UNH/NOAA Joint Hydrographic Center

Performance and Progress Report—Executive Summary

Project Title: Joint Hydrographic Center
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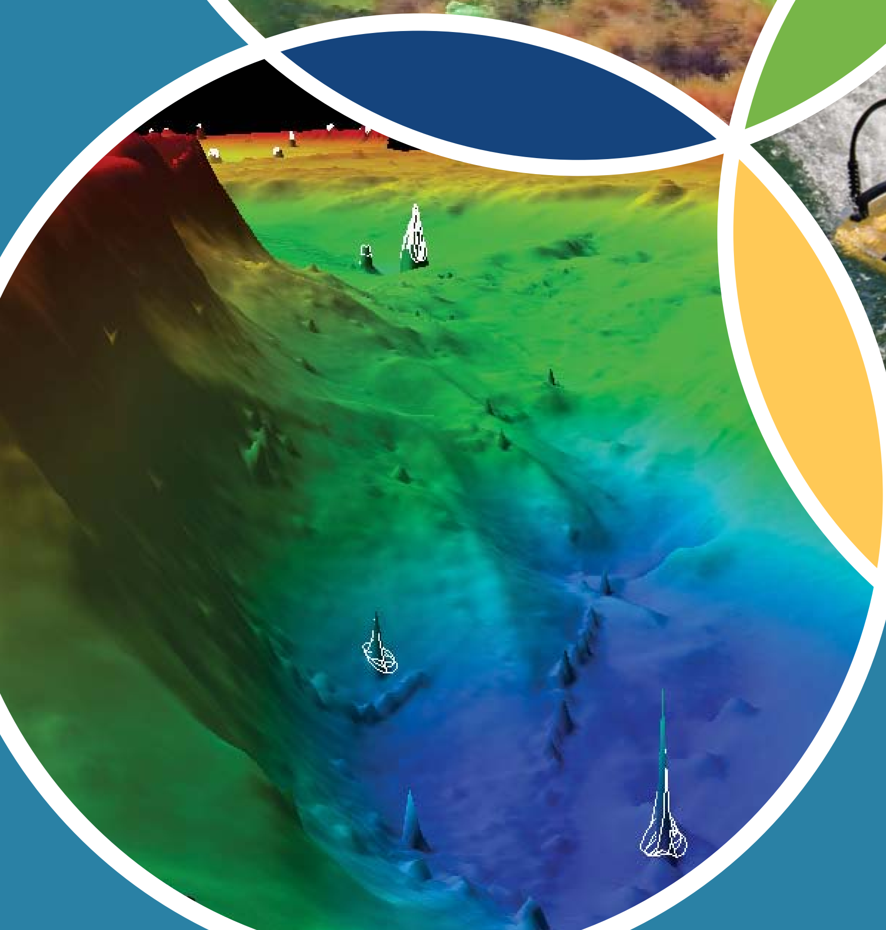
Principal Investigator: Larry A. Mayer



2015

Flyers from the 2015 JHC/CCOM Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded sixteen years ago with the objective of developing tools and offering training that would help NOAA and others to meet the challenges posed by the rapid transition from the sparse measurements of depth offered by traditional sounding techniques (lead lines and single-beam sonars) to the massive amounts of data collected by the new generation of multibeam echo sounders, and to promote the development of new ocean mapping technologies. Since its inception, the Center has been funded through Cooperative Agreements with NOAA. The most recent of these, which was the result of a national competition, funded the Center for the period of 1 July 2010 until December 2015. Over the years, the focus of research at the Center has expanded, and now encompasses a broad range of ocean mapping applications.

An initial goal of the Center was to find ways to process the massive amounts of data generated by multibeam and sidescan sonar systems at rates commensurate with data collection; that is, to make the data ready for chart production as rapidly as the data were collected. We have made great progress over the years in attaining, and now far surpassing, this goal and, while we continue to focus our efforts on data processing in support of safe navigation, our attention has also turned to the opportunities provided by this huge flow of information to create a wide range of products that meet needs beyond safe navigation (e.g., marine habitat assessments, gas seep detection, fisheries management, disaster mitigation, and national security). Our approach to extracting "value added" from data collected in support of safe navigation was formalized with the enactment on the 30th of March 2009 of the Ocean and Coastal Mapping Integration Act—and our establishment of an Integrated Ocean and Coastal Mapping (IOCM) Processing Center at UNH to support NOAA and others in delivering the required products of this new legislation. In 2010 the concept of IOCM was demonstrated when we were able to quickly and successfully apply tools and techniques developed for hydrographic and fisheries applications to the Deepwater Horizon oil spill crisis.

In the time since our establishment, we have built a vibrant Center with international reputation as the place, "where the cutting edge of hydrography is now located" (Adam Kerr, Past Director of the International Hydrographic Organization in Hydro International). In the words of Pat Sanders, then President of HYPACK Inc., a leading provider of hydrographic software to governments and the private sector:

"JHC/CCOM has been THE WORLD LEADER in developing new processing techniques for hydrographic data. JHC/CCOM has also shown that they can quickly push new developments out into the marketplace, making both government and private survey projects more efficient and cost effective."

Since our inception, we have worked on the development of automated and statistically robust approaches to multibeam sonar data processing. These efforts came to fruition when our automated processing algorithm (CUBE) and our new database approach (The Navigation Surface), were, after careful verification and evaluation, accepted by NOAA, the Naval Oceanographic Office and other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has, or is, incorporating these approaches into their products. It is not an overstatement to say that these techniques are revolutionizing the way NOAA and others in the ocean mapping community are doing hydrography. These new techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that has never before been achievable in hydrographic data. The result has been: "gained efficiency, reduced costs, improved data quality and consistency, and the ability to put products in the hands of our customers faster." (Capt. Roger Parsons, former NOAA IOCM Coordinator and Director of NOAA's Office of Coast Survey).

The acceptance of CUBE and the Navigation Surface represents a paradigm shift for the hydrographic community—from dealing with individual soundings (reasonable in a world of lead line and single-beam sonar measurements) to the acceptance of gridded depth estimates (with associated uncertainty values) as a starting point for hydrographic products. The research needed to support this paradigm shift has been a focus of the Center since its inception and to now see it accepted is truly rewarding. It is also indicative of the role that the Center has played and will continue to play, in establishing new directions in hydrography and ocean mapping.

Another long-term theme of our research efforts has been our desire to extract information beyond depth (bathymetry) from the mapping systems used by NOAA and others. We have made significant progress in the development of a simple-to-use tool (GeoCoder) that generates a sidescan-sonar or backscatter "mosaic"—a critical first step in the analysis of seafloor character. There has been tremendous interest in this software throughout NOAA and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE's role in bathymetric processing, GeoCoder is becoming the standard approach to backscatter processing. An email from a member of the Biogeography Team of NOAA's Center for Coastal Monitoring and Assessment said:

> *"We are so pleased with GeoCoder! We jumped in with both feet and made some impressive mosaics. Thanks so much for all the support."*

Beyond GeoCoder, our efforts to support the IOCM concept of "map once, use many times" are also coming to fruition. In 2011, software developed by Center researchers was installed on several NOAA fisheries vessels equipped with Simrad ME70 fisheries multibeam echosounders. These sonars were originally designed for mapping pelagic fish schools but, using our software, the sonars are now being used for multiple seabed mapping purposes. For example, data collected on the *Oscar Dyson* during an acoustic-trawl survey for walleye pollock was opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. In 2012, seafloor mapping data from the ME70 was used by fisheries scientists to identify optimal sites for fish-traps during a red snapper survey. Scientists on board ship said that the seafloor data provided by Center software was "invaluable in helping accomplish our trapping objectives on this trip." In 2013, tools developed for producing bathymetry and other products from fisheries sonars were installed on NOAA fisheries vessels and operators trained in their use. In 2015, one of our industrial partners began providing fully supported commercial-grade versions of these tools and they are being installed on NOAA fisheries vessels. All of these examples (CUBE, GeoCoder, and our fisheries sonar tools) are tangible examples of our (and NOAA's) goal of bringing our research efforts to operational practice (R2O).

The Center was also called upon to help with an international disaster—the mysterious loss of Air Malaysia Flight MH370. As part of our GEBCO/Nippon Foundation Bathymetric Training Program, researchers and students in the Center are compiling all available bathymetric data from the Indian Ocean. When MH370 was lost, the Government of Australia and several major media outlets came to the Center for the best available representations of the seafloor in the vicinity of the crash. The data we provided were used during the search and were displayed both on TV and in print media.

As technology evolves, the tools needed to process the data and the range of applications that the data can address will also change. We have begun to explore the use of Autonomous Underwater Vehicles (AUVs) and Autonomous Surface Vehicles (ASVs) as platforms for hydrographic and other mapping surveys and are looking closely at the capabilities and limitations of Airborne Laser Bathymetry (lidar) and Satellite Derived Bathymetry (SDB) in shallow-water coastal mapping applications. To further address the critical very-shallow-water regimes we are also looking at the use of personal watercraft and aerial imagery as tools to measure bathymetry in that difficult zone between zero and ten meters water depth. The Center is also bringing together many of the tools and visualization techniques we have developed to explore what the "Chart of the Future" may look like.

In the last few years, a new generation of multibeam sonars has been developed (in part as a result of research done at the Center) that have the capability of mapping targets in the water-column as well as the seafloor. We have been developing visualization tools that allow this water-column data to be viewed in 3D in real-time. Although the ability to map 3D targets in a wide swath around a survey vessel has obvious applications in terms of fisheries targets (and we are working with fisheries scientists to exploit these capabilities), it also allows careful identification of shallow hazards in the water column and may obviate the need for wire sweeps or diver examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component to our efforts to map submerged oil and gas seeps and monitor the integrity of the Macondo 252 wellhead as part of the national response to the Deepwater Horizon oil spill. The Center's seep mapping efforts continue to be of national and international interest as we begin to use them to help quantify the flux of methane into the ocean and atmosphere. The initial water-column studies funded by this grant have led to many new opportunities including follow-up work that has been funded by the National Science Foundation, the Office of Naval Research, the Dept. of Energy, and the Sloan Foundation.

The value of our visualization, water-column mapping, and Chart of the Future capabilities have also been demonstrated by our work with Stellwagen National Marine Sanctuary aimed at facilitating an adaptive approach to reducing the risk of collisions between ships and endangered North American Right Whales in the sanctuary. We have developed 4D (space and time) visualization tools to monitor the underwater behavior of whales, as well as to notify vessels of the presence of whales in the shipping lanes and to monitor and analyze vessel traffic patterns. Describing our interaction with this project, Dan Basta, Director of the Office of National Marine Sanctuaries, said:

> *"…I am taking this opportunity to thank you for the unsurpassed support and technical expertise that the University of New Hampshire's Center for Coastal and Ocean Mapping/NOAA-UNH Joint Hydrographic Center provides NOAA's Office of National Marine Sanctuaries. Our most recent collaboration to produce the innovative marine conservation tool Whale-Alert is a prime example of the important on-going relationship between our organizations. WhaleAlert is a software program that displays all mariner-relevant right whale conservation measures on NOAA nautical charts via iPad and iPhone devices. The North American right whale is one of the world's most endangered large animals and its protection is a major NOAA and ONMS responsibility. The creation of WhaleAlert is a major accomplishment as NOAA works to reduce the risk of collision between commercial ships and whales, a major cause of whale mortality.*

> *"...WhaleAlert brings ONMS and NOAA into the 21st century of marine conservation. Its development has only been possible because of the vision, technical expertise, and cooperative spirit that exist at CCOM/JHC and the synergies that such an atmosphere creates. CCOM/JHC represents the best of science and engineering and I look forward to continuing our highly productive relationship."*

Statements from senior NOAA managers and the actions of other hydrographic agencies and the industrial sector provide clear evidence that we are making a real contribution to NOAA and the international community. We will certainly not stop there. CUBE, the Navigation Surface, GeoCoder, and the Chart of the Future offer frameworks upon which new innovations are being built and new efficiencies gained. Additionally, these achievements provide a starting point for the delivery of a range of hydrographic and non-hydrographic mapping products that set the scene for many future research efforts.

