IOCM Research in Support of Super Storm Sandy Disaster Relief

NOAA Co-operative Agreement NA14NOS4830001

Final Report: Executive Summary

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Executive Summary

Overview

This report documents research conducted under co-operative agreement number NA14NOS4830001 between the National Oceanic and Atmospheric Administration (NOAA) and the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire (UNH). The co-operative agreement was competitively awarded to CCOM to support "relevant research and development activities associated with with FY13 Disaster Relief Appropriations Act-related LIDAR and acoustic coastal/ocean mapping and marine debris mapping data processing problems," as called for by the original Federal Funding Opportunity (FFO) document. This report covers a performance period from October 2013 to September 2015.

The primary objectives of the research were to develop methods for detection, aggregation, and characterization of marine debris; to examine the performance envelope of a variety of remote-sensing instruments; to investigate methodologies for data product construction and communication; and the public communication of the results of the research through outreach efforts, expressed within the framing structure of surveying in a storm-response scenario.

To support these objectives, research was conducted in five primary themes that were aligned with the programmatic priorities of the original FFO:

1. "LIDAR, habitat, and specialized data processing," which looked at extracting extra information from Light Detection and Ranging (LIDAR) return waveforms in order to support habitat research and change monitoring, with particular emphasis on submersed aquatic vegetation (SAV); determination of the minimum observable differences in repeated LIDAR mapping; methods for habitat classification and change detection; use of satellite-derived bathymetry (SDB) for change detection in shoreline and volumes; use of SDB to highlight areas of charts that might require update; use of satellite imagery for SAV mapping; and the limitations of these various instruments.

2. "Marine object management," which developed a robust method for detection of marine debris with multiple non-ideal detectors and use of semi-empirical prior knowledge on likely prevalence of marine debris as a means to control the complexity of this problem; and methods to package these results and com-

municate them correctly, and compactly, between parties involved in a storm response.

3. "Improved storm-response surveying with phase-measuring bathymetric sidescan echosounders," which developed methods for processing phase-measuring bathymetric sidescan (PMBS) data through conventional hydrographic tools; developed best practices for surveying with these instruments in a storm-response scenario; examined the concerns relevant to object detection with such systems; proposed methods for data analysis to assist in storm-response (and general) surveying; and demonstrated how PMBS systems could be integrated into a conventional multibeam echosounder (MBES) survey scheme.

4. "Visualization," which developed a new tool to assist with the automated selection of viewpoints for complex data, with particular application to marine debris identification; and developed this into a crowd-sourcing opportunity.

5. "Outreach," which communicated the purpose and results of the research via the public website; interaction with K-12 students and their educators through the SeaPerch and Ocean Discovery Day events; the development of infographics in print and interactive electronic form; and the co-development of a museum exhibit on the theme of hurricanes and marine debris.

This final report demonstrates that all of the proposed milestones for the project were achieved, and in many cases exceeded. Many of the techniques developed were also found to have impacts beyond the scope of the current project. A total of 25 publications were generated as part of the project, including one journal article, 11 conference papers or presentations, and 13 white-papers or best practice documents. The project website, `http://sandy.ccom.unh.edu` contains all materials related to the project, including the original proposal, all progress reports, all white-paper and best-practice documents, and all available conference papers or presentations. The website also hosts the crowd-sourcing marine debris experiment, and the interactive infographics.

Research Conducted

LIDAR, Habitat, and Specialized Data Processing

Research in this theme was focused primarily on applications, rather than instruments, since LIDAR and satellite imagery were both used for shoreline/bathymetric change detection and habitat monitoring/classification. A Super Storm Sandy-affected area in Barnegat Bay, NJ, was chosen as a common site for testing many of the techniques developed, primarily due to data availability.

