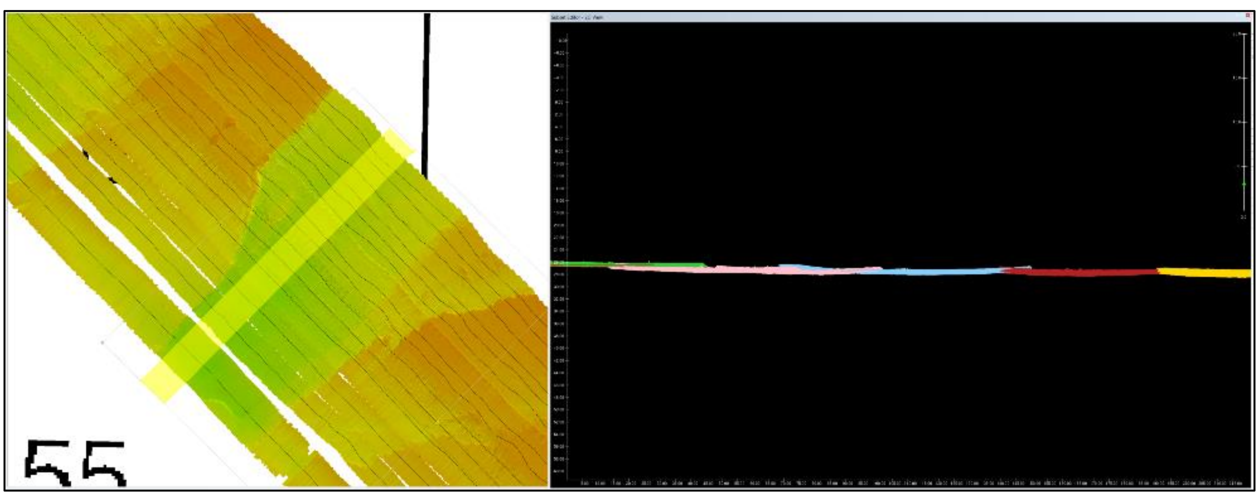

Figure 44. Plan view (left) and cross section view (right) of processed MBES data exhibiting sound velocity errors and motion artifacts in data files causing misalignment. Image: NOAA.

The MBES dataset was conducted as a reconnaissance-level survey. Navigation issues online resulted in two files from 14 and 16 August being rejected. Their exclusion from the final bathymetric data left gaps between adjacent line files, areas of no-data. Likewise, the proliferation of SV and motion artifacts may obscure presentation of cultural materials, especially small features or those with minimum vertical relief. Consequently, while review of MBES data is a helpful source to determine the presence/absence of cultural materials, the area mapped by the ASV should not be considered cleared. Additional tools, such as a side-scan sonar and further MBES surveys together with additional sensor modalities such as magnetometer should build upon this existing coverage to fill the gaps.

Additionally, a series of six dives were made in the St. Lawrence River on previously identified sites to collect photogrammetry models and imagery. Due to high currents, photogrammetric survey was not possible at many sites due to the need of a diver to hold position in the water column high above the site. To effectively collect the required data for modeling in this environment a diver propulsion vehicle would be required. However, the site of L'*Iroquoise* was in an area of sufficiently low current that a complete model was possible (Figure 45). While this model was successful, it should be noted that a great deal of vegetative growth reduced the overall quality possible. A more clearly resolved model could be achieved at a time of year with less growth. Other sites visited, generated a collection of still images referenced in Appendix A. Underwater Photography Log. Examples of side-scan sonar results from AUV-based operations are provided in Figure 46 and Figure 47.

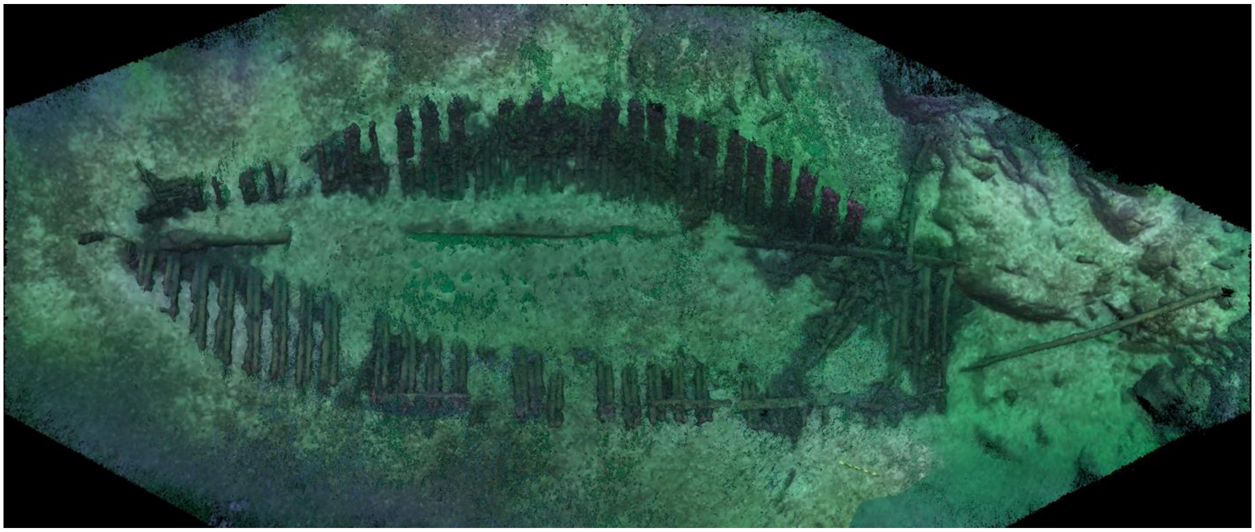

Figure 45. Photogrammetric model of *L'Iroquoise*. Image: NOAA.

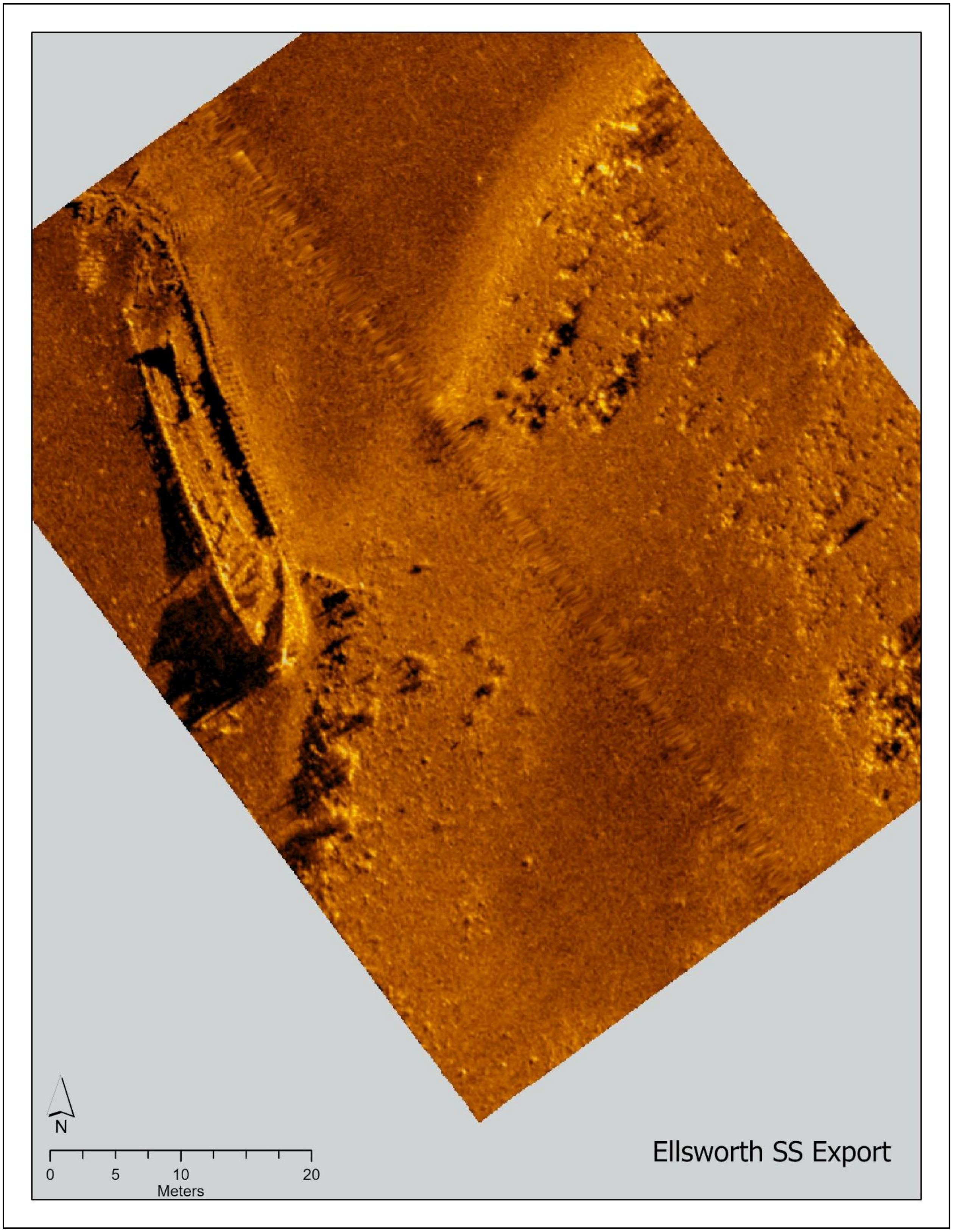

Figure 46. AUV-based side-scan sonar images collected over the site of *Ellsworth's* historic vessel remains. Image: NOAA; Side-scan sonar processing: NOAA.

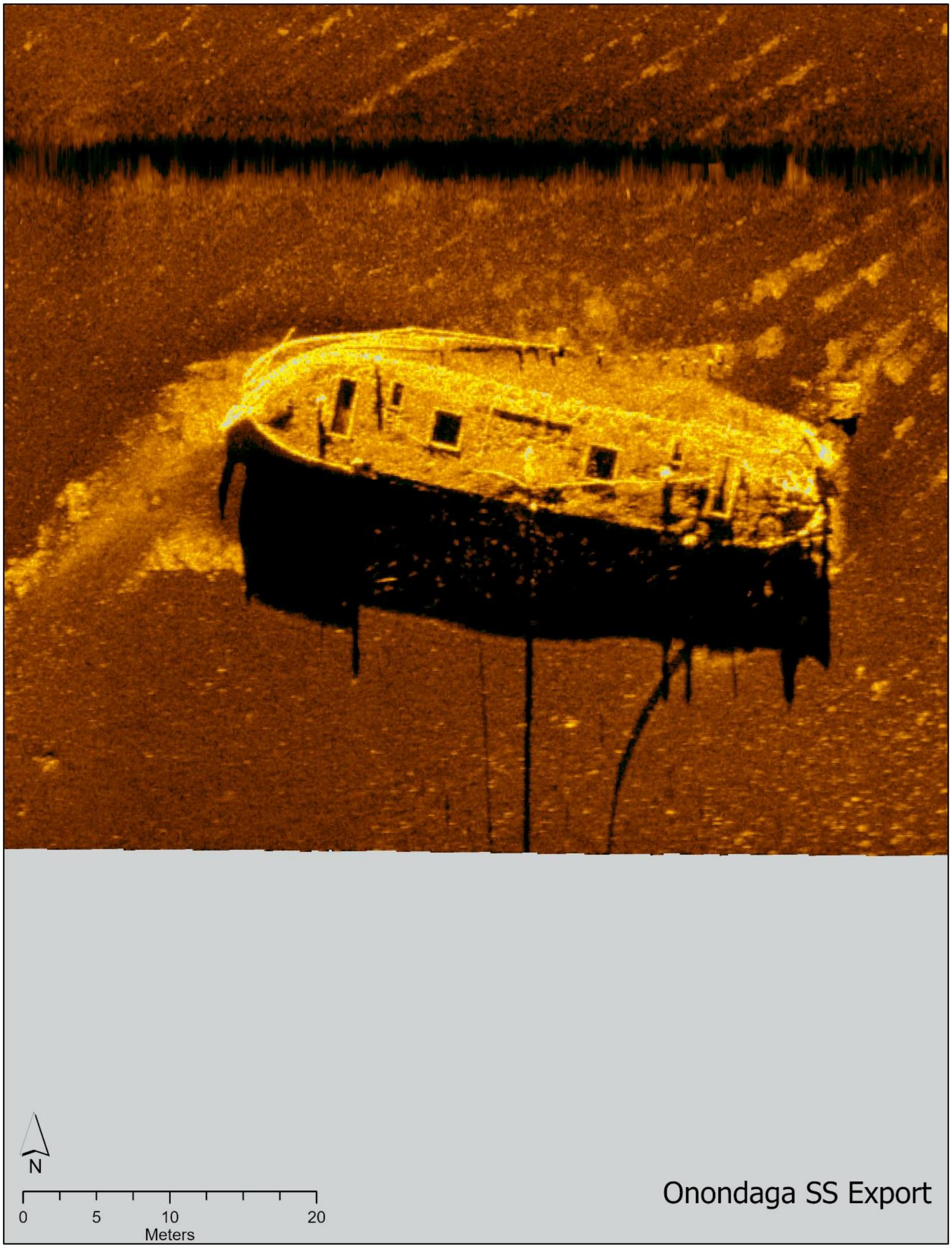

Figure 47. AUV-based side-scan sonar images collected over the site of *Onondaga's* historic vessel remains. Image: NOAA; Side-scan sonar processing: University of Delaware.

Significant Archaeological Findings

Of the 34 acoustic targets identified in Lake Ontario SSS data, three acoustic targets (Survey Area 3_10_A, Survey Area 3_10_B, and Survey Area 3_10_C) were identified as a potential novel archaeological resource. In addition, ten acoustic anomalies were identified as associated with historic vessel remains that have been previously reported by local remote sensing surveyors. Of these ten acoustic anomalies, three are documented in the State of New York online Cultural Resource Information System (CRIS) database. Each of these ten resources is individually discussed below. The remaining 21 acoustic targets were not classified due to low data resolution.

OER21NY_Survey Area 3_10

This potential cultural material was identified via side-scan sonar survey. Multiple acoustic targets (labeled 10_A, 10_B, and 10_C) were generated using SSS processing software to measure the material in different survey track lines. The material is oblong in shape, measuring approximately 22-23 m in length and 3 m in width. Height off the bottom, calculated from the acoustic shadow, is approximately 1.1- 1.5 m. On one of the passes, parallel lines visually consistent with the frames of a vessel were observed (Figure 48), suggesting the site may be the remains of a wooden wreck. This observation requires further evidence before a positive identification can be made.

