Final Report
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1. *Institution/Organization:*
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4. *Summarize requested amendments (if any) to the original Grant Agreement or Work Cost/Budget and provide the approval date(s).*

A one-year no-cost extension was granted on April 9, 2004, extending the grant to June 30, 2005. This no-cost extension was requested because our field work started in June, 2004 rather than in September, 2003, thus delaying the project about 1 year. A second 1-year no-cost extension was requested in June 2005 and granted in October 2005, extending the grant to June 30, 2006. We had planned a field program and a required project meeting for May/June, 2005 but field commitments of a number of the participants made it necessary to move these meetings to later in 2005 or 2006. Our planned 2005 dive series to the Chevaux de Frise was postponed from fall 2005 to June 2006.

INTRODUCTION

The importance of underwater archaeological sites has long been recognized, and there continues to be much interest in techniques that aid in the location and description of these underwater resources. Standard geophysical tools of the underwater archaeologist include the magnetometer and side-scan sonar, and these are supplemented by traditional echosounding, photography and visual description. In shallow water these observations can be made from the water surface or by traditional diving techniques while in deep water newer technologies such as remotely-operated vehicles or submersibles are required. High-resolution multibeam swath bathymetry is a relatively new underwater remote sensing technique used to map the sea-floor surface in high resolution, and the technique is becoming increasingly valuable as a tool for recognizing and describing potential cultural resources at or near the sea bed. In addition to its use in site-specific scientific and cultural studies of the sea-bed, high-resolution multibeam data is also being routinely collected as part of hydrographic and engineering surveys in near-shore and shallow-water settings. When properly processed, these data also can reveal the presence

and characteristics of potential cultural resources. In the case of engineering surveys for cables, pipelines, dredging and other underwater construction projects, an assessment of cultural resources in the project area is often required, and the multibeam data collected to aid in the design of the project should be used as one of the sources of information when evaluating cultural resources in the area.

A multibeam system operates by transmitting a sound beam perpendicular to the ship track, and then processing the returned sonar data to determine a number of depths across the ship track (Figure 1). For example, the Simrad EM 3000, a high-resolution multibeam system used by the Marine Sciences Research Center at SUNY Stony Brook during this study, forms 127 echosounder beams in a swath width four times the water depth. The system used at that time pinged up to 20 times per second, resulting in a dense coverage of depth and backscatter (the strength of each of the received beams, which can vary according to the bottom texture) from a swath along the ship track. The depth resolution of the system was 1 centimeter, and the depth accuracy was about 5 cm. However, accuracy of the depth data also depends on corrections being made for ship motion and water-column sound velocity. The result of a multibeam survey is a high-resolution map of the sea floor that includes both bathymetric and imaging data that shows a wide range of sea-bed morphological features.

There has been an increasing recognition of the value of multibeam sonar data for archaeological studies, and other investigators have identified and studied archaeological targets using multibeam techniques (e.g., Avnstroem et al. 2002; Lawrence and Cowie-Haskell 2003; Wright et al. 2002; Mayer et al., 2003). The value of this mapping technique is being further demonstrated through our ongoing investigations in the Hudson River where the New York State Department of Environmental Conservation (NYS-DEC) has been supporting a river-wide study of river-bed morphology and sediment distribution patterns in support of benthic habitat studies (the Hudson River Benthic Mapping Project; Nitsche et al., 2005). One of the tasks in that study was the collection of high-resolution multibeam data from waters greater than about 5 m deep in the tidal portion of the Hudson River from the Veranzano Narrows to Troy, a distance of 158 river miles. In addition to revealing river-bed morphology (including natural features and man-made alterations) and backscatter distribution patterns (related to sediment characteristics), the multibeam data have also revealed the existence and location of several hundred river-bed features that appeared to be ship wrecks or other features of potential cultural significance (Figures 2 and 3).

Our discovery of such a large number of features with potential cultural significance has underscored the fact that although high-resolution multibeam data sets can reveal such features, there has apparently been little systematic attempt to assess the potential value of multibeam technology for underwater archaeology. Our studies in the Hudson River are likely to be typical of future uses of multibeam data in coastal archaeological studies in that multibeam data collected in support of scientific or engineering studies will reveal features of potential cultural significance. One goal of our NCPTT project was to summarize our experience in collecting and interpreting multibeam data for archaeological purposes. The Hudson River project will be used as a case study, but the project is relevant to archaeological research globally.

Our project has a two-phase approach to evaluating the use of multibeam swath

bathymetry as a new tool for underwater archaeology. The first phase entailed field-work to examine suspected archaeological sites on the bottom of the Hudson River recently identified during the NYS-DEC multibeam survey. We proposed to work at a number of sites in the lower Hudson River where our existing data has revealed features of interest. At these sites we planned to collect more remote sensing data (i.e., higher-resolution multibeam systems, high-resolution side-scan sonar, magnetometer, and videography data), to conduct scuba diver inspection, and to compare the extant multibeam data with results from the additional studies to determine the value of the initial multibeam observations. The second phase of the proposed project entailed discussing the methods with other workers in the Hudson River and elsewhere in order to review and analyze the study results and to review our experience in the use of multibeam data derived from hydrographic or other surveys to suit archaeological needs.

The Hudson River has been the focus of human activity for millennia, from the earliest colonization by Native American peoples approximately 12,000 years ago through modern times. The archaeological resources of the estuary and surrounding lands are very rich, diverse, and have significant research potential. However, a considerable portion of the human record in the Hudson River Valley is virtually invisible using traditional archaeological methods. Rising sea level has drowned sites that were once habitable by prehistoric peoples, and countless shipwrecks and other maritime features are hidden beneath the river's surface. Our recent studies have strongly suggested that the river contains prehistoric Native American sites along with hundreds of concealed sites from the rich maritime heritage that began with Henry Hudson's exploratory voyage in 1609. The upcoming 2009 Hudson-Fulton-Champlain Quadricentennial Celebration in New York will provide a unique opportunity for public outreach, and an underwater perspective on Hudson River history has the potential to be among the highlights of the 400th anniversary of Henry Hudson's voyage. The spectacular images of submerged archaeological resources that can be provided by high-resolution sonar imagery provide a basis for the understanding and communication of this important aspect of American history.

The Hudson River is among America's most significant waterways in terms of its rich human history. As noted above, Native American peoples have lived in the river valley for approximately 12,000 years, hunting, fishing, and gathering plants along the Hudson's banks, and he presence of submerged prehistoric archaeological deposits in shallow embayments along the river was confirmed during a recent Stony Brook University field camp survey in Croton Bay that yielded stone artifacts. In addition to submerged prehistoric sites such as camps drowned by rising sea level as well as possible fish weirs and Native American watercraft, the river conceals sites from a rich historical period of maritime heritage that began with Henry Hudson's exploratory voyage aboard the *Half Moon* in 1609. The river has been the focus of maritime innovation important to New York State and United States history, and investigation of shipwrecks here is adding to our knowledge of watercraft types, evolution, and construction. George Washington viewed the river as the strategic key to the success of the Continental forces, and efforts by both the Americans and British to control the river are reflected by the shipwrecks (including the two American frigates *Congress*, 28 guns, and *Montgomery*, 24 guns) and marine defenses left in the wake of the Revolutionary War. In particular, our field research undertaken with NPS NCPTT and NOAA-OE support has recently positively identified a number of pieces of the wood from the Chevaux de Frise, wooden structures deployed in the Hudson River by

Continental forces designed to keep British forces from traveling up the Hudson River.

Robert Fulton's efforts to develop a viable steamboat on the Hudson River contributed to the transformation of all shipping worldwide when his *North River Steamboat of Clermont* raced from New York City to Albany in record time in 1807. Steamboats were an integral part of river life through much of the nineteenth century, though nearly all of the tragedies on the Hudson River involved steam-powered vessels. One of the better-known maritime disasters involved the sidewheel steamboat *Henry Clay*. A boiler explosion led to the sinking of the vessel and loss of about 70 lives in 1852. Many steamboats were completely salvaged when they reached the end of their life through accident or design. In 2005 we confirmed the discovery of portions of a ~320-foot sidewheel steamboat at the edge of the Hudson River. The submerged wreck, which we believe has been partially salvaged, is one of only a few known Hudson River sidewheel steamboats. Hudson River sloops and schooners, and their successors, canal barges, were the life blood of generations of workers on the river who moved goods and people between the cities of the lower Hudson and northern and inland waterways and thus to the rest of the continent and to the world. Many Hudson River towns have lost their role as important seaports, and in some towns these once bustling areas have long been depressed. In addition, many of the people who made their living on the Hudson River were outside mainstream society, and their stories are poorly known. Study of their material culture can fill substantial gaps in our understanding of historical lifeways. We have identified at least five potential Hudson River Sloops and a large number of barges with a range of sizes and ages all along the Hudson River. These well preserved shipwrecks and other maritime features submerged beneath the river provide a direct link to this past. The discovery and investigation of this immense number of submerged archaeological sites in the Hudson River has the potential to enhance our understanding of local, state, and national history, as well as to advance the field of nautical archaeology.

Our NCPTT grant was one of several grants that have supported our archaeological studies in the Hudson River. We pursued our NCPTT project goals by collecting a set of higher-resolution multibeam data and diver observations in the Hudson River. In addition, we were able to combine efforts with a funded project from the NOAA Office of Exploration (NOAA-OE, "Exploring the Maritime Archeology of the Hudson River: Looking Beneath the Surface to a Revolutionary Past", $35,000) and with funds received through a Memorandum of Understanding between the Marine Sciences Research Center and the New York State Department of Environmental Conservation intended to supplement the NOAA-OE and NPS NPCTT awards (NYS-DEC, $15,000) to further several of the objectives of the NCPTT award and to work at additional sites. Specifically, the NCPTT award allowed us to lease a magnetometer that was used to detect the presence of ferrous materials at several Hudson River sites. The ship time and personnel support for the magnetometer study was provided by NOAA-OE funds. In addition, the NOAA-OE and NYS-DEC awards allowed us to collect complementary higher-resolution multibeam and high-resolution side-scan sonar data and to conduct additional diver observations at yet more sites in the Hudson River. All of this data contributed to our overall NPCTT project objectives of evaluating the archeological significance of multibeam data and of developing a useful approach for collecting and interpreting multibeam data for archaeological purposes.

FIELD STUDIES

Multibeam Studies

As noted previously, we conducted our systematic mapping of the Hudson River using a Simrad EM3000 multibeam echosounder (http://www.km.kongsberg.com/) which has been described as a high-resolution multibeam system. The system operates at a frequency of 300 kHz, each of the 127 beams is 1.5 degrees wide, and the beam spacing is 0.9 degrees in the center of the swath. The resolution of such a multibeam system is limited by beam width, frequency, ping rate and water depth and which in turn affects the size of a river-bed object that can be resolved. A number of recent developments in multibeam technology have led to new multibeam sonar systems capable of creating higher-resolution depth data which can provide more details of river-bed features. These improvements have come through some combination of higher frequency, narrower beams, more closely-spaced beams, and higher ping rates. Two higher-resolution multibeam systems were used in the Hudson River to attempt to provide better images of river-bed features of potential archaeological significance: the Simrad EM 3002 and the Reson 8125.

Multibeam sonar has become an important tool for scientific, hydrographic and engineering studies in marine and fresh-water environments that require detailed information about the bed. A modern multibeam echosounder is a complex tool in that a number of components need to work together correctly and a variety of data needs to be collected at the time of the survey to obtain a high-quality result. Also, specialized software is required for data processing and display and to create the final survey products. There are a number of online resources that provide extensive information about the field of hydrography and especially the equipment and techniques used for the acquisition and processing of multibeam data. Important resources include the Links and References section of The Hydrographic Society of America (http://www.thsoa.org/pg_linkandref.htm), the publications of the US Army Corps of Engineers (especially EM_1110-2-1003 to be found at http://www.usace.army.mil/publications/eng-manuals/em.htm), and the Office of Coast Survey at the National Ocean Survey (National Ocean and Atmospheric Administration - NOAA, especially "NOS Hydrographic Surveys Specifications and Deliverables" at http://chartmaker.ncd.noaa.gov/hsd/hydrog.htm or http://nauticalcharts.noaa.gov/). Important academic institutions include the Ocean Mapping Group at the University of New Brunswick (http://www.omg.unb.ca/omg/), the Center for Coastal and Ocean Mapping (C-COM)/Joint Hydrographic Center at the University of New Hampshire (http://www.ccom.unh.edu/), and the Lamont-Doherty Earth Observatory (home of the MB-System, an open-source software package for the processing and display of multibeam, interferometry and sidescan sonar data; http://www.ldeo.columbia.edu/res/pi/MB-System/).

The multibeam data being described here generally falls within the general category of International Hydrographic Organization (IHO) Order 1 or occasionally Special Order surveys (http://www.iho.shom.fr/publicat/free/files/S-44-eng.pdf). Order 1 surveys require a horizontal accuracy of 5 m, a vertical accuracy of 0.5 m (increasing to 0.72 m at 40 m water depth), and the ability to detect a cubic feature with dimensions of about 2 m. Special Order surveys require a horizontal accuracy of 2 m, a vertical accuracy of 0.25 m (increasing to 0.40 m at 40 m water depth), and the ability to detect a cubic feature with dimensions of about 1 m.

