Object Detection with Phase-Measuring Bathymetric Sidescan Sonar Depth Data

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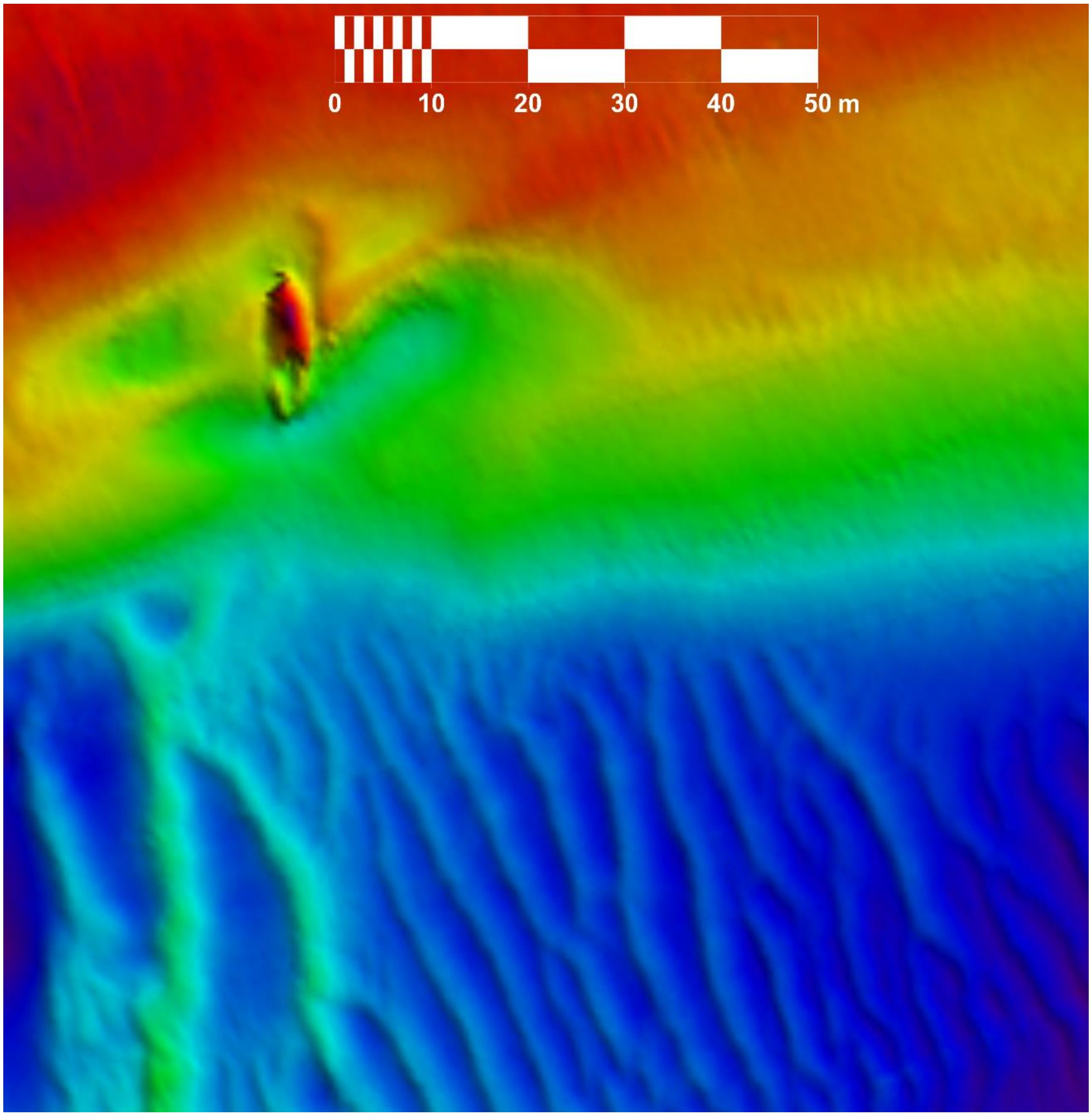

A shipwreck and bedforms are visible in a phase-measuring bathymetric sidescan sonar survey of Fire Island Inlet, New York. The depth color scale ranges from 6 m (red) to 12 m (purple) and the grid size is 50 cm; no manual editing has been performed.

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Background

Phase-measuring bathymetric sidescan (PMBS) sonar systems offer simultaneous collection of sidescan imagery and bathymetric soundings within a wide angular field of view. These echosounders are of interest for coastal storm response surveys in shallow water due to their wide swath angles (up to 220°), compact form factors, and relatively low hardware costs. Importantly, the wide angular field of view allows a vessel to survey shallow hazards at increased athwartship distances.

Challenges of PMBS surveying have been identified as high data rates yielding extremely large raw bathymetry datasets; requirements for data processing of soundings with manufacturer-specific software; variable acrosstrack sounding density; and characteristically broad vertical distributions (or 'noisiness') of soundings, especially in the outer swath. These aspects are of particular concern for rapid processing of large datasets and detection of objects such as marine debris. Objects on the seabed may be obscured in regions of high sounding density due to typical noisiness of raw soundings, or omitted in swath regions near nadir with low data density.

Methods have improved in recent years for the rapid processing of PMBS data into bathymetric surfaces using commercial-off-the-shelf software. Specifically, the Combined Uncertainty and Bathymetry Estimator (CUBE) algorithm implementation in CARIS HIPS 8.1 has been identified as one viable data processing path which can accommodate large datasets and produce bathymetric surfaces requiring minimal additional editing (CARIS processing guides for PMBS data are available at *sandy.ccom.unh.edu*). The representation of objects on the seabed using this data processing path is of particular interest for surveys intended to locate marine debris, measure least depths for hazards to navigation, and monitor changes to the seabed.

Purpose

The purpose of this document is to provide general guidance for visual detection and recognition of objects in PMBS data collected and processed with commercially available echosounders and software, respectively, such as those which may be used during storm response surveying. Examples of objects ranging in size from sunken barges to mooring blocks are presented from two PMBS datasets in Super Storm Sandy-affected regions to illustrate the representation of objects in gridded bathymetric surfaces. While every combination of PMBS echosounder, survey environment, and data processing method presents its own unique set of capabilities and limitations for the representation of objects on the seafloor, these examples inform general recommendations for bathymetry-based object detection and recognition using PMBS in shallow water. This document may be updated as additional examples are developed.

Overview of Object Detection in Bathymetry

One of the primary purposes of surveying after a storm is to detect bathymetric changes that may be associated with the presence of objects previously undetected or nonexistent, as well as any changes in the orientations of known objects from pre-storm condition. Detection and recognition of an object often involves human interpretation of raw soundings and processed gridded surfaces; additional investigation may be required, such as visual confirmation using divers or remotely operated vehicles.

In the context of detection and recognition from human interpretation of bathymetric data alone, the size of an object relative to the echosounder sample size and the processed bathymetric grid size matter greatly. PMBS systems generally operate at high frequencies yielding raw sample spacing on the order of 1-10 mm; this extremely fine range resolution is achieved at the cost of typical range limits of 200 m or less due to increased acoustic attenuation at high frequencies. While some PMBS models (e.g., GeoAcoustics GeoSwath Plus) provide raw sample data to the user, others (e.g., EdgeTech) employ outlier removal techniques during acquisition and typically require application of raw sample binning methods to reduce data volume and noise in the resulting soundings. Manufacturer strategies vary to achieve a balance between resolution, data volume, uncertainty, and preservation of objects.

Regardless of the PMBS model deployed, an object may be detected only when soundings (ideally from multiple survey passes) collectively represent its surfaces and indicate its distinct shape relative to the ambient seafloor. Single survey passes may suffer from data artifacts that appear as objects in the bathymetry, resulting in apparent hazards that are difficult or dangerous to refute without additional swath coverage. Overlapping survey passes are typically useful for confirming the presence or absence of an object on the seafloor, but even regions of dense, independent soundings must be interpreted carefully. Processing raw data into gridded bathymetric products, typically on the order of 10-50 cm grid size in shallow water, may have significant impacts on the representation of an object.