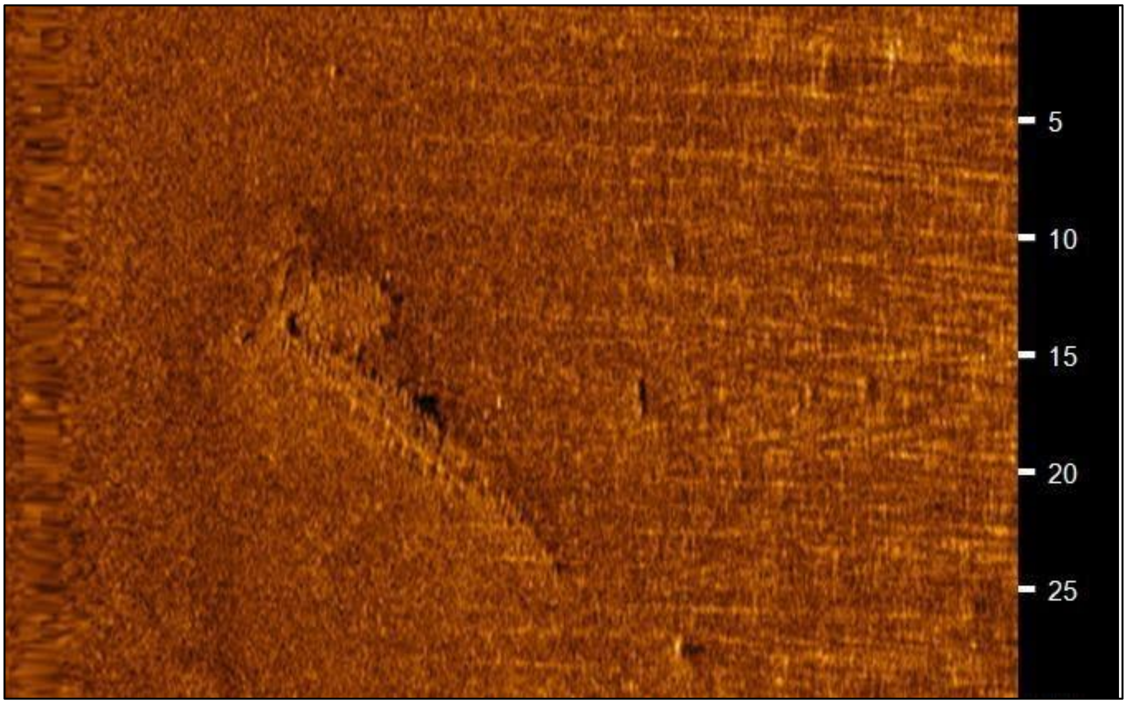

Figure 48. Side-scan sonar image of Survey Area 3_10. Note oblong shape consisting of potential frames, presumably attached to a keel timber. Scale bar is in meters. Image: NOAA.

OER21NY_Onondaga_Shipwreck

This target is the remains of a schooner barge that was previously discovered by a local researcher. The site has been tentatively identified as the *Onondaga* (Figure 49)(see sonarguy.com for more details). The barge *Onondaga* was built at Garden Island, Ontario in 1870 by Henry Roney (Canadian Hull Number 2913). The vessel was enrolled at Kingston, Ontario in 1871 and served throughout the Great Lakes as a coal carrier. In 1902, the vessel transferred to the Hall Coal Company. A newspaper article in the Watertown Herald (Nov. 9, 1907) reports that while traveling off shore, the barge sunk in heavy seas with a cargo of coal.

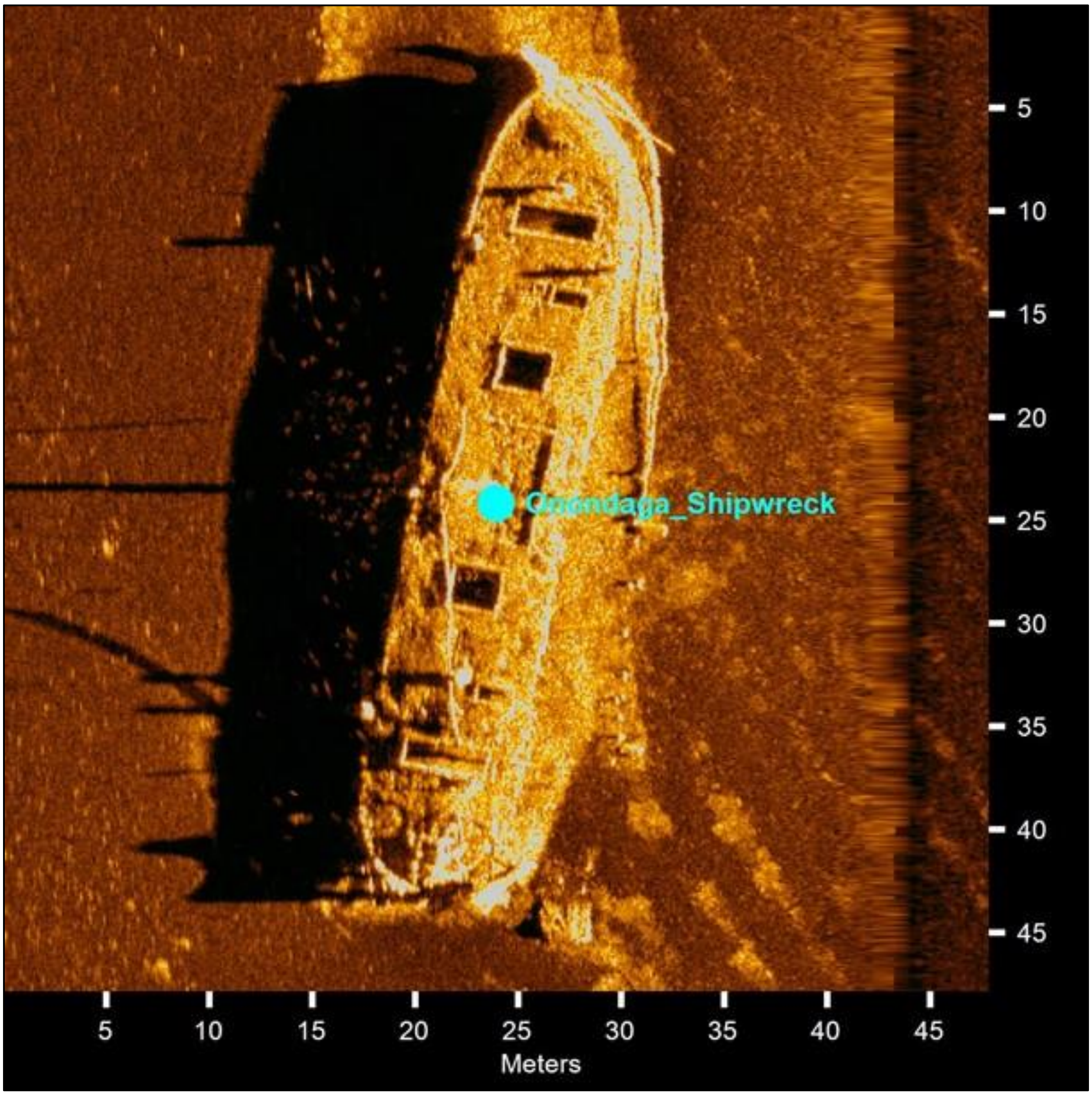

Figure 49. Side-scan sonar image of the schooner barge *Onondaga*. Image: NOAA.

Today, the shipwreck site consists of an articulated vessel sitting upright on the lakebed. The port side of the vessel has collapsed, although the main mast and rigging are still standing. Four deck hatches can be seen in the acoustic image; three of which are missing their hatch covers. A scour pattern is present around the wreck site, as can be seen in Figure 50. Vessel length and width are calculated at 40 m x 11 m, respectively.

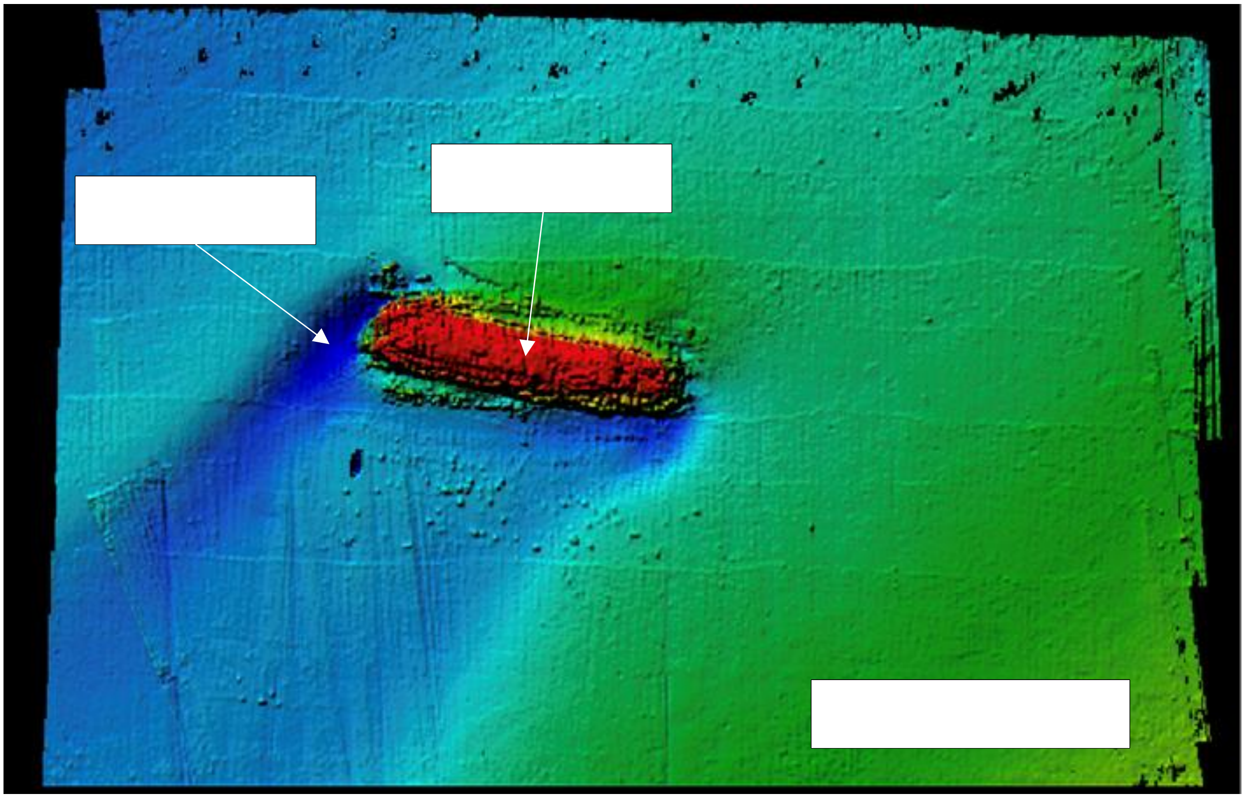

Figure 50. Bathymetric data of the *Onondaga* shipwreck site captured using the AUV. Image: University of Delaware.

Regarding site condition and disturbances, the hull and masts are in excellent condition considering age and local environment. The site hosts an active colony of Dresseinid mussels; at present, these mussels do not appear to be actively degrading materials or contributing to structural deterioration from added weight of the organisms. The mussels also obscure architectural details, reducing the archaeological value (Figure 51). Furthermore, their presence does reduce the aesthetic appeal of the wreckage. Nevertheless, an eligibility determination for the National Register of Historic Places is recommended as a next step, along with preliminary site documentation via dive or ROV survey.

Figure 51. Photograph of the mast on *Onondaga* taken during the AUV survey over the site. Note Dresseinid mussel coverage. Image: University of Delaware.

OER21NY_Ellsworth_Shipwreck

The remains of a steamer tentatively identified as the steamer *Ellsworth* were located via side-scan sonar survey. The site was previously identified by recreational surveyors (see sonarguy.com for more details). Built at Seneca Lake, New York as a sailing vessel, Ellsworth was outfit in 1871 as a steam vessel that traversed both the Great Lakes and coastal waters of the U.S. eastern seaboard.

Purchased by Abner C. Mattoon of Oswego, NY; Ellsworth served primarily as a cargo carrier. From 1871-1872, Mattoon used Ellsworth to ferry passengers and cargo down the East coast to Peas Creek in Florida as part of the burgeoning homesteading effort.

In July 1877, while in use by the Mattoon family for a vacation cruise through the Thousand Islands, a fire broke out destroying the upperworks and sinking the wreckage. An 1878 failed salvage attempt was followed by successful raising of the engine in 1879. The wreckers also attempted to raise the hull; however, it broke upon surfacing and was abandoned.

The site was located via remote sensing. The site consists of a semi-articulated vessel sitting on the lakebed (Figure 52).

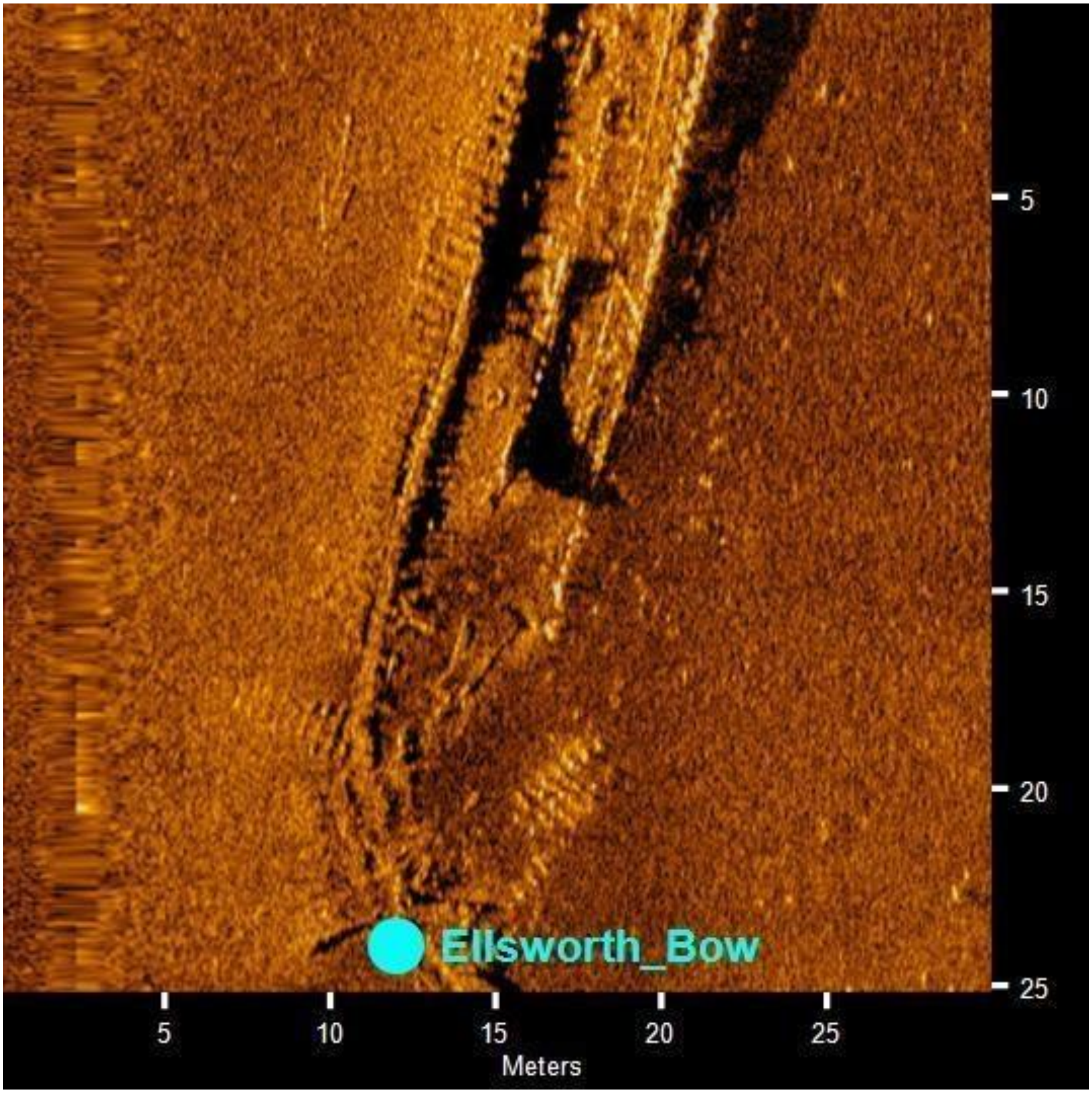

Figure 52. Side-scan sonar image of the bow of the *Ellsworth*. Image: NOAA.

