IOCM Research in Support of Super Storm Sandy Disaster Relief

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1 Introduction

At 1930 EDT on October 29, 2012, Super Storm Sandy\(^1\) made landfall on the U.S. east coast near Brigantine, NJ (Blake et al., 2013). The convergence of the storm with an intense low-pressure system, its unusual approach direction (from the east rather than from the south) and its coincidence with astronomically high tides made Super Storm Sandy one of the deadliest and costliest hurricanes in U.S. history, causing 147 deaths in the U.S. and more than $50 billion in damages (costs are still being tallied) (Sullivan and Uccellini, 2013). Most of the damage caused by Super Storm Sandy was focused on the coastal zone, with flooding (the hurricane caused record high storm surges in New York, New Jersey and Connecticut), high winds and powerful waves resulting in the destruction of buildings, homes, roads, vehicles, and many other objects over hundreds of miles of coast. While the damage caused by the storm can easily be documented by airborne or satellite imagery for those areas that are above sea level, the impact of the storm on those areas at or below sea level (i.e., the presence of debris and changes in the shape of the seafloor that can create navigational hazards, or the impact on benthic habitat) is much more difficult to assess.

In the immediate aftermath of an event like Super Storm Sandy, the primary concern is for disaster relief, followed by recovery operations. In many cases delivery of relief supplies and recovery operations (even just getting first responders to the site) can rely on recovery of critical infrastructure such as ports and approaches, for example in ensuring that a channel has been cleared of any navigationally hazardous debris. After the initial relief operations, the emphasis can turn to environmental impacts and recovery of the natural resources in the affected area. In both cases, detailed and timely information on the state of the near-shore environment is essential.

The consequences of Super Storm Sandy highlighted a number of areas where the current state of the art in design of surveys, collection and processing of data, and visualization of that data in response to events of the magnitude of Super Storm Sandy were lacking. Consequently, NOAA issued a Federal Funding Opportunity (FFO) under the FY13 Disaster Relief Appropriations Act to advance understanding of these issues. This report is the fifth in a sequence of progress reports to document work conducted under this FFO at the Center for Coastal and Ocean Mapping at the University of New Hampshire.

In this fifth progress report, we report on ideas for survey optimization when using PMBS systems in storm response scenarios, and in particular on using PMBS to implement both stages of the classical hydrographic technique of pre-survey with a sidescan, and then development with an echosounder; we also report on an investigation of the ability of PMBS data handling systems to maintain information on objects throughout the data processing effort. We report on improvements in habitat

\(^1\) There is some difference of opinion on nomenclature for the event. Some sources prefer "Hurricane Sandy," others "Post Tropic Cyclone Sandy," and still others "Super Storm Sandy." For continuity with the proposal document and general usage, we have preferred "Super Storm Sandy" in this context, but use the term without intent of limitation or precise meteorological description.
classification techniques being applied to LIDAR waveform data collected in the Sandy-affected region, expanding on our previous research to include groundtruth data, and showing that the classification success can be on the order of 85% overall. As part of this effort, we have also normalized datasets from a number of LIDAR systems used in the Sandy-affected area, which allows for them to be compared with each other; we provide details of the datasets available and their timelines. Next, we report on the development of new techniques to support multi-algorithm object detection with application to marine debris detection, including a computational framework to allow for data fusion, and then discuss updates to available satellite imagery data and the processing methods used for it, along with some preliminary work on mapping vegetation using the various bands of the imagery. Finally, we provide an update on the status of our visualization tool designed to assist analysts attempting to identify marine debris from remote-sensing data of many kinds, and highlight some more outreach activities both on our website, and through infographics.

Previous progress reports, and more information on the design, goals, and objectives of the project, can be found on the website, http://sandy.ccom.unh.edu.
2 Research Activities

2.1 Phase Measurement Bathymetric Sonar Data Processing

Research into the application of phase-measuring bathymetric sidescan (PMBS) sonar for storm response surveying continued in the present reporting period with completion of two documents intended to assist survey planning and data analysis with PMBS systems. These documents, described in greater detail below, are available on the Sandy research website (sandy.ccom.unh.edu) and reference previous work under the Sandy supplemental research grant to investigate rapid processing methods for PMBS data with the aim of improving survey efficiency in response scenarios.

2.1.1 Considerations for PMBS and MBES Selection

PMBS sonar systems provide co-located depth estimates and sidescan imagery, which may be used in combination to improve survey efficiency in storm response scenarios. A primary point of interest for PMBS systems is their relatively wide angular swath widths which support correspondingly broad seafloor coverage in shallow water survey environments, such as coastal regions, ports, and harbors. These wide angular swath widths (with a typical 'field of view' of $220^\circ$) enable wider survey line spacing than traditional single-head multibeam echosounders (MBES, typically 160° or less); dual-head MBES may achieve angular swath widths similar to those of PMBS systems. Another potential advantage of the characteristically wide PMBS field of view is the ability to provide soundings on structures extending to depths shallower than the echosounder, allowing vessels to survey shallow hazards from larger and presumably safer distances. Finally, the co-located sidescan pseudo-imagery is conducive to human visual analysis of bedforms and objects on the seafloor, such as marine debris, which may be especially useful in regions where bathymetry data are ‘noisy’ or tall, slender features (e.g., masts or antennas) are not well represented in the bathymetry.