Simrad EM 3002: The EM 3002 (http://www.km.kongsberg.com/) is an upgrade of the EM 3000, operating at the same frequency (300 kHz) and using the same transducers as the EM 3000. However, the upgraded processing electronics ping at a higher rate and create twice the number of depth measurements across the bed at an angular spacing of 0.5 degrees. The cross-track spacing of the pings can also be adjusted resulting in more depth measurements being made at the outer portion of the swath. However, the widths of individual beams remain the same as the EM 3000. These changes result in more depth measurements being made per area of the sea bed, and thus greater spatial resolution of the seafloor bathymetry and of seafloor structures. We were able to use the EM 3002 on June 17 to 20, 2004 when the system was in New York Harbor as part of a Kongsberg-sponsored tour of US and Canadian ports. This was an early version of the EM 3002 and it may differ slightly from the version available today. For this study, the EM 3002 was mounted on the M/V CONCAT, an experimental vessel for shallow-water survey. The M/V CONCAT is a catamaran with jet drives constructed so that it collapses to fit in a standard 40-foot shipping container that can be loaded on a truck or ship for transport to a new area. During our four-day field study, we collected new multibeam data over at least 95 features of potential cultural significance that had been identified during our Hudson River Benthic Habitat study.

Reson 8125: The Reson 1825 (http://www.reson.com) operates at 455 kHz and creates up to 256 beams, each with a cross-track width of 0.5 degrees. The system also pings at a rate comparable to the EM 3002. The higher frequency of the Reson 8125 results in a more precise depth measurement (depth resolution is 0.6 cm) and the narrower beam width results in a smaller seabed footprint and thus the ability to resolve smaller seabed features. New data was collected over at least 100 previously identified features of potential cultural significance during a five-day cruise on the NOAA Ship RUDE from June 7 to 11, 2004. The NOAA Ship RUDE also used a Klein 5000 high-resolution side-scan sonar that also operates at 455 kHz, creating a high-resolution image. About 30 sea-bed features were examined with both the EM 3002 and the Reson 8125 systems.

Multibeam data was analyzed using the SwathEd software package developed by Ocean Mapping Group at the University of New Brunswick (http://www.omg.unb.ca/omg/research/swath_sonar_analysis_software.html), Fledermaus 3-D visualization software (http://www.ivs3d.com), and the commercial multibeam and side-scan processing software CARIS HIPS and SIPS (http://www.caris.com). A number of other software packages could also have been used to create a variety of products from these multibeam survey data. We discuss here the steps and software that were used in the systematic mapping undertaken during the NYS-DEC Hudson River Benthic Mapping Project and in the NPS NPCTT and NOAA OE studies that focused on specific potential cultural resources.

Typical multibeam data processing consists of several steps which include (1) editing the depth and navigation data and adding tide information, (2) creating digital elevation files (DEM) suitable for contouring, and (3) visualization of the depth data so that seabed features can be recognized as anomalous, described and quantified. Additional steps are needed to process and display backscatter data. During the NYS-DEC Hudson River Benthic Mapping Project we used the SwathEd software package to process the EM 3000 multibeam data and to create DEM files

with a grid spacing of 1 m. The DEM files are suitable for contouring and can be exported and used in GIS mapping software such as ArcView. Sun-illuminated images were created from the depth files by shining a synthetic sun over the digital seabed and exported as geotif images which also could be imported into GIS software such as ArcView. These images can be created with illumination coming from different directions to reveal different aspects of the sea-bed terrain. Sun-illuminated images highlight smaller-scale features on the seabed such as sand waves, rock outcrops and ship wrecks, making it easier to pick these features out of a otherwise uniform bed (Figure 3). The DEM data was imported into Fledermaus which allows the operator to "fly around" the data set and examine the sea bed from different orientations, and thus gain a more complete understanding of the seabed topography. The DEM and geotif images were also imported into ArcView software where they were displayed and studied. Anomalous features (targets) were identified based on the sun-illuminated imagery by creating an ArcView shape file, clicking on the anomalous feature, assigning a unique identifying number and entering identifying information. This summary target file could then be exported from ArcView. The target file generated from the 1 meter gridded EM 3000 multibeam data was used to plan follow-on investigations and provided the basis for this study.

A somewhat different processing regime was generally followed for the higher-resolution multibeam data sets because our interest was in characterizing specific targets rather than mapping areas. Data collected during these studies was processed using the software package CARIS HIPS and SIPS (RESON 8125) or with SwathEd software and then read into CARIS HIPS and SIPS (EM 3002). We worked with the CARIS package because initial data processing on the NOAA Ship RUDE was done with this package. In addition, CARIS HIPS and SIPS has a feature called "subset editor" which allows all depth measurements made within an area to be displayed, shaded and viewed in 3D from any angle. The size of the area that can be investigated the subset editor appears to be limited, and the tool is best used for areas less than a few 100 m on a side. Using this feature meant that we did not need to routinely make DEM grids, but we could view the depth measurements in the vicinity of a possible cultural feature directly with the editor. Depth data can still be gridded as desired and imported into ArcView GIS software.

The capability to view all multibeam depth measurements is important because the detail available on the individual swath data is greater than the detail available on the gridded depth data. For example, two multibeam depth measurements beneath the transducer that are 1.5 degrees apart in angular measure will be 0.17 m apart on the sea bed where the water depth is 10 m. Similarly, two depth measurements made on subsequent pings are 0.36 m apart if the sonar is making a depth measurement every 0.1 second (ping rate 10 Hz) and the vessel speed is 8 kts (3.6 m/s). Gridding at 1 m serves to average all returns within the grid and thus reduce any noise in the depth measurement, but it also reduces the spatial resolution. Also, we used inertial navigation for these surveys that was based on differential GPS (DGPS) fixes. The inertial navigation provides some smoothing for the DGPS fixes, but the accuracy of the final navigation is to +/- 1 m. Thus if any fix can be in error by up to 1 m, adjacent lines can be in error by as much as 2 m. This navigational uncertainty also reduces the resolution of the gridded data set. The highest resolution of sea-bed features is thus obtained by viewing all of the depth measurements on a single track. If multiple tracks need to be assembled to view a large feature in high resolution, then the adjacent tracks may need to be shifted horizontally to overlap correctly.

Magnetometer Studies

Ferrous metal objects on the bottom of the river or in river sediments create magnetic fields that, when measured, provide information about the location and amount of ferrous metal on the sea floor. We conducted a test of the geomagnetic technique in support of our archaeological studies in the Hudson River from the NOAA Ship RUDE on June 10 and 11, 2004. Two Geometrics G-881 Cesium magnetometers were deployed by Frank Nitsche and Angela Slagle from the Lamont-Doherty Earth Observatory (LDEO; one magnetometer was leased by the NCPTT project and one magnetometer was provided by LDEO). The raw data were recorded on a laptop computer using Geometrics MagLog software. The two magnetometers were rigged with one above the other to measure the vertical gradient of the earth's magnetic field and were towed at the water surface behind the ship (Figure 4). In the vertical configuration, the total magnetic field and magnetic field variations from the side will be received by both magnetometers equally whereas vertical variations of the magnetic field will affect both magnetometers differently. This minimizes the effect of the changing Earth's magnetic field, from the ship and from the surrounding rocks and allows an estimate of the distance to the magnetic feature. The magnetometer tow cable used was only 60 m (200 ft) long which means that the magnetic signature of the ship was part of the measured signal. To minimize this effect, we towed the magnetometer in one direction, e.g. from south to north, at each site. Changes in towing direction causes shifts of 50 to 100 nT in magnetometer readings.

Magnetometer studies were concentrated in three areas: an area where unusual submerged parallel ridges had been found previously, near the Chevaux de Frise (Revolutionary War structures built in the Hudson River), and in the Hudson Highlands south of West Point. While the vertical gradiometer increases the sensitivity for small objects beneath the sensors, it also decreases the sensitivity for magnetic anomalies that are located outside the tracks. Therefore we chose a line spacing of 10 m and ran the surveys so that adjacent lines would have the same heading. In total we collected ~21 km of magnetometer profile lines.

Diver Studies

While geophysical information such as the acoustic and magnetometer data described above provide important information about the location and probable character of seabed cultural features, closer examination of features of potential interest is necessary in order to provide the information needed for a detailed understanding of their significance. Two diving expeditions were organized to the Hudson River and fully or partially supported by NPS NCPTT funds. The first expedition occurred during October 2004 (supported by NOAA-OE, NYS-DEC and NCPTT funds) and the second expedition occurred during June 2006 (fully supported by NCPTT funds). Diving on Hudson River targets also occurred during October 2005 (supported by NOAA-OE and NYS-DEC funds). In all cases, the features selected for diving were initially identified from multibeam mapping conducted as part of the Hudson River Benthic Mapping Project and then surveyed with higher-resolution multibeam sonar systems such as the EM 3002 or Reson 8125. Overall, five of the seven dive targets were imaged by each multibeam system, and three of the seven dive targets were imaged by both multibeam systems. Two dive targets were only imaged during the EM 3002 field work supported by NCPTT (one in 2004 and one in 2005). Diver

studies in 2004 and 2005 were conducted by the Lake Champlain Maritime Museum led by Art Cohn. Diver studies in 2006 were conducted by the West Point Divers led by John DeFrancesco. We collected additional high-resolution side-scan sonar images with a EdgeTech 272TD side-scan sonar with Isis Sonar logging software operating at the nominal 500 kHz frequency setting (actually 390 kHz) at all of the LCMM dive sites in late 2005.

Diving in the Hudson River requires great care and experience due to near zero visibility, strong tidal currents, and persistent commercial vessel traffic. In many nearshore areas where underwater shipwrecks have been discovered, the shipwreck sites have been developed as underwater historic preserves and sport diving is encouraged. Two such underwater historic preserves in the vicinity of our study area are in Lake George (http://www.dec.state.ny.us/website/dlf/publands/submerge/index.html) and Lake Champlain (http://www.lcmm.org/shipwrecks_history/uhp/uhp.htm). The consensus of the divers who have worked on our dive sites in the Hudson River is that sport diving should not be encouraged at these sites because of the dangerous conditions.

RESULTS

Results of Multibeam Studies

The high-resolution multibeam bathymetric maps created for the Hudson River Benthic Mapping Project revealed the existence of a number of anomalous sea-bed features that appeared to be shipwrecks or other features of potential cultural significance. Some of the anomalous features appear to be shipwrecks and one can get a general idea of the shape and size of the features from the existing multibeam data. However, there is often not quite enough information in the multibeam data to determine important details about the seabed features, details that could proved necessary to identify the type and possibly age of any given vessel. We anticipated that new very high resolution multibeam data would be able to provide these additional critical details.

Direct comparison of sun-illuminated 3D images of a vessel hull created from EM 3000 (Figure 5, left) and EM 3002 data (Figure 5, right) gridded at 0.5 m suggests that the gridded newer, higher-resolution data provides a somewhat more detailed image of the seabed than does the older, lower-resolution data. However, the value of the higher-resolution data is better demonstrated when all of multibeam depth values collected by the EM 3002 are plotted and viewed in a sun-illuminated 3D image (Figure 6, top). In this image the vessel hull is much more clearly imaged and it is clearly thinner than the 0.5 m grid size of Figure 5. The lower panels of Figure 6 show a cross-section of depths drawn along the length of the hull (center) and across the hull (lower), allowing the vessel characteristics to be clearly determined. A direct comparison of the resolving capability of the three multibeam systems can be observed in Figure 7 where the hull of a sailing vessel is imaged by all three systems plus a high-resolution side-scan sonar. The EM 3002 (center) and Reson 8125 (right) views are from nearly the same orientation and are based on all seabed data while the EM 3000 view (left) is based on depth data gridded at 0.5 m. The lower panel shows a side-scan sonar image of the same hull, with stronger echoes darker and weaker echoes and shadows lighter. While all four images show the basic characteristics of the

hull, additional information is shown in the higher-resolution multibeam images. In particular, the Reson 8125 image shows at lease one important detail in the stern of the vessel (towards the viewer; the hull planking terminates before the stern is reached) that is difficult to discern on the other multibeam images and from the side-scan sonar image.

The side-scan sonar image of Figure 7 also demonstrates on other aspect of acoustic mapping, using backscatter (or returned signal strength) to study seabed character. There is a streak of high backscatter (lighter color) material to the left (downcurrent) of the vessel. Such backscatter patterns can be determined by side-scan sonar as well as multibeam systems, and the nature and distribution of these backscatter patterns can also provide important information about sea-bed conditions, including those that may be caused by the presence of the potential historical artifact.

We have evaluated the higher-resolution multibeam data at the positions of a number of anomalous features identified on the Hudson River Benthic Mapping Project multibeam data, and the targets previously identified can be put in at least six general categories: debris, modern vessels, historic vessels, curious mounds, other cultural artifacts and unknown. As additional information becomes available, we seek to verify these interpretations, create new categories as necessary, and move features out of the unknown category.