Objects on the order of 10 m or larger in at least one dimension, such as a commercial vessel, are highly likely to be well-represented in the bathymetry owing primarily to the large number of soundings on the object. Medium-sized objects on the order of 1-10 m in all dimensions, such as an automobile, are also likely to stand out if ensonified by more than a single ping, but their detection and recognition may require higher sounding density from slower or multiple survey passes. Small objects on the order of 1 m or less in all dimensions, such as a mooring block, may be possible to detect but difficult to recognize in PMBS data. In a worst-case scenario, insufficient sounding density fails to suggest the presence of an object; alternatively, soundings associated with a hazard of any size may be present in the raw data but filtered as outliers or bin-averaged with adjacent seafloor depth estimates to the extent that the object is not detected in the final bathymetric product.

Overviews of Datasets

Datasets collected with different PMBS systems are used in this document to demonstrate the representation, detection, and recognition of objects in gridded bathymetric products. It must be noted that all PMBS systems behave differently and these examples are intended to illustrate the general nature of PMBS data processed using commercial off-the-shelf software (namely, the CUBE algorithm in CARIS HIPS 8.1). The two datasets presented here are located in Sandy-affected areas in Delaware and New York and include objects of many sizes:

1. Redbird Reef, Delaware, includes large objects surveyed with a GeoAcoustics GeoSwath Plus PMBS deployed from a GAVIA autonomous underwater vehicle (AUV) by University of Delaware.

2. Fire Island Inlet and offshore Shinnecock Bay, New York, include small objects surveyed with an EdgeTech 4600 PMBS deployed from the R/V *Noot Valmaakt* by Williamson and Associates under NOAA project OPR-C331-KR-13.

All examples of PMBS data in this document have been processed in CARIS HIPS 8.1 using the CUBE algorithm as described in their respective manufacturer's CARIS PMBS processing guide (*sandy.ccom.unh.edu*). This processing path, traditionally employed for multibeam data, has been shown to handle large PMBS datasets and generate gridded bathymetric products requiring minimal additional editing. Importantly, no manual editing has been performed on any of the examples; additional processing parameters are noted below.

Large Objects – Redbird Reef, Delaware

Redbird Reef is an artificial reef approximately 30 km off the Atlantic coast of Delaware consisting of sunken subway cars, commercial vessels, a Navy barge, military vehicles, and clusters of ballasted tires. A post-Sandy survey was conducted on November 10, 2012, using an AUV equipped with a GeoAcoustics GeoSwath Plus PMBS. The AUV operated at a nominal altitude of 6 m above the seafloor with survey line spacing of approximately 20 m, typically resulting in at least 50% overlap between swaths on adjacent passes (or swath coverage from at least two survey passes for all targets). This dataset includes multiple large objects such as subway cars, a barge, and a sunken ship (not listed on the Delaware reef guide). Bedforms adjacent to the subway cars are also included as an example of relatively small detectable features in this survey, indicating that other small objects would likely be detected if present. Figure 1 provides an overview of the survey site, with examples taken from the barge, shipwreck, and a pair of crossed subway cars (labeled A, B, and C, respectively).

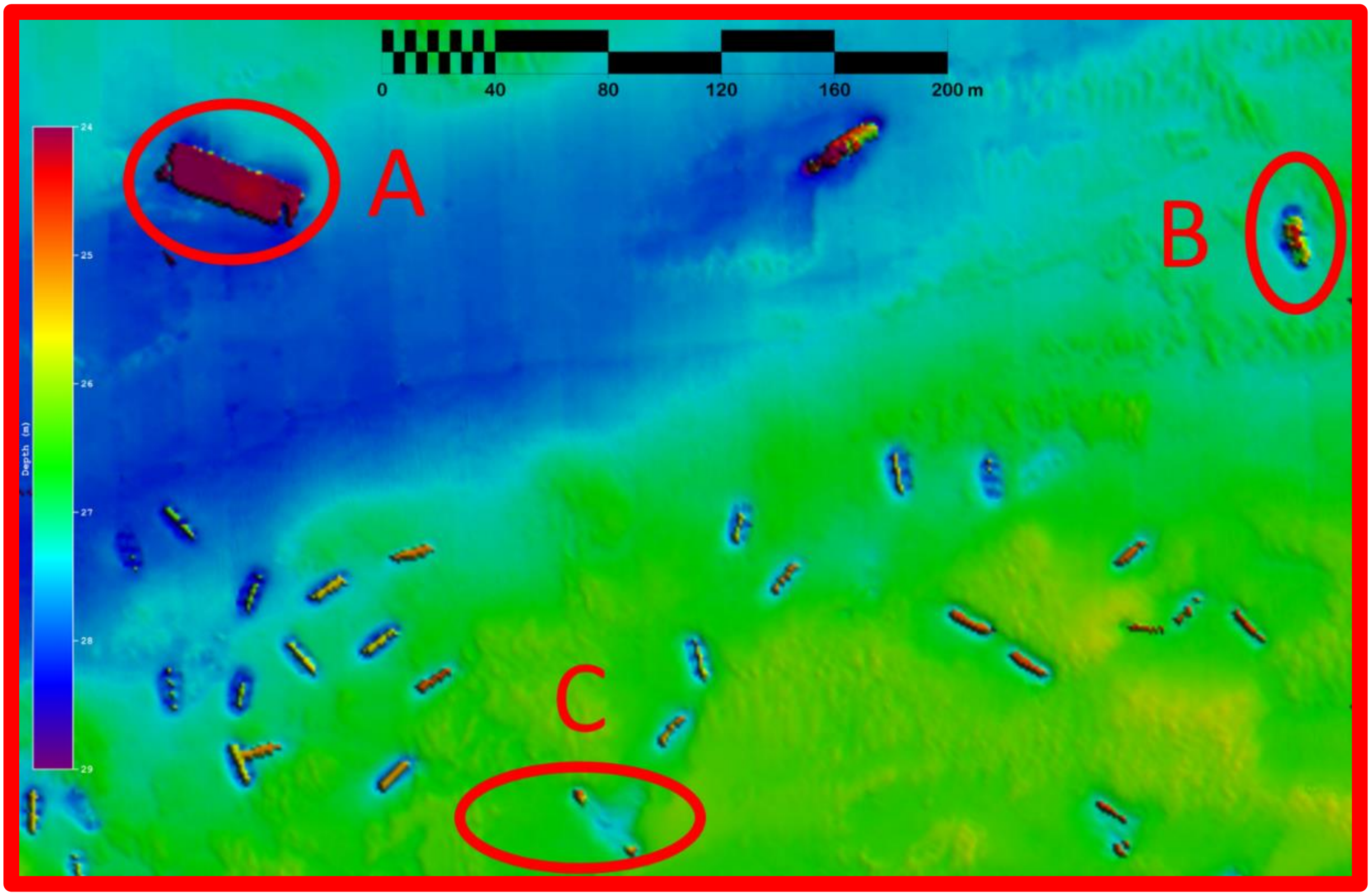

Figure 1. Overview of a Redbird Reef survey with a GeoAcoustics GeoSwath Plus PMBS. The depth color scale ranges from 24 m (purple) to 29 m (dark blue). Data were gridded at 100 cm using CUBE in CARIS HIPS 8.1. Study sites for object detection are a Navy barge (A), a sunken vessel not listed on the Delaware reef guide (B), and two overlapping subway cars with adjacent bedforms (C).

Processing method

GeoSwath Plus data were processed in CARIS HIPS 8.1 using the workflow for multibeam echosounder (MBES) data in conjunction with the document 'CARIS 8.1 GeoSwath Processing Guide' available on the project website (*sandy.ccom.unh.edu*). Two filters were applied during data conversion:

1. An amplitude filter was applied to remove soundings in the lowest 10% of the amplitude range for each swath. These low-amplitude samples frequently suffer from phase measurement blunders which result in depth estimate outliers.

2. A range filter was applied to remove soundings less than 2 m and more than 100 m from the transducer. This filter eliminates an artifact associated with sampling the transmit pulse or 'ring-down' of the transmitter (< 2 m) and intermittent range outliers of unknown origin (> 100 m). This filter is not expected to remove legitimate soundings because the AUV altitude was expected to be greater than 2 m throughout the survey and the sampling range limit was set to approximately 25 m during data acquisition.