A series of topics were investigated relating to potential survey efficiency gains with PMBS sonars, as outlined in the proposal deliverables. The typical operating parameters of PMBS and MBES systems intended for shallow water operations were compared to examine their expected relative advantages and tradeoffs in a storm response scenario. Three commercially available and widely used models of each type of sonar system were selected as representative echosounders for this comparison in the areas of range resolution and capability; angular and across-track swath widths; and backscatter information. These comparisons suggest that PMBS data can increase the effective swath width compared to single-head MBES systems under ideal survey conditions, with the drawbacks of reduced alongtrack ping density, increased sensitivity to refraction artifacts, and increased sounding uncertainty in the outer swath (typically beyond the MBES swath width). Statistical data processing techniques such as the Combined Uncertainty and Bathymetry Estimator (CUBE) are necessary to handle the increased ‘noisiness’ of PMBS data and increase effective swath width, such as by gridding at different (fixed) resolutions to achieve standard deviations of raw soundings in grid cells below a certain threshold (e.g., 1 m). Data
gridded at 30-50 cm resolution using CUBE were also shown to emphasize seabed features which may not be readily apparent in the raw data.

It is clear from these comparisons that the successful application of a PMBS or MBES system depends on the survey objectives and requirements. PMBS sonars are most likely to offer survey efficiency gains when deployed for rapid surveys intended to locate medium to large objects (several meters or larger in all dimensions) in shallow water where swath geometry, not acoustic attenuation, is the limiting factor in acrosstrack seafloor coverage. In this scenario, real-time analysis of the collocated sidescan imagery provides a second layer of confidence that objects and hazards are detected, especially in the outer swath where acrosstrack imagery resolution on the seafloor is finest but depth estimate uncertainty tends to be greatest.

2.1.2 Evaluation of Redbird Reef Data
A set of PMBS data collected over Redbird Reef, an artificial reef site 30 km off the Atlantic coast of Delaware, was examined for possible survey efficiency gains through increased line spacing and reduced swath overlap. The reef site includes sunken subway cars, a barge, multiple vessels, and multiple fields of bedforms on the order of 10-20 cm in amplitude with 1-2 m wavelengths (more detailed descriptions are included in the ‘object detection’ document available at sandy.ccom.unh.edu). The PMBS data were collected from an autonomous underwater vehicle (AUV) with an altitude of approximately 6 m above the seafloor and processed without manual editing using the CUBE algorithm implemented in CARIS HIPS 8.1, as outlined in a ‘best practices’ processing guide available on the Center’s Sandy research website. Several combinations of survey lines were used to mimic line spacing strategies with different amounts of swath overlap (Figure 1) and evaluate the resulting CUBE bathymetric surfaces.

These trials showed that all major objects in the artificial reef, including scour around objects and bedforms in object-free areas, were readily apparent with line spacing of at least seven times the echosounder altitude. A small data gap existed at nadir, which is a consideration for most PMBS systems. Despite this data gap and increased uncertainty in outer swath soundings, the CUBE surfaces created from PMBS data effectively represented all the reef objects apparent in traditional MBES data collected simultaneously from a surface vessel. Of particular interest for this comparison, data quality in the outer swath suggests that the PMBS range limit could likely have been extended during acquisition. Such an adjustment in a response scenario may support line spacing of up to ten times the echosounder altitude, in line with PMBS manufacturer claims, where minimal swath overlap is necessary.
Figure 1: PMBS data collected at Redbird Reef, off the coast of Delaware, were rapidly processed without manual editing in a combination of line spacing strategies to evaluate bathymetric surfaces and the representation of objects with various levels of swath overlap. The survey was conducted using an autonomous underwater vehicle (AUV) at an altitude of 6 m above the seafloor with line spacing of approximately 20 m and a range limit of approximately 25 m, yielding half-swath overlap between adjacent lines. Under a response scenario with real-time analysis of sidescan imagery collected from a surface vessel, the data quality and representation of reef objects (including scour and bedforms) suggest that the acquisition range limit could likely be extended to 30-40 m and line spacing could be set to approximately 60 m, or ten times the echosounder altitude.