Debris: A relatively small number of the anomalous features identified on the Hudson River Benthic Mapping Project multibeam data are resolved as pilings or other apparent debris by the higher-resolution multibeam data. Figure 8 shows examples of two apparent pilings, each about 8-10 m long and about 0.5 m in diameter. These pilings were recognized as anomalies on the original multibeam data in part because of the scour and sediment tails they create. Many other types of debris are also recognized, including distinctive "donut"-shaped deposits apparently created as material dropped from the water surface impacts the bottom (Figure 8, right). Several of these donut-shaped deposits were crossed during our higher-resolution multibeam studies, and the deposits are typically raised ring-shaped features about 12-20 m in diameter and standing 0.5 to 1 m high. Similar features have been observed in a number of places in the New York metropolitan area.

Modern vessels: Several of the anomalous features are resolved as relatively modern pleasure craft ranging from about 6 to 12 m in length. The examples in Figure 9 show a sailing vessel (left), a power vessel (center) and a vessel of uncertain type (possibly a sailing vessel, right). These vessels are quite well preserved and not buried by sediment, suggesting they are fairly recent and/or constructed of materials that do not degrade. They also stand quite high off the bottom and have prominent scour moats and wakes.

Historic vessels: The majority of the anomalous features are resolved as vessels with possible cultural significance (Figure 10). They generally lie in an upright position on the bottom, are missing the uppermost structures such as decks, and a significant portion of the vessel is buried. These vessels often generate sediment tails that can extend many hundreds of meters away from the vessel. Figure 10 shows examples of three historic vessels, all of which have been visited by divers during hour Hudson River studies. These vessels are an Erie Canal barge often used for transporting grain (left), a Hudson River Sloop often used for river-borne

goods transport (center), and an articulated Morris Canal barge often used to transport coal. These vessels appear to date from the mid 1800s. Divers also visited the vessel imaged in Figures 5 and 6 (probably a late nineteenth century sloop-rigged New York City harbor lighter) and the vessel imaged in Figure 7 (the abandoned hull of a nineteenth century schooner). Except for the abandoned hull, the vessels visited divers appeared to have been in distress when lost as many were carrying cargo, usually coal. The results of the harbor lighter dive series will be discussed below; the detailed results of the other Hudson River historic shipwreck dives are presented elsewhere.

Curious mounds: For some of the anomalous features, the higher-resolution data doesn't provide much additional information (Figure 11). Many of these mounds have overall dimensions similar to those of the historic vessels, but they are more fully covered by sediment and thus few details of a potential buried feature are present in the surface relief. The burial may indicate that the features have been on the river bed longer or that they are present in a portion of the Hudson River where there is active modern sediment deposition. The mounds could also be debris dumped from a surface ship, although many of the deposits thought to be deposited cargo have a distinctive "donut" shape.

Other cultural artifacts: Several of the anomalous river-bed features appear to be cultural artifacts although they are clearly not vessels. This category includes a series of apparent Revolutionary War structures built north of West Point (the Chevaux de Frise) and an anomalous set of ridges. The ridges were not specifically studied during this investigation and will be discussed elsewhere; however, we did conduct diver studies on the Chevaux de Frise which will be discussed shortly.

As noted previously, the Chevaux de Frise were a series of defensive structures built in the Hudson River during the Revolutionary War in an attempt to keep the British Fleet from sailing up the Hudson River. These structures were square log caissons, each side measuring roughly 40 feet (12 m), loaded with stones to sink them to the bottom. A number of these structures were built and sunk across the river in a line. Each caisson had projecting booms, probably tipped with iron spikes, meant to ensnare passing enemy ships (Diamant, 1994). NYS-DEC sonar mapping revealed three groups of possible remnants of the Chevaux de Frise near the western, central and eastern part of the Hudson River. Subsequent high-resolution mapping using the Reson 8125 multibeam sonar, Klein 5000 sidescan sonar, and magnetometer mapping confirmed the location, dimension and morphology of the submerged features and suggested the presence of minor amounts of ferrous materials (Figures 12 and 13).

Results of Diver Studies

As has been noted, diver studies have been supported by both NCPTT and NOAA-OE funding. The results of the NOAA-OE dive series are reported in detail elsewhere. Here we present results from two dive series partially or wholly supported by the NCPTT award and that have a particular emphasis on comparing the multibeam results with diver observations. These dive series occurred in 2004 (Lake Champlain Maritime Museum; partially supported by NCPTT) and 2006 (West Point Divers; fully supported by NCPTT) (Figure 14). We attempted some unsuccessful underwater photography at one dive site, but overall we decided that during

these initial dives in the Hudson River it was more important for the diver to locate and observe the features than it was to have the diver spend time attempting photography. We think that diver-based photographic, laser or acoustic imaging of these cultural features is possible, but it will take more time and equipment than was available to us.

We show here one example of the results of the NOAA-OE / NCPTT dive series to illustrate the degree to which the very high resolution multibeam data has aided in the description and documentation of a vessel in the Hudson River (Figures 5, 6 and 15). The dives at this site occurred in October, 2004. The vessel was easily located on the river bed at the position indicated based on the multibeam mapping. Seven dives were conducted to describe, measure and document the vessel. Visibility was variable but generally poor (less than 1 foot, and near zero during periods of high current). Measurements and descriptions were relayed to the surface via an acoustic link, and the diver was debriefed after each dive. Based on diver descriptions, the vessel has an overall length of 67 feet 8 inches (20.6 m) and a maximum beam of 20 feet 3 inches (6.17 m). The deck is missing, and the hull is divided into three areas: the bow, hold and stern. The hold is filled to within 6 inches (15 cm) of the top of the hull. Figure 15 shows a sketch of the vessel based on diver observations plotted on the same scale as the EM 3002 multibeam image. The multibeam image clearly hints at the bulkheads that divide the hold from the bow and stern compartments, although many finer details, such as the stump of a mast in the bow, lodging knees along one side of the vessel or the possible smaller walls within the stern cabin. Diver observations suggest that the transom is missing, and that the top of the stern planking marks the place where the transom would have begun. The ship, probably a late nineteenth century sloop-rigged New York City harbor lighter, was carrying a cargo of small coal chunks when it was lost. Preliminary study indicates a sinking date of the second half of the nineteenth century, and this may be possibly be one of several ships known to have been lost in Haverstraw Bay during an gale in the 1870s.

A high-resolution side-scan sonar record was collected at this site in 2005 a year after the dive operations using the EdgeTech 272TD side-scan sonar operating at 390 kHz (Figure 16). This figure provides additional details on the structure of the vessel (including the presence of additional crossbeams), but generally confirms the diver and multibeam descriptions in Figure 15. Also of interest is the fact that the bumpy side-scan sonar pattern in the hold of the vessel is due to the cargo of coal, and that the coal has evidentially spilled into the stern cabin as well as on to the sea floor to the right of the vessel where the sonar also displays a bumpy pattern. There also appear to be additional timbers to the right and off the bow of the vessel (in the downstream direction).

The Lake Champlain Maritime Museum dive team is very experienced in archaeological diving in harsh conditions. They reported that the very high resolution multibeam images definitely aided in their first-hand observation of the vessel, a task made more difficult than normal because of the very low visibility. A clear presentation of the river-bed feature allowed the divers to plan their discovery of the vessel and presented a framework in which to place their very detailed observations. The dive team laid out a tape measure when traversing the wreck, and all observations were tied to the distance along the tape and thus back to the multibeam image.

A second example of the role of multibeam bathymetry as an archaeological tool for identifying and describing submerged cultural artifacts in the Hudson River comes from the Chevaux de Frise dive series conducted in June 2006 (Figures 12 and 17). Very high resolution multibeam data had supported the interpretation that these a certain set of seabed features in the Hudson River were in fact the bases of some of the Revolutionary War Chevaux de Frise. The dive series conducted in 2006 by the West Point Divers was designed to determine whether direct observation would support that hypothesis. Visibility at the dive site was variable but generally poor (usually 0.5 to 1 foot), and most observations were relayed to the surface via hard-wired communications. Three sites were investigated. No man-made features were observed at the second and third dive sites. Post-cruise evaluation of the dive series showed that those dive sites were 10 to 20 m away from the dive targets, too far away to expect the diver to find the targets in low visibility. Diver examination of the first dive site (which was precisely at the target site) showed several articulated rough-hewn timbers roughly 12 inches (30 cm) on a side. Three of the timbers lie next to each other and appear to be joined by iron bolts. One end of the center timber was angled with two diagonal bevels and with remnants of iron fasteners on the beveled faces. One of the adjacent timbers was notched. A perpendicular timber was found lying beneath the upper timbers, and a group of six large stones (appx. 8 inches (20 cm) in diameter) was found near the timbers. This diver description of the probable Chevaux de Frise structure can be compared with a timber of one of the original Chevaux de Frise that was recovered in 1836. The timber was originally about 30 feet (9 m) long, and the upper portion of the timber, with its iron tip intact, was given to the museum at George Washington's headquarters in Newburgh, NY, in 1850 where it is now on display (Figure 17). The submerged timbers compare favorably with the piece at Washington's headquarters, strengthening the identification of the underwater features as historically-important Revolutionary War structures.

PROJECT MEETINGS AND INFORMATION DISSEMINATION

We held a meeting of the Hudson River Archaeology Study Group at the New York State Museum in Albany, NY on September 19, 2005. The purpose of this meeting was to evaluate our progress in using a range of geophysical techniques at the beginning the task of characterizing the potential cultural resources on the bed of the Hudson River. The group heard presentations about the background of the Hudson River Archaeology project and the results of the 2004 multibeam investigations (Flood), about the magnetometer program (Nitsche), about the results of the 2004 dive program (Kane), and about the overall significance of the program for the enhancing our understanding of the cultural history of the Hudson River (Cohn). This last point is particularly important as the 400th anniversary of Henry Hudson's voyage to the Hudson River and the 200th anniversary of Robert Fulton's steam vessel Claremont are to be celebrated in 2008 and 2009. The group evaluated the role of geophysical techniques in evaluating the importance of Hudson River underwater archaeology and agreed to the features selected for the 2005 Hudson River dive series. The meeting laid the groundwork for a meeting on Hudson River shipwrecks and other underwater cultural resources in Albany on May 15, 2006, called by Betsy Blair and Charles Vandrei at the New York State Department of Environmental Conservation. At that and subsequent meetings we reviewed a strategic plan put forward by Betsy Blair entitled "Hudson River Estuary Submerged Historic Resources," a plan designed to ensure that the submerged historic resources in the Hudson River are protected,

understood and appreciated by the public. This is particularly important because much of the bed of the Hudson River is owned by New York State, and historical resources are under the protection of New York State and Federal laws.

We have made several presentations at archaeological meetings describing the status of our studies of the Hudson River archaeology and the role of multibeam data in studies that were supported by the NCPTT program. We presented a paper at the 2005 Conference on Historical and Underwater Archaeology (Merwin et al., 2005), the annual meeting of the Society for Historical Archaeology. Members of this group are very active in underwater archaeology and this venue provided an important opportunity to introduce the underwater archaeology community to our work in the Hudson River. We also presented two papers at the 2006 Annual Meeting of the Middle Atlantic Archaeological Conference (Flood and Merwin, 2006; Merwin and Flood, 2006) that summarized our work on this project and described the importance of multibeam bathymetry for underwater archaeology. The sessions on underwater archaeology were well attended and included presentations by NOAA as well as several state and local groups with interests in locating and describing underwater cultural resources.

RECOMMENDATIONS AND CONCLUSIONS

Archaeologists are increasingly at the forefront of technology, making use of new and improved methods to better read the cultural record. Nautical archaeology is benefiting from newly available high-resolution techniques for locating and identifying potential cultural resources on the bottoms of lakes, rivers and in all water depths in the oceans. In particular, high-resolution multibeam techniques can provide detailed information about large areas of the underwater landscape in a fashion that that makes it possible to quickly identify man-made features and possible cultural resources. The archaeological community in particular, and the world community in general, is becoming more aware that many of the materials lost or disposed of in the ocean or other water bodies remain on the bed for a considerable length of time, disappearing from the sea bed through burial, corrosion, and/or consumption. As a result there are significant cultural resources in all water depths, including in shallow and nearshore waters where more high-resolution bathymetric data is becoming available. Multibeam sonar technology is now being used more often to characterize the sea bed as part of scientific and habitat studies as well as for hydrographic and engineering surveys (including surveys for dredging, pipelines, cables, construction and contaminated sediment remediation) in all water depths, and especially in near-shore and shallow water settings.

A detailed assessment of potential cultural resources is often a part of any underwater engineering project, and the geophysical data collected to aid in the design of the project can also help in the location and assessment of potential cultural resources. While this is true for magnetometer and side-scan sonar data, data that is often collected specifically to search for underwater obstacles, it is particularly true of multibeam bathymetry data because that data is often processed to create a contoured map to provide a basis for the engineering design rather than to create a high-resolution image of the sediment surface. This multibeam data, when properly processed, displayed, and analyzed, may provide important new insights into potential cultural features on the sediment surface, information that may affect the design of the project. If

the multibeam data is collected and processed following the specifications of the National Ocean Survey (http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm, present specifications dated June 2006), then sun-illuminated images at 0.5 to 1.0 m grid spacing will be generated as part of the multibeam data reduction and evaluation process. Those images will be particularly important for assessing the presence of potential cultural resources that have altered the form of the sediment surface either through being exposed at the surface or through affecting deposition patterns over a somewhat larger area.