The vessel is segmented into two distinct bow and stern pieces. The bow measures 5 m in length, 11 m in width, and sits flush with the lakebed. The stern of the vessel measures 7 m in length by 5 m in width. Overall vessel dimensions are approximately 38 m x 5 m. Debris is scattered on the lakebed, including one potentially large sonar contact that appears to be an anchor.

Given the wrecking history, the site appears relatively undisturbed. Zebra mussels are present; however, the iron framing elements of the vessel are still visible and distinct features can be distinguished. Additional investigation of the site is recommended, including site mapping and interpretation. The Chasing ROV was used to investigate the site—the video may present an opportunity for development of a photogrammetric model. Further work is required to assess this potential. The site should be monitored for active signs of disturbance. Finally, an eligibility determination for the National Register of Historic Places should be conducted.

OER21NY_Gildea_Site

The remains of a wooden vessel measuring approximately 40 m in length, this shipwreck site was reported by Mr. Daniel Gildea to the State of New York in 2020. The site is currently documented in the CRIS system as 04509.000152, the "Ray Bay Shipwreck." Mr. Gildea also reached out to NOAA staff at the time given the site was located within the proposed Lake Ontario National Marine Sanctuary boundary, prompting NOAA to utilize the "Gildea Site" nomenclature.

As part of the 2021 field project, staff conducted preliminary reconnaissance of the shipwreck remains. Data resolution from this initial survey is poor, and the site is recommended for additional survey and mapping.

OER21NY_Dauntless

Built in 1906, the yacht *Dauntless* was one of the largest passenger boats on the St. Lawrence River for its time. The yacht served the Brown Boat Line, carrying passengers Clayton, NY and Alexandria Bay, NY. Sometime after 1921, *Dauntless* was salvaged for its materials and the hull was razed. In the 1970s, the site was again salvaged by divers.

Today, only the lower part of the hull remains. The site is used primarily for recreational diving although there is no buoy in place. The vessel remains measure 21 m in length, 3.3 m in width, and rise 1 m off the riverbed. An attempt was made during field operations to place divers on the wreckage. Unfortunately, divers were unable to locate the site remains and the dive was terminated.

OER21NY_A.E._Vickery

Built as a bulk cargo carrier at Three Mile Bay, New York, the schooner *A.E. Vickery* was initially launched as the *J.B. Penfield* in 1861. Following a successful career serving in the Great Lakes, *A.E. Vickery* went ashore near Alexandria Bay, NY in 1889 while carrying a cargo of corn bound for Chicago, IL. The hull reportedly filled quickly with water, although the crew were able to escape to the nearby Rock Island lighthouse. Unable to raise the wreck, the cargo was later salvaged by a local diver.

Today, the hull of *A. E. Vickery* is largely intact, and sits upright at the base of the Winter Island/Rock Island shoal. A local dive club maintains a site mooring, and the site is a favorite for commercial dive operators. Overall dimensions are 28 m in length x 8.5 m in width x 3.6 m in height. The wreck rests on the sloping edge of the riverbank, with the bow at the shallowest point. The bow is intact with a large windlass on the forepeak. Most of the decking remains in situ, and open hatch covers allow wide access into the main hold through to the stern of the vessel. The masts and rigging of the vessel are down with some material distributed across the deck and a large portion of rigging adjacent to the vessel near the stern running deeper into the channel. This site is in an area of high current, which is managed by staying in the lee or interior of the wreckage.

OER21NY_Oconto

The steam propeller *Oconto* was built in 1872 as a commercial cargo carrier. Serving throughout the Great Lakes, *Oconto* measured 40 m in length and was registered at 505 tons. While traveling through the St. Lawrence River Narrows in 1886, *Oconto* struck Granite Shoal and sunk in approximately 30 m of water. Contemporary newspaper clippings indicate that the wreck location was notorious, having claimed "the tug Conqueror and the Oneida" two years prior. The sinking took several hours, giving the passengers and crew time to safely evacuate. The cargo of silk and other sundries (cotton, shoes, woolen goods, and boots) was estimated at several hundred thousand dollars, prompting a failed salvage attempt.

Today, the largest portion of the *Oconto* measures approximately 28.5 m in length, 7 m in width, and 1.5 m in height off the lakebed. The remains are split into several sections and sit at the bottom of a steep slope. The water depth (49 m) and strong currents at the site suggest ROV is the best suited tool for further site mapping.

OER21NY_Maggie_L.

The sailing schooner *Maggie L.* was built in Picton, Ontario in 1889. Measuring just over 20 m in length, the vessel served as a cargo carrier between eastern New York and Canada. In 1929, the schooner collided with the freighter *Keystate* off Clayton, NY. The bow was sheared off in the collision, while the remainder of the hull settled at the base of a ledge on the river bottom.

Today, the remains of *Maggie L.* are used as a recreational dive site and the site is registered in the State of New York CRIS system as 04549.000166: Maggie L Shipwreck. A local dive club maintains a site mooring while operators are known to place historic artifacts on site to generate points of interest for tourists. The hull measures 21 m in length, 6.5 m in width, and sits approximately 1 m off the lakebed.

Overall, the hull demonstrates moderate levels of degradation. Parts of the deck machinery and masts are still in place, though the masts are sheared off above the fife rail. The aft deck shows a higher degree of structural integrity than the fore areas towards the missing bow. Dreissenid mussels are present, however much of the original timbers remain unobscured. Given the recreational site use, the site is a good candidate for detailed mapping and stabilization efforts.

OER21NY_L'Iroquoise

Built by the French during the Seven Years' War, the 75-foot sailing vessel *Iroquoise* served on Lake Ontario following the fall of Fort Frontenac in 1758. Damaged in February 1760, the French abandoned the vessel and British forces repurposed it as *Anson* six months later. While traveling on the St. Lawrence River, HMS *Anson* struck Niagara Shoal and could not be saved. The British salvaged what they could and burned the wreck to the water line. Volunteers for the St. Lawrence River Historical Foundation documented the wreck in the 1990s.

Today, the site is the oldest known shipwreck in the Thousand Islands region. Located in 80 feet of water, the site measures approximately 20 m in length, 8.5 m in width, and 1 m in height. Given the vessel age, the structure remains remarkably well preserved, consisting of the keel, floors, and frame pairs through the turn of the bilge. Partial remains of longitudinal bilge stringers are also present. While the stern has collapsed, several framing elements remain in situ. L'*Iroquoise* is recorded in the State of New York CRIS system under 04514.000480:Iroquoise/Anson Schooner Shipwreck and has been determined eligible for the National Register of Historic Places. A previous survey of this site was conducted by the St. Lawrence River Historical Foundation in the 1990s. An updated detailed mapping survey of the remains is recommended, as well as identification of potential stabilization efforts.

OER21NY_Work_Boat

The remains of a small wooden work boat were identified by divers in the 1970s while searching for the historic powerboat *Squaw*. Colloquially called the *False Squaw*, the work boat site consists of a small outboard motorboat measuring 7.7 m in length, 2.75 m in width, and 1.4 m in height off the lakebed. As the site has only been identified as an outboard motorboat, additional survey may yield further insight into history and past use.

Considerations for National Register of Historic Places Eligibility

Over the course of field operations, one novel potential historic resource was identified in Lake Michigan and one novel potential historic resource was identified in Lake Ontario. As these resources were identified in remote sensing datasets but were not visually surveyed, additional investigation is required before a National Register of Historic Places (NRHP) determination of eligibility can be made.

In addition, this project also located six previously identified resources in Lake Ontario and the St. Lawrence River that are not currently inventoried in CRIS. Of these, the two historic shipwrecks identified in eastern Lake Ontario—the barge *Onondaga* and the steamer *Ellsworth*—are recommended for formal determination of eligibility. Both sites are in good condition given their distinct histories. Furthermore, both demonstrate few anthropogenic impacts. For the barge *Onondaga*, the remains demonstrate excellent levels of both structural and archaeological . The steamer *Ellsworth*, too, demonstrates a good level of archaeological integrity and a fair level of structural integrity given the extent of damage caused by the initial wrecking event and subsequent historic salvage. These resources both demonstrated regional levels of significance due to their integrity of location, integrity of design, integrity of setting, and integrity of materials. As such, the suggested criteria for consideration are criteria C and D for the barge *Onondaga*, and criterion A for the steamer *Ellsworth*.

Conclusions

This project consisted of two remote sensing based archaeological surveys conducted in Lake Michigan and Lake Ontario. The survey work supports the on-going research efforts at the newly designated Wisconsin Shipwreck Coast National Marine Sanctuary and the proposed Lake Ontario National Marine Sanctuary. The survey areas, drawn to encompass historical locations tied to the history of these Great Lakes, yielded a total of 34 magnetic anomalies and 17 sonar targets (generated for 5 distinct sites) in Lake Michigan and 57 magnetic anomalies and 34 sonar targets (generated for 29 distinct sites) in Lake Ontario. From these, one novel archaeological resource was identified in Lake Ontario. Additionally, survey work in Lake Ontario located six known historic resources that were not registered in the State of New York CRIS database.

Archaeological Conclusions

In answering the research questions, the project team found that the scope of submerged cultural heritage resources within the proposed sanctuary study areas varies, with exposed archaeological resources demonstrating fair to excellent degrees of structural and archaeological integrity. In Lake Michigan, the level of archaeological integrity was not assessed, however the level of structural integrity was correlated to the local environment and site history. Visible processes influencing site formation in the vicinity of Two Rivers, WI include the dynamic shoal environment in nearshore waters, and colonization by Dreissenid mussels in offshore areas.

In Lake Ontario and the St. Lawrence River, sites demonstrated a good degree of archaeological integrity as demonstrated by intact structures and the presence of standing rigging, as was the case with the barge *Onondaga*. Similarly, while Dreissenid mussels are present, sites demonstrated a good degree of structural integrity with noticeable deterioration traced to initial salvage or wrecking events. Several sites are actively used by recreational divers and should be assessed for further anthropogenic impacts.

Of the anomalies and potential archaeological resource located during the survey, all should be systematically evaluated for the presence of historic materials.

Technological Conclusions

A principal scientific objective of this project was focused upon testing various autonomous platforms and instruments as tools for archaeological remote sensing. The study utilized an array of tools across numerous environments differentiated by water depth and proximity to shore. Autonomous systems, paired with common geophysical survey and navigation systems, were deployed to environments appropriate to their design and function. The UAV was deployed over land and surf-zone lake areas; portable ASVs were deployed in nearshore, coastal, and riverine areas; larger ASV and AUV systems were deployed offshore to survey in open-lake areas. Throughout the project, scientists noted that all autonomous vehicles performed largely as expected. The following observations, therefore, pertain only to the equipment and devices tested under this specific project regime of environments, operations support and planning, as well instruments and data types. Stated observations and conclusions are not meant to generalize the utility of autonomous systems or to inform survey designs other than those focused on cultural resource characterization.

Technological conclusions are herein presented categorically based upon platform types and environments defined in previous sections. Namely: UAV, AUV (both offshore and nearshore as the same unit was deployed in both environments), ASV nearshore, and ASV offshore. The basic framework for technical assessment was through comparison with a hypothetical crewed platform using similar technology.

Uncrewed Aerial Vehicle

A single UAV system was deployed during all project exploration activities, conducting aerial magnetometer surveys over water in beach and surf zones. This system proved remarkably effective at consistently executing precise, narrowly spaced survey flight patterns based on a 5 m horizontal line offset and low (1-2 m) altitude above the water. Data collected rendered products suitable for identifying small magnetic anomalies in nearshore areas. These tools accessed areas not possible by most water-born vessels, but too far over water for similar terrestrial methods. As such, they were extremely useful at creating a contiguous data output in areas where typical marine and terrestrial methods would leave gaps.

A major limitation to this system, however, was the duration of each individual flight and, as result, total daily coverage. Battery supply on the UAV platform enabled 20-30-minute flights, with extensive pre and post flight procedures occupying more time than the actual deployment. As a result, when compared to marine and terrestrial methods that operate in a near continuous fashion, the UAV approach was less productive. Nevertheless, its ability to map challenging geographies was a benefit, and production limitations could be overcome by operating multiple platforms and sensors in future applications.

While a person equipped with a terrestrial magnetometer (or gradiometer) system could continuously record samples for hours at a time, they could not access many of the coastal areas covered with the UAV system. Likewise, a crewed boat towing a marine magnetometer could survey indefinitely, it would also not be able to safely navigate within areas traversed by the UAV system. For this reason, along with its ability to consistently and precisely navigate along the plan survey grid, it demonstrated considerable value as an archaeological survey tool in coastal environments.

Autonomous Underwater Vehicle

A single AUV system was deployed in both nearshore and offshore environments during the project. This device was the University of Delaware’s Iver3 system with integrated sonar and camera devices. Throughout the unit was reliable, effective, and manageable as a survey platform. It required a skilled team of operators, but results derived in the form of sonar and visual imagery were equal to or exceeded the quality possible from a crewed vessel equipped with similar instrumentation.

Navigation and referencing of raw sonar data was better than typical results obtained via manual layback typically applied to position towed side-scan systems from surface vessels. Likewise, the AUV operated within the water column and was not subject to the motion experienced by a surface vessel and telegraphed through an instrument cable to a towed sonar system. As a result, sonar files recorded from the AUV were less likely to be impacted by motion artifacts and had improved navigation when compared to a standard output from a towed side-scan sensor deployed by a crewed vessel.

The Iver3 AUV proved particularly useful for imaging known archaeological sites. This offered a rapid acquisition option for sonar-based site characterization—very useful for consistent long-term monitoring of archaeological resources. Once deployment parameters (altitude and line orientation) were optimized, the AUV could also repeat missions and provide consistent results. These capabilities provide numerous benefits of note for archaeological survey:

- AUV can provide results beyond depths accessible by divers, while also functioning effectively in water depths within normal diver capabilities.
- AUV can provide results faster than diving operations or protracted ROV missions, though there are benefits for other data acquisition modes. These considerations are relevant at a planning scope.
- AUV can operate from vessels of opportunity and require minimal vessel setup in comparison to integration of similar vessel-based (towed or mounted) geophysical equipment.
- AUV can be used for repeated observations in a monitoring framework, especially once optimal mission parameters are derived. AUV could be a power site monitoring tool, similar to the utilization of other geophysical tools but without the added complication of vessel mobilizations.
- A “reconnaissance” dive can be completed in 30 minutes or so for shipwrecks in 200 feet of water; subsequent dives can then be quickly tailored to operate the vehicle closer to archaeological features to collect a high frequency acoustic image.
- AUV does require a specially trained operating team, however, the complexity of operation is not significantly greater than other geophysical tools.