Bathymetric surfaces were created in grid sizes ranging from 10-100 cm in increments of 10 cm using the CUBE algorithm for outlier rejection and depth hypothesis selection. Lines containing AUV maneuvers outside of normal survey operations (e.g., slow turns or stopping while pinging) were removed because the large number of overlapping swaths produced patches of extremely high density soundings and consistently caused shoal artifacts in the gridded surfaces. No additional filtering or editing was performed. Examples of objects were taken from the resulting 'full' dataset of all normal survey lines and from a 'reduced' dataset designed to simulate sparse sounding coverage from wider line spacing.

Navy barge

Redbird Reef includes a sunken Navy barge approximately 50 m in length, 15 m in width, and protruding 3 m from the seabed (Fig. 1, A). This barge represents a category of very large object that is readily detectable in all portions of the PMBS swath and in bathymetric surfaces gridded at 10-100 cm (Fig. 2). A clear trade-off exists between resolution, noisiness, and coverage of the surfaces. For example, the 10 cm grid appears to preserve the railing along its northeast and southeast (upper right and lower right) edge and indicate where sounding density is too low to produce hypotheses (southwest, or lower left). The 10 cm grid also preserves depth artifacts associated with sparse swath coverage at nadir and phase-wrapping errors in the target angle estimates (Fig. 2, 10 cm grid, parallel to the southeast wall; Fig. 3, left, starboard swath of soundings at constant range). As grid size increases from 10 cm to 100 cm, data density (soundings per grid cell) becomes sufficient to produce a seafloor surface free of major artifacts, except for the region in the southwest with insufficient sounding density. Detail in the surface is reduced with increasing grid size, ultimately failing to preserve the barge railing and any adjacent bedforms in the 100 cm grid. In this example, a grid size of 30 cm appears to provide a reasonable compromise between removing artifacts and preserving detail.

The barge bathymetry examples in Fig. 2 include data from five adjacent survey lines with at least half-swath overlap. In surveys with wider spacing and less overlap between adjacent swaths, the representation of objects in the outer swath is of increased importance; this region is also where PMBS systems typically exhibit the greatest depth measurement noise. Figure 3 shows barge soundings in the outer swath and near nadir from separate survey pass gridded individually at 30 cm. In this example, the barge is a large, acoustically strong target that is clearly evident even in the outer swath.

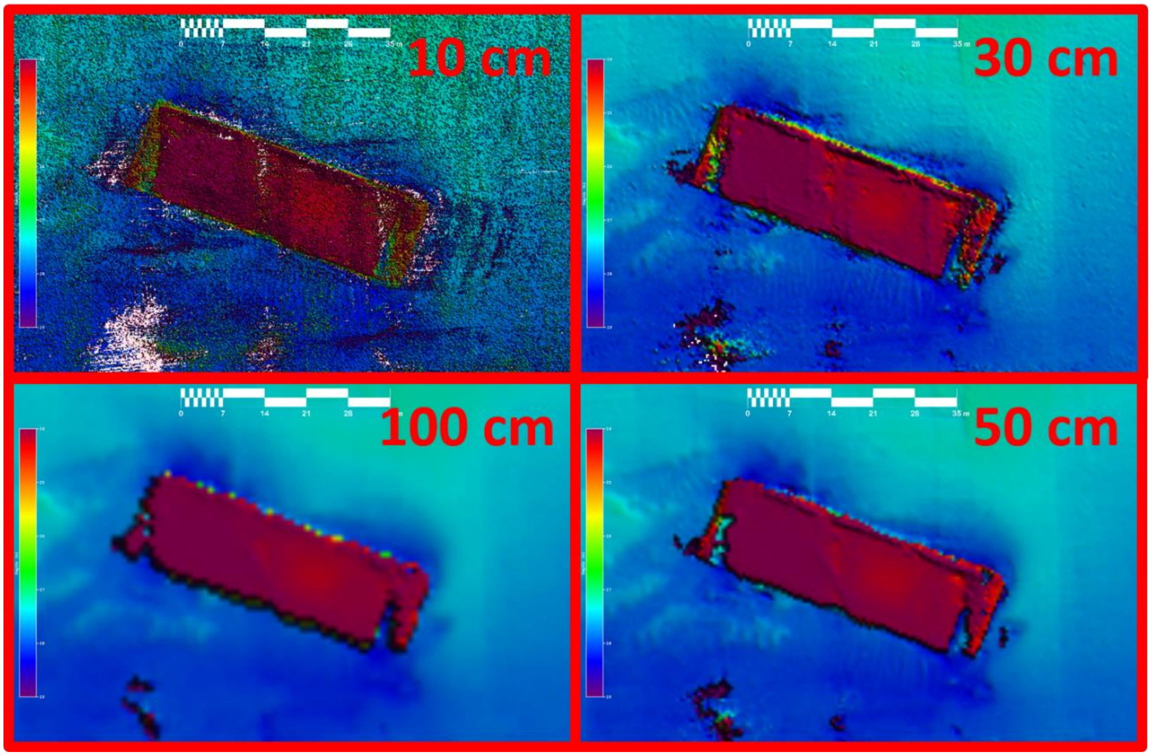

Figure 2. A sunken Navy barge appears clearly in PMBS data gridded at 10 cm, 30 cm, 50 cm, and 100 cm (clockwise from upper left). Depth ranges from 24 m (red) to 27 m (purple) in this image; the scale bar is 35 m in total length. These examples illustrate that increasing grid size effectively removes most artifacts associated with 'noisiness' of the PMBS data at the expense of suppressing other features of interest, such as adjacent sand waves northwest of the barge and a railing along the northeast and southeast edges of the barge deck. Note that the region of low sounding density in the lower left portion of the image results in surface artifacts at all grid sizes.

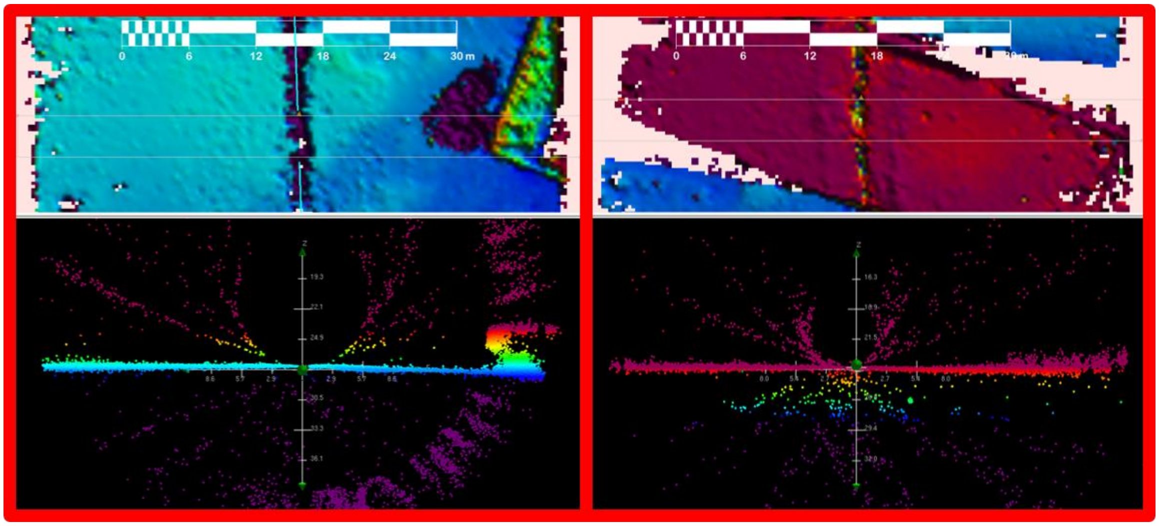

Figure 3. CUBE surfaces (top) and subsets of raw data viewed alongtrack (bottom) for two separate survey lines including coverage of the Navy barge. Left: A survey line passing approximately 20 m from the barge clearly shows its corner in the outer swath to starboard. The high scattering strength of the barge and possible small multipath effects yield many phase-measuring artifacts; these are apparent as the half-ring of soundings coinciding with the range to the barge on the starboard side of the swath. Right: A survey line passing directly over the barge readily detects the flat top surface and captures the railing on the northeast edge, but leaves an acoustic shadow beyond the edges of the top surface. An alongtrack 'trench' appears at nadir over the seabed and barge, possibly due to overwhelming specular reflection and low sounding density in this portion of the swath.