We make the following recommendations for the use of multibeam data in archaeological studies based on our experience in the Hudson River and nearby waters.

- Multibeam data should in general be collected and processed following NOS Specifications. These specifications present a recent (2006) summary of the steps taken for NOS hydrographic surveys where there is an emphasis on identifying anomalous features on the sediment bed that may be a hazard to navigation. Additional guidance comes from U.S. Army Corps of Engineers engineering manual EM_1110-2-1003, but USACE guidelines are somewhat more focused on areas that are frequently dredged, and thus less likely to contain important cultural resources.

- High-resolution sea-bed mapping is a rapidly changing field with new and updated equipment being introduced at all times. Information on new equipment and techniques is often presented at meetings such as those conducted by The Hydrographic Society of America and at University multibeam sites.

- Our experience in the Hudson River suggests that equipment operating at higher frequencies, with more and narrower beams and at faster repetition intervals will produce better images of features on the sediment surface. Thus the Reson 8125 produced better images than the EM 3002, and both produced better images than the EM 3000. However, nearly equivalent images were produced by all systems at 1.0 and 0.5 m grid interval suggesting that systematic mapping projects using a range of high-resolution multibeam sonars should provide important information about the presence of potential cultural artifacts at or near the sediment bed. Higher-resolution imaging systems (e.g., side-scan sonar systems or very high resolution multibeam systems) can then be targeted at anomalous features on the bed. New equipment should be used when possible at known archaeological sites to provide images with yet higher resolution.

- If an archaeological investigation needs to be done in an area where multibeam data has been used to create a contour map, then every effort should be made to reprocess the multibeam data to provide high-resolution sun-illuminated images of the sea bed at a resolution of about 2 m or better. If necessary, the raw digital data should be obtained and reprocessed for the archaeological assessment. Contour maps alone are only sufficient for finding the largest potential cultural artifacts.

- Appropriate software (and computers capable of running that software) needs to be obtained to work with the generally large multibeam datasets. Appropriate software includes programs capable of reducing multibeam data, measuring the size of seabed

features and generating mapping products as well as programs to allow 3D viewing of the digital data sets. These programs need to be capable of generating images suitable for importing into ArcView or other GIS software to allow the mapping results to be integrated with other data.

- It is relatively easy to identify man-made features, which are often angular and often occur as singular features, from natural features, which are often rounded and often occur periodically, on sun-illuminated images made from multibeam depth data.

- In many cases where there are flowing currents, the first evidence of an anomalous feature on the sediment surface is a wake or sediment tail that can be much larger that the obstacle that created it. Features that are buried can be the source of sediment tails for as long as there is a mound associated with the feature.

- Recent vessels have pronounced moats because the portion of the vessel above the sediment surface has not yet decayed either due to the young age or to fiberglass vessel construction. The size of a moat or sediment tail also will depend on the size of the vessel as well as local sedimentation rate, sediment type and current strength.

- Diving can be an effective tool for determining the nature and origin of a particular feature on the sediment surface, even in waters with low visibility. When visibility is low, the diving vessel must pay particular attention to occupy the given dive coordinates and place the dive float at location that is known with respect to the feature of interest. Some of the sea-bed features are too small to be reliably detected by conventional "fish-finder" echosounders, so that equipment should not be relied on to locate the dive target.

- Diving in the vicinity of shipwrecks or other seabed obstacles in low visibility and strong currents conditions can be very dangerous and requires divers with extensive experience and training. In these conditions, shipwrecks are not appropriate for development as underwater historic preserves where sport diving is encouraged. Even the most experienced and best trained divers should decline the opportunity to dive on particularly dangerous targets or in very dangerous conditions.

- High-resolution multibeam data being collected for engineering projects should routinely be made available for scientific and archaeological study. These kinds of data can be expensive to collect and process, and they can fulfill many needs beyond those for which the data was originally collected. Many of the underwater lands in the U.S. are publicly held and are the responsibility of State or Federal regulators, and high-resolution data, even if privately financed, should be more widely available. One caveat to this general statement is that the locations of submerged cultural resources that fall within the protective mandate of a State or Federal agency should not be released without ensuring that the resources are properly protected. Private submissions of high-resolution multibeam data collected in public waters to the U.S. hydrographic and multibeam data repository at NGDC (NOAA; http://www.ngdc.noaa.gov) should be encouraged.

- High-resolution multibeam systems (and closely-related interferometric sonars) definitely have joined the ranks of side-scan sonars and magnetometer sensors in the geophysical toolkit of the underwater archaeologist. High-resolution shallow-water multibeam systems have become more available in recent years, and a number of organizations are actively collecting such data throughout the world ocean.

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Hudson River Archaeological Study Group Meeting Attendees -- September 19, 2005	
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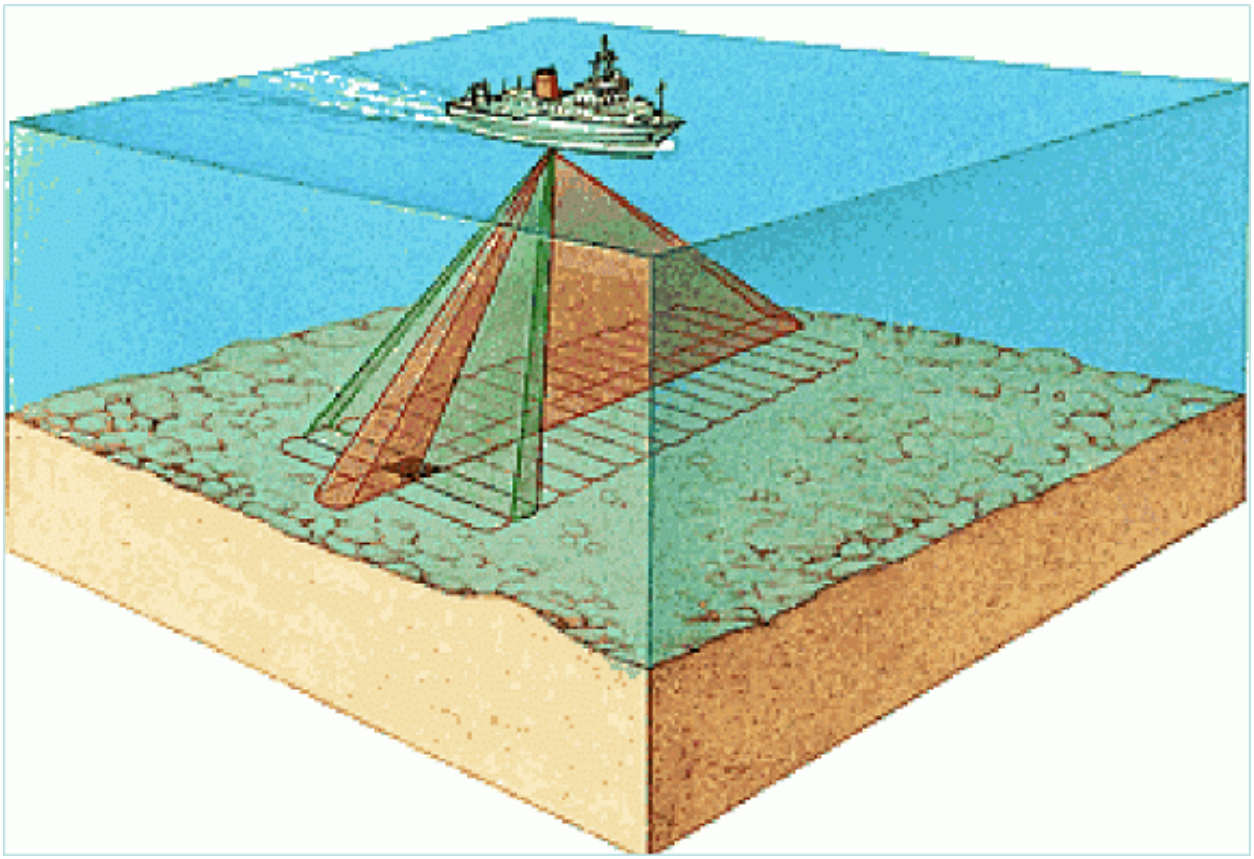


Figure 1. Sketch showing the operation of a multibeam echosounder (after DeMoustier, 1986). The multibeam transducer is mounted on the hull of the vessel and transmits an acoustic beam that is narrow in the fore-aft direction and wide in the cross-ship direction. The receive array detects echoes in beams that narrow in the cross-ship direction and wide in the along-ship direction. The echo for each beam is assumed to come from the area of the sea bed that is at the intersection of the transmit and receive arrays.

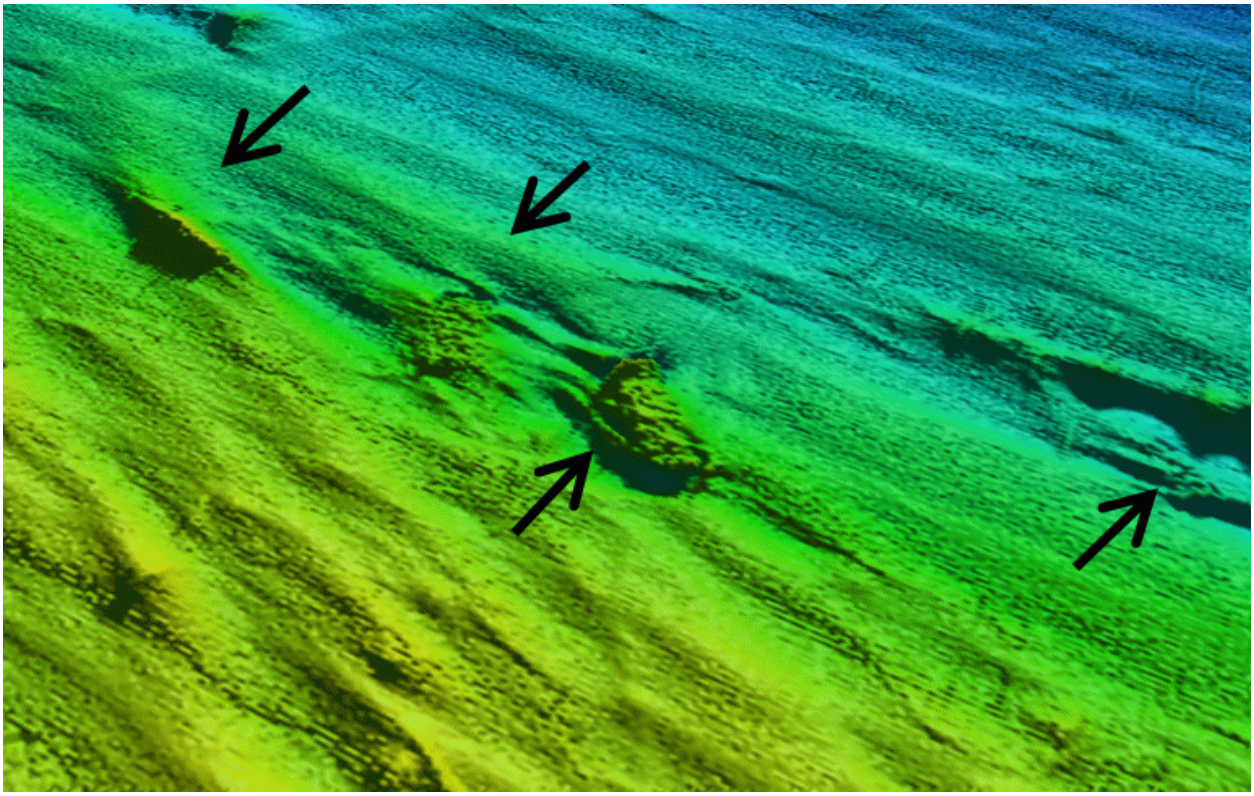


Figure 2. Image of potential shipwrecks in the Hudson River derived from multibeam data collected during the Hudson River Benthic Mapping Project. Arrows point to anomalous features on a sun-illuminated image package viewed obliquely (image produced by the Fledermaus software).