The availability of multiple LIDAR datasets for the area, from different LIDAR systems, was used to identify the minimum observable difference for repeated surveys,

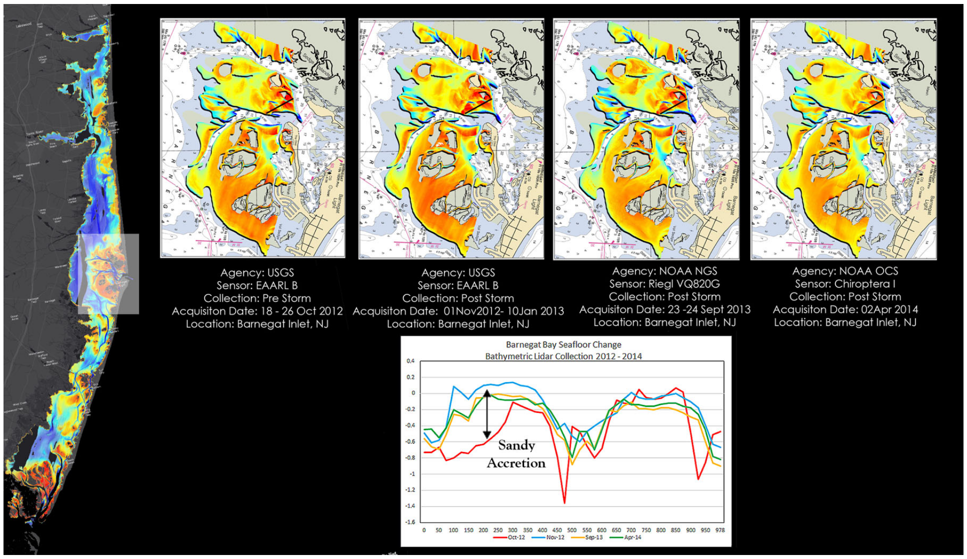


Figure ES.1: Depth as a function of distance for four bathymetric LIDAR collections over three years of data from three different LIDAR systems in the Barnegat Bay Inlet region. The change pre- and post-storm (red and blue lines) is clearly significant with respect to the self-noise of the systems.

i.e., the minimum amount that two surveys have to differ for the difference to be considered more than observational uncertainty. The results (Figure ES.1) indicate that the minimum difference considered to be "observational" is on the order of ± 0.1 m. SDB techniques cannot be used to provide absolute depths since it is assumed that there will be a lack of reference depths from a conventional survey in a storm-response scenario. Relative estimates of slope can be constructed, however, which are indicative of change (Figure ES.2) and can also be used to show levels of seasonal variability, which are used for calibration purposes.

Research into the use of LIDAR and satellite imagery for shoreline change was also conducted, which showed that a long-term trend for shoreline change rates could be derived from satellite imagery. The effects of Super Storm Sandy could be identified in some areas, implying that significant changes can be detected using these methods. Repeated LIDAR surveys were also used to derive direct estimates of deposition and erosion rates around Mantoloking, NJ. Procedure documents were generated for both processes.

Classification features, derived from LIDAR waveforms, were used as the basis of a classification scheme for SAV (Figure ES.3). Object-based image analysis (OBIA) was used in Trimble eCognition to construct a rule-set for four different habitat classes of sand, mixed macroalgae and sand, sparse eelgrass, and dense eelgrass, and comparison against ground-truth data showed an overall classification accuracy of 85%. The classifications used were shown not to be statistically different from manual classifications for the same area, and the rule-sets used were shown to be portable to different