This site-based survey approach was the most utilized during the current project.

Another approach utilized was an exploratory mode for mapping larger, contiguous areas of lakebed. While expecting to find historical sites based on position information provided from ambiguous historical source material, the AUV system ended up performing larger search-focused missions in Lake Ontario. In some cases, the target sites were located, while in other cases they were not. In each instance, however, the AUV managed to map larger geometries of lakebed. When mosaiced as contiguous areas, these deployments offered similar results to an exploratory sonar survey. This application of the AUV system in an exploratory and area-coverage mode should also be considered as a valid approach for archaeological survey with end-user implications beyond cultural resources-focused science objectives.

While further considerations of sustained exploratory mapping via AUV were not informed by project operations, they should be considered a topic of interest in similar studies. Based on the results herein, however, AUVs provided an attractive alternative for nearshore and offshore surveys for characterizing submerged cultural resources. They are similar in complexity to normal vessel-based geophysical tools but offer some flexibility in deployment options and the efficiency of repeating verified survey plans. This capacity would support sustained site monitoring via geophysical methods and offer an additional or alternative method to vessel or diver-based approaches at a similar cost of time and resources. Where the AUV would excel, however, is conducting operations beyond the limits of scientific and technical diving modes, or from vessels of opportunity that may not support the more involved integrations of non-autonomous systems.

Autonomous Surface Vehicle: Offshore

A single offshore ASV system was deployed during the current project scope: Ocean Infinity's C-Worker 8 with integrated MBES and INS instruments. The vehicle itself proved a versatile and reliable platform capable of operating in open-lakes in calm to moderate weather. Daily operations were comprised of multi-hour deployments involving several kilometers of transit, then hours of online operations, followed by several kilometers of return transit. Throughout, the vehicle was shadowed by a surface vessel. The C-Worker 8 was capable of sustaining daily operations and would generate the same online production in terms of survey data recording as a crewed vessel with similar equipment. This platform, therefore, would make an excellent force multiplier for crewed vessel operations or an effective tool as a standalone system for coverage-based exploratory mapping and identification of cultural resource sites. Data thus generated could be used for myriad other scientific applications, such as hydrography and benthic mapping. Likewise, consideration for additional or alternative sensors on this platform, such as side-scan sonar, interferometric sonar, or sub-bottom profilers could also be valuable in an archeological survey context.

Technical issues experienced with the C-Worker 8 system during the present survey stemmed mainly from software settings and operational procedures. Lessons learned from these issues would include verification of project geodesy during setup and mobilization, establishment of file logging procedures to ensure simultaneous writing of INS and sonar files, implementation of online logs as well as QA/QC and field processing logs, and also a procedure for selected verification of field data to ensure all file parameters align with end-user needs (for example, format of multibeam backscatter records).

Such issues, however, are not unique to an ASV platform; they can (and do) occur on crewed vessels alike. Direct physical interface with survey hardware, however, is much more limited while operating an ASV offshore. Immediate intervention while online may not be possible, but above procedures could be implemented on a daily or recurring bases coinciding with data downloads and platform servicing in port. Nonetheless, the ASV implementation in the context of exploration and testing demonstrated the value of this tool as a platform for cultural resource investigations.

Autonomous Surface Vehicle: Nearshore

Autonomous systems were also evaluated and multiple platforms were deployed. These were the portable ASV systems deployed in inshore, riverine, and coastal environments. They included the EchoBoat 160, EchoBoat 240, and EMILY, with each unit integrating slightly different sonar payloads. As small, portable systems they were particularly limited by offshore wave state. Exposure to elevated weather conditions contributed to flooding onboard the EchoBoat 240 during its first deployment in WI, thereafter being non-useable for survey operations for the remainder of the project.

During New York operations, site conditions were not amenable to use of the EchoBoat 160. As a result, the EMILY ASV and RV *Dogfish* were used to conduct localized side scan sonar surveys. The onboard Humminbird sonar systems on each of these platforms both suffered a firmware issue; while the RV *Dogfish* was also running the EdgeTech (thus resulting in a complete dataset), the files collected with the EMILY ASV during surveys adjacent to Stony Island, Stony Point, and within Sackets Harbor were corrupted. A more detailed explanation is presented in Appendix D. Humminbird Data Visualization. These areas were not resurveyed.

As a mitigation, similar sonar payloads—notably the EdgeTech and Humminbird sonar systems—were installed on crewed vessels to supplement online production. In New York, survey coverage via crewed vessel surpassed that accomplished by portable ASV. While ASV portability was useful across the scope of project geographies including beach and riverine environments, their sensitivity to weather conditions on the broader lakes limited their output. Working in tandem with small crewed vessels appeared to yield the best results.

Discrepancies from the Cruise Plan

Overall, the AUV survey, UAV survey, and the outreach events met the spirit and intent outlined in the initial cruise plan. There were, however, discrepancies from the initial cruise plan regarding ASV operations. Given the constraints of the C-Worker 8, the offshore ASV multibeam sonar coverage was significantly less than anticipated in both Wisconsin and New

York owing to the combined issues mentioned previously. As this project inherently involved the use of many platforms and technologies, there were bound to be challenges both from the systems and other operational constraints (weather, transportation, vessel support) which required the team members to collectively adjust to throughout the high tempo field campaign. As staff lacked the planned MBES coverage, there were not targets of interest available for AUV deployments. Instead, AUV dives were conducted over known sites or suspected sites.

The latter deployment occurred in New York and was enhanced through recommendations of local shipwreck diver Mr. Gildea. Mr. Gildea provided approximate coordinates based on his personal experience. While not all coordinates yielded archaeological findings, in two instances, the approximate locations were preliminarily surveyed with the hull-integrated Raymarine sonar aboard MV *Troublemaker* to determine an approximate location of historical materials. An AUV survey was then conducted at the location identified by the hull-integrated system. As such, combination of constituent knowledge, easy to use recreational sonar systems, and the professional survey-grade Iver3 AUV resulted in enhanced survey efforts.

The second discrepancy from the cruise plan was the inclusion of the Chasing M2 ROV into project work. Originally, the team did not anticipate collecting ROV data on shipwreck sites. Participation of additional project personnel, however, led to its incorporation which ultimately enhanced final data products. The ROV footage, recorded in ultra-high definition 4K resolution, will support assessment of archaeological integrity within the study areas.

Finally, the last discrepancy from the cruise plan involved the planned diversity and inclusion activities. Unfortunately, continuation of the COVID-19 pandemic and associated agency health and safety guidelines prohibited direct engagement with members of the public as planned in the project proposal.

Recommendations

It is highly recommended that additional visual survey and/or archaeological testing be conducted on the magnetometer anomaly and contact sites identified during project operations. In addition, several sites in New York should be further investigated for their archaeological potential and NRHP eligibility. While it is outside the scope of work for this project to pursue a National Register nomination, recommendations will be made to sanctuary staff in Wisconsin and New York to pursue these nominations.

Planned Publications

This report serves as the official record of field operations and findings. In addition, project personnel presented the preliminary results of this survey, with an emphasis on the technological footprint, at the Lakebed 2030 Conference (29 September-1 October 2021) hosted by the NOAA Office of Coast Survey.

Project personnel are considering several technological publications related to project methodology. No archaeological publications are planned. As such, this report serves to disseminate project findings through the academic community. A similar dissemination of geospatial data is planned through use of an ArcGIS story map that would be publicly accessible and hosted through the NOAA GIS server. The UM team is considering publication options based on the numerous tools integrated for use during the survey. The UD team is considering publication on the coordinated integration of the AUV, small ASVs, and ROV focused on operational lessons learned and fusion of sonar and optical data for a field robotics journal. There is also interest in publishing details on the challenges and data processing solutions worked on for the C-Worker data. Finally, the Marine Magnetics lead team may wish to publish on the field testing of the diver-held magnetometer that was utilized in the project.

Limitations and Challenges

Field operations were largely focused on remote sensing. As such, the limitations and challenges encountered during the project all impacted remote sensing surveys; these are broadly categorized here as technical difficulties, weather delays, and 'other.' Technical difficulties were issues directly related to the performance of scientific equipment in use during exploration activities. Weather delays were periods of meteorological conditions that prohibited on-water activities. 'Other' challenges were situations germane to field deployment of new or prototype technology. Impacts from each of these challenges affected the rate of online production and proliferated delays which required the deployment of additional survey platforms to maintain progress of data acquisition within the study areas. Each challenge is discussed in further detail below.

Technical Difficulties

During the fieldwork, project personnel did experience, and in many cases overcame, technical difficulties with both the survey platforms and survey instruments. In Wisconsin, use of the UAV at a new site with a background magnetic gradient that differed from previous projects required in-field tailoring of the sensor orientation and tweaking of the drone body orientation for optimal results. In order to streamline the on-site platform tuning, Marine Magnetics personnel collaborated with GEM Systems to design and deploy a radio link system that allowed for live streaming of the magnetometer data to the shore station. This radio link enables real-time monitoring of sensor measurements and key parameters while in flight, saving valuable field time. As is often the case with new technology, some in-field experimentation was required to establish a proven workflow for robust and error free data collection and backup. Lessons learned during the Wisconsin phase of the project resulted in an improved workflow for New York field operations. As such, the quality of collected aerial magnetometer data dramatically increased over the course of field operations.

Regarding the autonomous surface and underwater vehicles provided by University of Delaware, it was discovered shortly after arrival that the magnetometer power supply within the Iver3 AUV was out of commission due to internal damage from a previous field project during testing with Marine Magnetics of a new experimental cable. The magnetometer itself proved unaffected and was subsequently used on the project. As a result, the AUV instruments were unable to tow the magnetometer, but were still able to proceed with data collection from a suite of integrated systems including the side-scan sonar, swath bathymetry, sound speed, temperature, and the integrated camera. In addition to the AUV, University of Delaware personnel also experienced operational issues with an EchoBoat 240 ASV provided by Seafloor Systems for project use. During initial testing and preliminary data collection of the EchoBoat 240 and magnetometer (integrated during the project with the help of Marine Magnetics), lake water intrusion into the ASV body created an electrical short in the propeller. As a result, the EchoBoat 240 was not used to collect data for the duration of field operations but was used in outreach events and for a technical demonstration.

During New York operations, site conditions were not amenable to use of the EchoBoat 160. As a result, the EMILY ASV and RV *Dogfish* were used to conduct localized side-scan sonar surveys. The onboard Humminbird sonar systems on each of these platforms both suffered a firmware issue; while the RV *Dogfish* was also running the EdgeTech (thus resulting in a complete dataset), the files collected with the EMILY ASV were corrupted and these areas were not resurveyed.

Initially, the project team proposed to conduct AUV and C-Worker 8 ASV operations simultaneously from the R*3012*. Unfortunately, this was not possible due to the small vessel size, requisite equipment for each system, and personnel limitations. In addition to the above difficulties with instruments and survey platforms, the GLERL vessel R*3012* did experience a hardware malfunction while transiting back to shore after AUV operations. A damaged blade on one of the propellers required a replacement. This process removed R*3012* from service for two days. During this period, the field teams focused efforts on survey operations that could be conducted from shore stations or RV *Dogfish*.

Weather

Weather did negatively impact field operations. In Wisconsin, the very exposed nature of the nearshore survey environment resulted in the team having to carefully pick weather windows for both the UAV and smaller ASVs. The UAV operations were limited to wind speeds less than 7.8 m/s and could not be operated in the rain. Similarly, the smaller ASV systems provided by University of Delaware, too, were limited by sea state. The smaller EMILY and EchoBoat 160 ASVs were not operational in seas greater than 0.45 m. As the AUV and ASVs required open deck space or beachfront to operate, they could not be operated during periods of thunder or lightning. Overall, 5 days of UAV survey were lost due to weather—3 in Wisconsin and 2 in

New York. The ASV/AUV surveys by University of Delaware staff lost 2 operational days to inclement weather—1 in Wisconsin and 1 in New York. On the other hand, the much larger C-worker ASV could work in a more challenging sea state and is designed to reliably acquire sonar data in up to 1.2 m waves.

Other Challenges

This project constituted one of the first deployments of a C-Worker ASV by Ocean Infinity in Great Lakes waters and several challenges were encountered. A trailer malfunction resulted in the ASV's delayed arrival in Wisconsin, and while the platform arrived operational, a new acquisition software was being implemented which caused some delays in the startup. This was ultimately deemed not adequate for operations even with the best efforts from CARIS support being on site. OI reverted to using the original EIVA software installed. Delays from the transit, platform mobilization, and radio telemetry licensing conflicts impacted completion of scheduled mapping tasks in the Wisconsin study area.

Regarding the C-Worker's mobilization, the ASV team was intending to test a new CARIS Onboard 360 software program designed to process data in real time, thus simplifying technical aspects of multibeam data processing and assessment. Ultimately, despite participation of a software company representative, the program would not operate properly. This required the ASV team to revert to a different method of online data acquisition more consistent with their normal operating procedures. Having to revert software programs, however, cost the team time and contributed to the operators overlooking geodetic settings required for the project survey area. As a result, sonar data recorded by the C-Worker system did not use the correct geodetic settings for the study area.

Likewise, unexpected troubleshooting and in-field tuning of the systems left little time for onsite and real time data QA/QC. None of the sonar data recorded in the field was verified during mapping operations. This led to significant downstream impacts on final data products as the field team was not made aware of the geodetic issues nor the requirement to collect regular water column sound velocity casts during data acquisition.

Additionally, during initial operation in Wisconsin, C-Worker ASV operators were informed that the programmed frequency used by the C-Worker 8 radio beacon was restricted by the FCC due to that frequency being shared with some medical devices. Operations in Wisconsin were immediately terminated. A replacement beacon, using a separate frequency, was provided and the vehicle went back online in New York.

Delays due to transit, mobilization, and radio equipment compliance prevented the C-Worker ASV from recording any data in the Wisconsin study areas. The system was only operational in the Lake Ontario study area. However, review of raw data files collected by the C-Worker in post processing revealed substantial data quality issues related to geodesy, the lack of appropriate sound velocity corrections, and sensor noise while online. Acquired MBES data was reviewed to the fullest extent possible in terms of identifying signatures and targets representing potential cultural resources; none were found. While the derived bathymetry data was not to a high enough quality required for specific end user applications like hydrography, it was still valuable as an exploration tool. Moreover, lessons learned in terms of testing, calibration, and online field procedures will be carried forth into all future surveys performed in this manner.