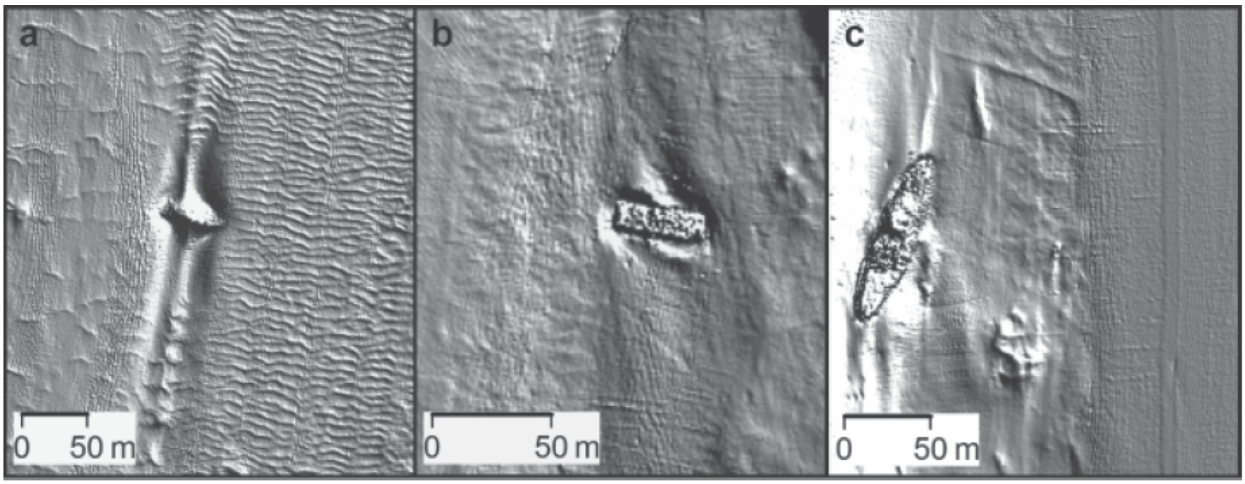


Figure 3. Images of potential shipwrecks in the Hudson River derived from multibeam data collected during the Hudson River Benthic Mapping Project. Examples of sun-illuminated images of possible shipwrecks in the Hudson River (image produced by SwathEd software; after Nitsche et al., 2005).

Figure 4. The magnetometer package towed during the Hudson River archaeological study. Two magnetometers are suspended beneath the surface float. The difference between the two magnetometers results in a measure of the vertical magnetic gradient. A GPS mounted on the float provides position of the magnetometer measurement, and a flashing light warns nearby vessels to keep away. (Figure from Frank Nitsche.)

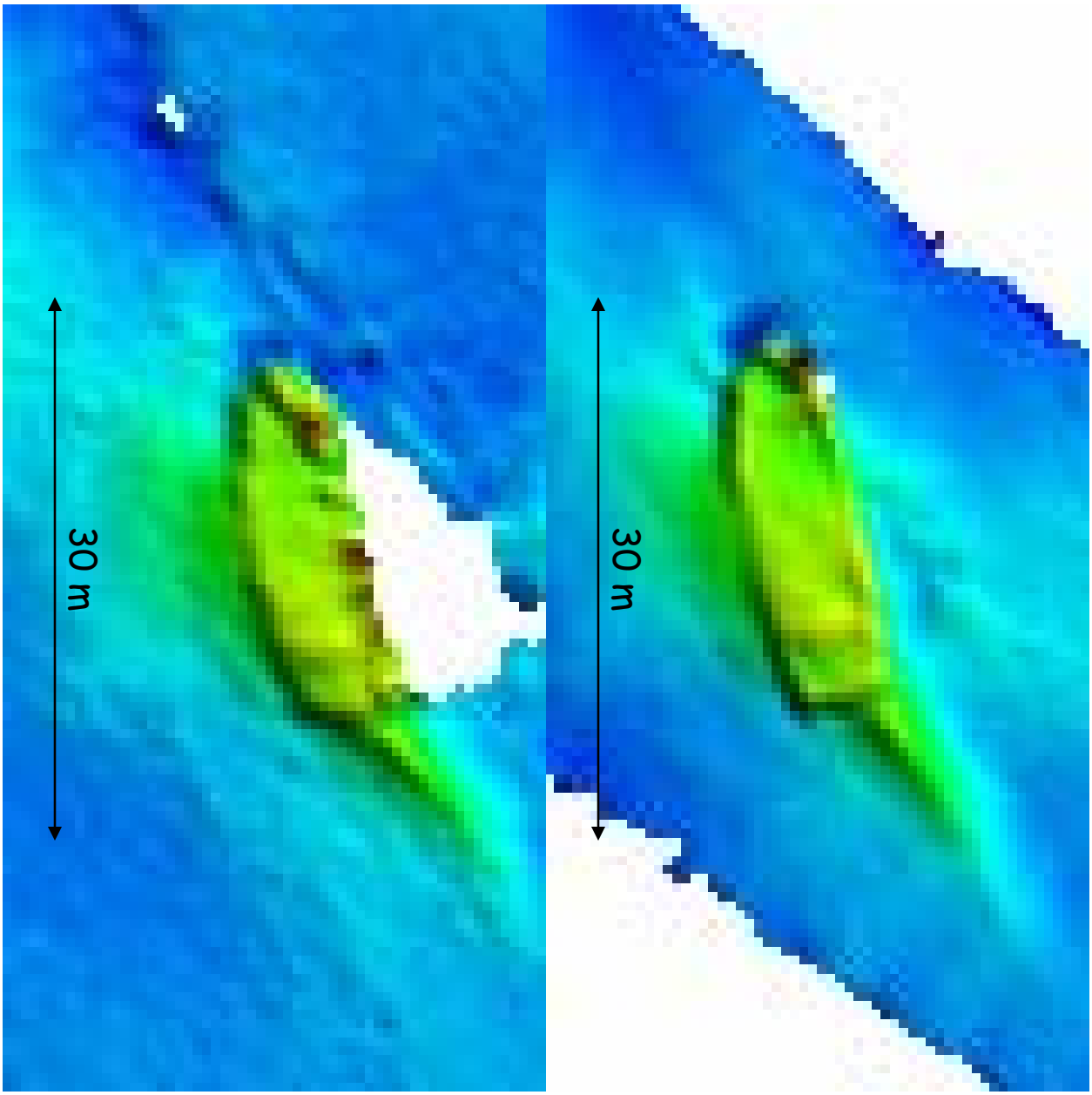


Figure 5. Comparison of gridded multibeam data collected over a potential shipwreck in the Hudson River (nineteenth century sloop) and gridded at 0.5 m. Left: multibeam data collected by the EM 3000 multibeam system during the Hudson Rive Benthic Mapping Project. There is a gap to the left of the target which is due to data loss of at the outer edge of the swath. Right: multibeam data collected by the EM 3002 during this project. Only a single swath of data was collected over this feature. Both systems create similar gridded data products at 0.5 m grid size.

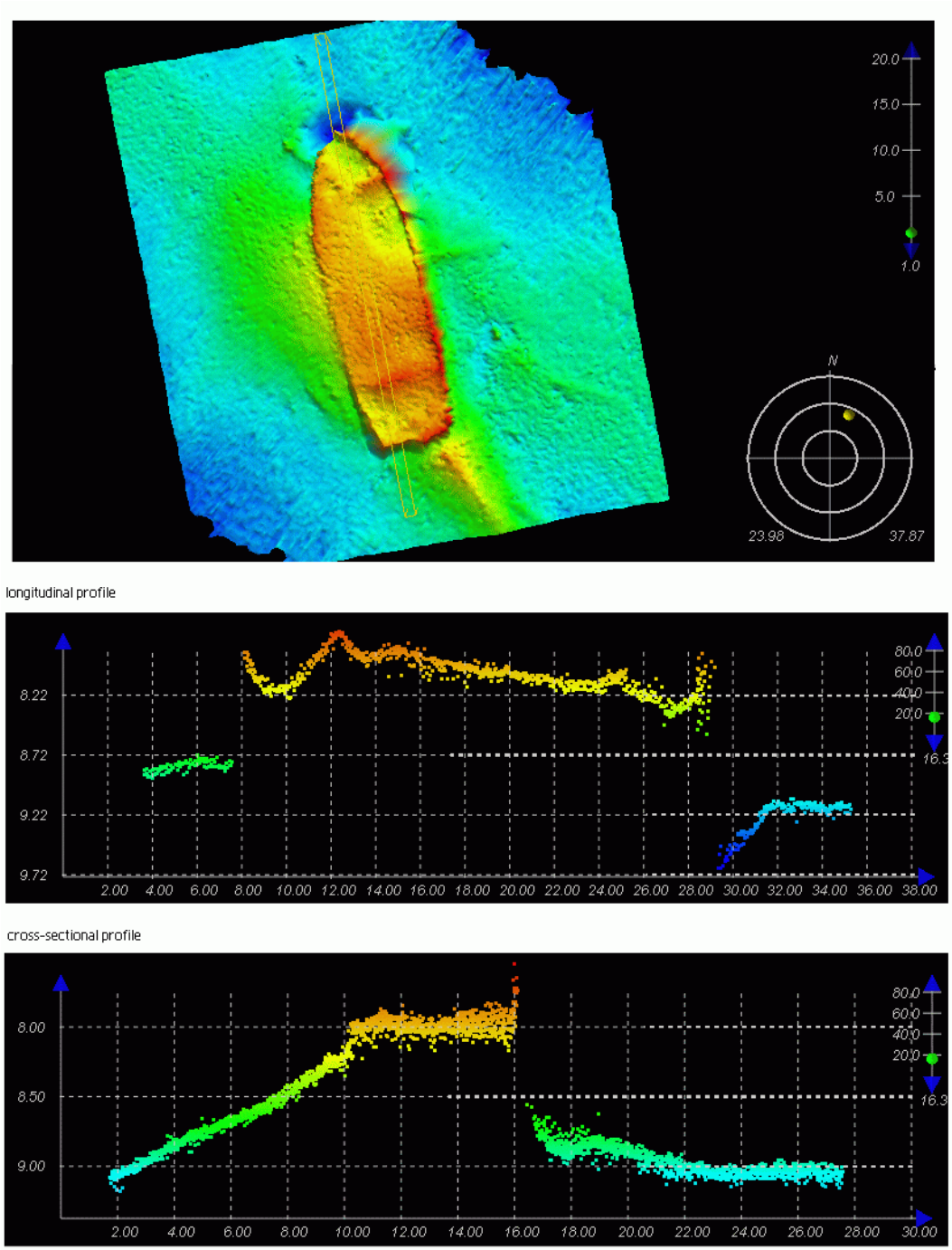


Figure 6. High-resolution image of multibeam data collected over the 19th century sloop imaged in Figure 5. Top: data display using the "subset editor" in CARIS HIPS and SIPS. All data points are plotted and the resulting surface is color-coded for depth and sun illuminated. Center: north-south profile of depth points along the axis of the vessel (north/bow to the left) The length and exposure of the vessel can be clearly determined. Lower: east-west profile of depth points across the width of the vessel (west / port on the left). The asymmetric depth pattern can be clearly seen.

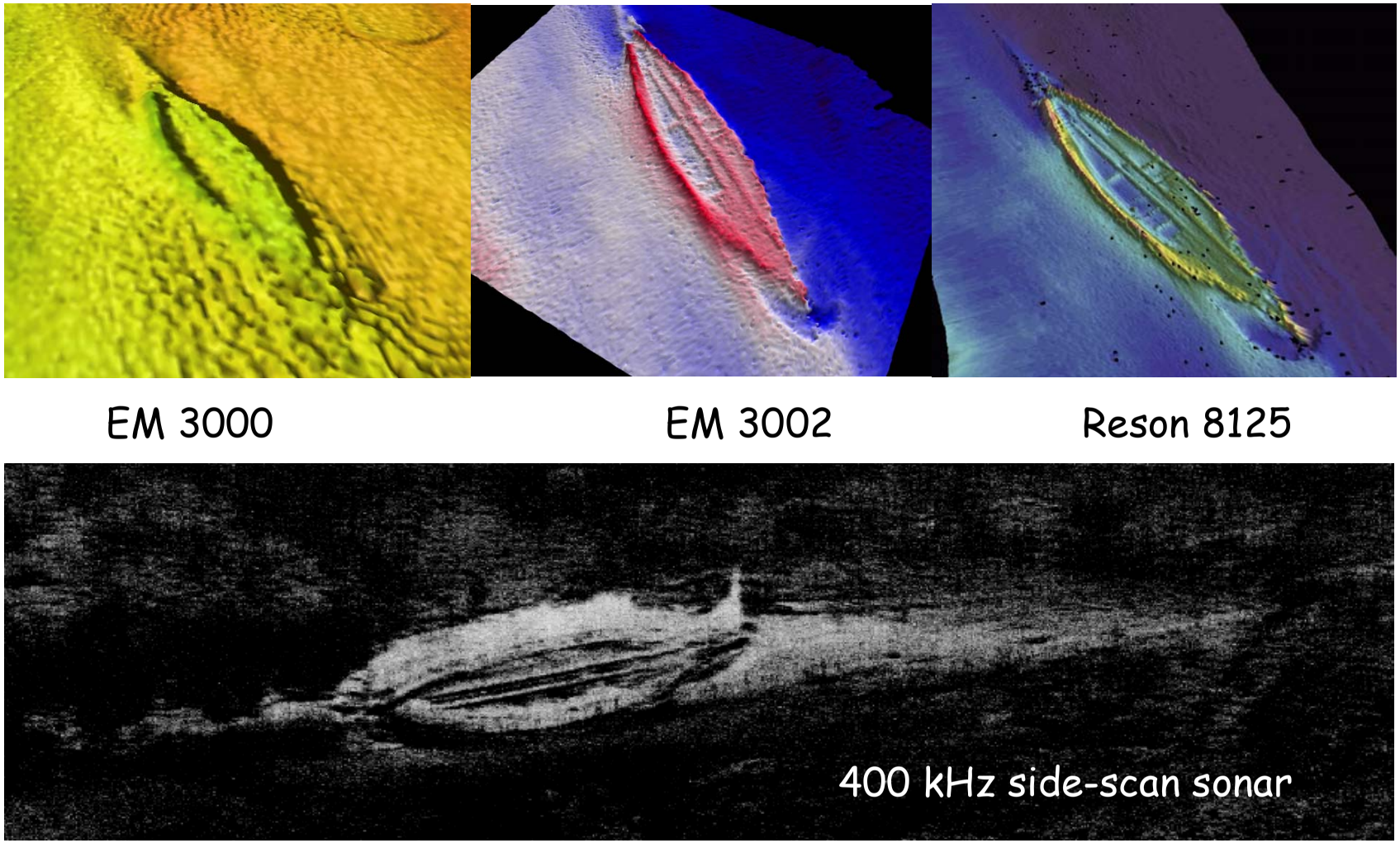


Figure 7. Comparison of multibeam data collected by three multibeam systems over the same sea-bed feature (a 38 m abandoned hull) from approximately the same viewpoint. Left: EM 3000 multibeam data gridded at 1 m. The irregular seabed at the forward end of the vessel is due to the overlap of swaths from two different tracks. This feature was crossed shortly after the survey vessel had turned, and the there was still an offset in the heave sensor. Center: EM 3002 multibeam data plotted with the CARIS subset editor (all data points are plotted). Right: Reson 8125 data plotted with the CARIS subset editor (all data points are plotted). Lower: side-scan sonar image collected with an EdgeTech 272DT / ISIS sonar system (stronger echoes are white).