Highlights from Our 2015 Program

Our efforts in 2015 represent the continued growth and refinement of successful ongoing research programs combined with the evolution of new programs developed within the seven research themes prescribed by the Cooperative Agreement with NOAA (Sensors, Processing, Habitat and Water Column Mapping, IOCM, Visualization, Chart of the Future, and Law of the Sea). In 2015, as in 2013 and 2014, some of our efforts have been diverted to research and data processing associated with an immediate need—response to Super Storm Sandy. This led to a rapid increase in the staff at the Center in 2014 (three new Center employees and six new NOAA contract employees). Although the costs associated with most of the new staff and much of the Super Storm Sandy related effort are not being covered by the Joint Hydrographic Center grant, the work being conducted draws upon, and is linked to, many of the efforts funded by the JHC grant. The selection of the Center as the venue for the Super Storm Sandy work is further evidence of the relevance of the JHC-funded work to NOAA and the nation.

As our research progresses and evolves, the initially clear boundaries between the themes have become more and more blurred. For example, from an initial focus on sonar sensors we have expanded our efforts to include lidar and satellite imagery. Our data-processing efforts are evolving into habitat characterization, mid-water mapping and IOCM efforts. The data-fusion and visualization projects are also blending with our seafloor characterization, habitat and Chart of the Future efforts as we begin to define new sets of "non-traditional" products. This blending is a natural—and desirable—evolution that slowly changes the nature of the programs and the thrust of our efforts. While the boundaries between the themes are often diffuse and often somewhat arbitrary, our Annual Progress Report maintains the thematic divisions; the highlights outlined below offer only a glimpse at the Center's activities, but hopefully provide key examples of this year's efforts.

Sensors

We continue to work closely with NOAA and the manufacturers of sonar and lidar systems to better understand and calibrate the behavior of the sensors used to make the hydrographic and other measurements used for ocean mapping. Many of these take advantage of our unique acoustic test tank facility, the largest of its kind in New England and now equipped with state-of-the-art test and calibration facilities. This year the facility was upgraded to include the ability to automatically measure sound speed in the tank and humidity in the highbay facility. Accurate understanding of sound speed is essential to our acoustic measurements, while understanding humidity fluctuations in the highbay is critical to the functioning of our measuring equipment and the long-term viability of the facility. Several sonars were calibrated this year including an MSI constant beamwidth transducer (Figure ES-1) and a new Kongsberg wideband transceiver (both to provide higher resolution in target detection), a NOAA fisheries sonar, a DIDSON imaging system (to explore its applicability to habitat studies) and two small Garmin transducers to understand their potential applicability to crowd-sourced bathymetric data collection. The broadband transceiver tested in our tank was later deployed on several cruises focused on quantitative measurements of gas bubbles and on the Swedish Icebreaker *Oden* in Petermann Fjord, northern Greenland, to identify seeps and other midwater targets as part of an NSF-sponsored study to understand the causes of the rapid melting of the Greenland Ice Sheet.

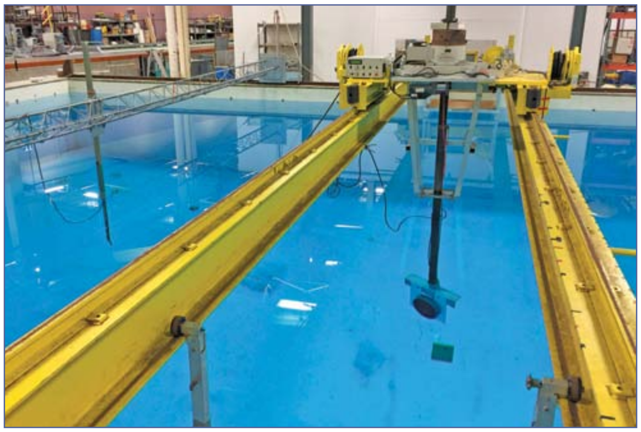


Figure ES-1. MSI Constant Beamwdith Tranducer being tested in the Center's acoustic test tank.

Part of this effort is the development and dissemination of best-practices documentation, and quality-assurance and performance-prediction software that have already been introduced into the NOAA fleet. In 2015, the MAC team peformed Shipboard Acceptance Trials (SAT) for upgraded multi-beam sonars on the research vessels *Kilo Moana* and *Nathanial B. Palmer.* Center staff also teamed with NOAA personnel to perform Quality Assurance Tests (QATs) on the NOAA Vessel *Ron Brown*. The MAC team also performed annual maintenance and inspections of the multibeam systems aboard the Schmidt Ocean Institute's R/V *Falkor* and the Ocean Exploration Trust's E/V *Nautilus* and continued with the development of a suite of publicly available software tools for the analysis and interpretation of multibeam sonar performance.

The expertise of the Center, with respect to MBES, has been recognized through a number of requests for Center personnel to participate in field acceptance trials of newly installed sonars. The Center has taken a lead (through funding from the National Science Foundation) in the establishment of a national Multibeam Advisory Committee (MAC) with the goal of ensuring that consistently high-quality multibeam data are collected across the U.S. Academic Research Fleet and other vessels. NOAA personnel have begun to accompany Center participants on MAC cruises and the experience gained from our MAC activities has been fed directly back into NOAA, aiding our support of NOAA mission-related research and education.

Figure ES-2. Point cloud of the Chase Ocean Engineering Facility using the VLP-16 Velodyne laser system.

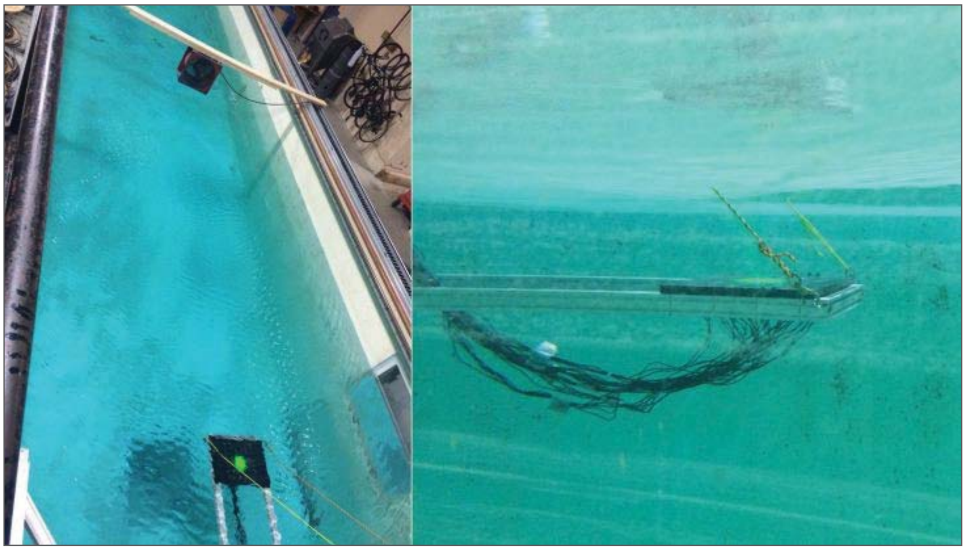


Figure ES-3. Laser pulse foot print under fan-generated wind conditions. Left—the fan mounted on the tow tank generates the capillary waves. Right—side view of the optical detector array submerged into the water.

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric lidar systems offer the possibility to rapidly collect bathymetric (and other) data in these very shallow regions but there still remains great uncertainty about the accuracy and resolution of these systems. Additionally, lidar (both bathymetric and terrestrial) offer the opportunity to extract other critical information about the coastal zone including seafloor characterization and shoreline mapping data. We have thus invested heavily in lidar-based research (mostly reported under the HABITAT and PROCESSING themes) but also with respect to the sensors themselves.

Shachak Pe'eri and NOAA Corps officer and graduate student John Kidd are exploring the use of inexpensive 2D laser scanners mounted on NOAA vessels to detect natural (e.g., shoals and boulders), and man-made (e.g., piers, piles) features that pose dangers to navigation. Initial laboratory testing (Figure ES-2) indicate that this approach may be a cost-effective addition to near-shore surveys.

To better understand the uncertainty associated with airborne lidar bathymetric (ALB) measurements we have re-invigorated our efforts in developing a lidar simulator—a device designed to emulate an airborne lidar system in the laboratory. As part of the Lidar Simulator project, we are investigating the effect of variation in the water surface, the water column and the bottom return on the laser pulse measurements in an ALB system. To do this, a planar optical detector array which was designed at the Center (Figure ES-3) is used to measure laser pulse intensity.

Our evaluation of new sensors and their applicability to hydrographic problems extends to the most efficient platforms to conduct surveys with. Through collaboration with Art Trembanis at the University of Delaware, we have been exploring the viability of using Autonomous Underwater Vehicles (AUVs) as a platform for hydrographic measurements and, over the years, we have conducted a series of "AUV Bootcamps"—research and engineering workshops focused on furthering the art of hydrographic surveying from autonomous underwater vehicles. The 2014 Bootcamp identified a number of issues limiting the overall accuracy of AUV-based surveys, and in 2015, Research Engineer Val Schmidt and Shannon Byrne from industrial partner Leidos Inc., quantified the results of these investigations showing that after just 17 minutes of operation the requirement for a Special Order Survey is likely to be exceeded. With appropriate navigation post-processing, however, the uncertainty increase can be mitigated by constraining the position estimate with solutions computed both forward and backward in time. When fully accounting for all biases, the AUV-generated surface differed from a surface ship-generated surface by less than 0.19 meters 95% of the time, with a mean difference of just 0.08 meters.

We have also begun a new effort designed to explore the feasibility of using Autonomous Surface Vehicles (ASVs) as a platform for the collection of hydrographic data. The initial focus of our efforts have revolved around the work of graduate student and NOAA Corps Officer LTJG Damian Manda whose thesis work focuses on development of small autonomous surface vehicles with hydrographic surveying targeted behaviors. Algorithms have been developed for use in hydrographic surveying applications. These behaviors allow a craft to start from a given line and complete a survey area without previous knowledge of the bathymetry.

The craft's adapts its path solution based on detected hazards and dynamically spaces survey lines depending on the depth to compensate for varying width multibeam swaths. Manda tested his software on Teledyne Z-Boats that are now in operation on the NOAA Ship *Thomas Jefferson*, and which have been loaned to the Center by industrial partner Teledyne OceanScience (ES-4).