2.1.3 Storm Response Survey Protocols
The evaluation of typical PMBS sonar parameters and comparison of CUBE surfaces created with various line spacing strategies highlighted several factors to consider when planning storm response surveys intended to identify navigationally significant objects and seafloor features while maximizing efficiency of operations. In particular, the data gap at nadir (between 0-30°, depending on manufacturer) and elevated uncertainties of outer swath soundings collected with PMBS systems underscore the utility of the co-located sidescan imagery for effectively extending swath coverage. Survey protocols were developed to maximize the acrosstrack distance over which hazards are likely to be detected, and thereby increase survey efficiency through wider line spacing, by extending range limits and incorporating real-time visual analysis of the sidescan imagery during data collection. In regions where PMBS depth estimates are sparse (near nadir) or vertically scattered with greater uncer-
tainty (outer swath), sidescan imagery provides operators with additional cues in the forms of acoustic ‘bright spots’ and ‘shadows’ indicating areas requiring additional survey coverage (Figure 2). These areas may then be immediately resurveyed using PMBS in a region of the swath where both bathymetric data and sidescan imagery quality are typically high, such as approximately 45-60° from nadir. Alternatively, the areas identified for further investigation may be resurveyed using MBES and traditional line spacing strategies to provide least depths over hazards.

![Figure 2: PMBS systems may support survey efficiency gains through increased angular swath width and real-time analysis of co-located bathymetry data and sidescan imagery. In the upper left image, one complete sunken subway car at Redbird Reef, Delaware, is detected in PMBS bathymetry data from a single survey line. The bathymetry includes a region of apparent scour (red arrow). PMBS sidescan imagery from the same line (upper right) assists in the identification of the complete subway car and also suggests the presence of scour and another object near the limit of the swath (red arrow). The lower composite image provides a closer view of the sidescan data showing the potential object in the outer swath (red arrow, lower right) with georeferenced bathymetry from additional survey lines (lower left) confirming the presence of a second subway car. This example demonstrates the potential for efficiency gains in response scenarios by increasing survey line spacing, evaluating sidescan imagery where bathymetric data may be inconclusive, and conducting more detailed surveys only when potential objects are detected.](image)
Overall survey efficiency in a response scenario could be expected to increase using these protocols when the overlapping swath coverage and areas resurveyed (e.g., for more detail over a shipwreck) sum to less than the total overlapping swath area resulting from traditional, closer line spacing. A potential drawback of this strategy is the increased staffing requirements during data collection; for instance, the concurrent objectives of the survey to identify hazards and maximize swath width practically require experienced sidescan operators for real-time analysis. Increased flexibility in ship maneuvers may also be required to adjust line spacing according to data quality and rapidly resurvey areas or objects needing additional data. Nonetheless, the survey protocols are designed to take full advantage of PMBS functionality and yield greater net efficiencies for post-storm surveys intended to detect marine debris and hazardous seafloor changes in shallow water.

2.1.4 Effective Object Detection in PMBS Bathymetry

The wide angular swath widths of PMBS systems may support increased line spacing to more rapidly complete storm response surveys. However, a primary purpose of such a survey remains the detection and, ideally, identification of all navigationally significant hazards. The general performance of two commercially available PMBS systems were evaluated in this regard using datasets collected at Redbird Reef off Delaware and at two sites near Long Island, New York. These sites were impacted by Super Storm Sandy and included objects ranging from approximately 1-2 m in all dimensions (fish habitat structures) to objects at least 10 m horizontally and protruding more than 3 m from the seabed (shipwrecks).

The Redbird Reef and Long Island surveys were used to examine the representation of objects of different sizes in PMBS data processed rapidly, and without manual editing, using commercially available software. This represents a processing path that may be used to maximize efficiency in a response scenario. Each dataset was gridded at resolutions ranging from 10 cm to 100 cm in increments of 10 cm to evaluate the representation of objects in the processed bathymetry. Trends in all datasets suggested that broadening vertical distributions of soundings in the outer swath, likely due to increasing angular uncertainties and refraction artifacts at large ranges, presented the greatest challenges for object detection. Data ‘noisiness’ was effectively suppressed in bathymetric surfaces gridded at resolutions approaching 100 cm but became a serious complication for object detection at grid sizes smaller than 30 cm (Figure 3), obscuring the boundaries of even large objects. Occasionally, depth anomalies were noted in regions covered by single survey passes. During these evaluations, such anomalies could not be confirmed as objects or ruled out as purely acoustic artifacts, highlighting the utility of a data acquisition method which examines bathymetry and sidescan imagery in real-time, identifies targets requiring additional data, and resurveys these targets in swath regions where data quality may be higher.
Figure 3: Depth and standard deviation of soundings in each grid cell may be used in conjunction to detect objects. The depth scale (left column) ranges from 25 m (red) to 27 m (purple) and the standard deviation scale (right column) 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 dataset as well as highlight changes between grids which may indicate the presence of objects.
In evaluating the ability to effectively locate objects of various sizes in PMBS bathymetric data, an important distinction exists between detecting the effect of these objects on the gridded surface (e.g., recognizing a region of elevated depth estimates distinct from the surrounding seafloor) and identifying the object itself (e.g., recognizing the shape and orientation of a sunken vessel). The gridded surfaces were found to preserve the general presence and shapes of objects of all sizes, but were insufficiently detailed for object recognition in most cases. Object identification was possible only after closer scrutiny of subsets of raw data from multiple viewing angles. These subsets included small but telling features, such as railings along a barge, collapsing walls of subway cars, and window frames in a vessel wheelhouse. The smallest objects in these examples (fish habitat structures 1-2 m in horizontal extent and 1 m in vertical relief) required closer examination of the raw data to ensure that the objects were detected in multiple survey passes and were not simply acoustic artifacts (Figure 4). These views confirmed detection of these objects but did not necessarily facilitate their identification.