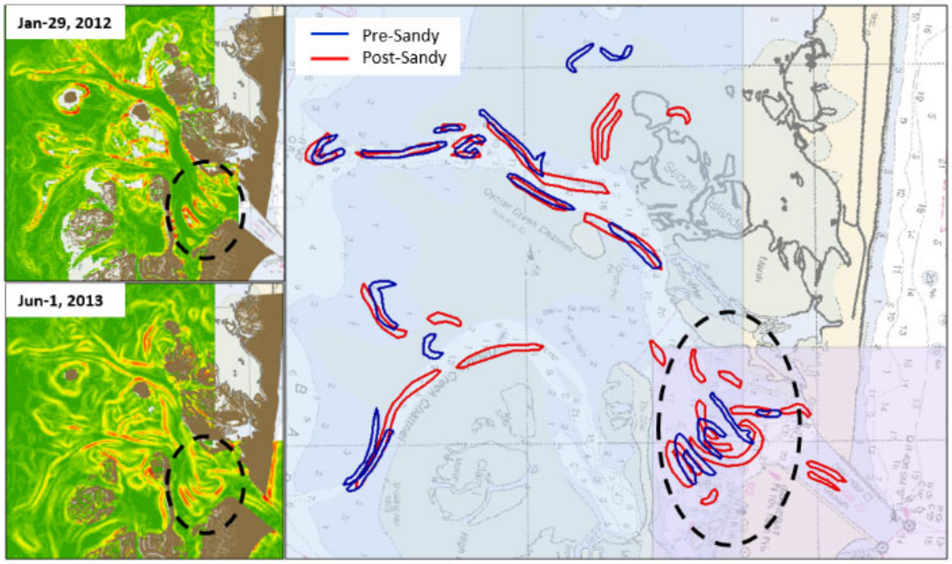


Figure ES.2: Preliminary results showing morphological changes at the entrance of Barnegat Bay Inlet pre- and post-Super Storm Sandy. The two images on the left are the slope maps from 2012-01-29 (pre-Sandy) and from 2013-06-01 (post-Sandy) acquired by WorldView-2 and Landsat 8, respectively.

areas and different LIDAR systems with compatible waveform features, although the specific parameterization of the rule-sets had to be adjusted.

Techniques were also developed to use satellite imagery for SAV mapping, particularly as a source for fine time-step estimates of change. Using Landsat 8, it was demonstrated that estimates of SAV density could be constructed from the tri-band imagery (Figure ES.4) and comparison against ground-truth data from a long-term study by Rutgers University showed agreement on the order of 75–88%, with some of the discrepancy potentially due to seasonal variability of the SAV.

Throughout the research, care was taken to ensure that the data products being generated would be compatible with the construction of Coastal Engineering Indices (CEI), although since there is currently no consensus on what a CEI would entail, no index was proposed. Procedures documents were developed for all of the techniques proposed, including use of SDB to assist in chart update and comparison, particularly so that they could be readily communicated to the Integrated Ocean and Coastal Mapping (IOCM) contract group at the NOAA-UNH Joint Hydrographic Center, a sister project, where they are currently in active use.

Marine Object Management

This theme focused on developing a model for the robust detection of marine debris using remote sensing techniques, accepting that this problem is inherently difficult because of the ill-defined nature of what constitutes "marine debris." The work uses

Figure ES.3: Benthic habitat map for the Barnegat Inlet flood tidal delta complex created using NOAA NGS Riegl VQ-820-G data (including auto-generated waveform features), Applanix DDS digital aerial imagery, and an object-based image analysis approach in eCognition.

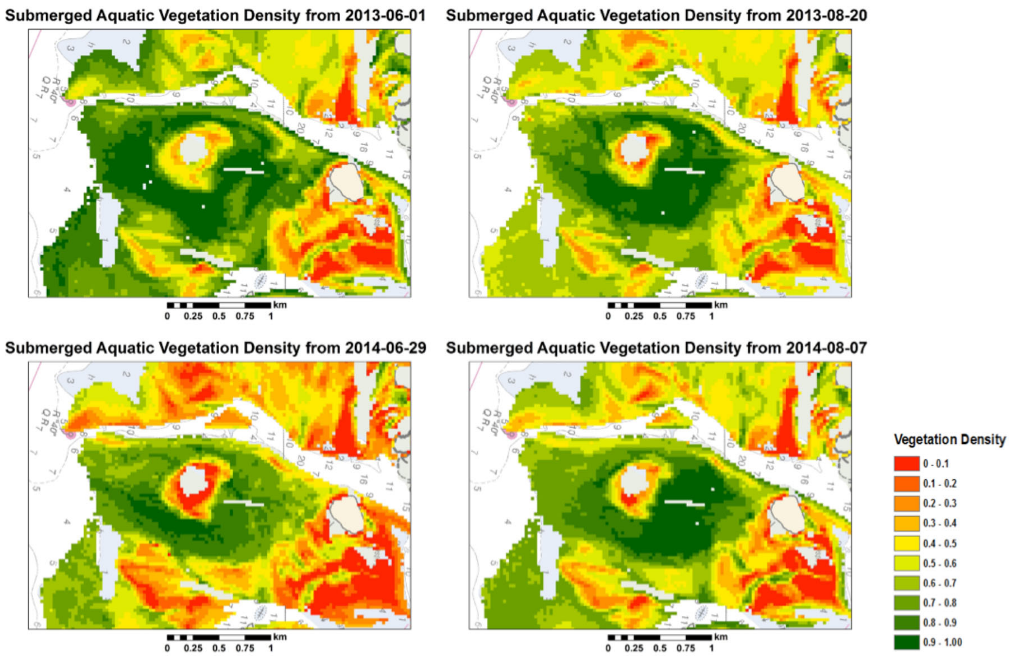


Figure ES.4: SAV density using Landsat 8 imagery from four different time periods in Barnegat Bay Inlet, NJ: (a) 2013-06-01; (b) 2013-08-20; (c) 2014-06-29; and (d) 2014-08-07. Density values range from 0% (red) to 100%, normalized to 1.0 (green).