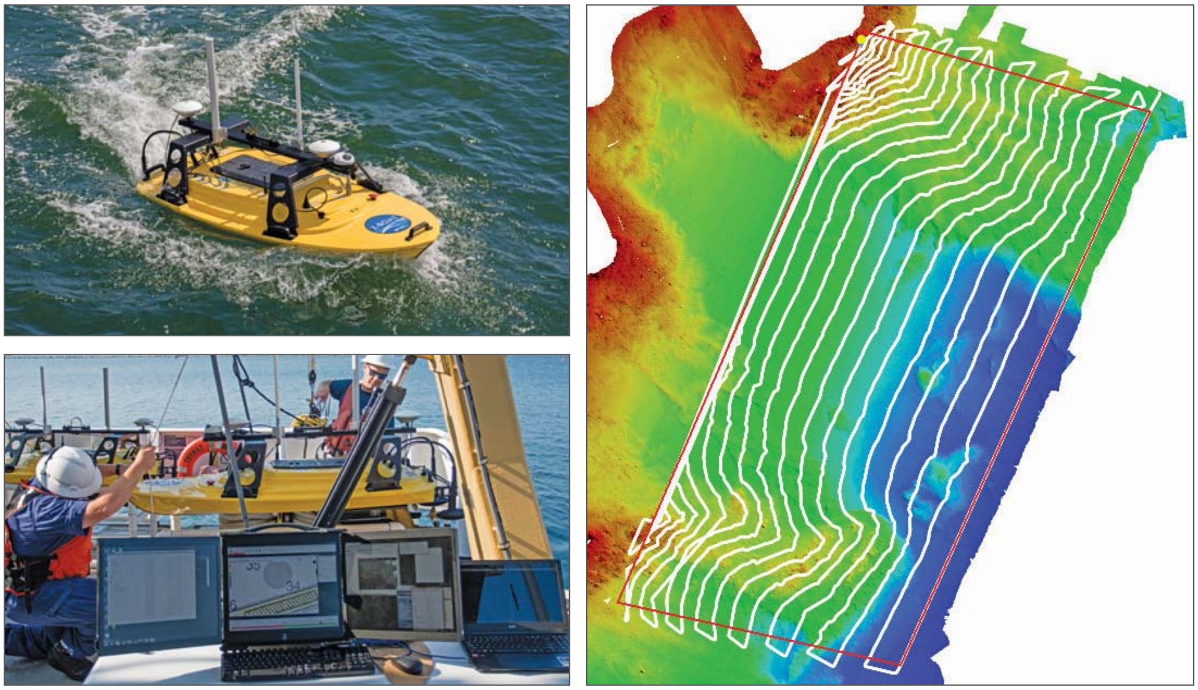


Figure ES-4. EMILY ASV being tested on NOAA Vessel *Thomas Jefferson* (upper). Adaptive path planning for bathymetric data collection from simulation using previously collected bathymetry (lower).

Processing

In concert with our efforts focused on understanding the behavior and limitations of the sensors we use, we are also developing a suite of processing tools aimed at improving the efficiency of producing the end-products we desire, but just as importantly at quantifying (and reducing if possible) the uncertainty associated with the measurements we make. These efforts, led by Brian Calder, are now directed to further development of the next generation of the CUBE approach to bathymetric data processing, an algorithm called CHRT (CUBE with Hierarchical Resolution Techniques). CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of the estimates of depth. This year's efforts have focused on testing, and working with a number of industrial co-developers, and NOAA representatives, to establish a test suite that will allow for CHRT 1.0 validation. The structure for the initial test suite has been defined, and a working group of interested industrial co-developers is being established in order to support this effort, with target representation initially from CARIS, Leidos, QPS, and NOAA. Additionally, Calder has collaborated with Paul Elmore (NRL Stennis) on an alternative uncertainty propagation equation for use in CUBE and CHRT. This modification will reduce over-emphasis of propagated uncertainty from the effects of horizontal uncertainty in the input observations while providing better control over the magnitude of the uncertainty being propagated.

The arrival of Dr. John Hughes Clarke to the Center greatly expands our expertise in understanding the factors that impact the quality of the swath mapping data we collect. NOAA, along with many hydrographic organizations, continually investigates the feasibility of working with ever wider angular sectors. This potentially allows higher productivity in shallow coastal waters but also exacerbates the position and integration issues that are compounded through obliquity. It also particularly exacerbates a source of uncertainly that has received much attention: unstable near-surface sound speed fluctuations that can provide a practical limit on achievable coverage. Hughes Clarke has been exploring this issue in a long-standing collaboration with the U.S. Naval Oceanographic Office.

A major operational finding has been that there are significant environmental limitations of working in areas where there are strong near-surface sound speed gradients. Using both rapidly dipping underway profilers and the built-in water-column imaging, the correlation between the oceanographic stability and the quality of the outer swath bottom detection is apparent. Of particular concern are small oscillations in the velocline that appear to correspond to short wavelength internal waves. These can be made much worse by repeated passage of vessels that trigger these internal waves in a manner similar to wakes. This would impact operation in heavily trafficked waters (ES-5).

Our efforts to understand uncertainty and improve data-processing flow have also expanded to an alternative type of swath-mapping sonar—those that use multiple rows of offset arrays to determine depth through the measurement of phase differences. These sonars can offer wider swath coverage (and thus increase survey efficiency) but there are a number of outstanding questions about the quality of the bathymetric data they produce and the difficulties associated with processing. To address these issues, Val Schmidt and others have been developing new approaches to phase-measuring bathymetric sonar (PMBS) processing ("Most Probable Angle" algorithm) and have been using this to quantify the uncertainty associated with these measurements. Schmidt has been working with manufacturers to help them find better designs, and with software developers of post-processing packages to help them better handle PMBS data such that it is more readily suitable for hydrographic work. As a direct result of these interactions, Edgetech and Klein systems now provide real-time bathymetric uncertainty estimates with their data. In addition, Klein has redesigned their bathy processing engine to produce nearly full coverage at nadir in water depths shallower than approximately 20 m, where their previous systems left a 60 degree gap. Further, Caris and Hypack now support ingestion of uncertainty from Edgetech and Klein systems.

Schmidt has been working closely with NOAA contractors Cassandra Bongiovanni, Juliet Kinney and Sarah Wolfskehl, who are co-located at the Center to help determine if recent post Hurricane Sandy surveys by the USGS with the SeaSwath system are suitable for nautical charting. In addition, as part of our work under the IOCM Super Storm Sandy Disaster Relief cooperative agreement, PMBS data sets have been evaluated for their effectiveness in post-storm survey. From these findings a series of recommendations have been produced for effective object detection from the bathymetry of PMBS systems. These include careful interpretation of the bathymetry data in the context of the sidescan imagery (Figure ES-6), scanning data in real time to ensure hazards to navigation are captured in the most favorable survey geometries, utilizing systems that produce real-time uncertainty with their measurements as well as binning and averaging data to reduce noise, and conducting thoughtful outlier rejection to ensure true outliers and not the tails of a noisy measurement distributions are omitted.

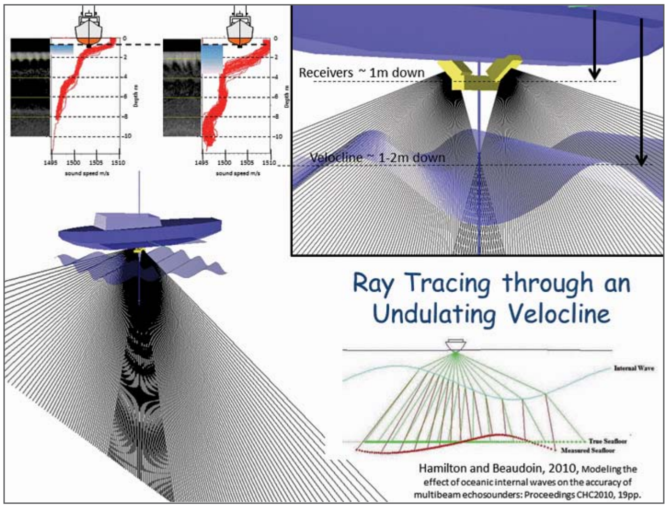


Figure ES-5a. The sound speed environment in which bottom tracking instability occurred and the geometry of the internal wave activity.

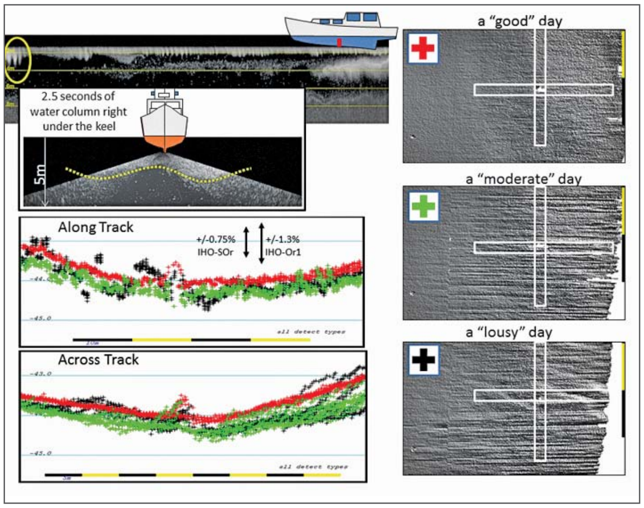


Figure ES-5b. The varying quality of outer swath bottom tracking (along and across track) as the vessel passed over crests and troughs of internal waves on the velocline (as revealed in the water column).

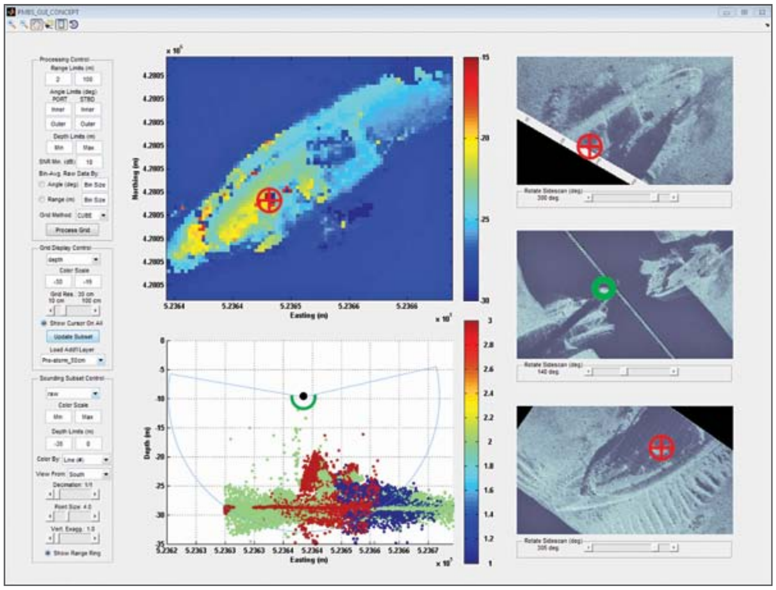


Figure ES-6. In this conceptual graphical user interface for PMBS sonar data, the raw soundings, gridded bathymetry, and all available sidescan imagery collected over a shipwreck are presented simultaneously to facilitate correlation of features across all data streams and improve detection of least depths over hazards. For example, the 'Show Cursor On All' option helps the user to identify the same location (red crosshairs) in the gridded bathymetry and the sidescan imagery from multiple passes for better context and correlation among targets. With the 'Show Range Ring' option selected, the range to a high-amplitude target selected in one sidescan image (green cursor, middle right) is depicted in the 3D subset (green range ring, lower left); this option helps to confirm the relationship between shallow soundings in survey line 2 (light green soundings) and the corresponding shallow sidescan feature.