The objects in the Redbird Reef and Long Island datasets were surveyed using different PMBS sonar systems and processed rapidly without manual editing. In both cases, the utility of a gridded bathymetric surface for object detection depended heavily on the grid size. Resolution of approximately 30 cm, which approximately matches the alongtrack sounding density, was determined to provide a reasonable compromise between suppression of outliers and preservation of detail. In fact, comparison of gridded surfaces at multiple resolutions became a useful tool in evaluating changes in object appearance or contextual clues, such as scour and bedforms, to build confidence in detection of an object. All cases benefitted greatly from multiple survey passes which were used to corroborate the presence of an object or support rejection of an artifact, highlighting the need for additional data when potential objects are identified. In this regard, the capability of the processing method for object detection and recognition depends heavily on the data acquisition method. Several recommendations for processing were provided in the object detection document which, in turn, correspond to additional recommendations for survey design and the separate survey protocols document.
Figure 4: Two structures separated by approximately 5 m are clearly visible in bathymetric surfaces gridded at 100 cm (top two images), 50 cm (middle right), and 30 cm (lower right). The color 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, increasing confidence in their detection but not necessarily supporting their identification.

2.2 Habitat

2.2.1 Classification of Habitat from LIDAR Waveforms
Substantial progress was made during this reporting period using eCognition to map submerged aquatic vegetation (SAV) in Barnegat Bay using LIDAR elevation and waveform feature data (i.e., reflectance and pulse shape deviation) and aerial imagery. eCognition (Trimble Navigation Limited, Sunnyvale, CA, USA) is an object-based image analysis software program designed to integrate multiple types of datasets. The ability to create layers and segment data on multiple scales (Figure 5)
allows for a high level of resolution in segmentation, and data may be classified using layers in conjunction with one another or individually. Rule sets are created by building conditional algorithms from features such as mean elevation, area of a segment, or relationship to sub-objects, based on the user’s contextual knowledge. The result is a highly-refined classification map that can be extrapolated beyond the geographic area used to train the rule set.

Figure 5: An example of multi-resolution segmentation, creating parent objects (left) from child objects (right). This allows for a greater degree of customization in classification.

In the current reporting period, final results were generated from the analysis of NOAA NGS Rieg VQ-820-G topo-bathymetric LIDAR data for benthic habitat mapping in Barnegat Bay. This analysis extended work done in earlier stages of the project, including the acquisition of reference data in the Barnegat Inlet study site and object-based image classification using the LIDAR-derived bathymetry, RGB aerial imagery, and auto-generated waveform features (see FY14 Q3 Progress Report). A map accuracy assessment was performed on the final benthic habitat map of the Barnegat Inlet project site (Figure 6) using the field data acquired in October, 2013 as the reference data set.
**Figure 6**: Final benthic habitat map for the Barnegat Inlet project site created using an OBIA approach with the following input layers: Riegl VQ-820-G waveform features (relative reflectance and pulse deviation), LIDAR-derived topo-bathymetric DEM, and RGB aerial imagery. All of the airborne data used in this portion of the project were acquired by NOAA’s National Geodetic Survey.

The overall map accuracy was found to be 85%, with user’s accuracies\(^2\) varying from 69% to 100% and producer’s accuracies\(^3\) varying from 73% to 100% (Parrish *et al.*, 2015). Analysis of the error matrices revealed that class confusion was primarily limited to sand and classes that are partially sand (e.g., mixed sand and

\(^2\) User accuracy is the probability that the indicated class is what exists in the real world.

\(^3\) Producer accuracy is the probability that a real habitat (as classified in the field) exists on the map.
macroalgae and sparse eelgrass). These results are quite encouraging and support the continued use of object-based image analysis (OBIA) procedures for habitat change assessment in Barnegat Bay. To enable other researchers to benefit from this work, the rule set developed in eCognition and used to create the habitat map shown in Figure 6 is being made publicly-available.