Motor vessel

A sunken motor vessel approximately 18 m long, 5 wide, and protruding approximately 3-4 m above the seabed is visible near the eastern boundary of the Redbird Reef survey (Fig. 1, B). Though the vessel is covered in only two survey passes and a small acoustic shadow exists to eastward, detection of this object is readily achieved from the CUBE surface gridded at 30 cm (Fig. 4). Recognition of the object as a sunken vessel is not readily apparent in larger grid cell sizes. Features of the vessel such as the sharp bow, wheelhouse window frames, and railings along the deck edges become clear during three-dimensional manipulation of the raw data, as demonstrated partially by the perspectives provided in the lower panels of Fig. 4. This vessel illustrates the utility of scrutinizing raw soundings for recognition of an object detected in a coarsely gridded surface.

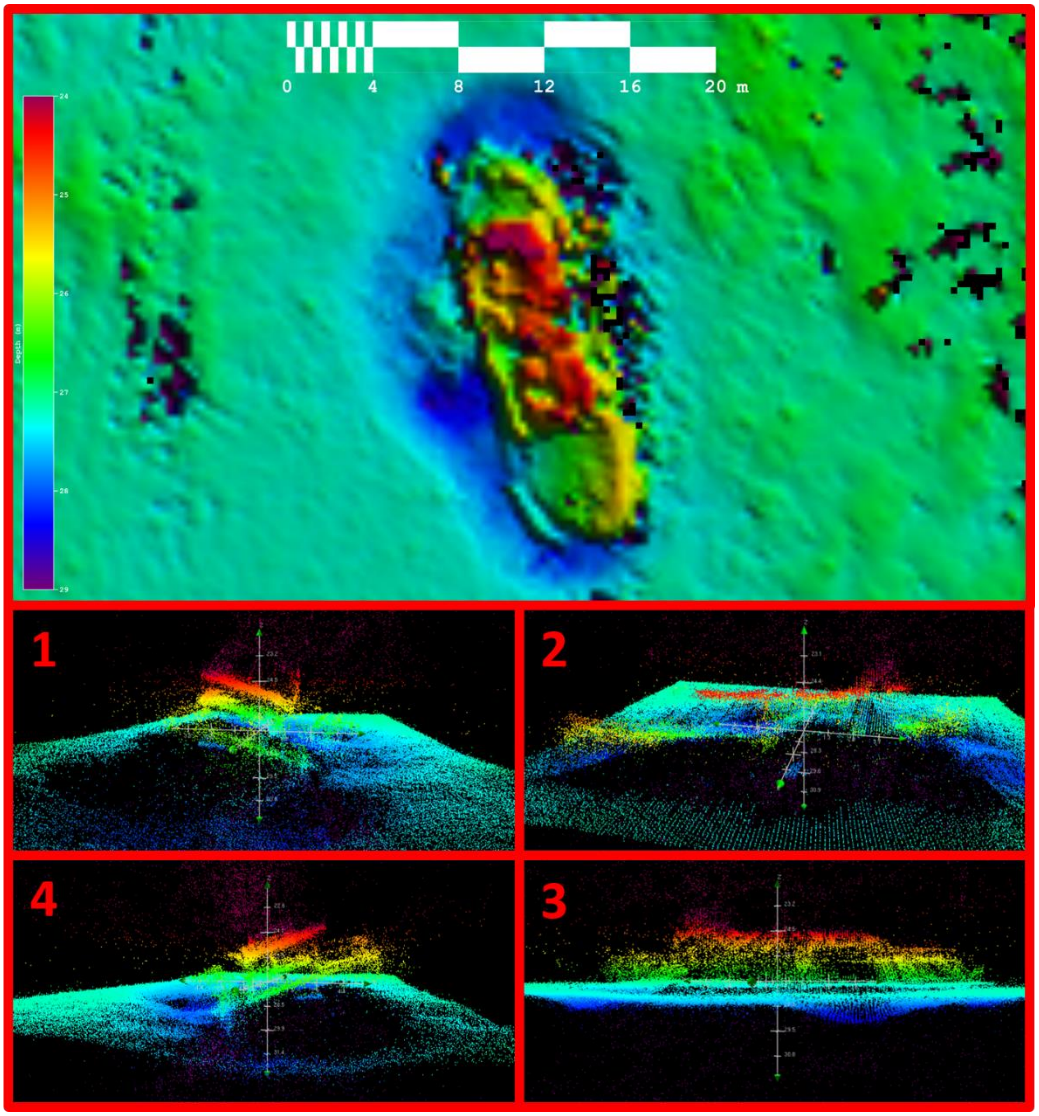

Figure 4. A sunken motor vessel is readily apparent in a CUBE surface gridded at 30 cm (top). The depth scale ranges from 24 m (red) to 29 m (purple). Though the gridded surface clearly indicates the presence of a large object with adjacent scouring of the seabed, many identifying features are visible only upon examination of the raw data viewed from various angles (lower images). Some features of the sunken vessel, including frames of the windows, are not presented in the gridded surface but are visible in the raw data and aid the recognition of the object. The raw data perspectives numbered 1-4 are from ahead, starboard, port, and astern, respectively.

Subway cars and bedforms

Two overlapping subway cars and an adjacent field of sand waves are visible in the southern portion of the Redbird Reef survey. Figure 5 shows the gridded depths and standard deviation of soundings in each grid cell at 10 cm, 30 cm, and 100 cm resolution. This region illustrates significant changes in the appearances of small and large features for object detection at different grid sizes. Most notably, the sand waves and central portion of the overlapping subway cars are generally not visible in the 100 cm grid, despite overlapping swath coverage. These features develop visually as grid size is reduced, indicating the value of viewing surfaces gridded at multiple resolutions. Figure 5 demonstrates that regions of elevated standard deviations of soundings may be useful for detecting edges of objects in PMBS data, even when suppressed in the gridded depth surface. Subsets of raw data (Fig. 6) show additional detail which aid in recognition of the overlapping subway cars.