Data Management and Data Sharing

This project generated approximately 750 GB of data, including reports, imagery, raw, and processed geophysical survey data, and geospatial data. All digital data produced during this project will be archived through the NOAA National Centers for Environmental Information. Records of archaeological findings will be shared with the State Historic Preservation Offices of Wisconsin and New York. The project PIs will maintain a copy of the digital data archive at ONMS and a physical backup of the digital archive will be stored on the NOAA campus in Silver Spring, MD.

As physical scientific samples were not collected during this expedition, no physical project materials will be archived or stored. Similarly, only expendable equipment was purchased with the budget. As such, no equipment has been inventoried by NOAA for permanent ownership.

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Appendix A. Underwater Photography Log

By: Joseph Hoyt, NOAA

NOAA Maritime Heritage Program Office of National Marine Sanctuaries Project: __OER21 Great Lakes Survey, Wisconsin__________			**Photographer:** Joe Hoyt **Page _1_ of _1_**	**Camera Make/Model:** Nikon D4 **Serial:** 2029895
Frame	**Date**	**Digital #**	**Description of Photograph (subject, orientation, scale)**	
1	2 August 2021	_DSC4787-_DSC4967	Photographs of the S.C. Baldwin shipwreck site. Images were taken to create a photomosaic. No scale.	
2	2 August 2021	_DSC4968-_DSC5027	Photographs of the S.C. Baldwin shipwreck site. Photos are sequential for creation of a photomosaic of the steam machinery. Image orientation varies. Diver is 6.5 feet for scale.	
3	2 August 2021	_DSC4928-_DSC5087	Photographs of the S.C. Baldwin shipwreck site. Photos are sequential for creation of a photomosaic of the vessel bow and structure. Image orientation varies. Diver is 6.5 feet for scale.	

NOAA Maritime Heritage Program Office of National Marine Sanctuaries Project: __OER21 Great Lakes Survey, New York__________			**Photographer:** Joe Hoyt **Page _1_ of _1_**	**Camera Make/Model:** Nikon D4 **Serial:** 2029895
Frame	**Date**	**Digital #**	**Description of Photograph (subject, orientation, scale)**	
1	12 August 2021	_DSC5161-_DSC5208	Photographs of the shipwreck site *A.E. Vickery* taken in the St. Lawrence River. Orientation varies. Diver measures approximately 2.1m.	
2	12 August 2021	_DSC5211-_DSC5788	Photographs of the shipwreck site *L'Iroquoise* taken in the St. Lawrence River. Orientation varies. Scale bar is 1m.	
3	13 August 2021	_DSC5798-_DSC5952	Photographs of the shipwreck site *Maggie L.* taken in the St. Lawrence River. Orientation varies. Diver measures approximately 2.1m.	
4	16 August 2021	_DSC5960-_DSC6055	Photographs of the shipwreck site *Keystorm* taken in the St. Lawrence River. Orientation varies. Diver measures approximately 2.1m.	
5	16 August 2021	_DSC6060-_DSC6130	Photographs of the shipwreck site *America* taken in the St. Lawrence River. Orientation varies. Diver measures approximately 2.1m.	

Appendix B. Detailed Workflow for Magnetometer Final Data Processing and Confidence Modeling

By: John Bright, NOAA

Oasis Montaj File Import and Project Setup

Preliminarily processed field data files, generated by Marine Magnetics BOB/BAM from Wisconsin and New York operations were imported into separate Oasis Montaj projects to account for the different geodetic systems in use at each location. These projects were named as follows

202103_MHP_OER_Benthic_Survey_WI
202103_MHP_OER_Benthic_Survey_NY

Slight variations existed between some of the supplied ASCII files. These were partly accounted for by the differences between aerial and marine magnetometer configurations necessitating slightly different raw file fields. For example, the marine magnetometer did not have an altimeter while the aerial system recorded height above water as an altitude measurement. Another variation occurred due to inconsistent availability of base station magnetometer data. When available, base station corrections were applied and relevant fields in the raw files populated with their respective values. Due to these minor variations, not all raw files conformed to a single raw file schema.

Semi-automated processing within Oasis Montaj using user-developed scripts required a standardized database schema. To satisfy this requirement, a uniform schema was established upon import into Oasis Montaj. Where values were present in certain fields, they were carried into the program. Where these values were missing, such as altitude values in the marine magnetometer files, non-numerical dummy values (*) were applied during Oasis Montaj import.

An important note: The Oasis Montaj software program uses the term “Channel” to refer to a database field commonly termed a “Column.” Likewise, the program assigns each database row a fiducial (FID) marker. Imported data is split into “Lines” much like separate database sheets that demarcate the geospatial extent of applied signal processing functions. Henceforth, the appropriate Oasis Montaj terms will be utilized while describing the final processing workflow.

In addition to the import file schema, a project directory was also established to standardize the organization of all associated files. This directory is defined in Table 31. Raw files imported into Oasis Montaj were copied into the 4_Data folder. All files produced during final processing, including the database, grids, and maps, also had designated folders. Exported products were likewise organized and saved. Establishing this directory enabled parity and uniformity between the WI and NY projects. It also allows the entire folder to be compressed and sent as a single file archive to other uses as needed.

Table 31. Standardized Oasis Montaj project directory established for the WI and NY magnetometer data processing.

Folder	Subfolder	Contents
1_Database		Oasis Montaj database files (.GDB) created during ASCII raw file import
2_Grids	GRID_DELIVERABES	Gridded results converted to .FLT format
	GRID_TEMP	Gridded results in Oasis Montaj .GRD format
3_Maps		Display map created in Oasis Montaj for previewing results
4_Data	Boat	Raw marine magnetometer files
	UAV	Raw aerial magnetometer files
5_Export	01_Proc	CSV file exported with all fields from final GDB results
	02_Anomalies	Identified magnetic anomalies in SHP format, XLS and XLSX table formats, georeferenced PDF format, and reference screen grabs.
	03_Tracklines	Processed track lines in SHP format
6_Background_Data		Background data, such as nautical charts, used within the Oasis Maps
7_Color_Bar		Color bar files for viewing residual anomaly and altitude results.
8_Script		Processing scripts developed for project workflow
10_Import_Templates		Template files saved to convert raw aerial and marine mag files to Oasis GDB
11_Database_Views		Saved working database views used for data review during processing and written into scripts.
202103_MHP_OER_Benthic_Survey_MAG_##.gpf (Oasis Montaj project file)		

Oasis Montaj Database Schema

All channels (fields) established within the Oasis Montaj final processing project are defined in Table 32 below. Channels highlighted in grey were those generated during the Oasis Montaj processing workflow. All other channels were direct imports of information within the ASCII files produced by BOB/BAM. When fields were missing among the raw files, such as sensor altitude for the marine magnetometer, they were dummied with a * character during import.

Once import of raw ASCII files was completed for the WI and NY datasets, as a series of five automated processing scripts were run to clean navigation data, review signal quality and altitude information, filter the total field signal, and generate final grids for assessment.

Table 32. Oasis Montaj database (GDB) schema for aerial and marine magnetometer data when imported for final processing[1]. This nomenclature was only used in the WI Oasis Montaj Project; in the NY DB it was shortened to Magnetic_Field[2]. This field was only utilized in the WI Oasis Montaj project but was not necessary in the NY datasets.

Channel	Description	Unit/Format
Mag_Easting	Corrected nav for mag sensor computed in BOB	meters (m)
Mag_Northing	Corrected nav for mag sensor computed in BOB	meters (m)
Reading_Date	Sample date	yyyy/mm/dd
Reading_Time	Sample time, UTC	hh:mm:ss.sss
Magnetic_Field_RAW[1]	Total field reading captured by UAV mag sensor	nanotesla (nT) or dummy
Magnetic_Field_PROC[2]	Total field corrected after leveling in BOB	nanotesla (nT) or dummy
Magnetic_Field_CORR	Corrected total field reading exported from BOB	nanotesla (nT)
Magnetic_Field_Bulk_Shifted	Intermediary correction generated in BOB	nanotesla (nT) or dummy
Magnetic_Field_FullLev	Refined correction exported from BOB, as needed	nanotesla (nT) or dummy
Altitude	Sensor or UAV GNSS altitude above water	centimeters (cm) or dummy
Signal_Strength	Raw measurement strength	microvolt (µV)
Base_Station_Correction	Difference sensor total field record and base station total field record	nanotesla (nT)
Bulk_Correction	Fixed correction applied to sensor data to compensate for constant-magnitude offsets due to sensor heading	nanotesla (nT) or dummy
Base_Mag_Field	Raw value recorded by deployed fixed total field sensor	nanotesla (nT)
Mag_Latitude	Corrected navigation for UAV mag sensor	decimal degrees (dd.dddddd)
Mag_Longitude	Corrected navigation for UAV mag sensor	decimal degrees (dd.dddddd)
Mag_Position_Change	What does this value represent?	Units?
GPS_Latitude	Raw UAV navigation	decimal degrees (dd.dddddd)
GPS_Longitude	Raw UAV navigation	decimal degrees (dd.dddddd)
GPS_Easting	Raw UAV navigation	meters (m)
GPS_Northing	Raw UAV navigation	meters (m)
GPS_Position_Change	What does this value represent?	Units?
X_Smth	Filtered sensor navigation	meters (m)
Y_Smth	Filtered sensor navigation	meters (m)
Dist_RAW	Cartesian distance between raw navigation points	meters (m)
Dist_Smth	Cartesian distance between filtered navigation points	meters (m)
X_ToRemove	Copied navigation into channel for blanking based on QA/QC criteria	meters (m)
Y_ToRemove	Copied navigation into channel for blanking based on QA/QC criteria	meters (m)
Magnetic_Field_PROC	Merged total field data channel copied from various import file formats	nanotesla (nT)
Mask_Mag_DS	Copied magnetic data channel manual cleaning or blanking based on QA/QC criteria	Nominal (1.0 or dummy)

nT_DS	Total field mag data, despiked	nanotesla (nT)
nT_DS_Intp	Total field mag data, despiked and interpolated across any small gaps	nanotesla (nT)
nT_DS_Intp_BG	Background signal computed from cleaned total field data	nanotesla (nT)
nT_Residual	Residual anomaly signal from difference of background and cleaned total field channels	nanotesla (nT)
nT_DS_Intp_BG_GEO	Background geological signal computed from cleaned total field data	nanotesla (nT)
nT_Residual_Geo	Residual geology signal from difference of geological background and cleaned total field data	nanotesla (nT)

Processing Scripts

The following automated scripts were implemented within the Oasis Montaj project to standardize all remaining processing tasks. This reduced the time required to accomplish results and prevented errors during intermediary steps. Standardized database schema, outlined above, facilitated script application by ensuring consistency in channel names and data formats.

Due to initial technical issues, additional processing was required on aerial magnetometer data files recorded in WI between 31 July and 2 August. These files required extra cleaning, shifts and leveling completed in the BOB/BAM interface as well as testing on correction methods in Oasis Montaj. To accommodate, an additional channel was added in the WI GDB called *Magnetic_Field_PROC*. This channel featured the preliminary processed data ready for final processing in Oasis Montaj.

Subject technical issues were resolved by 5 August, at which point preliminary processed results resided in the *Magnetic_Field_CORR* channel. To facilitate a streamlined, automated processing task within the WI dataset, all the values from 5 August and after were copied to the *Magnetic_Field_PROC* channel. Scripts used for the WI dataset ready total field values from this channel. All processing of the NY dataset, however, ready total field values from the *Magnetic_Field_CORR* channel.

1. Single_Mag_NAV-Process

This was the first script performed, used to clean navigation data and establish new channels of cleaned navigation data so the raw channels remained unaffected. Overview of the script is provided in Table 33 and stepwise description thereafter.

Table 33. First Oasis Montaj script, used for navigation cleaning.

Order	Purpose	Tasks	Output
First	Refine navigation data by despiking, interpolating across gaps, and smoothing	Copy channels, despike, dummy repeats, interpolate gaps, smooth with rolling statistics	X_Smth channel Y_Smth channel

	Create raw and processed distance channels based on cartesian distance between sample points	Use X and Y navigation channels to calculate distance between sequential sample points	Dist_RAW channel Dist_Smth channel
	Create masking channels for later use to blank data failing QA/QC criteria	Copy XY channels to new field for use in expression builder	X_ToRemove channel Y_ToRemove channel

I. Copy X,Y position channels into new channel for editing.
Channel *Mag_Easting* processed into new channel *X_Smth*
Channel *Mag_Northing* processed into new channel *Y_Smth*

```
SETINI    COPY.FROM="Mag_Easting"
SETINI    COPY.TO="X_Smth"
SETINI    COPY.DECIMATE="1"
SETINI    COPY.FIDSTART=""
SETINI    COPY.FIDINCR=""
GX        copy.gx

SETINI    COPY.FROM="Mag_Northing"
SETINI    COPY.TO="Y_Smth"
SETINI    COPY.DECIMATE="1"
SETINI    COPY.FIDSTART=""
SETINI    COPY.FIDINCR=""
GX        copy.gx
```

II. Create raw distance channel based on cartesian distance between sequential data points.

```
SETINI    DISTCHAN.USE_CARTESIAN="0"
SETINI    DISTCHAN.X="Mag_Easting"
SETINI    DISTCHAN.Y="Mag_Northing"
SETINI    DISTCHAN.Z=""
SETINI    DISTCHAN.OUT="Dist_RAW"
GX        geogxnet.dll(Geosoft.GX.Database.DistanceChannel;Run)
```

III. Dummy any repeat positions in the *X_Smth* and *Y_Smth* channels

IV. Interpolate over the dummy repeats

```
SETINI    DUMREP.CHANNEL="Y_Smth"
SETINI    DUMREP.METHOD="0"
GX        dumrep.gx

SETINI    DUMREP.CHANNEL="X_Smth"
SETINI    DUMREP.METHOD="0"
GX        dumrep.gx

SETINI    INTERP.GAP=""
SETINI    INTERP.EXTEND="3"
SETINI    INTERP.IN="X_Smth"
SETINI    INTERP.OUT="X_Smth"
SETINI    INTERP.METHOD="Linear"
SETINI    INTERP.EDGE="3"
GX        geogxnet.dll(Geosoft.GX.Database.InterpolateChannel;Run)

SETINI    INTERP.GAP=""
SETINI    INTERP.EXTEND="3"
```

```
SETINI    INTERP.IN="Y_Smth"
SETINI    INTERP.OUT="Y_Smth"
SETINI    INTERP.METHOD="Linear"
SETINI    INTERP.EDGE="3"
GX        geogxnet.dll(Geosoft.GX.Database.InterpolateChannel;Run)
```

V. Despike and smooth navigation with Rolling Statistics on each channel

```
SETINI    ROLLINGSTATS.IN="X_Smth"
SETINI    ROLLINGSTATS.OUT="X_Smth"
SETINI    ROLLINGSTATS.STATISTIC="6"
SETINI    ROLLINGSTATS.WIDTH="50"
SETINI    ROLLINGSTATS.SHRINK="1"
GX        rollingstats.gx

SETINI    ROLLINGSTATS.IN="Y_Smth"
SETINI    ROLLINGSTATS.OUT="Y_Smth"
SETINI    ROLLINGSTATS.STATISTIC="6"
SETINI    ROLLINGSTATS.WIDTH="50"
SETINI    ROLLINGSTATS.SHRINK="1"
GX        rollingstats.gx
```

VI. Create smoothed distance channel based on cartesian distance between sequential navigation points (use this channel as X-axis value in profile view to review data)

```
SETINI    DISTCHAN.USE_CARTESIAN="0"
SETINI    DISTCHAN.X="X_Smth"
SETINI    DISTCHAN.Y="Y_Smth"
SETINI    DISTCHAN.Z=""
SETINI    DISTCHAN.OUT="Dist_Smth"
GX        geogxnet.dll(Geosoft.GX.Database.DistanceChannel;Run)
```

2. Single_Mag_SET_XY

This was the second script performed, used to clean navigation data and establish new channels of cleaned navigation data so the raw channels remained unaffected. Overview of the script is provided in Table 34 and stepwise description thereafter.