The current classification has been applied primarily to the NGS Riegl LiDAR data, but since this is not the only sensor used in the response to Super Storm Sandy, nor the only sensor that is likely to be used in future responses, how this method can be applied to alternative sensors, and in different locations, is being investigated. The current rule set is being extended for LiDAR data sets that were acquired by multiple systems (specifically, the USGS EAARL-B, the NOAA Riegl VQ-820-G, and the AHAB Chiroptera topo-bathymetric systems) to improve the applicability of the rule sets across LiDAR sensors. These systems have all been used to collect LiDAR data across Barnegat Inlet and these data sets are being used as a platform to determine best practices for the rapid assessment of SAV after a major weather event. In order to do this, however, it was also necessary to process all of the data to the same region and datum, and to generate comparable products. The results, Figure 7, were generated by extracting the LiDAR data from their various source data formats, accommodating for the different levels of processing that had been applied by the data collectors, processing through VDatum to provide a consistent datum (in this case Mean Lower Low Water), and then gridding using Fledermaus [QPS, Zeist, the Netherlands] at the coarsest resolution of any of the datasets, in this case 2.5m. Details of the datasets available are given in Appendix A.

**Figure 7:** Digital elevation models of four sets of bathymetric LiDAR data collected in Barnegat Inlet, NJ, an entrance into Barnegat Bay.

In addition to the analysis of LiDAR using eCognition, visual classification of SAV habitat from pre- and post-Super Storm Sandy high resolution aerial imagery of the entire Bay is ongoing for the period from 2002 to 2014. For this reporting period, Barnegat Inlet was chosen as an area of focus due to the large amount of ground truth data collected and due to the overlap in data collected by all three LiDAR sys-
tems. To determine if automation of SAV classification using eCognition is feasible, manual classification of imagery from 2012 and 2013 was compared to the eCognition classification of 2013 Riegl data and imagery. Figures 8 and 9 illustrate the resolution differences between the manual classification from aerial imagery of Barnegat Inlet and Clam Island (a small area in the inlet) and the classification produced by eCognition. It is important to note that although both methods produce classification maps, eCognition allows for higher resolution. eCognition is also more efficient: while the initial development of the rule set can be time consuming, it can then be applied to multiple images and large data sets, creating a much more streamlined classification process versus the cumbersome manual classification method.

Figure 8: A comparison between manual classification of high resolution imagery from 2012 (a) and 2013 (b), and the preliminary classification generated by eCognition from 2013 imagery and Riegl data (c) near Clam Island in Barnegat Inlet.
2.2.2 Radiometric Corrections for EAARL-B LIDAR Data

Previously (Q4FY14), the development of techniques to extract a reflectance value from EAARL-B LIDAR data were reported, which require some level of radiometric correction before it can be used for, e.g., mosaicking purposes, or for habitat classifications. Analysis completed to date has shown that EAARL-B waveform features can be used to generate seafloor images in which different bottom types are distinguishable, but that application of an appropriate incidence angle correction is critical. The EAARL-B scan mechanism is designed to scan back-and-forth, passing nearly through nadir (within ~2°) on each scan line. This is a different design than that used in other bathymetric and topo-bathymetric LIDAR systems, which typically use a forward or aft tilt angle or circular scan pattern to maintain a nearly constant incidence angle on the water surface. As a result of the EAARL-B scan pattern, the utility of EAARL-B waveform features for habitat mapping is highly dependent on the quality of the incidence angle correction. While this work is ongoing, a number of incidence angle correction strategies were evaluated in the current reporting period.

To facilitate development, testing, and refinement of procedures for generating relative reflectance and other data layers for habitat mapping from EAARL-B waveform data, additional effort was focused on workflow automation using the ArcGIS ModelBuilder. Two models, which start with the EAARL-B point clouds with waveform features as input and result in corrected mosaics, are shown in Figure 10. The significance of this automation is that each time a step is modified in the procedure, only one specific tool within the model needs to be updated, and the effect of the change can be quickly assessed. Further benefits of this approach are: 1) it standardizes workflow testing procedures; 2) the increased automation minimizes the likelihood of human error; and 3) the overall process can be easily visualized in a graphical representation, as shown in Figure 10. Most importantly for the project...
team's current work, changes in the script used to apply the incidence angle correction can be quickly implemented in the model. The models developed in this work will be exported as Python scripts and made available as project deliverables.

![Diagram](image-url)

**Figure 10**: Automation of EAARL-B habitat mapping workflows using ArcGIS model builder. Shown here are two models, which take EAARL-B point clouds with waveform features as input and generate corrected, radiometrically-balanced mosaics.