a Bayesian hierarchical statistical model to generate a probability density map for marine debris presence, and builds an idea of the potential for debris abundance (Figure ES.5) from observations associated with previous storms. This is used to provide a prior estimate as to debris prevalence, which can help in constraining the overall estimation problem. Empirical data from the Gulf of Mexico Marine Debris Program, NOAA's Marine Debris Program and Office of Coast Survey responses to Super Storm Sandy were used for construction of the prior model, while NOAA Office of Coast Survey data in Jamaica Bay, New York, NY, was used for case-study testing of the methods developed.

The algorithm developed combines prior information with multiple non-ideal detectors of marine debris, which are based on automated analysis of data products typically generated in the normal course of survey operations. The logic is that in a storm-response scenario, it would be unlikely that there would be resources available for more specialized data collection. Each of the detectors is expected to be fallible, but since they are not all fallible in the same way, the research shows how they may be fused together to form a detector that is more robust.

A case study was conducted against ground-truth marine debris data collected by NOAA contractors as part of the Super Storm Sandy response, and was shown to develop probability maps that correspond to the density of objects identified by hand (Figure ES.6). Receiver Operating Characteristic (ROC) curves for the same area show an Area Under the Curve (AUC) value of 0.880 for the model when spatial context

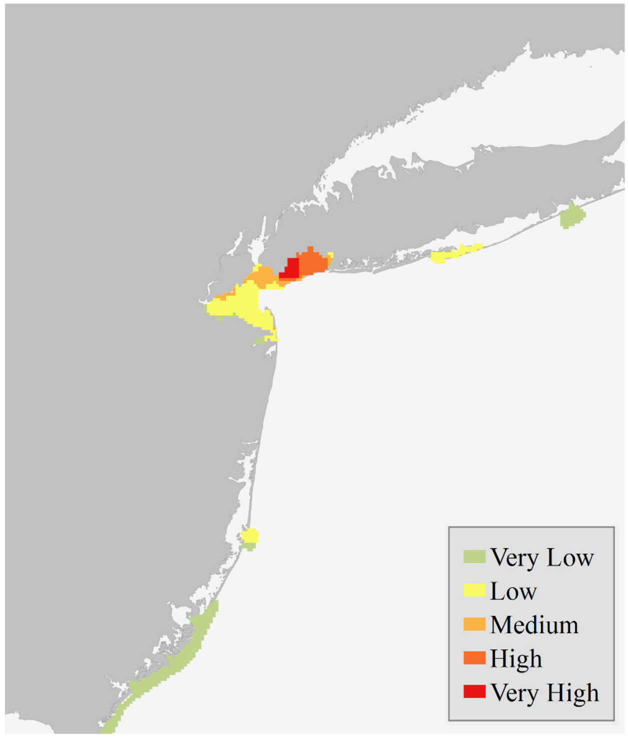


Figure ES.5: Predicted distribution density of marine debris in the SSS study area.

was taken into account, which indicates strong detection capabilities with few false positives. The ROC curves also demonstrate that the addition of spatial context to the estimation problem has positive benefit.

Finally, the research addressed the question of how to readily transfer information on marine debris objects between the various entities involved in a marine debris response, driven by the observation that no common vocabulary for such purpose existed. A "markup" language was developed from the core objects in the Geographic Markup Language (GML), a commonly-implemented standard, which allow marine debris objects described in the Marine Debris Markup Language (MDML) to be readily processed with standard applications.