Our efforts to understand the limitations and capabilities of PMBS have been greatly enhanced by the arrival of Dr. Tony Lyons. Dr. Lyons, supported mostly by the Office of Naval Research, brings a rich history of expertise in PMBS and Synthetic Aperture Sonar (SAS) design and processing to the Center; his Navy work has immediate applicability to the questions faced by NOAA and others regarding the efficacy of PMBS and SAS for hydrographic applications. The introduction of stable, commercially available autonomous underwater vehicles (AUVs) and improved micronavigation methods have made interferometric SAS and interferometric sidescan (or phase measuring) bathymetric sonar systems increasingly viable solutions for increasing aerial coverage rates in shallow water. Both of these technologies present a number of challenges, however, including: platform stability, acoustic multipath interference, low signal-to-noise (SNR) and water-column sound speed variation. The advantages of SAS interferometry may outweigh its problems when resolution and area-coverage rate is of concern since SAS interferometry outperforms multibeam echosounders in terms of bathy-metry measurement density while also providing co-registered intensity imagery, useful for target detection and mapping of habitat or sediment types.

We have also been exploring "crowd sourced" bathymetric measurements. Although there are a number of projects underway to collect bathymetric data with the intent of creating or updating charts, many (if not all) hydrographic offices are reluctant to accept non-professional survey data for chart update due to the liability issues involved. We are addressing this issue by investigating an alternative approach to the problem where instead of gathering data of uncertain provenance and then attempting to make it suitable for charting through some sophisticated processing, a more sophisticated data collection system is developed that by design gathers data that is of demonstrable quality, and preferably of sufficient quality to be used for chart update (Trusted Community Bathymetry—TCB). We have started testing equipment that could be used for a TCB system, determining the capabilities of potential component parts of such a system, and to thereby develop the requirements for a system design. Specifically, we have been testing an inexpensive Garmin GT-30/GCV-10 sidescan system (Figure ES-7) that is designed primarily for recreational fishermen, as a means to capture useful data that might be used for hazard assessment.

In concert with our efforts to improve the processing of bathymetric data, we are also focusing significant

Figure ES-7. Garmin GT-30 sidescan/downscan transducer (left) and GCV-10 black-box sonar module (right), being tested for Trusted Community Bathymetry applications at the UNH pier in New Castle, NH on 2015-06-08.

effort on trying to improve approaches to processing backscatter (amplitude) data that are collected simultaneously with the bathymetric data but have traditionally not been used by hydrographic agencies. Backscatter data are becoming more and more important as we recognize the potential for seafloor mapping to provide quantitative information about seafloor type that can be used for habitat studies, engineering evaluations and many other applications. However, it is essential to understand the uncertainty associated with the measurement of acoustic backscatter from the seafloor. The fundamental question is—when we see a difference in the backscatter displayed in a sonar mosaic, does this difference truly represent a change in seafloor characteristics or can the difference be the result of changes in instrument behavior or the ocean environment? The focus of our effort to address this difficult question is a continuing project we call the New Castle Backscatter Experiment (NEBEX). This project, which involves close collaboration with NOAA's Glen Rice and Sam Greenaway brings together several different existing lab efforts—Mashkoor Malik's Ph.D. thesis work; Carlo Lanzoni's work toward an absolute backscatter calibration for MBES; Yuri Rzhanov's imagery analyses; Sam Greenaway and Glen Rice's efforts to develop field procedures for proper backscatter data collection; backscatter mosaicing (GeoCoding); backscatter inversion; and backscatter ground truth (e.g., optical imagery, bottom sampling, and high accuracy positioning). Associated with this effort is our work calibrating individual sonars and addressing concerns raised by our NOAA partners about specific systems they are using in the field. In bringing together scientists with disparate backgrounds to address a common problem, the NEWBEX project epitomizes the strength of the Center. As problems arise, we can call upon local expertise (in signal processing,

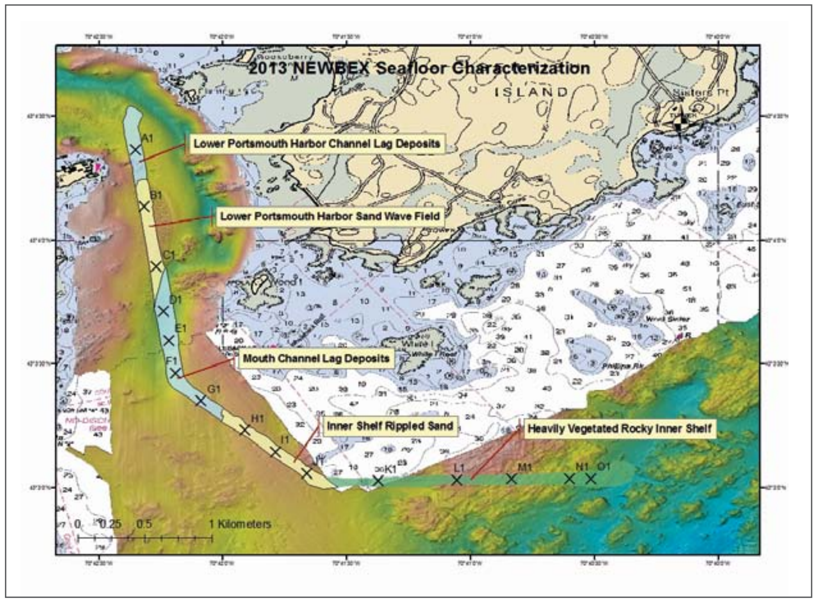


Figure ES-8. Location map of the NEWBEX transect, the 2013 sampling stations (targets), and an initial division of seafloor types.

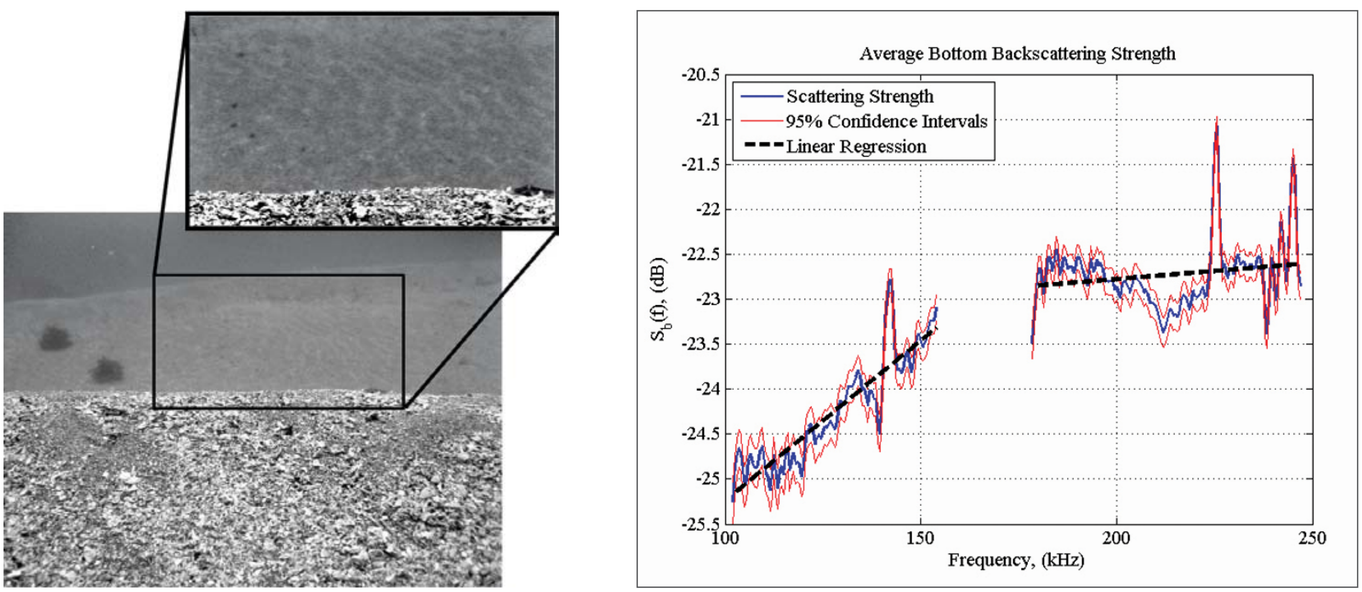


Figure ES-9. A diver's photographs of the Portsmouth sandwave field (left). Observations of seafloor backscatter in the Portsmouth sandwave field (right).

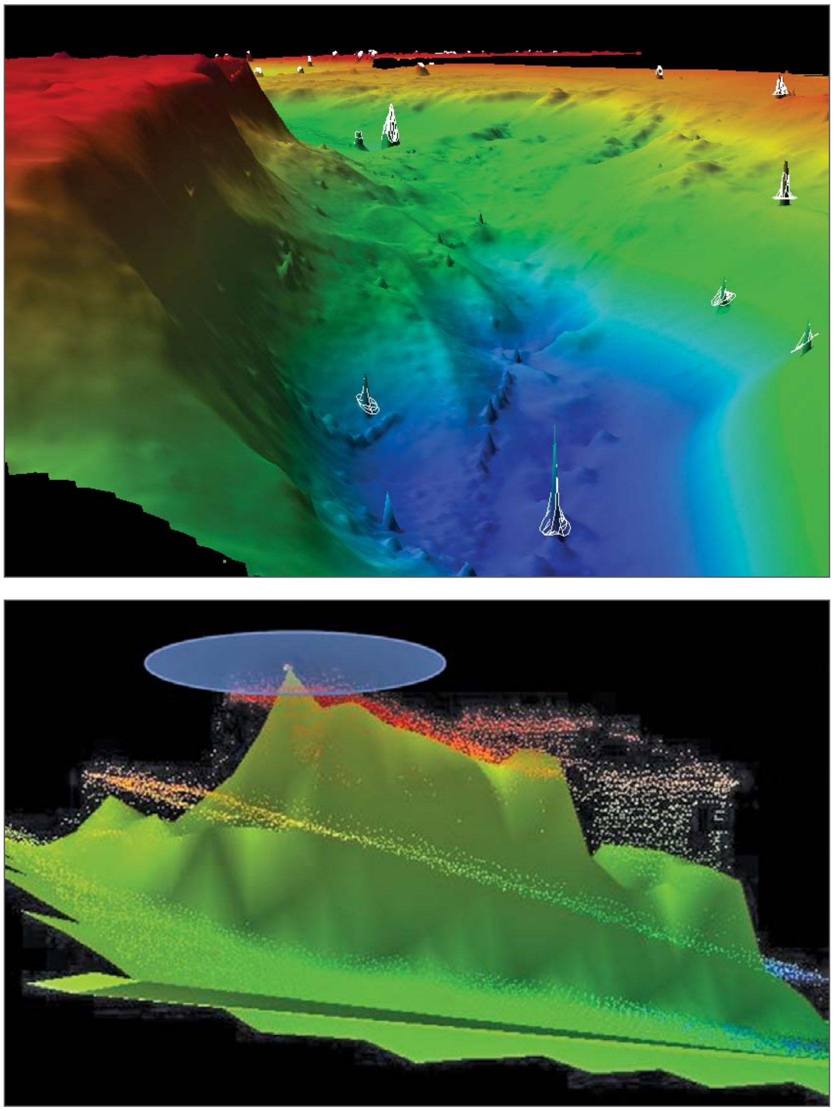


Figure ES-10 (upper). Anomalous grid data (aka fliers) detected by Flier Finder are shown in 3D view. The anomalous spikes are "lassoed" with a position stamp to facilitate prompt detection and removal Figure ES-10b (bottom). A wreck submitted in survey deliverables is represented by 1) a chosen least depth sounding, 2) gridded bathymetry, and 3) an S-57 feature. 1, 2, and 3 must be in agreement for all features submitted to HB. This is often not the case, so the developed algorithms scan these items and flag discrepancies for the hundreds (or sometimes thousands) of features submitted.

image processing, geology, acoustics, etc.) to quickly and collaboratively seek solutions. Tools and protocols developed as part of this effort (e.g., a backscatter "saturation monitor" developed by Glen Rice) and designed to ensure high-quality backscatter data are collected have already been implemented in the NOAA hydrographic fleet.