### 2.3 Marine Debris Detection

Marine debris is, unfortunately, not simple to define. A generic description of “something of non-natural origin in the marine environment” could include everything from fishing nets to wrecks, and in many cases might include objects intentionally placed in the environment (e.g., artificial reefs such as the Redbird Reef site). Detection and identification of marine debris is, therefore, a complex process that is likely to require a variety of algorithms to be effective. That is, any one algorithm is unlikely to be entirely successful, so a composite scheme of a number of algorithms or data sources merged together is more likely to be effective. So for example in a simple case, it might be sufficient to determine the shape of an object from the bathymetry in the region using a thresholding effect (Figure 11), but for a more complex shape an entropy approach (Figure 12) might be more appropriate, and in some situations,
some background information on the surrounding region (Figure 13) might be appropriate.

Figure 11: The simple case of a DTM with an obvious target that can be isolated by optimal thresholding (here using Otsu’s method), followed by use of a convex hull method to determine shape.

Figure 12: A more complex situation where a composite shape requires the use of entropy techniques along with an optimal edge detection (here using Canny’s method) to identify targets as regions.
Figure 13: Use of a region segmentation technique to split the background around a target into segments that can be used to parameterize the subsequent processing; the segments can come from a number of sources, including texture measures or angular backscatter curves.

A primary difficulty with techniques of this type is how to bring together all of the sources of information, and to provide means to incorporate structuring information in complex problems. A Bayesian approach is being investigated for this in the current research, since the method has sufficient flexibility to include multiple data sources, has a mechanism to provide “prior” information to structure the reconstruction of marine debris locations, and has a strong body of computational techniques that can be used to assist in the implementation (Cressie and Wikle, 2011; Gelman et al., 2014).

Initially, a simple model based on a log variance estimator has been developed, along with a single target being estimated. The computational framework works by postulating locations for the object, and then determining the probabilistic evidence for that location given the data and structuring information. Over time, the method develops a histogram of the likely target locations (Figure 14), which can then be used to determine the most likely location of the target (Figure 15). Of course, finding a single wreck on a simple background is relatively straightforward for many methods; the key here is that this method allows for new data sources to be added to the analysis, and for many more complex detection scenarios to be incorporated, an advantage that is the subject of current research.
Figure 14: Example of the output from the Markov Chain Monte Carlo sampler used to solve the Bayesian formulation of the object detection problem in Figure 15. In this method, the algorithm postulates multiple possible locations for the target (top left panel, here showing only the easting component); over time, a histogram of likely location can be determined (right panel), while diagnostics such as the autocorrelation of samples (bottom left panel) are provided to assist the investigator. After some time, the most likely position can be determined from the histogram (solid black line) and used for a target reconstruction.
Figure 15: Target detection using the proposed Bayesian method. The input DTM (top left panel) is processed with a log variance estimator (top right panel) to provide input to the object detection algorithm which (Figure 14) accumulates evidence for object location over time; the detected location (yellow cross, bottom panel) is the maximum a posteriori probability reconstruction of location from the accumulated evidence.

2.4 Satellite-derived Bathymetry

2.4.1 Data Availability

In the current reporting period, further Landsat 8 data has been acquired and processed for morphology change detection and SAV detection. The entirety of the Landsat 8 data dates from 2013-06-01 to 2014-09-17 (the full list of available data is given in Appendix B). Based on a search in DigitalGlobe websites, it seems that there are no new images of WorldView 2 (WV-2) available over Barnegat Bay, NJ.

2.4.2 Shoreline and Morphological Changes

In previous reports, methods were described that can be used to determine shoreline and morphological change based on satellite imagery. These procedures have been applied to the newly available data, and refinements of the methods applied have been documented in procedural guides available from the project website. The morphological processing uses data from the USGS EarthExplorer website and
ArcMap tools, while the shoreline change processing uses the USGS Digital Shoreline Analysis System (DSAS) along with ArcMap tools.

2.4.3 Submerged Aquatic Vegetation Determination
To supplement the other methods being developed to detect SAV within the Sandy-affected area, methods are being examined to determine the location of SAV from satellite imagery. Using different combinations of red, green, and blue bands from the imagery, the goal is to develop a hierarchy of algorithms, which can be organized as a decision tree, to separate vegetation by species group (i.e., to determine macroalgae and seagrass), and to assess population density (e.g., in bands 30-60%, 60-90%, and 100% coverage). Further analysis is required to develop these methods, and the research is ongoing.

2.5 Data Visualization
In a previous progress report (Q4FY14), a prototype tool called the Marine Debris Rapid Decision Tool was introduced. The purpose of the tool is to assist users in the time-consuming process of examining the data available to make a decision about a potential piece of marine debris. In many cases, the most time consuming part of the process is simply getting the data into the right viewpoint so that a decision can be made. The tool under development seeks to streamline this process through both automating the data manipulation and navigation tasks, and generating multiple views that are most likely to convey the shape and size information that is needed to make natural-or-debris decisions. The tool operates by generating many views of the available data, and ranking them in order of potential utility to make a decision what to show; the highest ranked data are provided first, hopefully speeding up analysis. Tools are also provided to quickly mark assessed dispositions of data.