Improved Storm-Response Surveying with Phase-Measuring Bathymetric Sidescan Echosounders

Research on the use of phase-measuring bathymetric sidescan (PMBS) sonars balanced concerns of exploring the limitations of these systems and developing best-practice information for their use in a storm-response scenario. The research highlighted historical problems with PMBS systems, and showed that hardware and software advances by some manufacturers have largely resolved these issues for their systems. These improvements have increased the ability of PMBS systems to detect and maintain in-

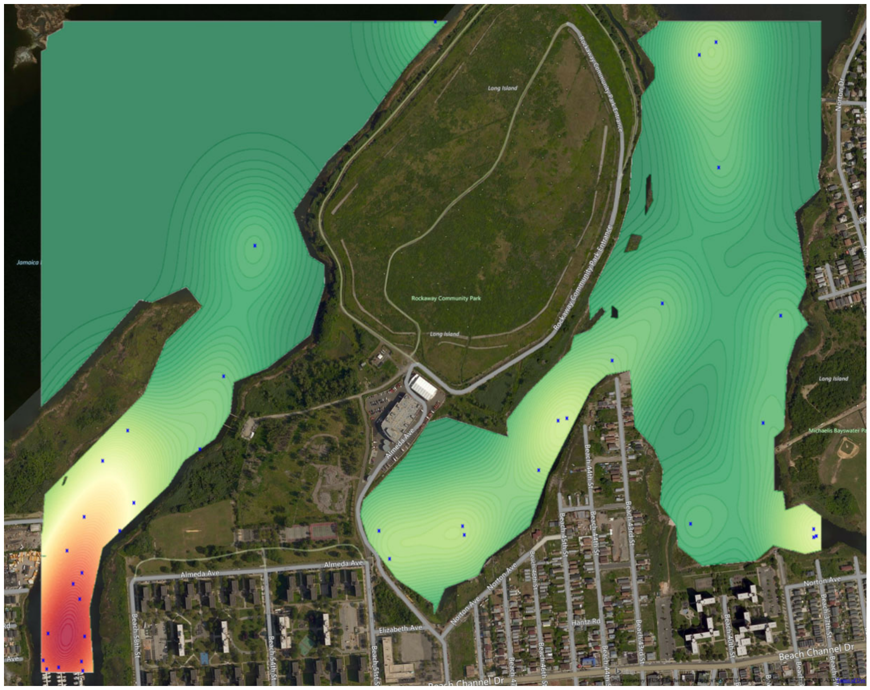


Figure ES.6: Results of the hot spot analysis in Jamaica Bay, New York, NY, with the ground-truth positions of the marine debris designated by human analysts showed as blue dots.

formation on objects of hydrographic significance (such as marine debris), such that they can now be routinely and reliably detected in data (Figure ES.7). Identification of objects remains a challenge, but it is argued that co-located sidescan generated by a PMBS in addition to the bathymetry improves on this situation, and its use is strongly recommended. It is argued that the most effective strategy for survey in a storm-response scenario may very well be to have more widely spaced survey lines in order to improve efficiency, relying on the sidescan data to identify potential targets, which can then be re-surveyed with optimal survey geometries.

A series of best-practice suggestions are presented, among them to require water column data, or sidescan in order to assist in object detection; to require uncertainty estimates from manufacturers of PMBS systems; use of the outer swath to increase detectability; to filter data to omit only outliers and not the tails of noisy data thereby maintaining the original statistics; and to build CUBE statistical surfaces to assist in data processing rates.

Previous arguments emphasized the importance of simultaneous sidescan and bathymetry information from PMBS systems; to capitalize on this, a prototype graphical user interface (GUI) was developed to demonstrate the benefits of co-analysis of such data (Figure ES.8), a tool which is conspicuously absent in conventional hydrographic data processing software. A mock-up of a suitable GUI demonstrates that simple techniques such as showing the same cursor position in all data views, or