In late December 2013, we finished an eight-month field campaign that established a "standard backscatter line" conveniently located near the UNH pier in New Castle, NH. This line was chosen in consultation with the officers of the NOAA Ship *Hassler* and will be crossed by the *Hassler* whenever she leaves or returns to her home port. In developing this line, we collected weekly 200 kHz calibrated EK60 data, weekly sediment samples at two locations, and several seasonal sampling trips where more sediment samples and bottom images were collected at a number of locations along the line. The line passes over a variety of seabed types including sand with shell hash, clean sand, sand with sand dollars, gravel, and a complicated region with a bedrock/cobble/gravel/sand mixture (Figure ES-8). The variety of sediment types provides an excellent test-bed for studying high-frequency acoustic backscatter from a range of seafloor conditions. Grain-size analyses suggest that the sediment composition of each of these regions is very stable.

The focus of the NEWBEX project this past year has been the analysis of stereo camera data and sediment samples within the Portsmouth Harbor sandwave field (Figure ES-9) and its comparison to broadband seafloor backscatter data. The main empirical result is Figure ES-8, which shows broadband seafloor backscatter over frequencies ranging from approximately 100-200 kHz. These observations show two distinct trends: a relatively steep rise in backscatter strength with increasing frequency between 100 and 150 kHz, and then a frequency dependence that is nearly absent about ~175 kHz. The challenge now is to identify the mechanisms that control this frequency response and the backscatter levels themselves, so that backscatter mosaics collected with MBES at similar frequencies can be properly interpreted.

Along with our efforts to understand and reduce the uncertainty associated with bathymetric and backscatter measurements, we have also worked collaboratively with NOAA to enhance the overall rate at which data are processed and brought into chart products. To facilitate the development of hydrographic processing software, a new software environment, HydrOffice, has been designed by Giuseppe Masetti and NOAA collaborators. HydrOffice allows new processing algorithms to be quickly developed and tested within the current data processing pipeline and, if they prove effective, quickly go into operation through implementation by industrial partners. The HydrOffice environment currently contains a number of "hydro-packages," including "Flier-finder," designed to automatically identify outliers in gridded products and "Feature scan," which checks the required agreement between gridded bathymetry and submitted feature files (e.g., wrecks) as well as the adherence of those feature files to current specifications (Figure ES-10a and b). Additional tools are available for reducing survey data volumes, managing sound speed profile data, and Bathymetric Attributed Grids (BAGs), the open-source basis for the IHO S-102 gridded bathymetric data exchange standard.

Our processing efforts have extended beyond acoustic systems to also look at the development of better ways to extract information about bathymetry, navigation and shorelines from lidar, photogrammetry or satellite imagery. Over the past year, many of our research efforts in this area have been focused on data in areas impacted by Super Storm Sandy and have been coordinated with the Super Storm Sandy grant team. As part of the Center's effort to support post-hurricane Sandy relief activities, members of the Super Storm Sandy grant team (Price, Nagel, Pe'eri and Madore), under the supervision of Calder, are developing processing approaches for establishing pre- and post-storm shoreline and erosion maps along the New Jersey coast using EAARL-B topo-bathy lidar collected by the U.S. Geological Survey (USGS). The processing work flow uses open source software to merge and grid the data, and ArcGIS to extract the shoreline and create maps of erosion, shoaling, and debris deposits that may pose navigational hazards (Figure ES-11).

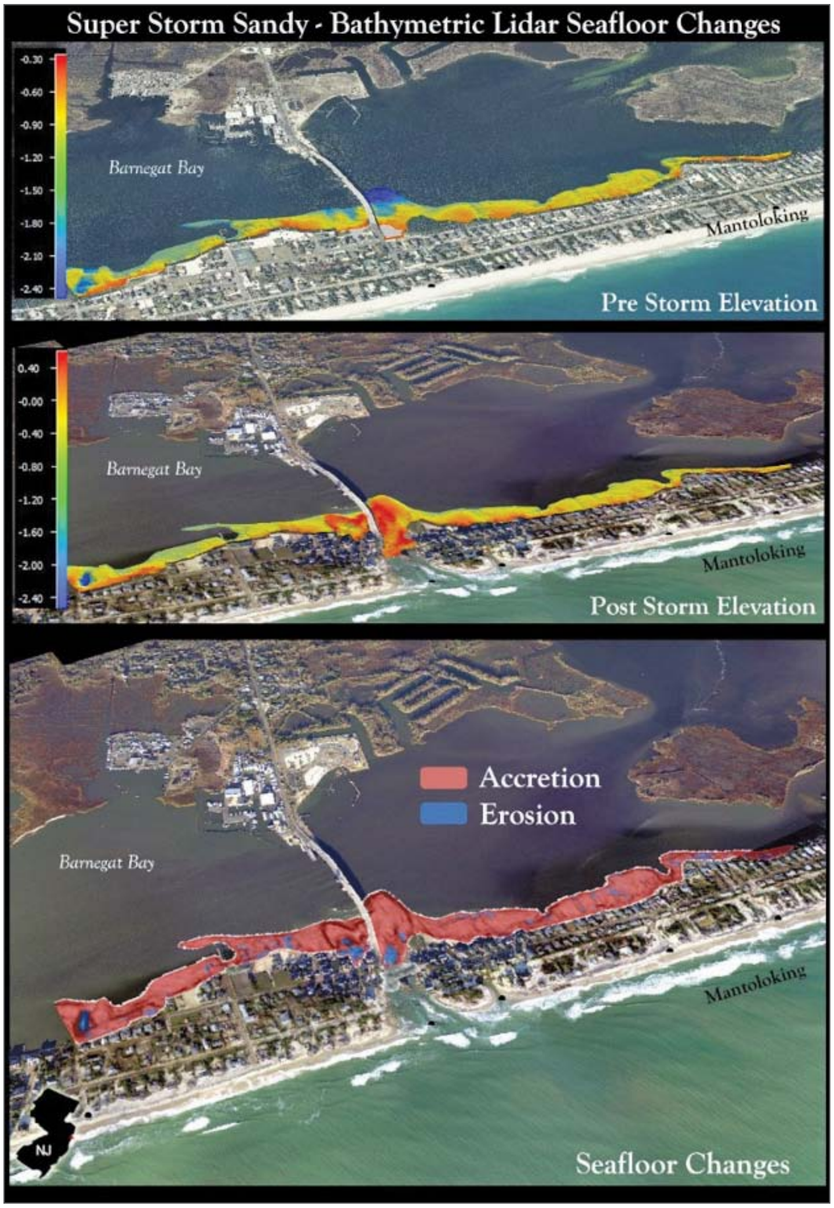


Figure ES-11. Super Storm Sandy seafloor changes from breaches and overwash in Mantoloking, New Jersey derived from pre- and post-bathymetric lidar. The storm deposited 33321.05 cubic meters in the area highlighted.

Also associated with the Super Storm Sandy effort is a project aimed at the automatic identification of marine debris. Typically, submerged marine debris is identified by a human operator through the subjective evaluation of sidescan-
sonar records. Our project explores the use of automated approaches to the identification and classification of submerged marine debris using the techniques developed for the detection of mines, unexploded ordinance and pipelines with the significant difference of a much wider, and significantly more diverse range of potential marine debris targets. An adaptive algorithm has been developed to appropriately respond to changes in the environment, context, and human skills that includes the creation of a predictive model, the development of a detection model, and the development of a reliable data exchange mechanism (Figure ES-12).

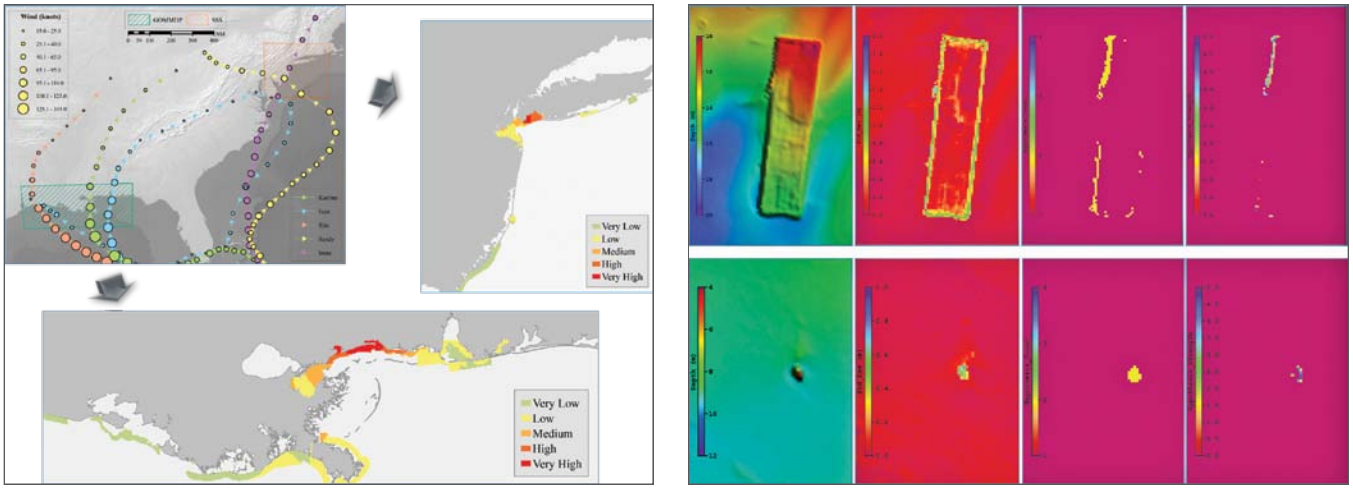


Figure ES-12. (Left) Prediction of marine debris top-left pane: study areas, and the best tracks (associated with peak winds) of the five hurricanes of interest. Predicted distribution density of marine debris in the Super Storm Sandy (top-right pane) and in the Gulf of Mexico (bottom pane) study areas. (Right) Example of DTM-based automatic detection algorithm for marine debris. The original inputs (showed on the first pane of the left) are analyzed using the CUBE standard deviation, the hypothesis count, and the hypothesis strength to recover information on the original soundings set (usually lost in pure XYZ surfaces)

We have enhanced our efforts to develop approaches for deriving bathymetry from satellite imagery and for assessing the value of these data for change analysis, habitat mapping, hydrographic survey planning, and for examining the adequacy of existing charts.

Working in collaboration with NOAA/NOS/OCS/MCD, we have evaluated the potential use of automatic-identification system (AIS) data, satellite-derived bathymetry (SDB), and airborne-lidar bathymetry (ALB) for evaluating the adequacy and completeness of information on NOAA charts. A new chart adequacy approach was developed using publically-available information in a commercial-off-the-shelf (COTS) Geographic Information System (GIS) environment. Carrying this work several steps further, Calder has outlined an approach for an objective assessment of the risk involved in taking a ship through a given area, which takes into account environmental effects, the nature of the seafloor, and potentially, the age of the prior survey and its technology. Combined with information on shipping traffic in the area, for example from AIS messages, an assessment of risk can be used to assess the knowledge contributed by a modern survey and therefore the relative return on investment of a survey being conducted. In principle, the area with the highest return should be the highest on the resurvey priority list. Once calibrated, the model can predict risk associated with transits within any cell of the analysis area, with or without the effects of unknowns—such as the potential for unobserved rocks or other obstructions in the water, or uncertainties in the estimated bathymetry of the area (Figure ES-13).