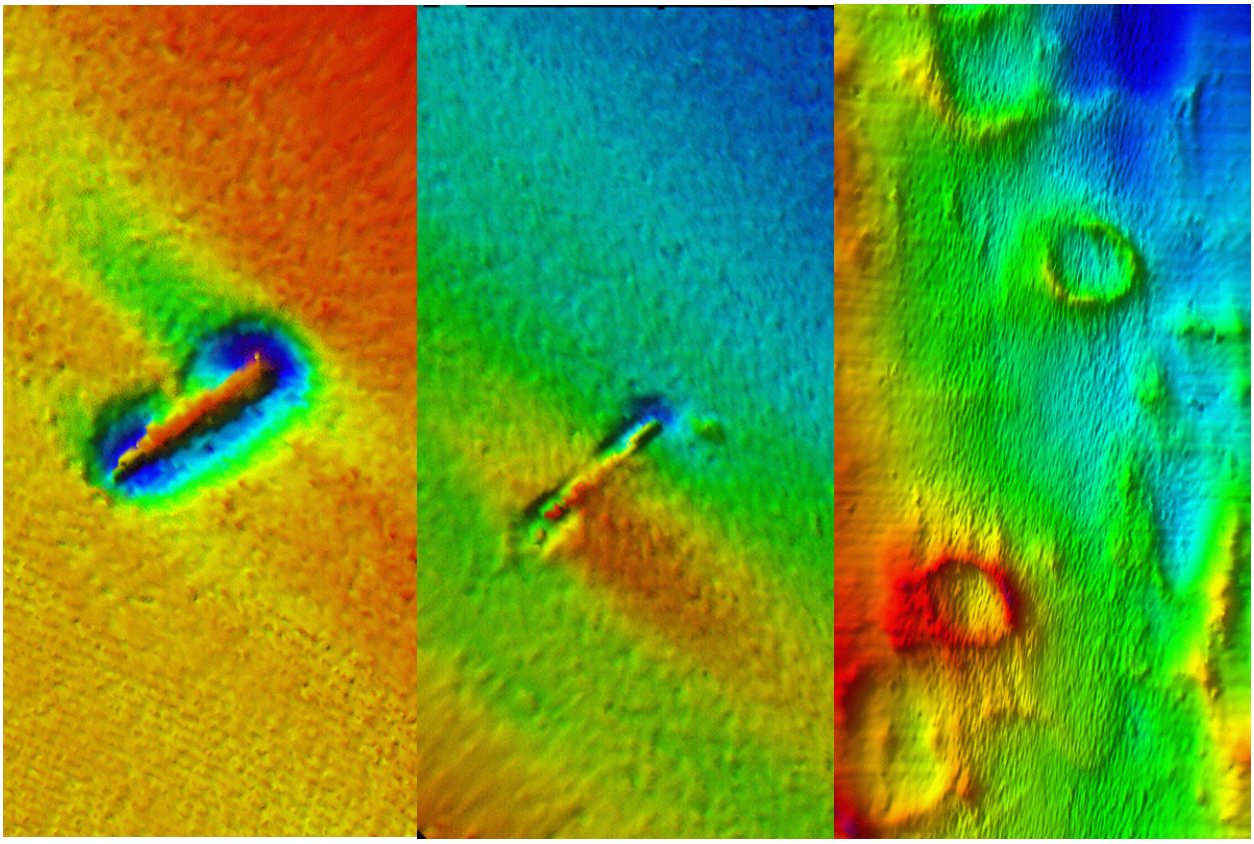


Figure 8. Multibeam depth data (Reson 8125 viewed with CARIS subset editor) for man-made features on the sediment surface related to debris. Left: piling (length about 8 m) with scour and sediment tail. Center: piling (length about 10 m) with scour and sediment tail. Right: rings (or "donuts") on the river bed. The rings are about 12-20 m in diameter, about 2 m wide and up to about 0.5 to 1 m high. It is thought that a ring is created when debris dropped from a ship impacts the bed.

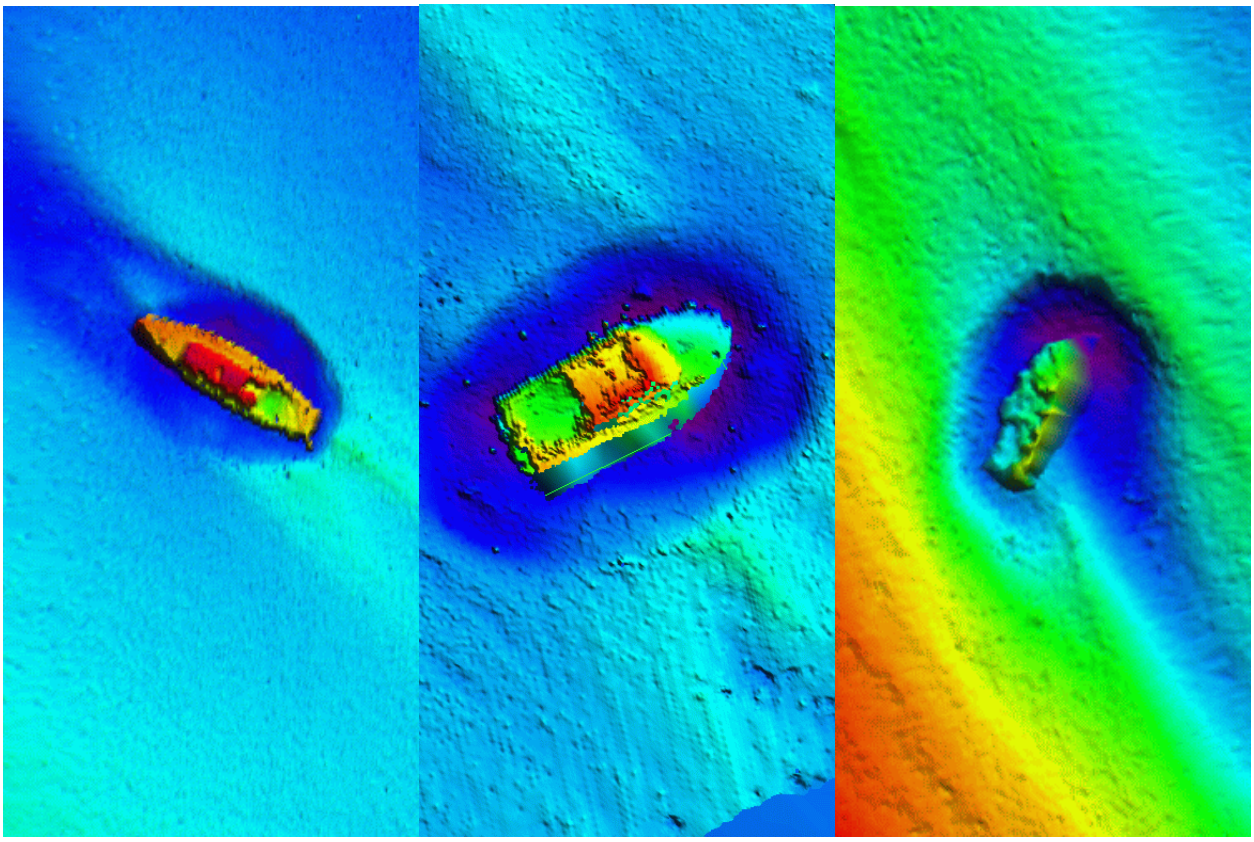


Figure 9. Multibeam depth data (Reson 8125 viewed with CARIS subset editor) for vessels from the modern era. Left: sailing hull about 12 m long. Center: motor vessel hull about 7 m long. Right: probably motor vessel hull about 6 m long.

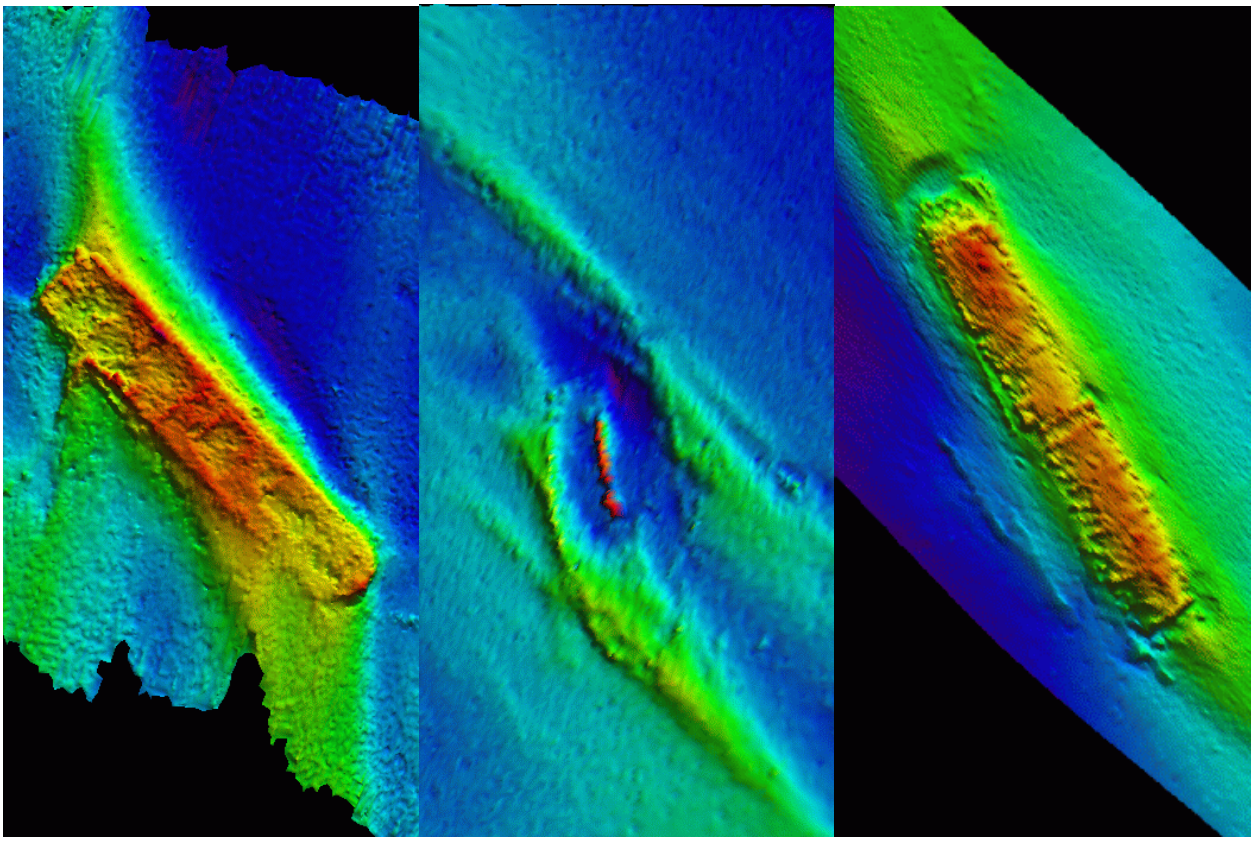


Figure 10. Multibeam depth data (left: EM 3002; center, right: Reson 8125 viewed with CARIS subset editor) for historic vessels. Left: probable Erie Canal barge 25 m long. Center: Hudson River sloop with an exposed length of 15 m (the stern is not imaged but the centerboard is imaged). Right: articulated Morris Canal barge with a length of 24 m.