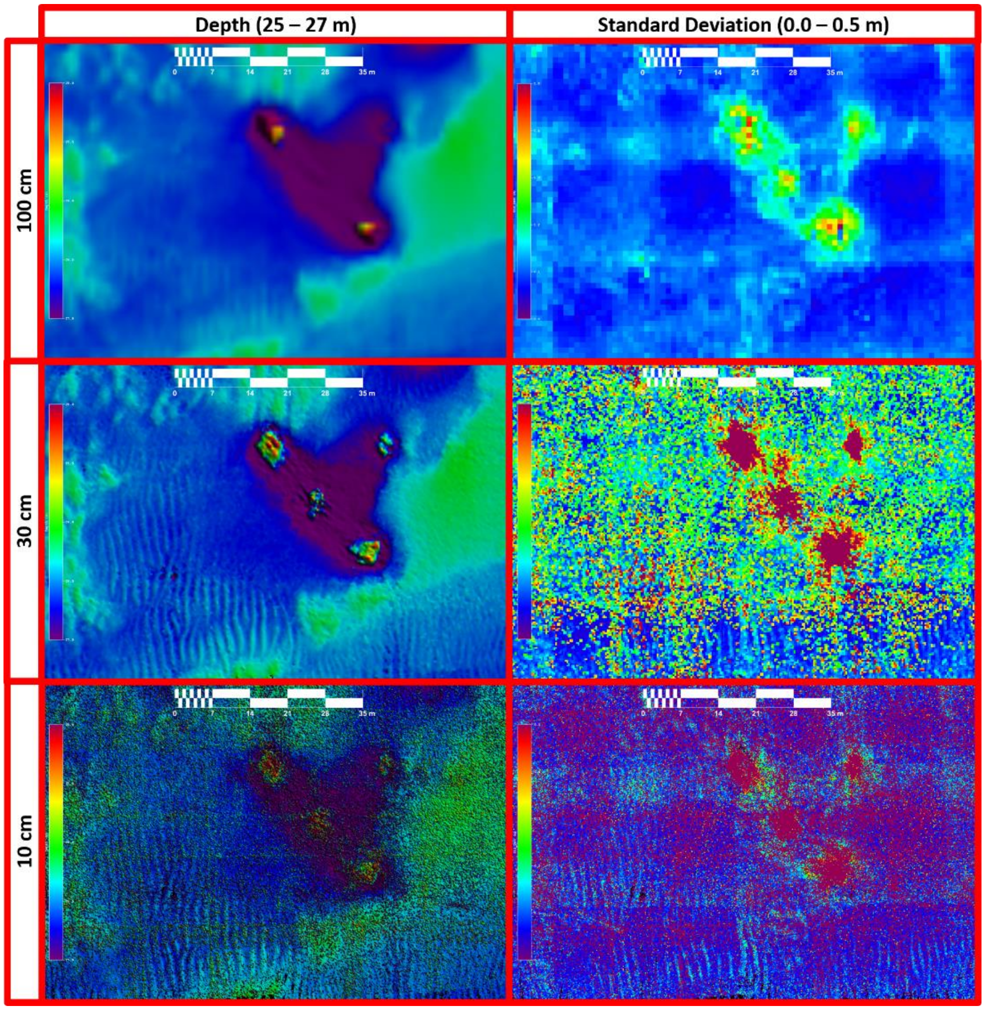

Figure 5. Depth and standard deviation of soundings in each grid cell may be used in conjunction to detect objects. The depth scale (left panels) ranges from 25 m (red) to 27 m (purple) and the standard deviation scale (right panels) ranges from 0 m (dark blue) to 0.5 m (purple); the scale bar is 35 m in total length in all images. The central portion of the overlapping subway cars is not visible in the depth surface gridded at 100 cm but stands out in the depth surfaces gridded at 10 cm and 30 cm; this region also stands out in all standard deviation grids. Sand waves on the order of 2-3 m in wavelength and 0.5 m in relief are clearly visible in the 30 cm grid, but appear overly smoothed in the 100 cm grid and partially obscured by surface artifacts in the 10 cm grid. These images demonstrate the utility of gridding at multiple resolutions to determine grid sizes appropriate for the particular dataset as well as identify changes between grids which may indicate the presence of objects.

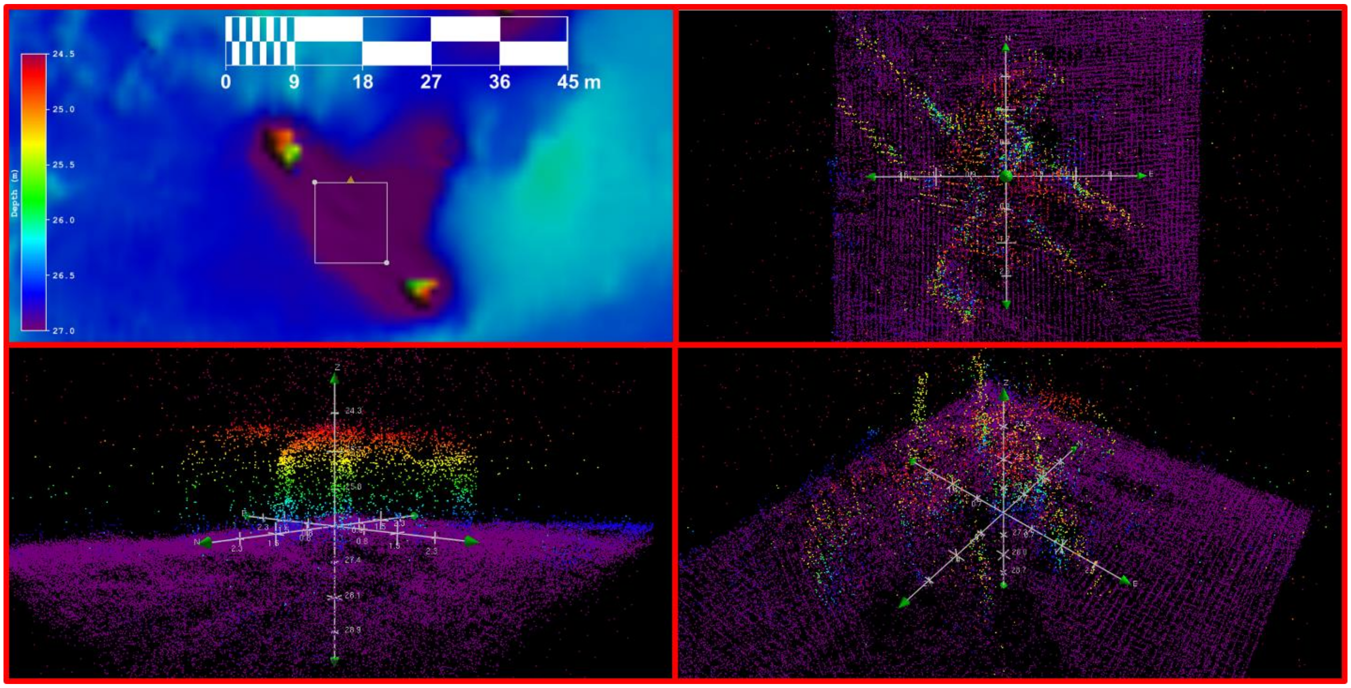

Figure 6. Subsets of raw data in the center of overlapping subway cars show features which are suppressed in the bathymetric surface gridded at 100 cm (upper left image) and unclear in finer grid sizes. The depth range is 24.5 m (red) to 27 m (purple). Clockwise from upper left: plan view of the gridded depth surface and selected raw data subset; raw data plan view; raw data viewed from the southeast; and raw data viewed from the northwest.

Small Objects – Offshore Shinnecock Bay and Fire Island Inlet, New York

Fire Island Inlet, connecting the Atlantic Ocean and Great South Bay of Long Island, New York, was impacted heavily during Super Storm Sandy. Surveys of the inlet and another site 4 km seaward of Shinnecock Bay were conducted under NOAA contract by Williamson and Associates in June, 2014, using an EdgeTech 4600 PMBS deployed from a surface vessel. These sites ranged in depth from 1-26 m and received 0-100% swath coverage overlap between adjacent survey lines. The PMBS data from these two sites include many objects ranging in size from small vessels to irregularly spaced structures comprising a fish haven; examples presented here illustrate the detection and recognition of objects smaller than those available in the Redbird Reef dataset.

Processing method

EdgeTech raw data were post-processed in proprietary Discover software with a median filter to produce soundings at athwartship spacing of approximately 40 cm for each swath. These soundings were then processed using the CUBE algorithm in CARIS HIPS 8.1 to create gridded depth surfaces with resolution ranging from 30 - 100 cm. No additional filtering or editing was performed.

NOTE: EdgeTech Discover software provides multiple options for 'bin-averaging' of raw soundings by angle or range. To investigate the impact of these binning methods on the reported least depths over small targets, a survey of a mooring block field in Portsmouth Harbor, New Hampshire, was performed with an EdgeTech 6205 PMBS aboard the R/V Coastal Surveyor *in April, 2014. EdgeTech Discover software was used to process the raw data in several angle bin sizes (0.25-1.00°) and range bin sizes (10-50 cm). CUBE surfaces were created using the* *same processing path employed for the examples in this document. Comparison of least depths reported in the gridded results showed negligible variability across the range of bin types and bin sizes. Because this evaluation was performed with objects that are on the order of 1 m in all dimensions, the effects of the EdgeTech filtering strategy and binning techniques on a tall or slender object such as a mast is not clear. The raw and unfiltered 'stave' data must be logged during data acquisition for closer examination of these objects using EdgeTech Discover software.*

Fish haven structures

The smallest detectable objects in this dataset are fish haven structures clustered 4 km south of Shinnecock Bay; Fig. 7 provides an overview of several structures in the fish haven that were surveyed in different regions of the swath. Area A (Fig. 7) includes an object near nadir that received swath coverage from only one survey pass; the CUBE gridded surface for Area A changes drastically depending on grid size, as demonstrated in Fig. 8. Closer inspection of grids at higher resolution and a subset of the Discover-processed soundings suggest the presence of two distinct objects. These objects are near nadir in relatively deep water (approximately 1 m of relief, 5 m from nadir, at a depth of 25 m) and not expected to cause acoustic 'shadowing' (which may otherwise be a deciding indicator between objects and artifacts at lower angles of incidence). The region between the two apparent objects has no soundings, suggesting that samples on the southwestern object may have been filtered as 'outliers' during data acquisition. Because this area is covered by only one survey pass, it is not possible to compare or corroborate soundings with any additional swath coverage of the same area.