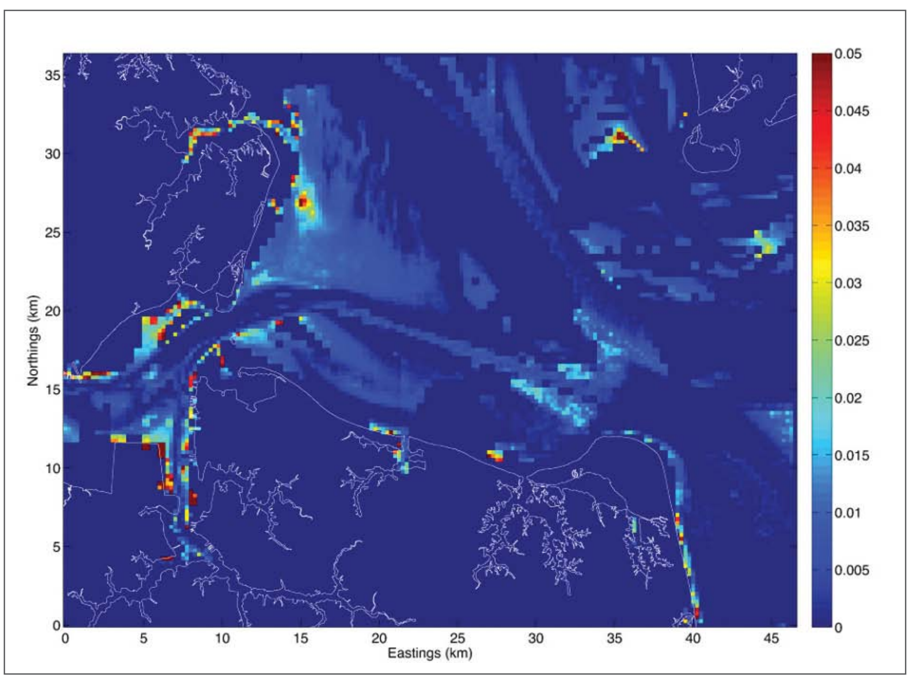


Figure ES-13. Simple difference between estimated risk without and with predicted unobserved objects and other uncertainties. Higher values indicate larger potential for reducing the estimated risk, and therefore are more persuasive targets for investment of survey resources.

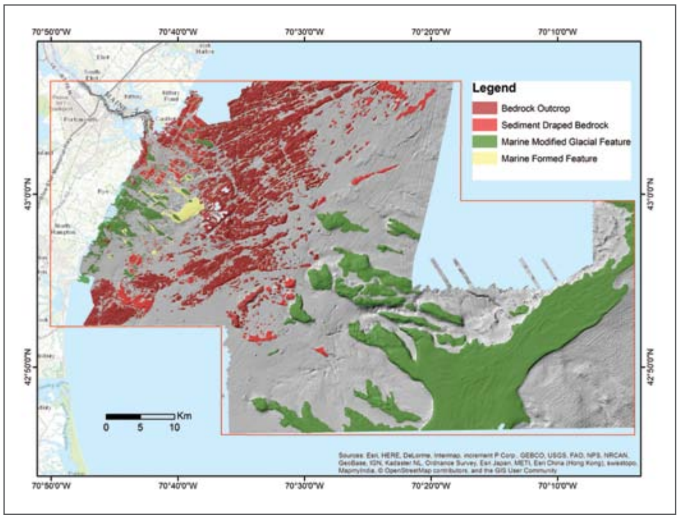


Figure ES-14. Major morphologic features (geoforms) on the New Hampshire and vicinity continental shelf draped over a shaded-relief raster surface of the bathymetry (10x vertical exaggeration). Analysis based on interpretation of bathymetry, backscatter and subbottom profiles.

Habitat and Water-Column Mapping

Our efforts to understand and calibrate the acoustic and optical sensors we use (SENSORS theme) and to develop software to process the data they produce in an efficient manner while minimizing and quantifying the uncertainty associated with the measurements (PROCESSING theme), are directed to the development of products that not only support safe navigation but that can also provide information critical to fisheries management and other environmental and engineering problems. These efforts focus on understanding and interpreting the backscatter (both from the seafloor and, with the recent advent of a new generation of multibeam sonars, in the water column) and generating tools to use this information to provide key information useful to marine managers. Our initial efforts in acoustic seafloor characterization focused around the development of GeoCoder, a software package designed to produce fully-corrected backscatter mosaics, calculate a number of backscatter statistics, and perform a constrained ARA (Angular Response Analysis) inversion that is designed to analyze the angular response of the backscatter as an approach to remote seafloor characterization. Although GeoCoder has been implemented by a number of our industrial partners, many questions remain about the calibration of the sonars (e.g., work described in the SENSORS and PROCESSING sections) and the inherent nature of the approaches used to segment and characterize seafloor properties.

This year's efforts focused on understanding the processes responsible for high-frequency acoustic backscatter (from both the seafloor and targets in the water column) and the accelerated development of tools and approaches to help understand the impact of Super Storm Sandy and map potential sand and gravel resources in the waters off New Hampshire.

Taking advantage of many years of high-quality multibeam sonar bathymetry and backscatter data collected by NOAA and Center researchers on the New Hampshire shelf (as well as some high-resolution subbottom profiler data), Larry Ward is leading an effort, partially funded by the Bureau of Ocean Energy Management (BOEM), to compile and interpret high-resolution multi-beam bathymetry and backscatter data for the evaluation of local marine sand and gravel resources (Figure ES-14). In addition to the identification of resources, another primary goal of the project is to explore best practices and workflows to take advantage of data collected for other purposes in support of seafloor characterization.

Another successful application of our seafloor characterization research has been our work with NOAA's Alaska Fisheries Science Center to explore new ways to assess rockfish in untrawlable habitats in the Gulf of Alaska. During an acoustic/trawl survey for walleye pollock in the Gulf of Alaska in the summer of 2015, Center personnel aided in the analysis of ME70 data using algorithms previously written for generating bathymetry and seafloor backscatter, and two new metrics developed at the Center to classify the seabed as trawlable or untrawlable based on ME70 data alone—a prime example of Research to Operations (R2O) (Figure ES-15).

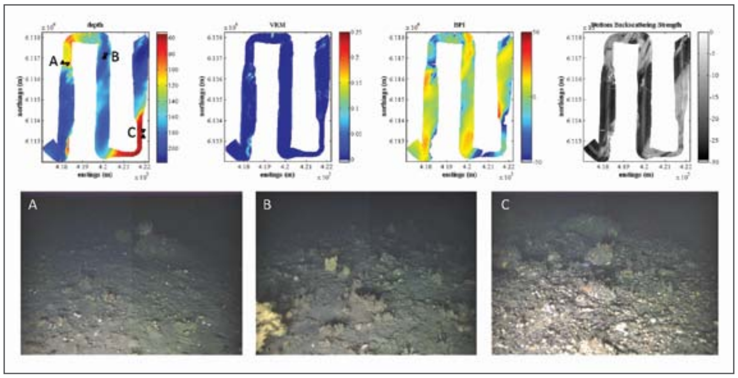


Figure ES-15. Seafloor backscattering metrics extracted from a survey grid during cruise DY1506 on the *Oscar Dyson* in June 2015. The metrics are derived from Simrad ME70 data and include bathymetry, a vector ruggedness measurement (VRM), bathymetric position index (BPI), and bottom backscattering strength. Camera drops (bottom) are conducted in two to three locations in each grid.

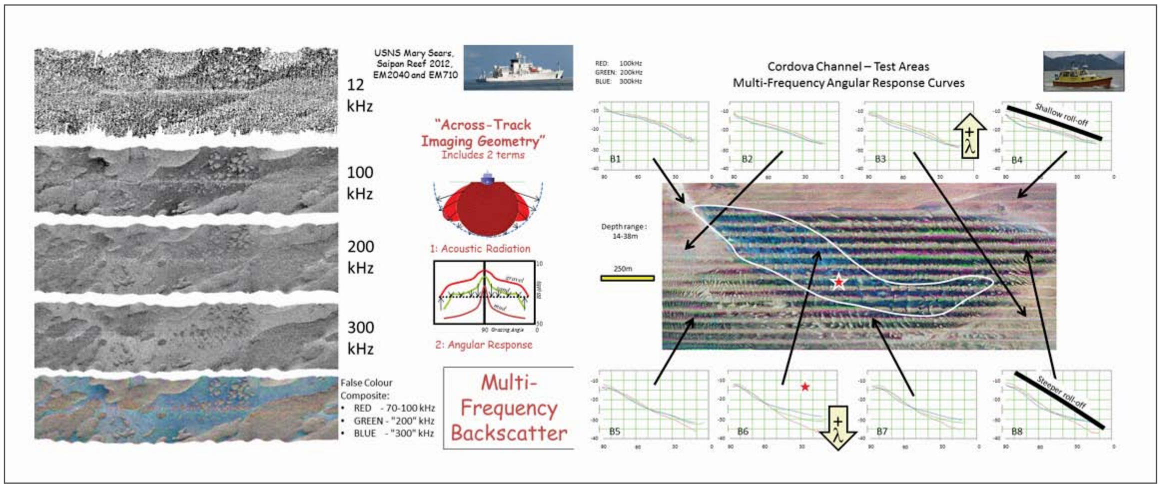


Figure ES-16. Example of changing relative backscatter contrast with sediment type and frequency (left); examples of changing shape of angular response curves with sediment type and frequency (right).

Along with the more traditional approaches to seafloor characterization described above, we continue to seek new and innovative approaches to use acoustic data to provide quantitative information on the nature of the seabed. One of the frustrations with traditional seafloor characterization approaches has been that ambiguities can remain where quite different seafloors can produce similar scattering characteristics. This is in part because we are only examining scattering using a single center frequency, analogous to looking at the seabed in a single color rather than a full color range. John Hughes Clarke has been exploring approaches to collecting multispectral backscatter data with multibeam sonars. One approach is to simultaneously operate multiple multibeam systems. This has now been implemented using co-located 70-100 kHz and 200-400 kHz multibeams (Figure ES-16).

Beyond the identification of seafloor sediment type, we are looking at means to quantify the acoustic response of eelgrass, a remarkably diverse and productive ecosystem that creates important habitats for a wide range of species. In July 2015, Teledyne Odom MB1 multibeam sonar data was collected from sites in the Great Bay estuary in New Hampshire, including sites that contained a mixture of nuisance macroalgae as well as eelgrass. Drop camera data were also obtained at these sites, in some cases on the same day. Significant differences were seen in the acoustic signatures of areas dominated by nuisance macroalgae (primarily *Gracilaria* and *Ulva* sp.) and areas dominated by eelgrass (Figure ES-17).