Table 34. Second Oasis Montaj script, used to define the coordinate reference system and X,Y channels within the GDB.

Order	Purpose	Tasks	Output
Second	Set the defined X and Y position channels for projecting and mapping data	Set XY coordinates, define DB coordinate reference system	X_Smth and Y_Smth set as defined position channels, WGS84 UTM 16N (WI) or 18N (NY) set at projection system.

VII. Run the script to define the channels used for navigating, projecting, and mapping data. Set coordinate system to project geodesy. Confirm results via information shown in Figure 53.

```
SETINI    SETCHPRJ.X="X_Smth"
SETINI    SETCHPRJ.Y="Y_Smth"
```

```
SETINI      SETCHPRJ.SETCURRENTXY="1"
SETINI      IPJSET.S1PCS="\"WGS 84 / UTM zone 16N\""
SETINI      IPJSET.S2PCS="\"WGS 84\",6378137,0.0818191908426215,0"
SETINI      IPJSET.S3PCS="\"Transverse Mercator\",0,-87,0.9996,500000,0"
SETINI      IPJSET.S4PCS="m,1"
SETINI      IPJSET.S5PCS="\"WGS 84\",0,0,0,0,0,0,0"
SETINI      IPJSET.S1NONE="*unknown"
SETINI      IPJSET.S2NONE=""
SETINI      IPJSET.S3NONE=""
SETINI      IPJSET.S4NONE="m,1"
SETINI      IPJSET.S5NONE=""
SETINI      IPJ.NAME="\"WGS 84 / UTM zone 16N\""
SETINI      IPJ.DATUM="\"WGS 84\",6378137,0.0818191908426215,0"
SETINI      IPJ.METHOD="\"Transverse Mercator\",0,-87,0.9996,500000,0"
SETINI      IPJ.UNITS="m,1"
SETINI      IPJ.LOCALDATUM="\"WGS 84\",0,0,0,0,0,0,0"
GX          setchprj.gx

SETINI      LOADDBVU.FILE=".\\11_Database_Views\\202103_NavProcess_Review.dbview"
GX          loaddbvu.gx
```

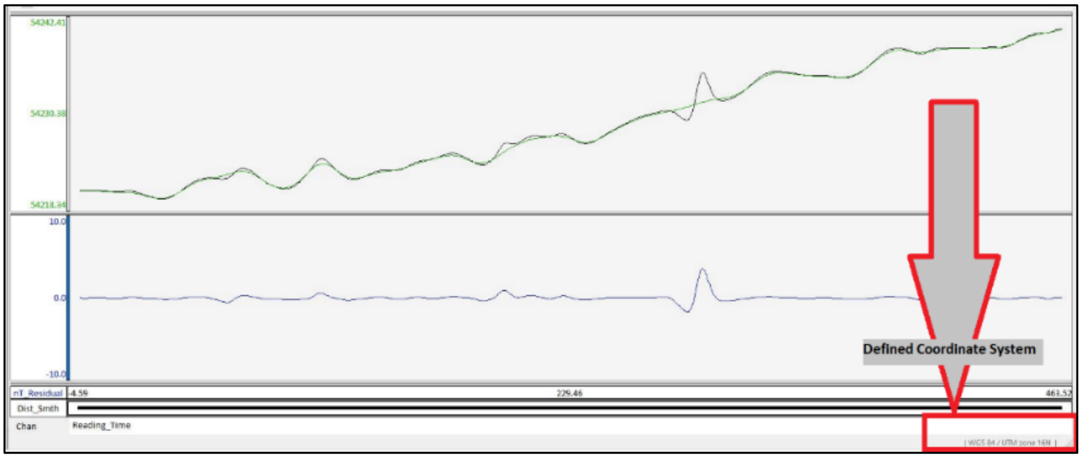


Figure 53. Means of verifying correct project parameters and selection of navigation channels in Oasis Montaj DB view. Image: NOAA.

3. Single_Mag_SignalQ

This was the third script performed, used to establish QA/QC checks related to signal quality. Overview of the script is provided in Table 35 and stepwise description thereafter.

Table 35. Third Oasis Montaj script, used to implement assessment of signal quality to identify records where signal strength dropped below 80 µV.

Order	Purpose	Tasks	Output
Third	Applies a signal quality query to identify any signal quality dropouts and update the X and Y position masking channels for blanking data	Apply expression builder query to populate the XY QC channels when Signal_Strength value drops below 80 µV	Updated X_ToRemove channel Updated Y_ToRemove channel

VIII. Run the script and review profile views of Signal_Strength versus X_ToRemove and Y_ToRemove channels (in two separate profile windows). Check that Dist_Smth is defined as the X-Axis value in each window (Not Fiducial [FID])

```
SETINI    MATHEXPRESSIONBUILDER.CHANNELINPUTBOX="C0 = (C1>=80) ? (C2) : (DUMMY);"
SETINI    MATHEXPRESSIONBUILDER.CHANNELEXPRESSIONFILE=""
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID0="C2"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE0="X_ToRemove"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID1="C0"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE1="X_ToRemove"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID2="C1"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE2="Signal_Strength"
SETINI    MATHEXPRESSIONBUILDER.CHANNELNUMSTORED="3"
SETINI    MATHEXPRESSIONBUILDER.CHANNELTRIGUNITS="Radians"
GX        geogxnet.dll(Geosoft.GX.MathExpressionBuilder.MathExpressionBuilder;RunChannel)

SETINI    MATHEXPRESSIONBUILDER.CHANNELINPUTBOX="C0 = (C1>=80) ? (C2) : (DUMMY);"
SETINI    MATHEXPRESSIONBUILDER.CHANNELEXPRESSIONFILE=""
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID0="C2"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE0="Y_ToRemove"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID1="C0"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE1="Y_ToRemove"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID2="C1"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE2="Signal_Strength"
SETINI    MATHEXPRESSIONBUILDER.CHANNELNUMSTORED="3"
SETINI    MATHEXPRESSIONBUILDER.CHANNELTRIGUNITS="Radians"
GX        geogxnet.dll(Geosoft.GX.MathExpressionBuilder.MathExpressionBuilder;RunChannel)
```

4. Single_Mag_nT-Process

This was the fourth script performed; it was used to process the total field magnetic data record and derive a residual anomaly channel. Overview of the script is provided in Table 36 and stepwise description thereafter.

Table 36. Fourth Oasis Montaj script, used to clean the total field channel, determine a background signal, difference the cleaned total field and background to produce a residual anomaly signal, then calculate a residual geology channel to visualize long-wavelength signals in the total field record.

Order	Purpose	Tasks	Output
Fourth	Copy magnetic data values to processing channel and manual mask channel	Copy channel	nT_DS channel Mask_MAG_DS channel
	Despike (DS) total field values	Apply min/max expression builder query (47500 to 57500 nT) to reject high/low values	nT_DS channel
	Interpolate (Intp) gaps remaining after DS, 10 fids max	Interpolate nT values across any gap 10 values or less	nT_DS_Intp channel
	Smooth DS, Intp channel with B-spline filter	B-Spline filter, set at 0.6 smoothness and 1.0 tension	
	Use x4 nonlinear filters to generate background (BG) signal channel		nT_DS_Intp_BG channel

	Use rolling stats to smooth BG field		
	Calculate residual anomaly channel		nT_Residual channel
	Use x1 nonlinear filter and B-Spline filter to generate background geological channel		nT_DS_Intp_BG_Geo
	Calculate residual geology channel		nT_Residual_Geo

IX. Copy the total field magnetic data channel for processing and manual masking
Channel *Magnetic_Field_PROC** copied to *nT_DS*
Channel *Magnetic_Field_PROC** copied to *Mask_MAG_DS*

```
SETINI     COPYMASK.FROM="Magnetic_Field_PROC"
SETINI     COPYMASK.TO="nT_DS"
SETINI     COPYMASK.MASK="Mask_MAG_DS"
GX         copymask.gx
```

*NOTE: this channel was selected for the WI data records. In the NY dataset, the *Magnetic_Field_CORR* was copied into the *nT_DS* and *Mask_MAG_DS* channels.

X. Apply a despike filter to remove any total field readings below 47500 and 57500 nT. These thresholds can be changed by the user.

```
SETINI     MATHEXPRESSIONBUILDER.CHANNELINPUTBOX="C0 = (C1<47500||C1>57500) ? (DUMMY) : (C0);"
SETINI     MATHEXPRESSIONBUILDER.CHANNELEXPRESSIONFILE=""
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDID0="C0"
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE0="nT_DS"
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDID1="MasterChannel"
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE1="Reading_Time"
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDID2="C1"
SETINI     MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE2="Magnetic_Field_PROC"
SETINI     MATHEXPRESSIONBUILDER.CHANNELNUMSTORED="3"
SETINI     MATHEXPRESSIONBUILDER.CHANNELTRIGUNITS="Radians"
GX         geogxnet.dll(Geosoft.GX.MathExpressionBuilder.MathExpressionBuilder;RunChannel)
```

XI. Interpolate across any gaps created by the previous step, provided they are ten readings or less; otherwise prolonged spike data will result in gap where no useable data is present (mark for infill if needed).

```
SETINI     INTERP.GAP=10"
SETINI     INTERP.EXTEND="1"
SETINI     INTERP.IN="nT_DS"
SETINI     INTERP.OUT="nT_DS_Intp"
SETINI     INTERP.METHOD="Linear"
SETINI     INTERP.EDGE="0"
GX         geogxnet.dll(Geosoft.GX.Database.InterpolateChannel;Run)
```

XII. Apply B-Spline filter to smooth the despiked and interpolated total field channel.

```
SETINI     BSPLINE.IN="nT_DS_Intp"
SETINI     BSPLINE.OUT="nT_DS_Intp"
SETINI     BSPLINE.SMOOTH="0.6"
SETINI     BSPLINE.TAU="1"
```

```
GX          bspline.gx
```

XIII. Calculate a background signal channel via application of x4 nonlinear filters to the cleaned total field record. Resulting channel is then smoothed via a rolling statistics filter. Nonlinear filter width and tolerance can be adjusted per noise level in the total field record. Script below shows values used in WI. Area of operations in NY exhibited increased geological signals, thus nonlinear filter windows were reduced to [10;1.0], [5;0.5], [2;0.025], and [1; 0.0125]

```
SETINI      UXO_REMOVE_BACKGROUND.INPUT_CHANNELS="nT_DS_Intp"
SETINI      UXO_REMOVE_BACKGROUND.SUBTRACT_BACKGROUND="0"
SETINI      UXO_REMOVE_BACKGROUND.INPUT_CHANNELS="nT_DS_Intp"
SETINI      UXO_REMOVE_BACKGROUND.OUTPUT_CHANNEL_SUFFIX="BG"
SETINI      UXO_REMOVE_BACKGROUND.FILTER1="Non-Linear"
SETINI      UXO_REMOVE_BACKGROUND.FILTER2="Non-Linear"
SETINI      UXO_REMOVE_BACKGROUND.FILTER3="Non-Linear"
SETINI      UXO_REMOVE_BACKGROUND.FILTER4="Non-Linear"
SETINI      UXO_REMOVE_BACKGROUND.FILTER1_PARAMETERS="100;10.0"
SETINI      UXO_REMOVE_BACKGROUND.FILTER2_PARAMETERS="20;5.0"
SETINI      UXO_REMOVE_BACKGROUND.FILTER3_PARAMETERS="10;0.25"
SETINI      UXO_REMOVE_BACKGROUND.FILTER4_PARAMETERS="5;0.125"
INTERACTIVE    OFF
SETINI      NLFILT.IN="nT_DS_Intp"
SETINI      NLFILT.OUT="nT_DS_Intp_NLFILT_BG1"
SETINI      NLFILT.WIDTH="100"
SETINI      NLFILT.TOLERANCE="10.0"
SETINI      NLFILT.IN=""
SETINI      NLFILT.OUT=""
SETINI      NLFILT.WIDTH=""
SETINI      NLFILT.TOLERANCE=""
INTERACTIVE    OFF
SETINI      NLFILT.IN="nT_DS_Intp_NLFILT_BG1"
SETINI      NLFILT.OUT="nT_DS_Intp_NLFILT_BG2"
SETINI      NLFILT.WIDTH="20"
SETINI      NLFILT.TOLERANCE="5.0"
SETINI      NLFILT.IN=""
SETINI      NLFILT.OUT=""
SETINI      NLFILT.WIDTH=""
SETINI      NLFILT.TOLERANCE=""
INTERACTIVE    OFF
SETINI      NLFILT.IN="nT_DS_Intp_NLFILT_BG2"
SETINI      NLFILT.OUT="nT_DS_Intp_NLFILT_BG3"
SETINI      NLFILT.WIDTH="10"
SETINI      NLFILT.TOLERANCE="0.25"
SETINI      NLFILT.IN=""
SETINI      NLFILT.OUT=""
SETINI      NLFILT.WIDTH=""
SETINI      NLFILT.TOLERANCE=""
INTERACTIVE    OFF
SETINI      NLFILT.IN="nT_DS_Intp_NLFILT_BG3"
SETINI      NLFILT.OUT="nT_DS_Intp_NLFILT_BG4"
SETINI      NLFILT.WIDTH="5"
SETINI      NLFILT.TOLERANCE="0.125"
```

```
SETINI    NLFILT.IN=""
SETINI    NLFILT.OUT=""
SETINI    NLFILT.WIDTH=""
SETINI    NLFILT.TOLERANCE=""
GX       geocsusace_gxnet.dll(Geosoft.GX.CS.UXO.UxoRemoveBackground;Run)

SETINI    ROLLINGSTATS.IN="nT_DS_Intp_BG"
SETINI    ROLLINGSTATS.OUT="nT_DS_Intp_BG"
SETINI    ROLLINGSTATS.STATISTIC="6"
SETINI    ROLLINGSTATS.WIDTH="25"
SETINI    ROLLINGSTATS.SHRINK="1"
GX       rollingstats.gx
```