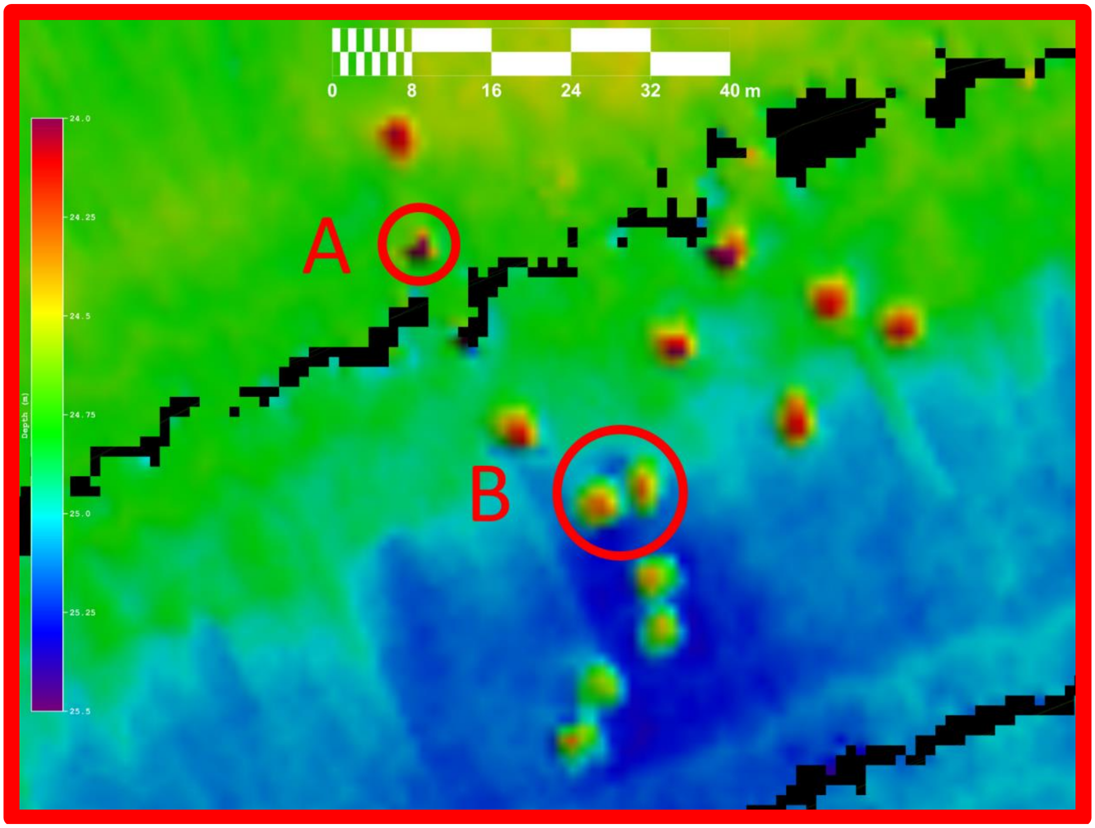

Figure 7. Overview of field of small fish haven structures, ranging from 1-4 m in horizontal dimensions and approximately 1 m in vertical relief above the seafloor. The depth color scale ranges from 24 m (red) to 25.5 m (purple) and the grid size is 100 cm. Areas A and B were selected to demonstrate the representation of small objects with different levels of sounding coverage in different portions of the swath. Area A was surveyed near nadir in only one pass whereas area B was covered in mid-swath during two adjacent survey passes.

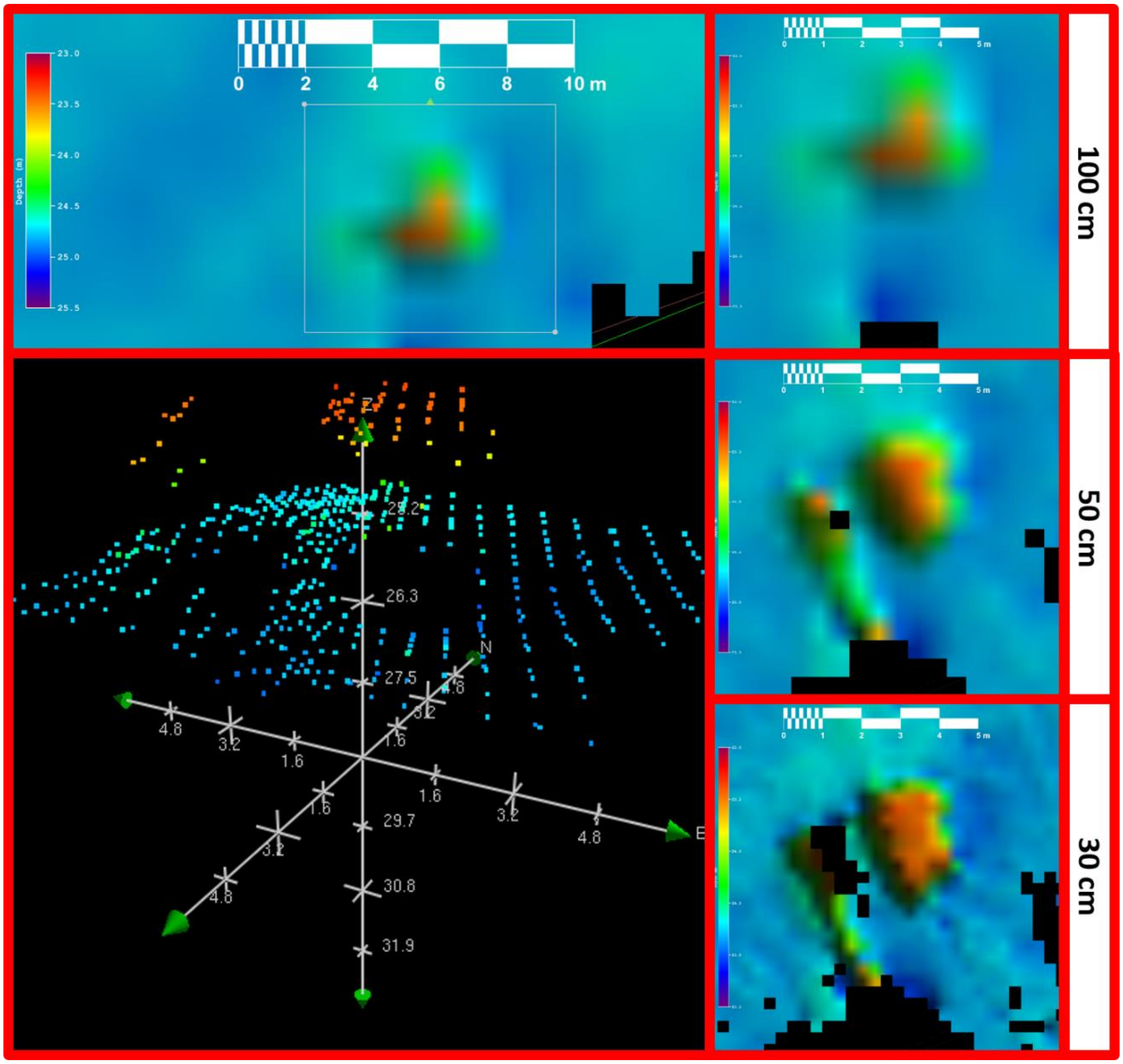

Figure 8. Area A appears to include one object when gridded at 100 cm (top images). The depth scale ranges from 23 m (red) to 25.5 m (purple); the scale bars are 10 m (left) and 5 m (right) in total length. Closer inspection of smaller grid sizes and a subset of the raw data looking northwest suggest the presence of two objects. It is unclear whether the smaller, southwestern object is an artifact in the raw data, as these soundings may represent the edge of a second block which was subsequently filtered by the echosounder's build-in outlier rejection method during data acquisition. Additional survey coverage of this area is necessary to resolve the ambiguity.

As shown in Fig. 9, Area B depicts the capability for detection of closely spaced objects on the order of 1-2 m in horizontal extent and 1 m in relief. Importantly, the fish haven structures in this area received swath coverage from two survey passes, and the general agreement between independent soundings on separate survey passes is evident in a subset of the raw data colored by line number (Fig. 9, lower left). The increased swath coverage improves confidence in the detection of real and distinct objects in this case.