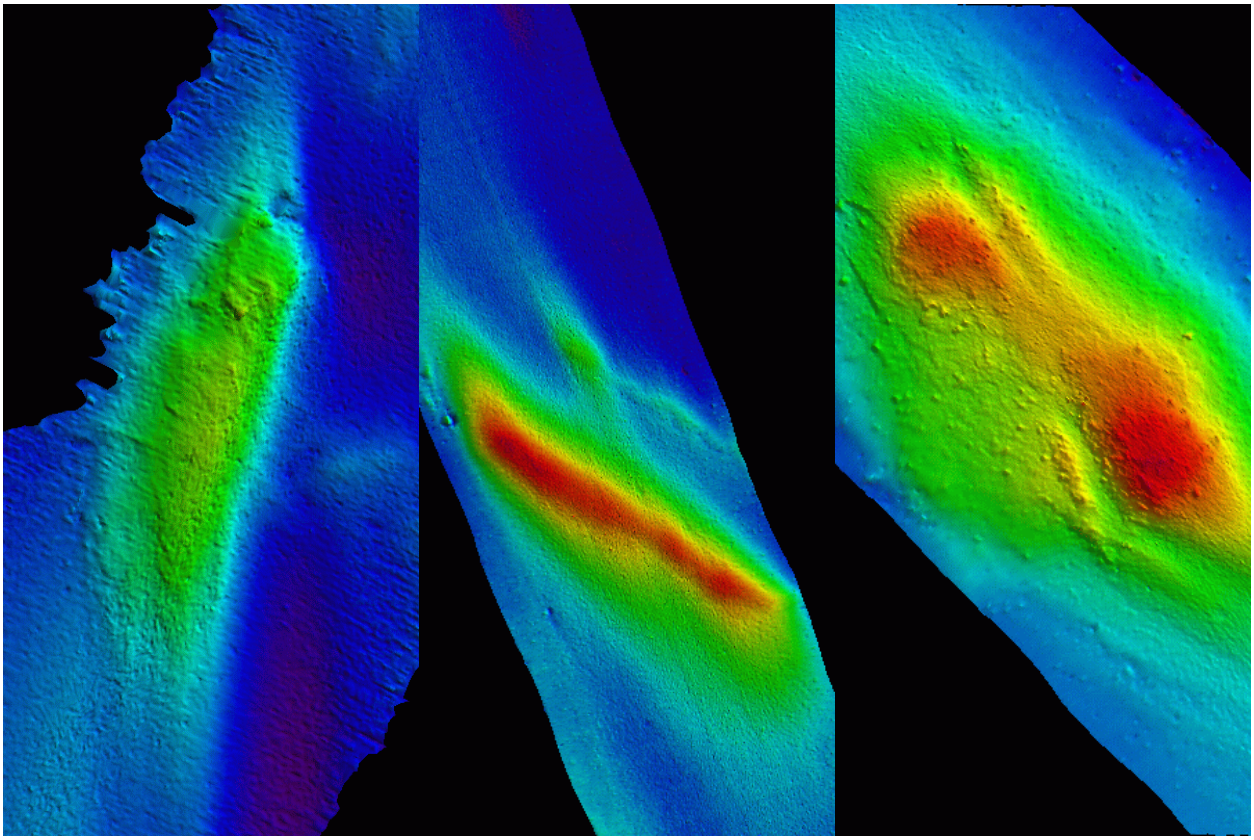
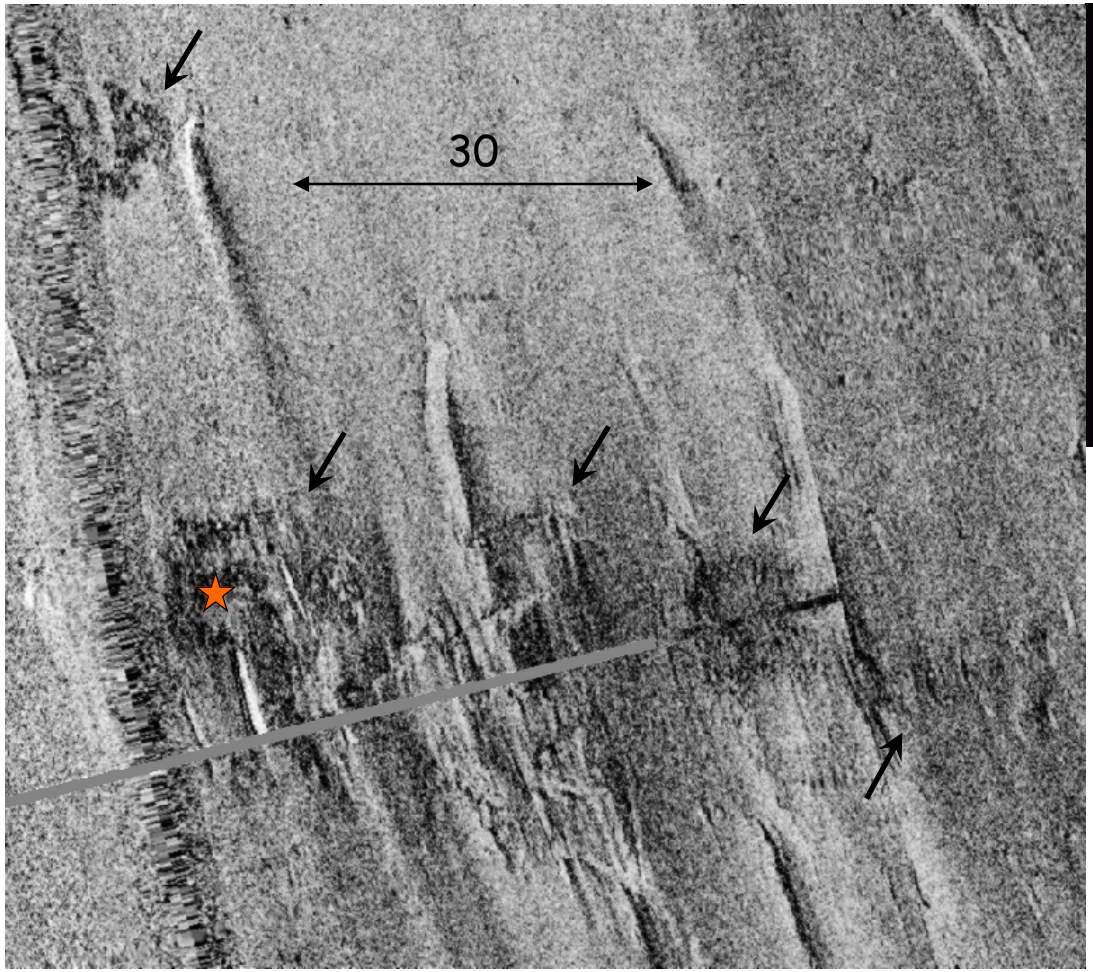


Figure 11. Multibeam depth data (left: EM 3002; center, right: Reson 8125 viewed with CARIS subset editor) for several curious mounds observed in the Hudson River. These features are about 20-25 m long and raised slightly above the surrounding sea bed, but there are no exposed structures. It is not known what has caused these mounds, but they may represent buried shipwrecks or other features of possible historical significance.



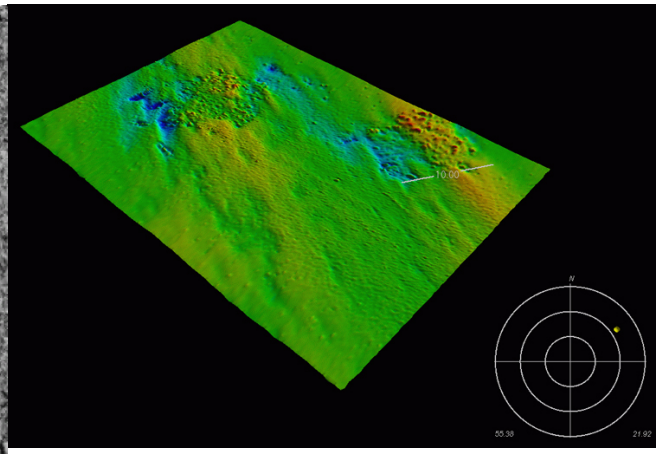


Figure 12. Left: Side-scan sonar record in the vicinity of the Chevaux de Frise that were constructed during the Revolutionary War in an attempt to stop the British war ships from traveling up the Hudson River. The square features (arrows) may be the bases of the different constructs. Some of the shorter linear targets may be the logs from these features. Upper: Oblique view of rougher patches on the Hudson River bed that appear to be the footprints of two Chevaux de Frise built in the Hudson River north of West Point. The square log structures were filled with stones and had iron-tipped spikes protruding from their tops. The sonar data suggest many logs are present on the river bed in this area, possibly logs used to construct these features. (Sonar data collected by NOAA Ship RUDE in 2004.) We conducted dives at the "star" during this project.

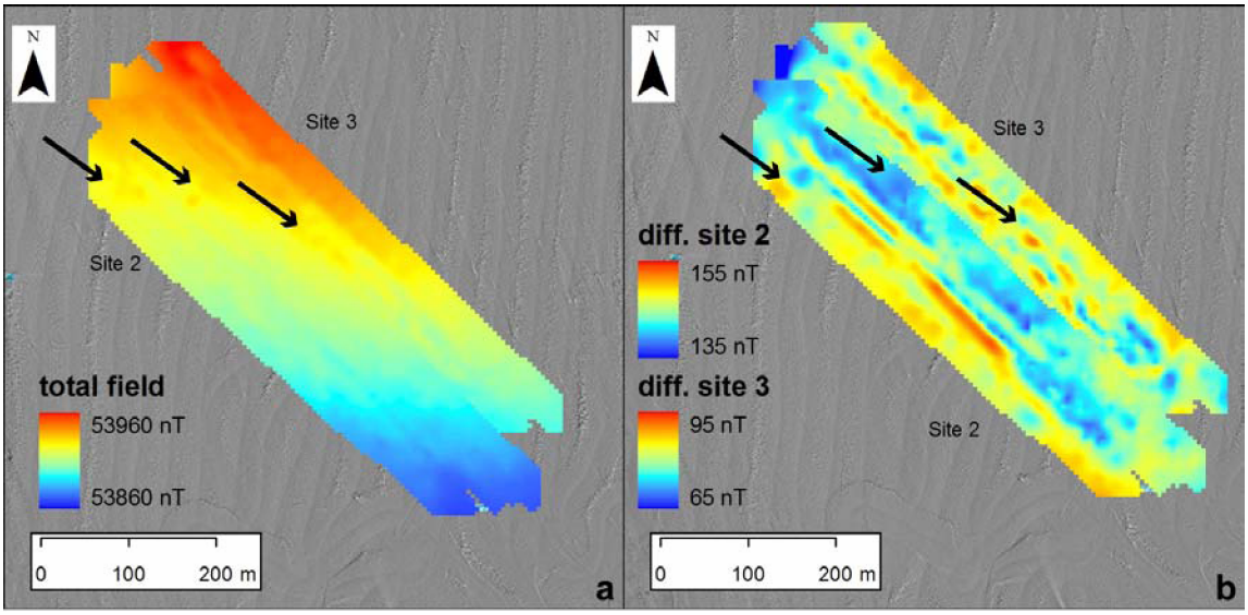


Figure 13. Magnetic field data at the Chevaux de Frise study site. (a) Total field of the lower sensor and (b) difference of the two sensors at this site. Background image consists of artificial illuminated bathymetry. Arrows mark indications of point source anomalies that are probably caused by ferrous iron. Note that the two mosaics displayed in this figure have different scales. (Figure from Frank Nitsche.)