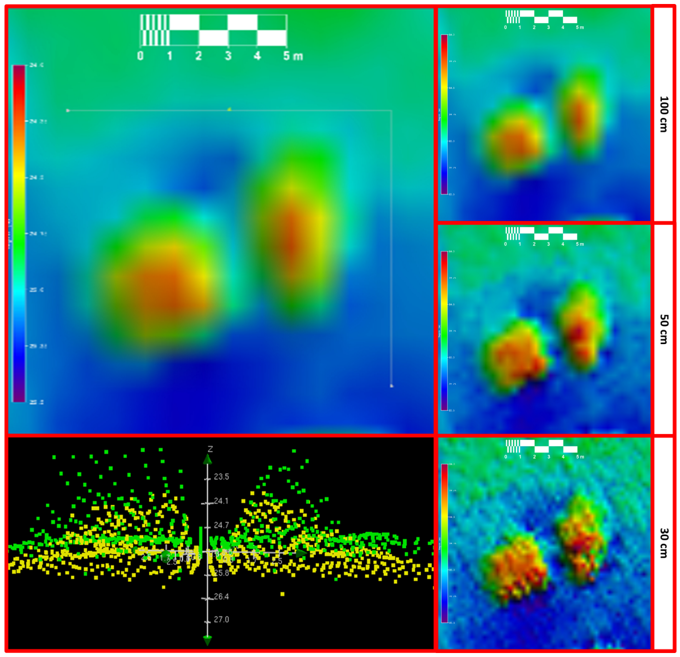


Figure ES.7: Visibility of distinct objects in PMBS data, here 5 m apart (note 5 m total length scale bar in all images). Evidence in multiple paths shows that these are distinct objects, but does not necessarily support identification.

showing a range-ring about the PMBS corresponding to a target position can radically improve user understanding of data.

Finally, the research demonstrates that PMBS estimates of depth constructed through completely automatic means using the CUBE algorithm applied to a shallow water survey in Plymouth Harbour, England, are comparable with MBES estimates in the same area, with the only significant disagreement being on steeply sloped areas.

Visualization

Visualization research focused on how to optimize operator output when attempting to identify marine debris. The Marine Debris Rapid Decision Tool (MDRDT) was developed (Figure ES.9) which automatically selects multiple, optimal views of the target object that are expected to best highlight the shape of the target and thereby assist the operator in identification. The views are embedded in a fully-functional 3D visualization system so that the viewpoint can be adjusted as required, but it is argued that the more often the views allow for early identification of the object without the need for adjustment, the more efficient the operator will be. Simplified tools to mark objects as debris, and to associate a confidence of identification, are provided.

The techniques developed for MDRDT were also applied in a web-based tool (Figure ES.10) as a model for a crowd-sourced approach to marine debris identification.

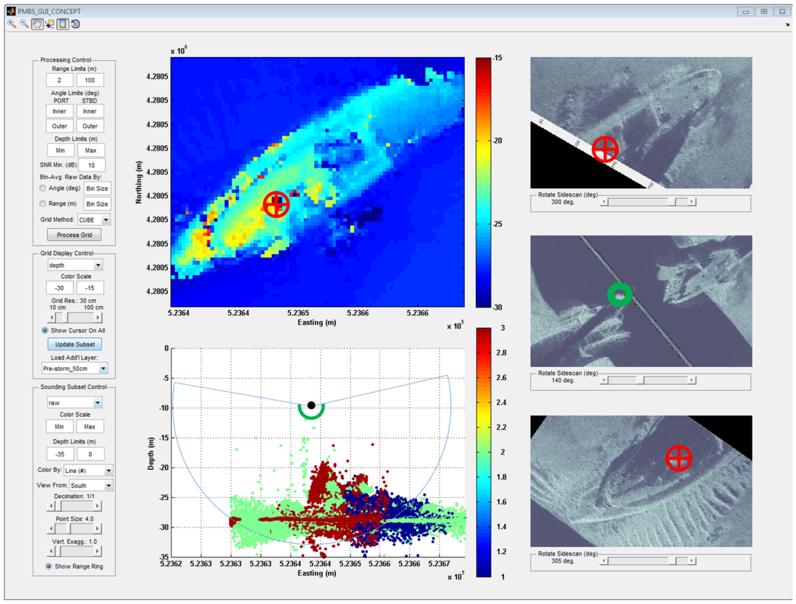


Figure ES.8: Prototype GUI for simultaneous review of bathymetry and sidescan imagery from a PMBS system. The "Show Cursor On All" option has been selected to assist in cross-identification of a target in all views (red crosshairs), and the "Show Range Ring" option has been used to correlate a target in sidescan with a particular range from the PMBS in the bathymetry.

It is argued that the lack of trained operators can be a significant limitation during a marine debris project, and therefore that it might be advantageous to use a group of volunteers to assist. An experiment hosted on the project website demonstrated that the identification performance of untrained volunteers, neglecting the (automatically identified) lowest quality volunteers, showed 84% agreement with a trained operator.

Outreach

Outreach efforts were conducted across a variety of media. The simplest outreach opportunities were afforded by the project's website, which was used to host all of the documents generated by the project, but was also used to host informal "infographics" explaining general topics such as marine debris and survey protocols as well as interactive infographics showing simplified versions of marine debris data, and experimental data analysis techniques.