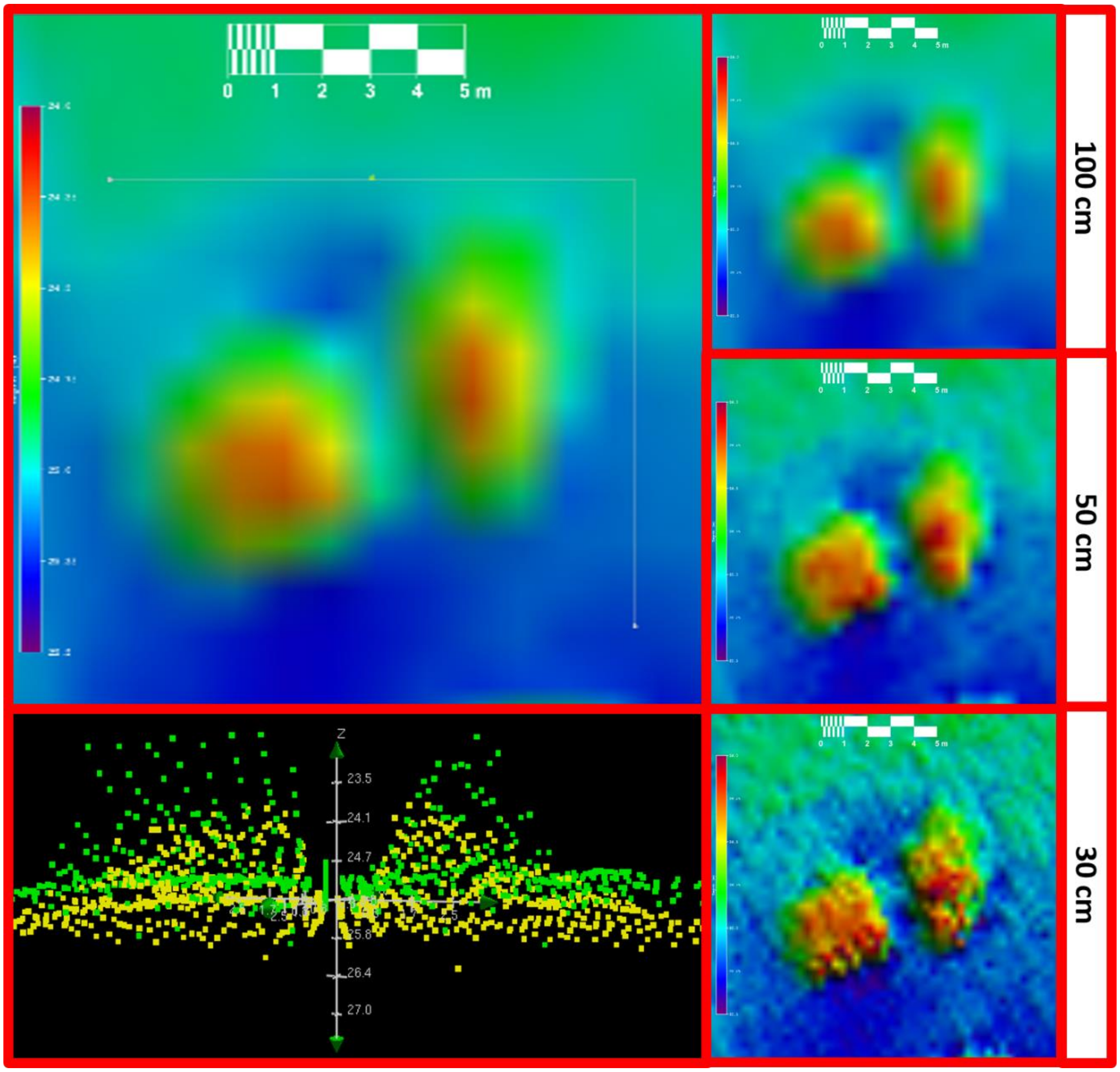

Figure 9. Two structures separated by approximately 5 m are clearly visible in bathymetric surfaces gridded at 100 cm (top left and top right), 50 cm (middle right), and 30 cm (lower right). The depth scale ranges from 24 m (red) to 25.5 m (purple); the scale bar is 5 m total length in all images. A northwest-looking subset of the raw data colored by line (yellow and green soundings, lower left) indicates that these objects are evident in two independent survey passes, with a gap of approximately 1 m, increasing confidence in their detection.

Depth artifacts

Overlapping swath coverage, such as that used to confirm object detection in Area B, is also useful for identifying and rejecting data artifacts in gridded bathymetric surfaces. Figure 10 includes an example of a potential object gridded at 50 cm, which is subsequently shown in a subset of raw data from two overlapping survey lines to be an outer swath artifact in one of the survey lines. The outer swath soundings (red) may have suffered from phase measurement noise or other transient errors, such as in surface sound speed or vessel motion. Importantly, these outer swath soundings are not corroborated by overlapping mid-swath (yellow) data which provide complete coverage of the area in question and uniformly indicate flat seafloor.

In some cases, apparent objects may not be confidently confirmed or rejected from bathymetry data. For instance, Fig. 11 includes soundings which appear to show a large block (approximately 10 m in all dimensions) extending to nearly the surface. This apparent object falls in a region of single swath coverage, so adjacent survey lines cannot be used to confirm or reject this detection. Several aspects of the apparent object's position relative to the survey line suggest that it is an artifact in the raw data. In an unlikely coincidence, the object in Fig. 11 is aligned exactly with the survey trackline and centered in the swath. The bedform patterns in the vicinity of the object also appear to be undisturbed in the raw data. Similar regions of elevated soundings centered in the swath were observed elsewhere in the raw dataset but were rectified in the final gridded surfaces by additional soundings from adjacent survey lines. Together, these characteristics of the apparent object suggest that it is not real and may instead be the result of acoustic interference or, perhaps, a layer of bubbly or aerated water near the surface which provided a series of strong acoustic targets and caused increased attenuation of the transmit signal. Additional data are necessary to confirm or reject this artifact.