The prototype interface is now a functional component within the real-time four-dimensional visualization system under development at CCOM (VTT4D) and currently work is being done on the algorithms to determine the best possible views to initially present to the user. The code base now loads targets in BAG files, and is being tested with an initial data set of actual marine debris targets (vehicles, wrecks, etc.) extracted from the Redbird Artificial Reef datasets.

3 Outreach

3.1 Online Debris Map Magic Lens
To assist in communication of data available via the project website (and, potentially, others), a new interactive mapping tool for sharing multi-layered maps via any websites has been developed. Previously, NOAA's websites and others have shown before and after imagery of storm affected areas by using an interactive slider which lets users slide to change between two images. These have been successful in engaging viewers and have been shared via social media and other channels, but they have some significant limitations. First, they only allow the display of a maximum of two images. More importantly, the slider action does not maintain the necessary context needed to properly explore the differences between the images.
The tool developed here implements the visualization technique known as a magic lens (of Figures 16-17). A base map layer image is displayed, and a variable number of magic lens windows are available to be freely moved over the top of the base map. The lenses reveal views of other data layers, such as post-storm imagery, multi-beam bathymetry, side-scan sonar data, etc. The base map can be zoomed and the lenses can be resized through intuitive use of the mouse scroll wheel. By not obscuring more of the base map than necessary, the overall context of the data in the lens is preserved. Multiple lenses can be overlapped to inter-compare data: for example one might notice something in the multibeam lens and use the sidescan lens to further investigate it using a different view.

The tool was implemented using HTML5-based WebGL, which is supported by modern browsers, and allows for complex hardware accelerated computer graphics entirely within a website. It was written to be extremely portable, and it is trivial to embed into any website along with whatever collection of images one wants to show. There is no need to edit the underlying code, and it will work with any set of map images as long as they have the same extents.

This tool will be used on the Sandy website to allow users to explore some of the various areas that have been used in the research. Imagery includes pre- and post-storm satellite imagery, sidescan and multibeam bathymetry, LIDAR surveys, and debris records. Because it is so easily portable, it will likely also be used on the broader CCOM website and will be made available to other NOAA offices to improve their websites as well.
Figure 16: Screenshot of the WebGL Magic Lens tool, showing a marina (Great Kills Harbor, NY) damaged during Sandy.
Figure 17: Screenshot of the WebGL Magic Lens tool, showing a marina (Great Kills Harbor, NY) damaged during Sandy.

3.2 Infographics

As part of the outreach strategy, infographics have been prepared to explain to the public some aspects of the research being conducted. Infographics are stand-alone images that focus on single topics, explaining the issues and presenting supporting data and information with rich imagery and simple visualizations. Most importantly, they are easily shared and distributed by the general public over social media channels, which means that they reach more viewers than traditional web content or links to such content.

Two infographics have been finalized, “What do marine debris look like?—And how well can we see them?” which demonstrates the capabilities of sonar and LIDAR to reveal and resolve submerged objects (vehicles, shipwrecks, etc.), which was reported on previously, and “Marine Debris Identification and Processing”, which visually explains the process from deciding where to survey for debris, to automatic target recognition, identifying debris, and finally salvage & cleanup (Figure 18).

Two more infographics are in preparation, one related to the work at CCOM on strengthening automatic target recognition capabilities, and one that provides de-
etailed pre- & post-Sandy bathymetry of the Redbird Reef site off the coast of Delaware, which shows clear evidence of the extremely destructive forces of Sandy.

These infographics are being released through multiple distribution channels including the project website and ccom’s Twitter and Facebook feeds.
Figure 18: Infographic describing the process of identifying, processing, and cleaning up marine debris.
4 Milestones

The proposed milestones for this reporting period were to develop written procedures for processing multi-use products from topo-bathymetric LIDAR, to document development and test of the marine debris approach, to promote outreach, and to provide a basic example of public-directed "citizen science" visualization and identification of marine debris on the project website. In addition, a carry-over milestone from the previous reporting period was to document survey planning methods for PMBS systems, which has now been completed. All of the current milestones have been met, although the public-directed visualization is not entirely complete. The website contains an interactive debris tool, and will shortly have the "magic lens" tool installed, but a user-driven component still needs to be added. This will be addressed in the next reporting period. In addition to the stated milestones, however, we have also made significant progress on milestones for the remainder of FY15, including classification of habitat based on LIDAR and satellite image data, and PMBS object detection.
Reference


### A. Available LiDAR datasets

Table 1: Available LiDAR datasets in the Barnegat Bay area. Dates obtained from LiDAR source metadata and from [http://www.lidarnews.com/PDF/LiDARMagazine_Wozencraft-HurricaneSandy_Vol3No2.pdf](http://www.lidarnews.com/PDF/LiDARMagazine_Wozencraft-HurricaneSandy_Vol3No2.pdf) and [http://coastal.er.usgs.gov/](http://coastal.er.usgs.gov/)