The project was afforded a more permanent outreach opportunity through a collaboration with the Seacoast Science Center (Rye, NH), a local interactive science museum. This collaboration supported the development of an interactive exhibit that explores hurricanes, the marine debris problem, methods for debris identification, and the decisions associated with whether and how to remediate debris. An

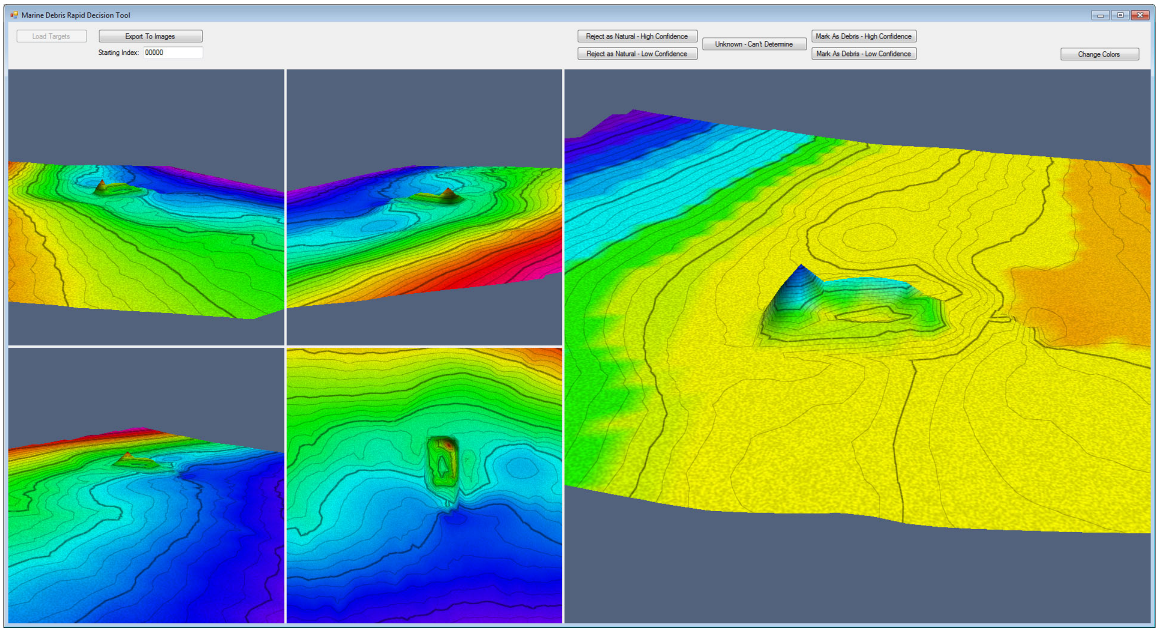


Figure ES.9: Screenshot of the Marine Debris Rapid Decision Tool. The multiple views of the target under investigation are automatically selected to assist the operator in identifying the target, ideally without having to adjust the viewpoints or manipulate the data.

interactive, touch-screen exhibit was developed with the aid of undergraduate computer scientists (Figure ES.11) which demonstrates principles of survey and marine debris identification. The exhibit will open at the Seacoast Science Center during winter 2015.

Further outreach opportunities were fostered through collaboration with UNH-led STEM events. The project provided several interactive demonstrations of mapping technologies and related research during the UNH Marine School's Ocean Discovery Day in 2014 and 2015, and partnered with the regional SeaPerch competition (Figure ES.12) in 2014 to introduce K-12 students and their educators to the problems of marine debris, the aims of the project, and the issues surrounding debris remediation.

Conclusion

The co-operative agreement has resulted in research on a number of themes, all of which have been documented through academic papers, conference presentations, and white paper documents, hosted on the project's website. This research has shown that there are significant benefits to be had through their adoption for the collection, processing, and dissemination of multi-use IOCM data products. Active efforts to transfer the research into operational use have taken place.