XIV. Calculate residual anomaly channel by differencing background channel from cleaned total field channel.

```
SETINI    MATHEXPRESSIONBUILDER.CHANNELINPUTBOX="C0 = c1 - c2;"
SETINI    MATHEXPRESSIONBUILDER.CHANNELEXPRESSIONFILE=""
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID0="c1"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE0="nT_DS_Intp"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID1="C0"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE1="nT_Residual"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID2="MasterChannel"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE2="Time"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID3="c2"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE3="nT_DS_Intp_BG"
SETINI    MATHEXPRESSIONBUILDER.CHANNELNUMSTORED="4"
SETINI    MATHEXPRESSIONBUILDER.CHANNELTRIGUNITS="Radians"
GX       geogxnet.dll(Geosoft.GX.MathExpressionBuilder.MathExpressionBuilder;RunChannel)
```

XV. Calculate geological background and residual using nonlinear filter and B-Spline filter to compute background, then differencing from cleaned total field to determine geological residual channel. Geological residual channel smoothed with rolling statistics filter.

```
SETINI    NLFILT.IN="nT_DS_Intp"
SETINI    NLFILT.OUT="nT_DS_Intp_BG_GEO"
SETINI    NLFILT.WIDTH="500"
SETINI    NLFILT.TOLERANCE="2"
GX       nlfilt.gx

SETINI    BSPLINE.IN="nT_DS_Intp_BG_GEO"
SETINI    BSPLINE.OUT="nT_DS_Intp_BG_GEO"
SETINI    BSPLINE.SMOOTH="1"
SETINI    BSPLINE.TAU="1"
GX       bspline.gx

SETINI    MATHEXPRESSIONBUILDER.CHANNELINPUTBOX="C0=C1-C2;"
SETINI    MATHEXPRESSIONBUILDER.CHANNELEXPRESSIONFILE=""
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID1="C0"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE1="nT_Residual_Geo"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID2="C1"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE2="nT_DS_Intp"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID3="C2"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE3="nT_DS_Intp_BG_GEO"
```

```
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDID5="MasterChannel"
SETINI    MATHEXPRESSIONBUILDER.CHANNELSTOREDVALUE5="Time"
SETINI    MATHEXPRESSIONBUILDER.CHANNELNUMSTORED="4"
SETINI    MATHEXPRESSIONBUILDER.CHANNELTRIGUNITS="Radians"
GX        geogxnet.dll(Geosoft.GX.MathExpressionBuilder.MathExpressionBuilder;RunChannel)

SETINI    ROLLINGSTATS.IN="nT_Residual_Geo"
SETINI    ROLLINGSTATS.OUT="nT_Residual_Geo"
SETINI    ROLLINGSTATS.STATISTIC="6"
SETINI    ROLLINGSTATS.WIDTH="10"
SETINI    ROLLINGSTATS.SHRINK="1"
GX        rollingstats.gx

SETINI    LOADDBVU.FILE=".\\11_Database_Views\\202103_nT_Comparison.dbview"
GX        loaddbvu.gx
```

5. Single_Mag_Gridding

This was the fifth and final script performed. It was used to process the total field magnetic data record and derive a residual anomaly channel. Overview of the script is provided in Table 37 and stepwise description thereafter

Table 37. Fifth Oasis Montaj script, used to automate the generation of two sets of gridded surfaces representing the processed total field and residual anomaly channel out to a 15m blanking distance as well as a direct gridded output of sensor altitude.

Order	Purpose	Tasks	Output
Fifth	Create direct grids for altitude and signal quality channels	Direct grid	Oasis Montaj GRD ArcGIS FLT
	Create interpolated continuous grids for total field and residual anomaly channels	Minimum curvature grid, cell size .5 m and blanking distance 15 m	Oasis Montaj GRD ArcGIS FLT
	Apply Blanking Distance to interpolated grids based on user-defined parameter for visualization coverage		

XVI. Generate Oasis Montaj grid files (GRD) for total field signal and residual anomaly signal using a minimum curvature gridding method. Cell size set at 0.5 m and blanking distance set at 15.0 m

```
Workspace: \Oasis_Montaj\202103_MHP_OER_Benthic_Survey_WI\2_Grids\GRID_TEMP
SETINI    RANGRID.LOCKED="0"
SETINI    RANGRID.RUNMODE="0"
SETINI    RANGRID.CHAN="nT_DS_Intp"
SETINI    RANGRID.GRID=".\\2_Grids\\GRID_TEMP\\202103_WI_TOT_UAV.GRD(GRD)"
SETINI    RANGRID.CS=""
SETINI    RANGRID.XY="0,0,0,0"
SETINI    RANGRID.LOGOPT="0"
SETINI    RANGRID.LOGMIN="1"
SETINI    RANGRID.DSF=""
SETINI    RANGRID.BKD="15"
SETINI    RANGRID.TOL=""
SETINI    RANGRID.PASTOL="99"
```

SETINI RANGRID.ITRMAX="100"
SETINI RANGRID.ICGR="16"
SETINI RANGRID.SRD=""
SETINI RANGRID.TENS="0"
SETINI RANGRID.EDGCLP=""
SETINI RANGRID.IWT="2"
SETINI RANGRID.WTSLP="0.0"
SETINI RANGRID.CHAN="nT_DS_Intp"
SETINI RANGRID.GRID=".\\2_Grids\\GRID_TEMP\\202103_WI_TOT_UAV.GRD(GRD)"
SETINI RANGRID.CS="0.5"
GX rangrid.gx

SETINI RANGRID.LOCKED="0"
SETINI RANGRID.RUNMODE="0"
SETINI RANGRID.CHAN="nT_Residual"
SETINI RANGRID.GRID=".\\2_Grids\\GRID_TEMP\\202103_WI_RES_UAV.GRD(GRD)"
SETINI RANGRID.CS=""
SETINI RANGRID.XY="0,0,0,0"
SETINI RANGRID.LOGOPT="0"
SETINI RANGRID.LOGMIN="1"
SETINI RANGRID.DSF=""
SETINI RANGRID.BKD="15"
SETINI RANGRID.TOL=""
SETINI RANGRID.PASTOL="99"
SETINI RANGRID.ITRMAX="100"
SETINI RANGRID.ICGR="16"
SETINI RANGRID.SRD=""
SETINI RANGRID.TENS="0"
SETINI RANGRID.EDGCLP=""
SETINI RANGRID.IWT="2"
SETINI RANGRID.WTSLP="0.0"
SETINI RANGRID.CHAN="nT_Residual"
SETINI RANGRID.GRID=".\\2_Grids\\GRID_TEMP\\202103_WI_RES_UAV.GRD(GRD)"
SETINI RANGRID.CS="0.5"
GX rangrid.gx

XVII. Generate direct gird or signal strength channel, cell size 0.5 m

Workspace: \Oasis_Montaj\202103_MHP_OER_Benthic_Survey_WI\2_Grids\GRID_TEMP
SETINI DIRECT_GRIDDING.DUMMY_ZEROS="1"
SETINI DIRECT_GRIDDING.CELL_SIZE="0.5"
SETINI DIRECT_GRIDDING.GRID=".\\2_Grids\\GRID_TEMP\\202103_WI_SIG_UAV.GRD(GRD)"
SETINI DIRECT_GRIDDING.CHANNEL="Signal_Strength"
SETINI DIRECT_GRIDDING.GRID_VALUE="2"
GX geogxnet.dll(Geosoft.GX.GridUtils.DirectGridding;Run)

XVIII. Convert all grids to ArcGIS FLT format for deliverable export.

Workspace: \Oasis_Montaj\202103_MHP_OER_Benthic_Survey_WI\2_Grids\GRID_DELIVERABLES
SETINI GRIDCOPY.IN=".\\2_Grids\\GRID_TEMP\\202103_WI_RES_UAV.GRD(GRD)"
SETINI GRIDCOPY.OUT=".\\2_Grids\\GRID_DELIVERABLES\\202103_WI_RES_UAV.flt(ARC)"
SETINI GRIDCOPY.ADDTOPROJECT="1"
GX gridcopy.gx

SETINI GRIDCOPY.IN=".\\2_Grids\\GRID_TEMP\\202103_WI_SIG_UAV.GRD(GRD)"

```
SETINI     GRIDCOPY.OUT=".\\2_Grids\\GRID_DELIVERABLES\\202103_WI_SIG_UAV.flt(ARC)"
SETINI     GRIDCOPY.ADDTOPROJECT="1"
GX         gridcopy.gx

SETINI     GRIDCOPY.IN=".\\2_Grids\\GRID_TEMP\\202103_WI_TOT_UAV.GRD(GRD)"
SETINI     GRIDCOPY.OUT=".\\2_Grids\\GRID_DELIVERABLES\\202103_WI_TOT_UAV.flt(ARC)"
SETINI     GRIDCOPY.ADDTOPROJECT="1"
GX         gridcopy.gx
```

At the conclusion of the fifth script, all final processing in Oasis Montaj was completed. As needed, minor adjustments were made to some of the filtering parameters in the *Single_Mag_nT-Process* script, at which point it was re-run along with the *Single_Mag_Gridding* to overwrite the previous results. The final residual anomaly grid, based on the *nT_Residual* channel, was then reviewed in the Oasis Montaj map interface. Here, using the data linking tool, anomaly locations were selected and assessed with the related DB entries.

Appendix C. Instructions on Processing Humminbird Side-scan Sonar Data in SAR HAWK

By: Dr. Art Trembanis, University of Delaware

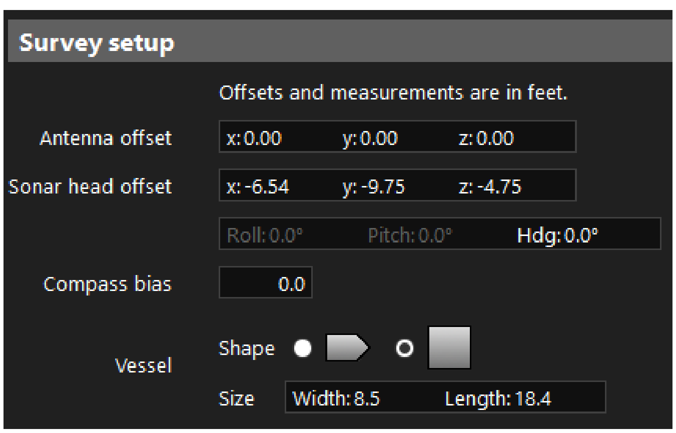
SARHAWK is a low-cost user-friendly software for processing Humminbird sonar files and was used for this project.

PART I: MOSAICING SIDE SCAN SONAR DATA IN THE MOSAIC VIEW WINDOW

Step 1: Isolate the data of interest. Create a SARHAWK project with a nomenclature that works for your file management system. Once you click create project SARHAWK will open and display a projection of the globe. This is the mosaic view window. At the top right of the task bar there is a stack of disks with a green plus. Click it and you can begin to load some data.

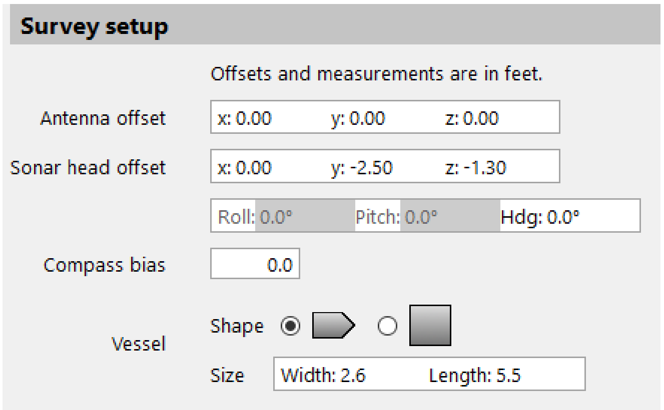
Step 2: Data is loaded in two ways. Quick look, or Playback. Quick look opens all of the chosen files with identical settings to generate a mosaic using the built in SARHAWK algorithms. This is most useful for quickly plotting the data and observing coverage area. Playback actually lets us tweak the gathered data, trim out turns, adjust gains of individual files, trim the data into new files, and all of the other types of things as we do in SONARWIZ. We will be working in playback because this actually lets us modify our data in the most informed way.

Step 3: Click the icon of the crossed wrench and flathead screwdriver. This is the configuration menu. Here you can input the vessel offsets. Below is a screen capture of the offsets for the pontoon boat when using the console head unit mount and having the transducer on the port pontoon with the pre-drilled holes on the transducer mounting plate (standard pontoon survey config. for SOLIX12MEGA).



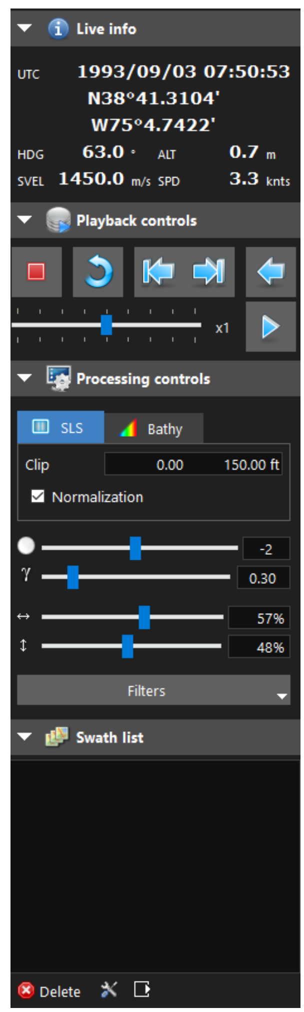
Vessel offsets R/V Dogfish pontoon

Sonar heading offsets, compass bias, pitch, and roll offsets are not used for our purposes. Additionally, the sonar head offsets are in reference to the Antenna, or head unit of the SOLIX, so the head unit is valued at zero across the board and acts as the reference point.



Vessel Offsets EchoBoat 160

Step 4: For this project, first bring in the data files you want via quick look with the desired swath width. This will allow you to visualize your survey lines and mosaic coverage to make sure the files you have chosen are what you want, and that your survey covered all of the area you wanted. The SOLIX records to maximum side-scan range automatically, so you can trim the data to as close or as far as you want range wise.



Step 5: Once you know that the files you have are the ones you want to process, delete the files you loaded in via quick look and then open the playback upload menu from the disk stack/green + icon. Select the same files as before. You can select a single file to upload and play back, or batch process your files, its ultimately up to personal preference. The map will reappear after files have been uploaded but now there is a playback menu on the left side of the screen (pictured to the left).

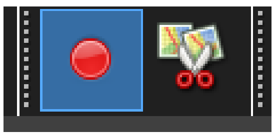
The stop button will stop the playback of the file. The circular arrow will restart the playback of the file you are currently observing. The skip forwards and backwards buttons allow you to move between the sonar files that you have uploaded. The leftward facing arrow allows you to seek the initial file that you started with, allowing you to play back through all of the files in the order they were uploaded. The slider will change the rate at which files are played back for you.

The white circle is your brightness adjustment. The gamma is your gain adjustment.

The arrows allow you to adjust your vertical and horizontal feathering.