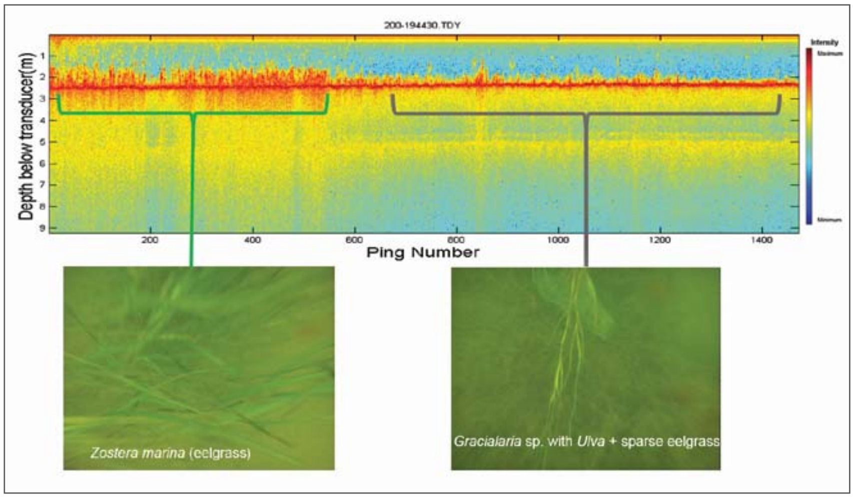


Figure ES-17. Along-track plot of water column backscatter amplitude at nadir from a survey line over a boundary between an eelgrass-dominated area and a nuisance macroalgae dominated area.

Along with our work that uses acoustic data to attempt to extract critical habitat data, we are working on techniques to quantitatively analyze lidar, hyperspectral and optical imagery. This past year, our efforts were closely linked to the Super Storm Sandy work where Center researchers have developed several approaches for the analysis of topo-bathy lidar data to directly map benthic habitats and to document changes in submerged aquatic vegetation habitat that resulted from the hurricane. One approach to this (linked to our lidar simulator work) is to better understand the impact of various substrate types on the returned lidar waveform. The hypothesis is that different bottom types manifest themselves as different signatures in the ALB bottom return waveforms.

We are investigating several other approaches to interpreting imagery and lidar data for habitat characterization—in particular, the distribution of Submersed Aquatic Vegetation (SAV). Multispectral imagery has been analyzed on a pixel-basis for spectral information to derive the density of SAV. Because of the frequency of satellite-derived multispectral imagery, time series can easily be generated and the impact of an event like Super Storm Sandy clearly discerned (Figure ES-18).

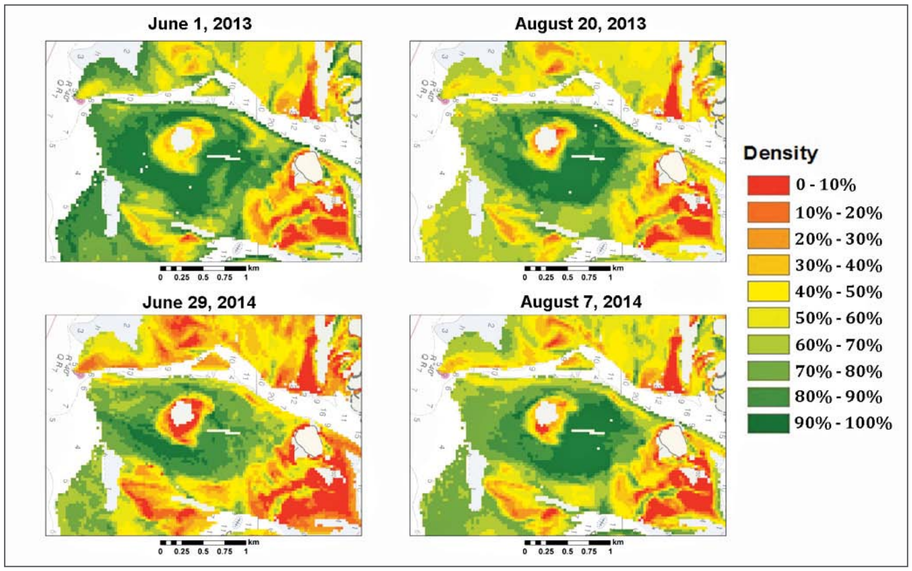


Figure ES-18. The SAV density using Landsat 8 imagery from four different time periods in Barnegat Bay Inlet, NJ.

We are also taking an "object-based" approach to identifying SAV. Seagrass beds were mapped using aerial imagery, lidar bathymetry, and lidar waveform features (specifically from the NOAA Riegl VQ-820-G system and the AHAB Chiroptera system) using the eCognition software package, which segments data layers at an object level rather than a pixel level, and can include holistic *a priori* structuring information from the analyst. Habitat maps generated using lidar and eCognition were compared to those created using traditional manual classification methods with no statistically significant differences being found between the methods (Figure ES-19).

We are developing tools and approaches specifically designed to help ground-truth our habitat and hydro-

Figure ES-19. Habitat map from Barnegat Inlet generated using manual classification using imagery alone (left) and eCognition classification using lidar and imagery (right).

graphic studies. During conventional hydrographic operations, survey units are required to take sediment samples in order to determine, among other things, the suitability of an area for anchoring. Working with input from the NOAA Ship *Hassler*, Center researchers developed a reliable and robust camera system that can be deployed readily by field personnel, and which matches the operational tempo of NOAA field units (Figure ES-20).

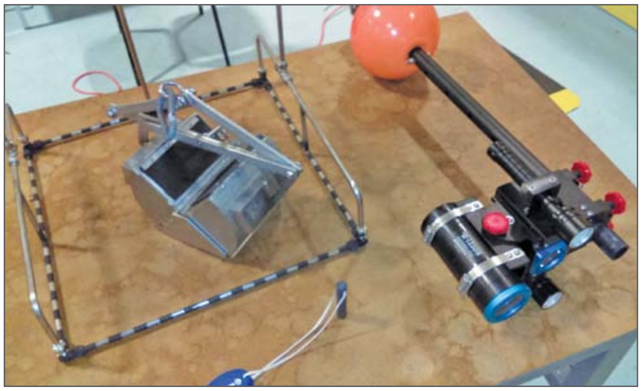


Figure ES-20. Complete Grab Camera system with lightweight imaging frame

We have also developed a suite of automated video mosaicking algorithms and software to generate mosaics of benthic communities dominated by different algal species. These mosaics have been used as ground-truth for acoustic data and to spatially characterize benthic habitats at an unprecedented scale (Figure ES-21). In addition to seafloor video and acoustic data, fish behavior video has been collected with the goal of connecting fish abundance and behavior patterns with native and non-native algal assemblages (Figure ES-22). The fish videos, in combination with our other data (e.g., video mosaics) will provide the opportunity to determine how non-native species affect ecosystem processes.

The efforts described above have focused on the seafloor. A new generation of multibeam sonars now has the ability to simultaneously map both the seafloor and the water column. The ability to image the water column and the seafloor over wide swaths with high-resolution offers great opportunities for new applications and increased survey efficiencies. The Center has been very active in the development of new tools to capture, analyze and visualize water-column data and these tools proved extremely valuable in our efforts to map the deep oil plume and monitor the integrity of the Macondo wellhead during the Deepwater Horizon crisis (see the 2010 Annual Progress Report for a full description of our activities related to Deepwater Horizon). Immediately following the Deepwater Horizon explosion and leak of the Macondo wellhead, we proposed using a 30 kHz multibeam sonar with water-column capability— a Kongsberg Maritime EM302—as a potential tool for mapping deep oil and gas spills and monitoring the well head for leaks. At the time of the spill, such a system was not available so we used fisheries sonars instead. In August and September of 2011, we finally had the opportunity to take the EM302 multibeam echo sounder on board the NOAA Ship *Okeanos Explorer* to the Gulf of Mexico and demonstrate the use of water-column data for the detection and characterization of methane gas seeps over large areas. During this relatively short cruise with less than two weeks of active mapping, we mapped 17,477 km^2 of the northern Gulf of Mexico making 573 seep observations. The results from this cruise suggested that wide-scale mapping of seeps in the deep Gulf of Mexico is viable—an objective that is important for both scientific and industry management perspectives.

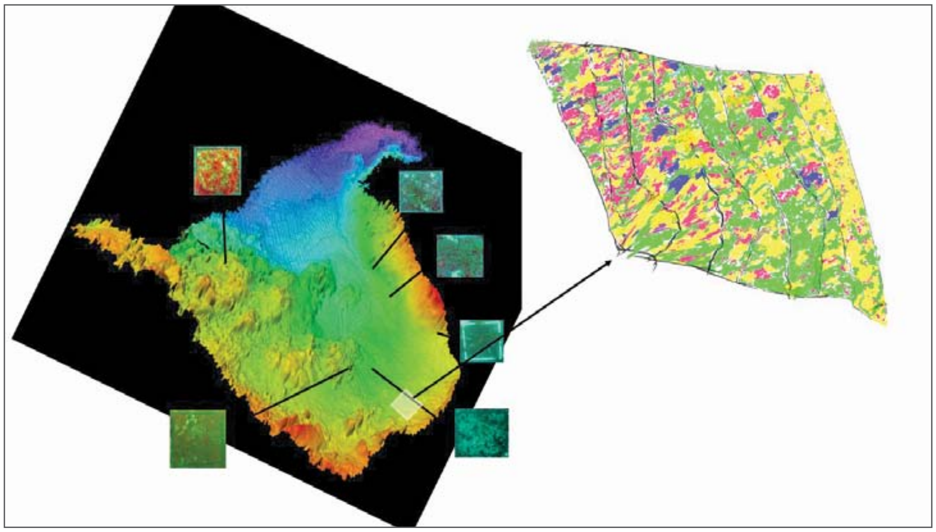


Figure ES-21. Mosaic of a mixed seaweed assemblage at Nubble Light House in York, ME. Each color denotes a different seaweed species or free space.

The tools developed for mapping oil and gas, originally in response to the Deepwater Horizon spill, have attracted a great deal of interest in the community and have fostered a number of follow-on studies, including the remarkable find-

Figure ES-22. Two fish, juvenile Pollock (lower fish) and Cunner, that utilize seaweed habitats as refuge from predators and to forage for food.

ing of previously unknown seep activity on the Atlantic Margin in 2013 and 2014. Epitomizing the role of the Ocean Exploration Program, this initial work in seep mapping and analysis has led to follow-up funding from several other agencies, including NSF, DOE, and the Sloan Foundation. These follow-up projects each seek to look deeper into our ability to be quantitative about the flux and fate of the oil and gas that have been the target of our seep mapping.

The seeps we map might consist of oil droplets, gas bubbles or both. In order to discriminate between oil and gas and to better understand how we can use acoustics to map and monitor subsurface dispersed oil droplets, a better understanding is required of the acoustic response of oil droplets. Graduate student Scott Loranger has built an apparatus to create oil droplets of varying size and density and measure the acoustic response of these droplets (Figure ES-23). One of the main goals of this project is to be able to provide better quantitative response tools for monitoring the dispersion of subsea releases of oil, whether the dispersant be anthropogenic or natural.

One of our objectives has been to refine the use of acoustic echosounder measurements of methane gas seeps in order to more accurately assess the flux of methane gas exiting the seabed and rising through the water column. This has been the subject of several recent externally-funded proposals, not least of which is a DOE-funded project aimed at more accurately estimating target strength (TS) profiles of gas bubbles as they rise through the water column.

IOCM—Integrated Ocean and Coastal Mapping

A critical component of the Center's 2010–2015 proposal was to establish an Integrated Ocean and Coastal Mapping Processing Center that would support NOAA's new focused efforts on Integrated Coastal and Ocean Mapping. This new Center brings to fruition years of effort to demonstrate to the hydrographic community that the data collected in support of safe navigation may have tremendous value for other purposes. It is the tangible expression of a mantra we have long-espoused, "map once—use many times." The fundamental purpose of the new Center is to develop protocols for turning data collected for safety of navigation into products useful for fisheries habitat, environmental studies, archeological investigations and many other purposes, and conversely, to establish ways to ensure that data collected for non-hydrographic purposes (e.g., fisheries, ocean exploration, etc.) will be useful for charting.