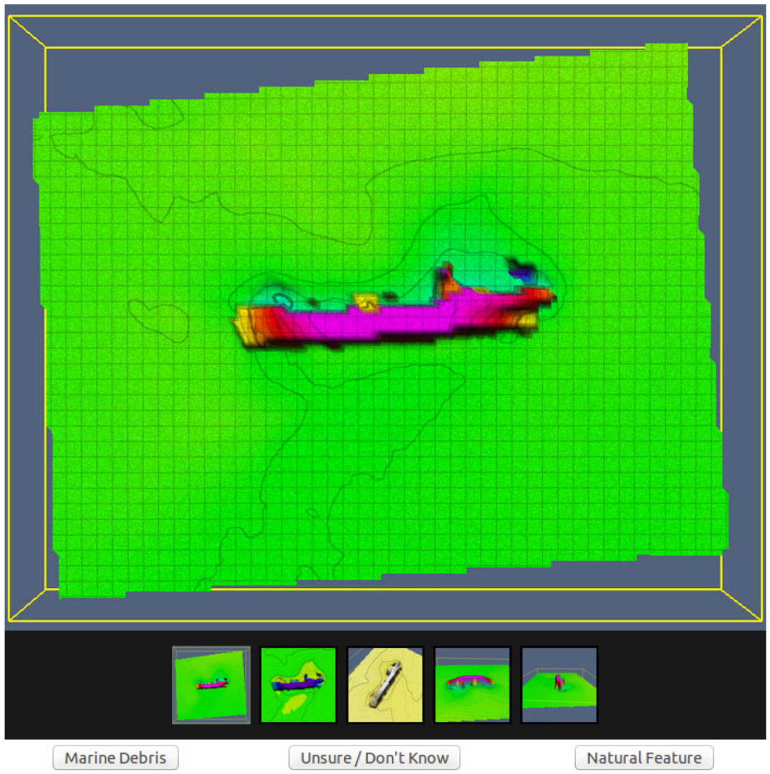
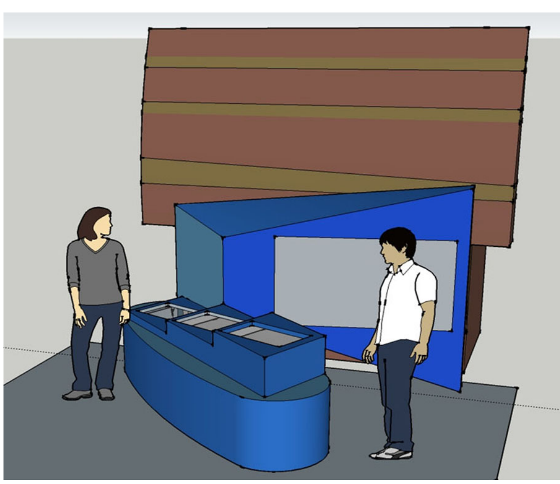


Figure ES.10: A screenshot of the web-based crowdsourcing interface. Users see a single zoomed-in image, and can scroll through or click on the thumbnail images at the bottom to view each of them as many times as needed.



(a) Conceptual design.

(b) Exhibit screenshot.

Figure ES.11: The "A Hurricane Hits Home" exhibit at the Seacoast Science Center, Rye, NH, and an example screen-shot from the interactive exhibit.

Figure ES.12: SeaPerch afternoon "team challenge" event, 7 June 2014. Clockwise from top left: divers deploying simulated "marine debris" in the engineering test tank; a team adapting their SeaPerch; a dual-Perch marine debris removal system; SeaPerch ROVs removing simulated debris.

In addition to the specific benefits associated with the immediate fields of application of the various techniques developed, there is potential for wider impact of many of the techniques. LIDAR-derived waveform features could be used more generally for rapid habitat assessment as an add-on product for conventional LIDAR surveys, and the use of multiple passes of satellite imaging could be used to provide a baseline for seasonal or long-term habitat change. The marine debris detection model could also be used for general hydrographic feature detection and management, and the techniques developed for PMBS data collection and processing could be used to support the use of such systems for general hydrography. The techniques developed to select viewpoints for marine debris inspection could also be applied to the general problem of selection of data orientation for hydrographic data processing. And the proposed crowd-sourced debris identification application could be used for future storm events, or even for general hydrographic practice.

Many of the techniques developed for this project have already had an influence on practice within the IOCM sister-contract at the Joint Hydrographic Center. It is argued, however, that there is significant potential for loss of capabilities as the immediate projects (eventually) come to an end. It is recommended that efforts to preserve the gains achieved through this project are pursued.