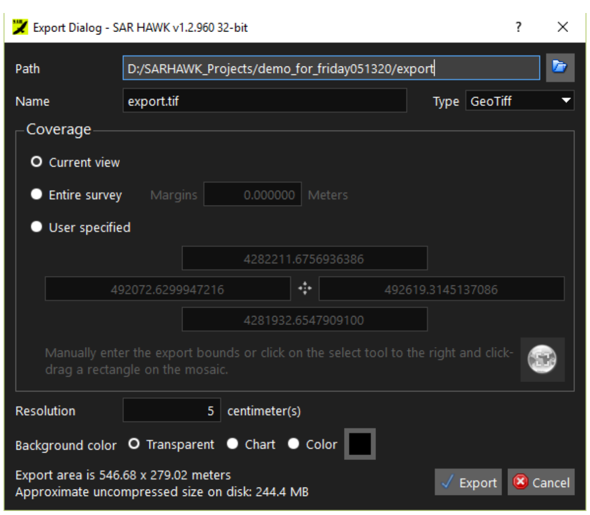
The swath list lists all of the uploaded swath(s). Selecting a file from this list and then using the crossed wrench and screwdriver icon below the swath list allow for making all of the adjustments listed above to the selected file even after it has played back in a separate pop-up menu. You can also select batches of swaths and tweak them. The order of the swaths in this menu are the order that they are layered on the map, so you can adjust the position of files with overlap relative to one another to display the prettiest file at the top for your final mosaic. If you want to keep a swath in the project, but not have it display, click the check mark at the left of the swath name and it will disappear and reappear as you toggle the check mark.

Step 6: When you press play, your file will begin to play back and display in the MOSAIC VIEW window. This is where the creativity of SARHAWK processing begins. The two icons at



the left are found on the top task bar. While the **record button** is highlighted, the program will draw the mosaic onto the base map of the MOSAIC VIEW window. However, if you click the icon and it is not highlighted, it will no longer draw. This can allow you to tweak what portions of the file you are playing back are displayed (i.e. you could stop recording during a turn to allow the turn data to disappear.) You can toggle this button as much as you want, and it will only draw as it plays back when you have the record button highlighted. As well, the **scissors icon** is another helpful tool. This is the file trimming tool, and much like the record button when you click the scissors the program automatically slices you a new file with the same nomenclature as the original file, but with a number in parenthesis. This is to say if you were clipping REC001, your first snip would make you a new file that is only what has played back so far and it would be called REC001(1). The next snip would yield REC001(2) and it would be the data that has elapsed since the last clip.

Step 7: Once you have trimmed your files and adjusted the display settings, layering, and other desired modifications you can export the mosaic as it appears on the SARHAWK GUI. To do so, first click the stop button of the playback options menu at the left. Then, click on the icon of the floppy disc and the project thumbnails in the top task bar. This will open the export menu. This menu gives you the option to write the file path for the export file. Additionally, you can



name the file and select the export type from the dropdown menu. The supported exports include GeoTiff files, google earth KMLs, and tiled tiffs/maps. You can export the current view on your screen, or the entire survey with selected margins around the mosaic. The resolution and background colors are also important options for your export depending upon the application that you tend to use to display the exported mosaic. To wrap it all up it even gives you an expected file size and area for the export, which is valuable information to have at times.

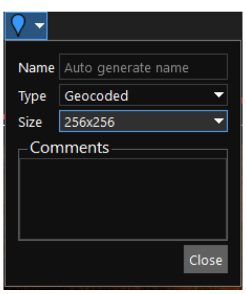
PARTII: CONTACT GENERATION AND EXPORT
CREATING CONTACTS WITH THE WATERFALL VIEWER

Step 1: Load data into SARHAWK for playback, just as you did for creating survey mosaics above.

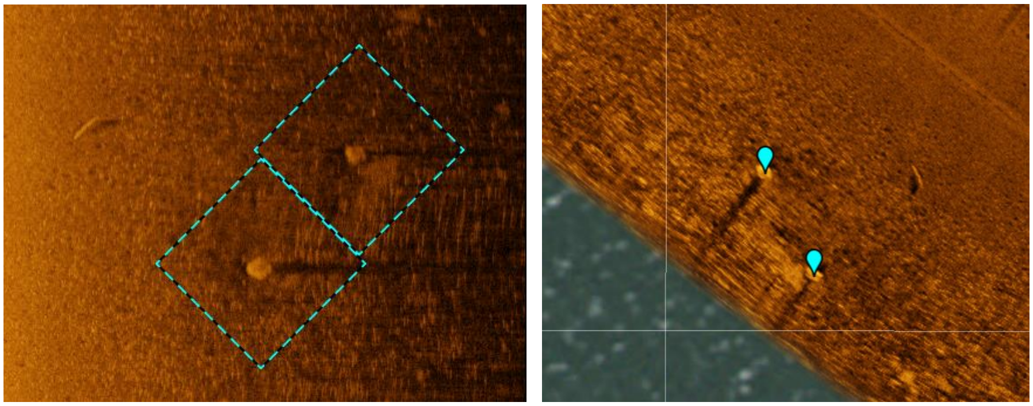
Step 2: When data is playing back, you can enter the **WATERFALL VIEW** tab to take a closer look at the side scan data stream as it is playing back. To do so, click the waterfall view icon from the top tool bar. This will open another SARHAWK window. This window can be utilized separately from the rest of the SARHAWK interface, or you can move it about the GUI and stack/aggregate the windows as you please for the best layout.

Step 3: Upon entering the WATERFALL VIEW window the side scan waterfall display will appear much like it does when you are collecting data on the SOLIX system. However, the playback control features control the data flow through this window, and you can pause and scroll through the waterfall as it displays for convenience. There is some rollover though and you can only look so far back once you have played the data stream. You can also tweak the display settings just as you did when mosaicking the data.

Step 4: In this section the waterfall tools will be explained (pictured at the right). When in the waterfall viewer, your mouse will turn into a crosshair. Selecting the magnifying glass allows the user to zoom in on desired areas on the mosaic by drawing rectangular polygons on the screen using the mouse crosshairs. The area inside the rectangle will be zoomed. Pressing the square with the outward facing arrows will return the view to the original waterfall view.



The blue teardrop is your contact selector tool. This tool becomes very important for selecting features of interest. Selecting the dropdown menu of the contact selector tool allows you to name contacts, select the size of contact thumbnails, and add comments to the contact of choice. The name for each contact must be changed before selecting the object(s) of interest, or else you can just allow SARHAWK to auto generate contact names for the project that will follow a sequential numbering system if naming the contacts isn't all that important to you. Once you click on an object of interest with the blue teardrop selected, a dotted box will appear around the object you click on that is scaled based upon the settings that you gave the contact tool (pictured below). The new contacts will also appear on your mosaic view window. To manage whether these are displayed or not on the mosaic view window you can enter the dropdown menu that is associated with the icon on the top toolbar of the mosaic view screen that looks like a computer monitor with a gear. Simply click the option for "mark position with a pin" and the pins can be toggled on and off in the mosaic view.



Example sonar contacts (not from this specific project). Image: University of Delaware.

CREATING CONTACTS IN THE MOSAIC VIEW WINDOW

Contacts may also be generated exclusively in the mosaic view window, although this is not seen as the most efficient way to do so given that you are looking at an entire mosaic rather than an individual waterfall stream as it is being played back.

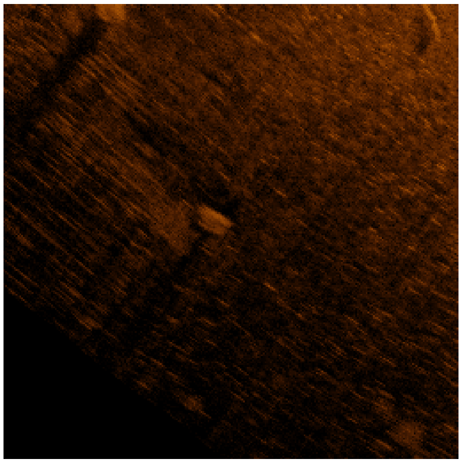
Just as there is a blue teardrop in the waterfall view screen, there is one on the top toolbar of the mosaic view window. Select the teardrop, set your desired settings, and click in the mosaic to create contacts, just like in the waterfall view.

EXPORTING CONTACTS

On the top toolbar of the mosaic view window there is a menu with the blue teardrop over a spreadsheet. This is the contact manager. Inside your contacts will be displayed with their names and other metadata. Contact measurements can also be performed here using the tools in the top task bar of this tab (pictured at the right). The crosshairs allow you to mark the center of the contacts, the blue bar is for measuring the contact shape itself, and the green bar is for measuring the shadow length. Of the table icons at the right (found on the upper tool bar), the left table displays the tile or thumbnail of each contact. The center table will display the metadata for each contact, and the right icon is known as the staging table.

To export contacts, use shift+click or ctrl+click to select the contacts you wish to export. Then, right click over your selection and select the option to move them to the staging table. Once they are in the staging table you can use the icons at the right to export the contacts as a .csv file or export them to a contact report .html. An example of what the contact report looks like is pictured below.

Contact Report

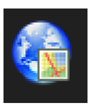


Name: Contact_1
Time: 2001/3/27 2:15:51.621 UTC
Lon/Lat WGS84: W75°7.993', N38°41.182'
Easting/Northing: ,
Range:
Heading: 128.017°
Sonar Altitude: 0.600m
Sonar depth: 0.000m
Image Resolution: 0.1977109375ft

Measured Width: ft
Measured Length: ft
Measured Shadow: ft
Height from Shadow: 0.000ft
Comment:

Image: University of Delaware.

PART III: OTHER USEFUL TOOLS ON THE SARHAWK MOSAIC VIEW INTERFACE



The globe icon allows you to change your chart background if the desired background is different from the default google earth imagery that SARHAWK displays in the mosaic view window

The ruler tool can be used to measure distances on the mosaic view window, much like you would in google earth or similar applications.

The magnifying glasses will zoom the whole mosaic view window in our out. The box with outward facing arrows will zoom out the whole window until all of the data loaded is in view. The boat icon will center the view over the vessel as files are being played back and the view will move with the vessel as the data is played back.

Appendix D. Humminbird Data Visualization

By: Hunter Tipton and Dr. Art Trembanis, University of Delaware

The University of Delaware team experienced some technical issues during the Sackets Harbor portion of fieldwork that led to a gap in data products from several side-scan sonar surveys. The sonar systems used during these surveys were Humminbird Helix and Solix series side-scan sonars. A lack of access points, suitable vessel support, and choppy sea state conditions were prohibitive to operation of the EchoBoat 160 at the field sites in New York. As a result, the EchoBoat 160 platform was not utilized for data collection during the New York portion of field work. Instead, a sonar EMILY ASV (donated by Hydronalix) and its onboard Humminbird Helix 10 system were used to conduct surveys and collect side-scan data. The Humminbird Solix 12 aboard the research vessel Dogfish was also used for gathering recordings of the side-scan sonar waterfall during field operations. During the operation of sonar EMILY, several technical issues arose that ultimately led to the collection of unusable data during its surveys. A firmware issue with the RV Dogfish's Solix 12 also led to erroneous recording of some sonar files. These erroneous side-scan recordings illustrate a tradeoff present when utilizing consumer grade sonars. Despite being accessible and user-friendly devices, their ability to collect and log survey grade side-scan sonar data is at times unreliable when compared to higher cost professional grade sonar systems.

The first of the issues with sonar EMILY was a faulty GPS sensor that resulted in erroneous georeferenced side-scan sonar files. When sonar files were played back in SAR HAWK software, the GPS locations of each sonar ping were populated with false values that placed the files randomly around the globe. These issues were observed throughout the files that were recorded during these surveys and led to a lack of data visualization. When the sonar files were played back, each ping of the sonar file possessed a new and random geographical position, prohibiting the meshing of these pings into a coherent georeferenced sonar waterfall or mosaic. It is also worth noting that this was the second sonar EMILY ASV used during this field expedition, as the sonar EMILY system used in the Wisconsin portion of fieldwork was overcharged and experienced electrical issues. These electrical issues led to the shipment of a second EMILY system and a field technician to New York so that surveys with the platform could continue. We greatly appreciate the support and effort of the Hydronalix team for making this technology available to us and supporting the project with the contributions of their technology and personnel support throughout the field operations.

The second problem facing sonar EMILY lied in its navigational capabilities. The sonar EMILY system, in the configuration we received, was not autonomous and had to be driven by an operator to collect data. This leads to surges in throttle and steering that distort the sonar pings and blur the imagery as a result. Data voids were also caused by the short period wave action of the lake and from any telemetry dropouts as the system must transmit the data live from the ASV to a shoreside control system to be viewed and recorded. The white water and swell caused by windy conditions resulted in the transducer of the EMILY's sonar system surging out of the water. Distortion caused by data voids and abrupt navigational movements makes detecting potential geological and archaeological targets extremely difficult and complicates the interpretation of sonar data. In addition to navigational errors stemming from human navigation, the vessel also encountered radio control interference that resulted in erratic movements and circular paths. This was particularly evident when the sonar EMILY vessel went into a fault mode and was navigating on its own and failed to respond to radio controller inputs. In this case the operator, Andrew Wood, had to enter the water and swim to recover the vehicle as it spun out of control. The operational hardships experienced while surveying with sonar EMILY illustrate the challenges of conducting fieldwork with experimental robotic systems (which was one of the key objectives of the project), as both the sonar system and electrical hardware of the platform independently malfunctioned in ways that compromised data quality.

The final and most impactful contributor to data visualization errors was the inability to verify successful recording in the field when collecting data with the Humminbird Solix and Helix systems. When operating either of these systems the user begins and ends the data recording session manually in the user interface of the sonar head unit. During recordings, a red circle icon flashes in the corner of the sonar's display while data is rolling across the screen to give a visual cue that confirms recording is taking place. Upon completing a recording a similar effect is observed in the recording menu of the sonar interface where yellow circle icons populate in a table beneath the 2D (single beam sonar), DI (down imaging sonar), and SI (side imaging sonar) headers. Users can also observe a duration and megabyte counter in the same table that act as further confirmation of a successful file recording. However, file storage on the micro-SD cards used to log data from the Humminbird systems are two-part structures. A .DAT file with a generic name, such as "REC0001", indexes a separate folder containing .IDX and .SON files of the same nomenclature as the .DAT file. For some recordings the .DAT file would populate empty when the SD card was plugged into a PC for backup following data collection. Without a .DAT file the sonar recordings cannot be played back in the SAR HAWK software even if the associated sonar files (e.g. .IDX and .SON) are full and complete. As a troubleshooting step, these problematic files were put back into the sonar head units, and the head units themselves would play back the sonar recordings despite lacking the capability to visualize when loaded into SAR HAWK for post processing. This caused a situation where in the field data was collected via recording, and recordings were played back on the head unit to verify the presence of data. However, once the data was then removed from the sonar and brought into the computer for post processing, further visualization was not possible in the SAR HAWK software. An eventual flashing of the firmware of the affected sonar head unit after the timeline of this study led to the completion of successful recordings with the Solix 12 system. This confirmed that the faulty data files collected for this study were affected by an unapparent software issue occurring within the data files of each recording. This was an issue that could not be detected until after field efforts had concluded and data was starting to get post processed for mosaicking.

As noted previously the above details relate to technical issues that affected some but not all the Humminbird sonar files collected from various platforms during the expedition. Overall the operational ease and low cost of these systems still makes them capable sonar units for use in both basic vessel operations and in generating a pre-survey reconnaissance dataset and for use in habitat mapping, marine debris, and bathymetry.