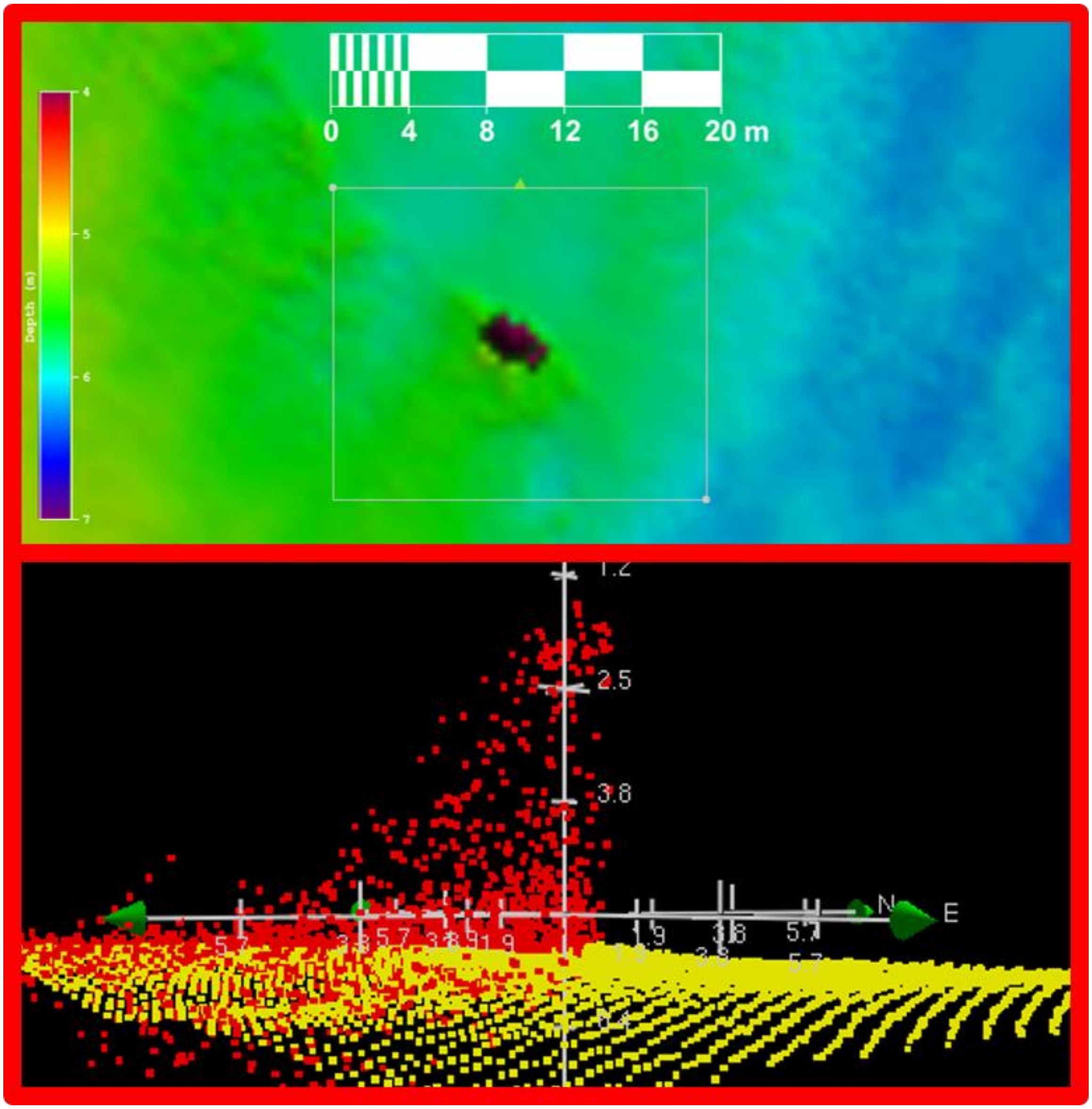

Figure 10. A bathymetric surface gridded at 50 cm suggests the presence of an object (center of upper image, purple rectangle approximately 2 m by 4 m). The depth color scale ranges from 4 m (purple) to dark blue (7 m) in the upper image. A subset of raw data colored by survey line (lower image) indicates that the potential object is likely an outer swath refraction artifact (center of lower image, elevated red soundings at edge of swath coverage). Mid-swath (yellow) soundings from an adjacent survey line consistently indicate a flat seafloor with no objects.

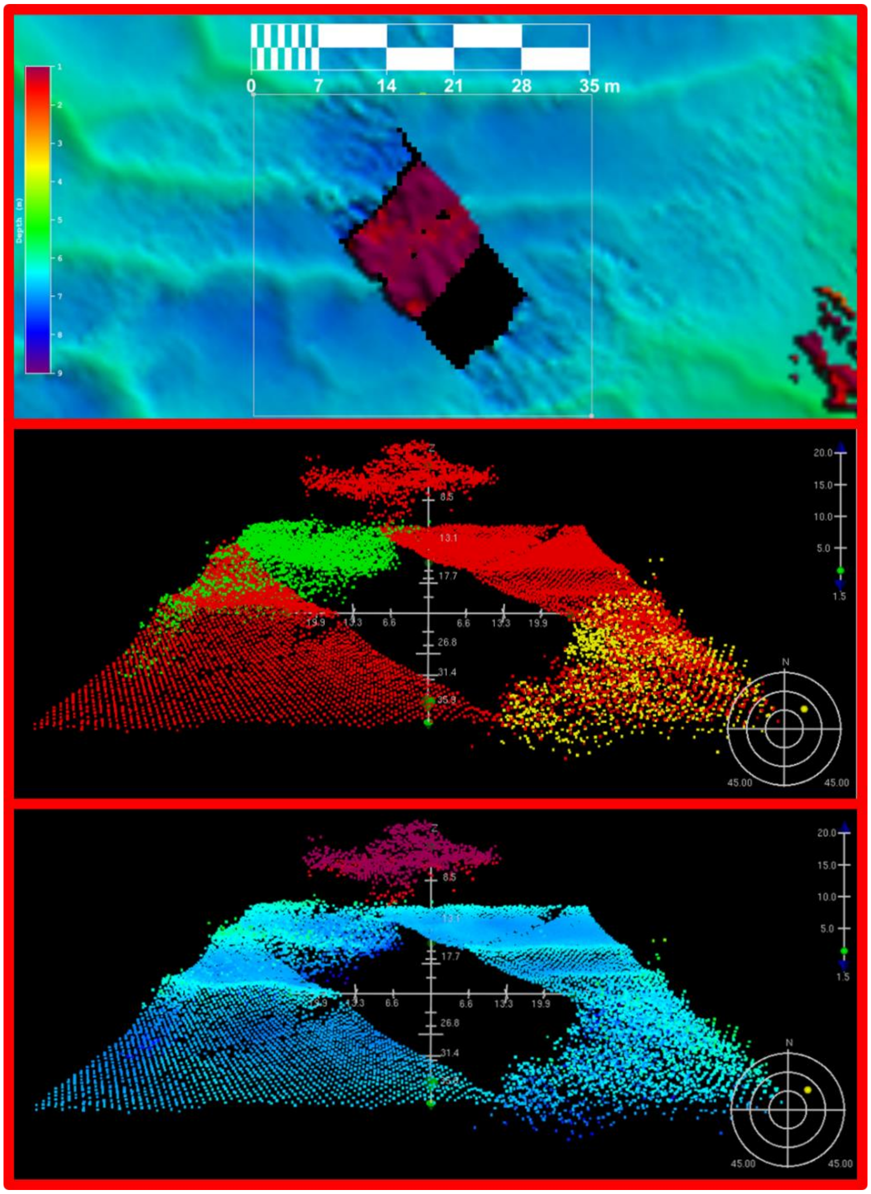

Figure 11. A large potential object (approximately 10 m in all dimensions) appears in the bathymetric surface gridded at 50 cm (top image). The depth color scale ranges from 1 m (purple) to 9 m (dark blue). Subsets of the raw data show that the apparent object is perfectly centered in the swath of only one survey pass (red soundings, middle image), not covered in any other survey pass (green and yellow soundings, middle image), and surrounded by undisturbed scour marks its immediate vicinity (blue and green soundings, bottom image. These observations, considered alongside similar clusters of very shallow soundings which are shown to be artifacts using overlapping swath coverage, suggest that the apparent object is not real. Additional survey coverage is necessary to confirm or reject this potentially significant hazard.

Suggestions for PMBS Object Detection and Recognition

As demonstrated in the examples above, visual detection and recognition of objects in PMBS bathymetric data are often distinct and subjective processes. Commercial-off-the-shelf software may be used to rapidly process large PMBS datasets into gridded bathymetric surfaces of varying resolution, illustrating the trade-offs between suppression of artifacts in the PMBS raw data and preservation of detail of objects. In these examples, the coarsest grids (100 cm) have proven useful for detecting the presence of objects (or apparent objects) ranging in sizes from 1-50 m in horizontal extent and 1-3 m in vertical relief from the surrounding seafloor. Additional inspections of finer-scale bathymetric surfaces and subsets of raw data are necessary for recognition of all but the largest objects. Likewise, rejection of artifacts appearing as potential objects requires examination of raw data. Overlapping swath coverage is frequently the deciding factor in corroborating soundings associated with objects and negating depth artifacts. These trends in detection and recognition of objects in PMBS bathymetry data are highlighted in the following recommendations.

Survey recommendations

1. Ensure at least 100% swath coverage of the survey area, noting that the nadir and outer swath regions may include sparse or noisy data. Provide overlapping swath coverage wherever operational conditions and scheduling constraints allow.

2. When possible, identify potential objects or depth artifacts while underway and resurvey these areas in mid-swath (e.g., at an acrosstrack distance of one to two times the echosounder altitude above the seafloor) where data density and noisiness are typically of highest utility for object detection.

Processing recommendations

1. Create CUBE bathymetric surfaces at several grid sizes to evaluate the suppression of artifacts and preservation of object detail given the raw data density and quality.
2. After detection of an area of interest, compare the area in coarse and fine grids to examine changes which may be useful for confirming the physical presence of an object and informing its preliminary identification.
3. Examine subsets of all sounding data covering the object of interest. Use overlapping swath coverage, wherever available, to assess the agreement between soundings collected on separate survey passes.
4. If necessary, use additional contextual clues to confirm or reject the detection of an apparent object. For instance, look for acoustic ‘shadows’ toward the outer swath in single survey passes which would result from the physical presence of an object, keeping in mind that data gaps could possibly result from other processes (e.g., data filtering during acquisition). Likewise, adjacent bedform modifications or scour marks around an apparent object could indicate its long-term presence. In all cases, look for similar artifacts throughout the survey to identify potential complications during data acquisition, such as bubbles near the transducer(s) which would typically reduce the performance of any echosounder.
5. Acknowledge cases when data density, data quality, and contextual clues are insufficient to clearly confirm or reject an apparent object.