<table>
<thead>
<tr>
<th>Super Storm Sandy LiDAR Data Collection</th>
<th>Type</th>
<th>Sensor</th>
<th>Data Acquired</th>
<th>Federal Data Distribution</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>USACE Post-Sandy LiDAR: CT</td>
<td>Topographic</td>
<td>Leica ALS60</td>
<td>Nov-2012</td>
<td>1 week – 1 month</td>
<td>Obtain LiDAR for digital elevation models and contours for use in damage assessment to USACE projects.</td>
</tr>
<tr>
<td>USACE Post-Sandy LiDAR: Eastern Long Island, NY</td>
<td>Topographic</td>
<td>Optech Gemini</td>
<td>Nov-2012</td>
<td>1 week – 1 month</td>
<td></td>
</tr>
<tr>
<td>USACE Post-Sandy LiDAR: MA &amp; RI</td>
<td>Topographic</td>
<td>Optech ALTM3100</td>
<td>Nov-2012</td>
<td>1 week – 1 month</td>
<td>Depict elevations above and below the water in the NY coastal zone.</td>
</tr>
<tr>
<td>USACE Post-Sandy LiDAR: MD &amp; VA</td>
<td>Topographic</td>
<td>Optech Gemini</td>
<td>Nov-2012</td>
<td>1 week – 1 month</td>
<td></td>
</tr>
<tr>
<td>USACE Post-Sandy LiDAR: NJ &amp; NY</td>
<td>Topographic</td>
<td>CZMIL</td>
<td>Nov-2012</td>
<td>1 week – 1 month</td>
<td></td>
</tr>
<tr>
<td>USGS LiDAR: Post-Sandy (DE, MD, NC, NY, VA)</td>
<td>Topographic</td>
<td>Optech Gemini</td>
<td>Nov-2012</td>
<td>2 weeks – 1 month</td>
<td>Obtain MHW shoreline, dune crest (DHIGH) and dune toe (DLOW) elevation.</td>
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<tr>
<td>USGS LiDAR: Pre-Sandy (NJ)</td>
<td>Bathymetric</td>
<td>EAARL-B</td>
<td>Oct-2012</td>
<td>2 years</td>
<td>Pre- and Post-Hurricane Sandy highly detailed and accurate digital elevation maps of NJ coastline.</td>
</tr>
<tr>
<td>USGS LiDAR: Post-Sandy (NJ)</td>
<td>Bathymetric</td>
<td>EAARL-B</td>
<td>Nov-2012</td>
<td>2 years</td>
<td></td>
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<tr>
<td>USGS LiDAR: Pre-Sandy (NJ)</td>
<td>Topographic</td>
<td>EAARL-B</td>
<td>Oct-2012</td>
<td>1 year</td>
<td></td>
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<tr>
<td>USGS LiDAR: Post-Sandy (NJ)</td>
<td>Topographic</td>
<td>EAARL-B</td>
<td>Nov-2012</td>
<td>1 year</td>
<td></td>
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<tr>
<td>USACE LiDAR: Post-Sandy Fire Island (NJ)</td>
<td>Topographic</td>
<td>CZMIL</td>
<td>Sept-2013</td>
<td>1 year</td>
<td>Data collected to depict the elevations above and below water.</td>
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<tr>
<td>NOAA NGS LiDAR: Post Sandy Barnegat Bay NJ</td>
<td>Topographic</td>
<td>Rieg VQ820G</td>
<td>Sept-2013</td>
<td>6 months</td>
<td>Research efforts for testing and developing standards for LiDAR.</td>
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<td>NOAA OCS LiDAR: Post-Sandy Barnegat Bay, Atlantic City, NJ</td>
<td>Topographic</td>
<td>Chiroptera</td>
<td>03Apr14</td>
<td>4 months</td>
<td>Provide current surveys to update (NOS) nautical charting products following Sandy.</td>
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</tbody>
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**Figure A1:** Super Storm Sandy LIDAR data collection overview.
## B. Landsat 8 Datasets

<table>
<thead>
<tr>
<th>Date of Landsat 8 Image</th>
<th>Time of Acquisition</th>
<th>Cloud Coverage</th>
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<td>2013-06-01</td>
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<td>2013-07-19</td>
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<td>Partly</td>
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<td>2013-08-20</td>
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</tr>
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<td>2013-11-24</td>
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<td>2014-04-10</td>
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<td>2014-05-19</td>
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</tr>
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<td>Minimal over ocean</td>
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<td>15:39 GMT</td>
<td>Minimal/Clear</td>
</tr>
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<td>Partly</td>
</tr>
</tbody>
</table>