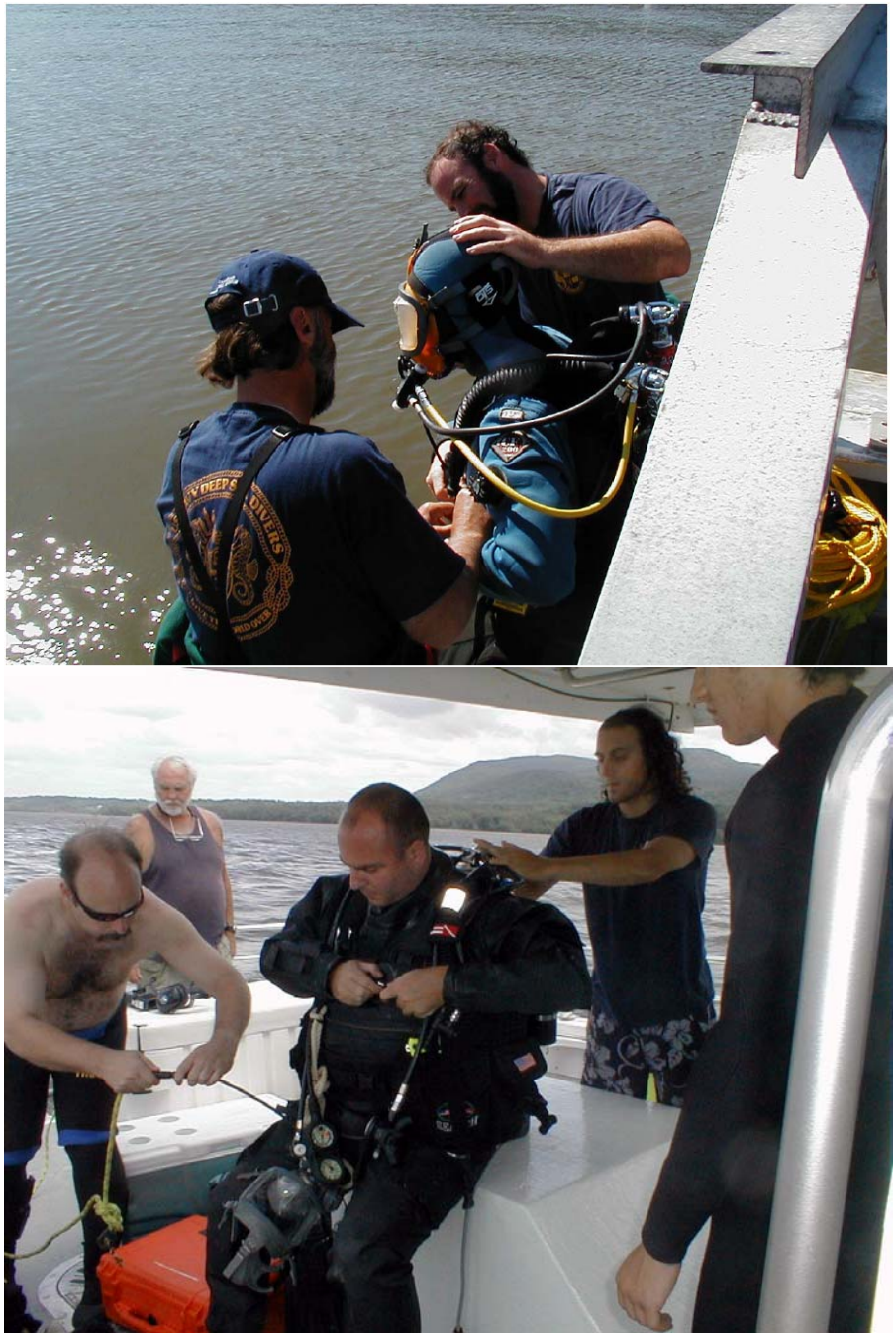


Figure 14. Top: Adam Kane from the Lake Champlain Maritime Museum suited up for a dive in the Hudson River. He is wearing a dry suit and a full-face mask with an underwater communications module. He is being assisted by Pierre LeRocque (far side) and Art Cohn (near side, suited up ad backup-diver). Bottom: John DeFrancesco of the West Point Divers prepares for a dive at the Chevaux de Frise site. He is wearing a full-face dive mask with communications to the surface.

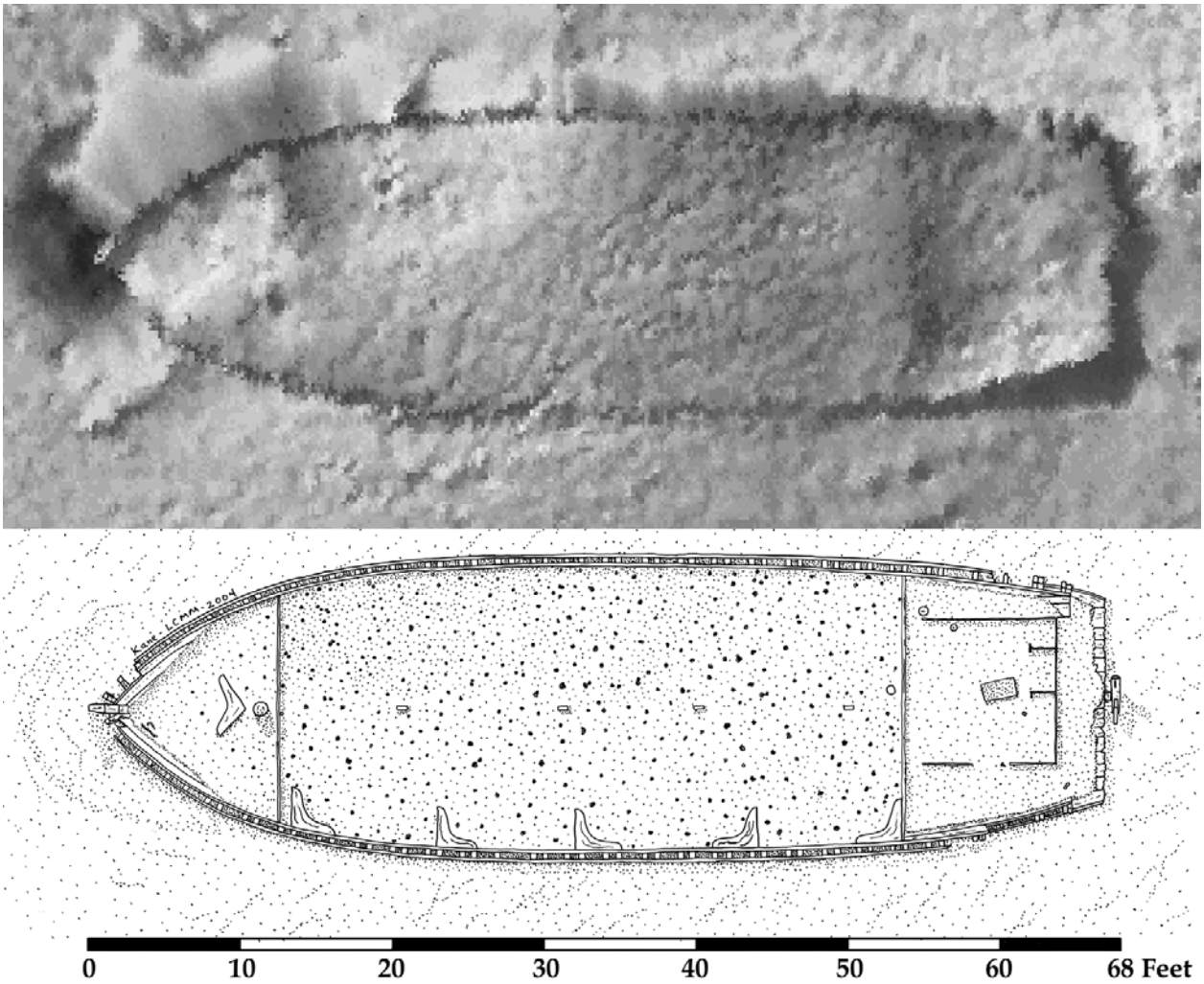


Figure 15. Results of diver investigation of 19th century sloop probably rigged as a New York City lighter. Top: multibeam image of vessel hull. Bottom: sketch of the vessel hull based on diver observations (hull length is about 68 feet or 21 m long). Visibility was limited to 0.5 to 1 foot making observations difficult. The multibeam image assisted the divers in planning their investigation and in putting their detailed observations in context. (Figure from Adam Kane.)

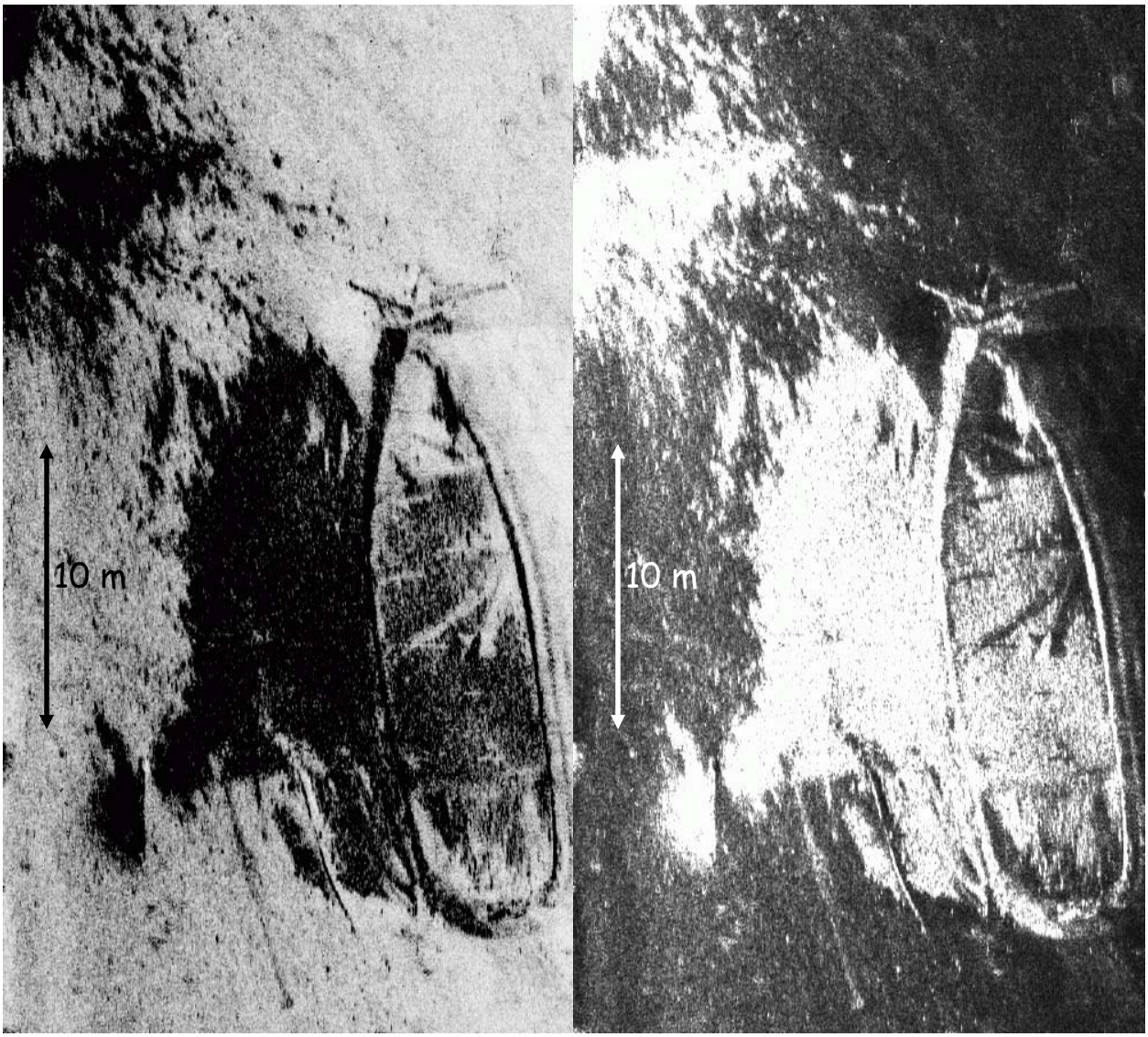


Figure 16. Side-scan sonar record over the vessel in Figure 15 collected about a year after the diver study. The same image is on both sides. On the left-hand side the strong echoes are black while on the right-hand side strong echoes are white. The two different images highlight different aspects of the sonar record. Of particular interest is the "bumpy" sonar texture in the hold related to the coal and the additional beams imaged on and adjacent to the hull.

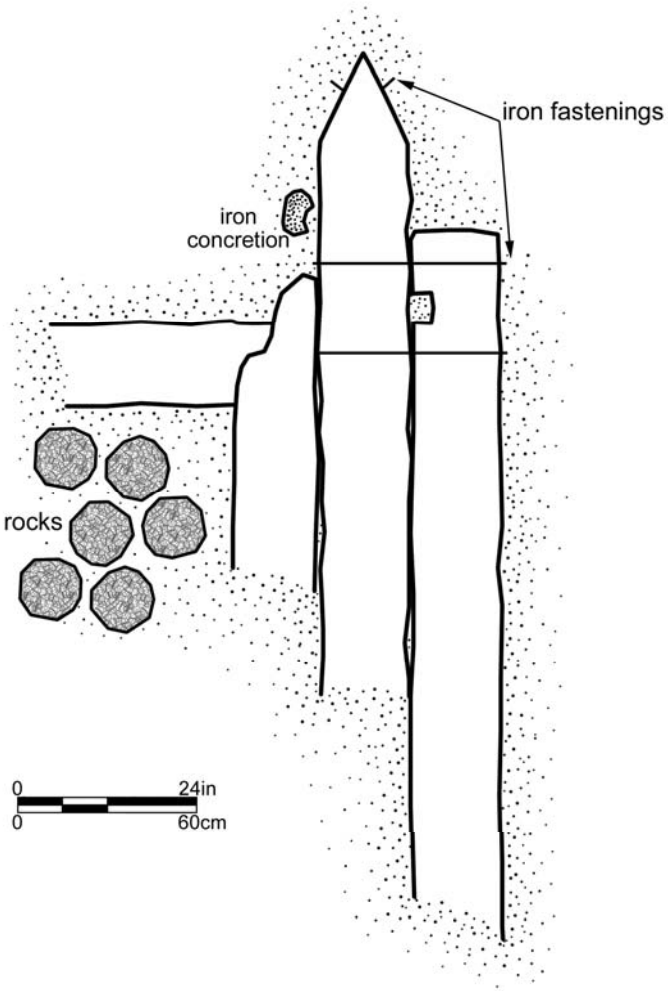


Figure 17. Results of diver investigations in the Chevaux de Frise area. Left: sketch of timbers, some of which are bolted together, and stones observed by divers on the sea bed. These materials are likely remains of the Chevaux de Frise. Up: photograph of the top of a Chevaux de Frise spike on display at the museum at Washington's Headquarters in Newburgh, NY. The timbers observed by divers are similar to those on display at the museum, suggesting that they are of similar origin.