Our efforts on the NOAA fisheries vessel *Oscar Dyson* were the epitomy the IOCM concept. In 2011 and 2012, while the *Dyson* was conducting routine acoustic trawl surveys, we were able to simultaneously extract bathymetry data. To date, more than 452 square nautical miles of bathymetric data have been submitted for charting from the ME70—a fisheries sonar not purchased for seafloor mapping. One of the most exciting aspects of this effort was the discovery, in the 2011 ME70 data, of a previously uncharted shoal that led to a chart update and a Danger to Navigation (DTON)

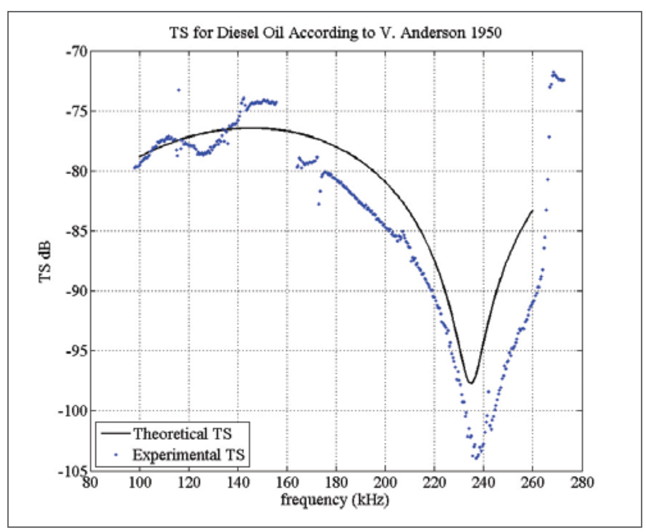


Figure ES-23. An example of broadband acoustic backscatter from an oil droplet (blue dots) compared to a theoretical model by Anderson [1950] (black line).

warning. This past year (see HABITAT Theme above), we used the ME70 to discriminate between trawlable and untrawlable habitats. Thus, from a single fisheries sonar (ME70) and a fisheries cruise dedicated to acoustic-trawl surveys, seafloor habitat data, bathymetric data for charting and a specific Danger to Navigation were derived—all from a sonar that was not purchased to map the seafloor.

In 2015, our IOCM efforts focused on collaborations with the Office of Coast Survey, Office of Ocean Exploration and Research, National Marine Fisheries Service and with NOS's Marine Modeling and Development Office. Many of the efforts previously described (particularly those described under HABITAT, MIDWATER MAPPING, LIDAR AND DATA PROCESSING themes) can just as easily be listed under the IOCM theme. Our report highlights those projects that, for the most part, have been specifically incorporated into NOAA's IOCM projects and, in particular, outline some of the IOCM-relevant results of the Super Storm Sandy Contract team.

NOAA continues to require seafloor acoustic backscatter as a deliverable for all hydrographic surveys, yet there are still questions about the current approach to collecting and processing backscatter. Under the leadership of Glen Rice and with input from many members of the Center, information is being gathered and synthesized to develop a "business case" for how Office of Coast Survey deals with backscatter, while Center personnel continue to work closely with the commercial sector to advance backscatter processing approaches.

The collection of multipurpose data from NOAA hydrographic vessels (e.g., backscatter data that can be useful for habitat mapping) is only one aspect of the IOCM effort. Just as important is the design of protocols to ensure that as the fisheries vessels use their multibeam sonars they produce bathymetry and other outputs that can serve hydrographic and other purposes (exemplified in our work with the NOAA ME70 fisheries sonar on the NOAA Ship *Oscar Dyson*). The approaches developed at the Center are now being put into practice. Simrad ME70 fisheries multibeam echosounders (MBES) are now installed on each of five NOAA Fisheries Survey Vessels (FSVs). Weber's ME70 software for producing bathymetry and seafloor backscatter is being integrated with the Hypack acquisition software that is standardly used on these vessels (Figure ES-24). This integration enables the ME70 sonar to simultaneously collect water-column and bathymetric data, improving survey operations aboard the FSVs by increasing data collection, enabling visualization of ME70 bathymetry in real-time, and providing mapping and data processing tools.

Super Storm Sandy supplemental funding provided an accelerated opportunity to turn many of the on-going research projects in the lab into products needed to help understand and mitigate the impact of one of the worst storms recorded in U.S. history. This was achieved through funding of a research team (the Sandy Grant team under the supervision of Brian Calder) who developed a number of algorithms and processes specific to the Sandy need based on on-going research in the lab, and a production team (the Sandy Contract team under the leadership of Juliet Kinney and supervision of Andy Armstrong) that applied these algorithms to generate products that were designed to help NOAA and others measure the impact of the storm and design mitigation processes. Common to many of these procedures was the concept of using the data sets available for as many applications as possible—the very essence of IOCM. Our progress report summarizes some of the

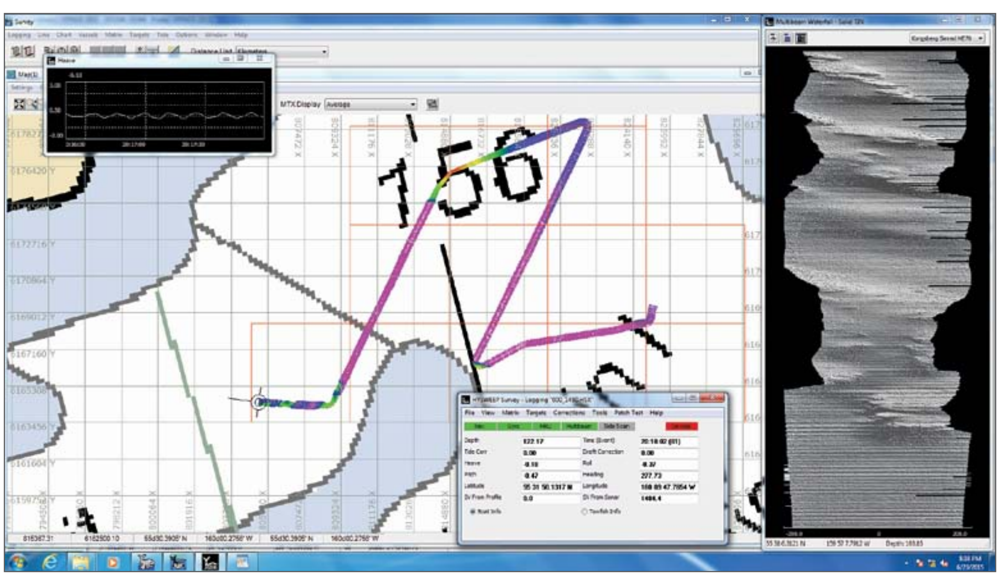


Figure ES-24. Hypack screen capture during acquisition of ME70 data on the *Oscar Dyson* in June 2015.

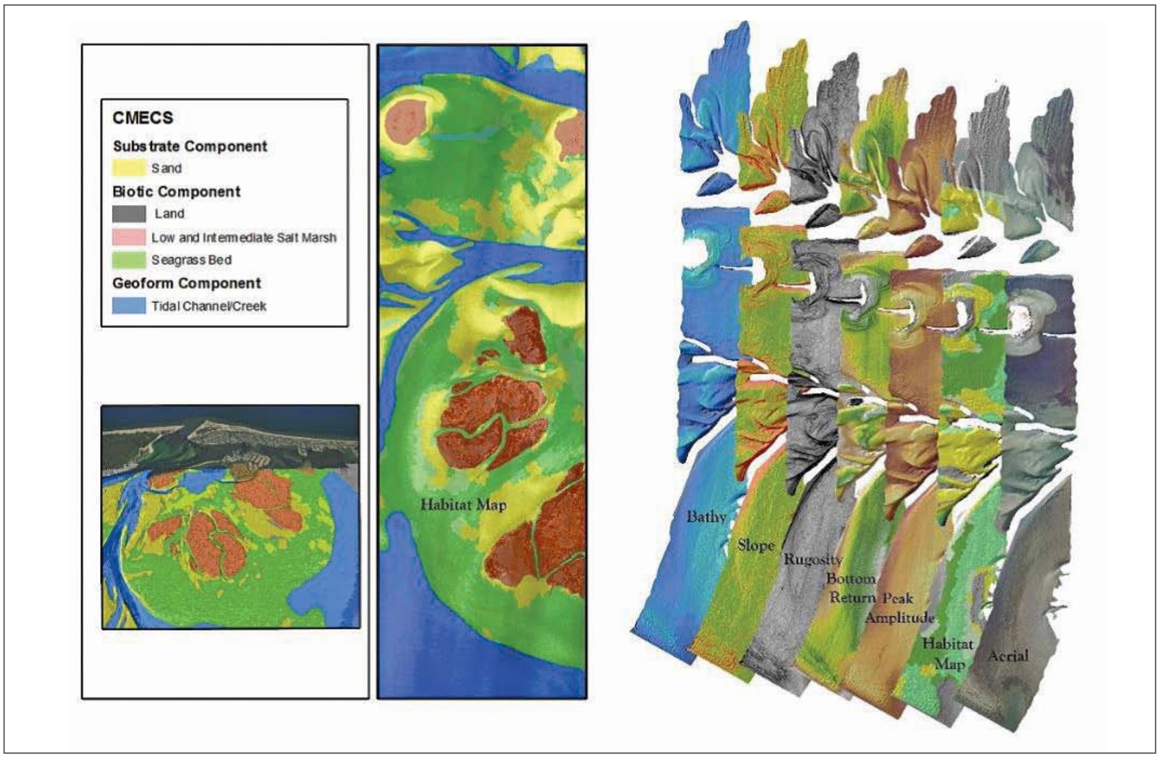


Figure ES-25. Example of characterization of habitat and input/associated input layers for the general approach developed by Center researchers for application to Super Storm Sandy (and other) regions.

most relevant IOCM products that came out of this effort, including creating protocols for:

1. Bringing USGS Phase Measuring Bathymetric Sonar (PMBS) data into chart products;
2. Bringing third party (USGS and ACOE) multibeam sonar data into NOAA charts ;
3. Integrating FEMA and state and local government collected single beam sonar products into NOAA charts;
4. Improving chart adequacy using merged source (multiple lidar, imagery, and sonar sources) data (Figure ES-24);
5. Use of USGS EAARL-B DEMS, Remote Sensing Division Lidar and USACE CZMIL data for charting;
6. Use of Remote Sensing Division Lidar for charting;
7. Producing habitat maps from EAARL-B reflectivity;
8. Producing object-based habitat maps in standard (CMECS) format from acoustic and other data sources (Figure ES-25).

Visualization

We continue to focus on the developing innovative approaches to data visualization and fusion, and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team, under the supervision of Lab Director Colin Ware, has produced a number of novel and innovative 3D and 4D visualization tools that were designed to address a range of ocean-mapping applications. Ware and Thomas Butkiewicz continue to refine their advanced flow visualization techniques that are critical for successful communication of the complex output of today's increasingly high-resolution oceanic and atmospheric forecast simulations. By applying well-founded perceptual theory to the design of visual representations, the contents of these models can be effectively illustrated without overwhelming the viewer. The integration of non-traditional interfaces, such as multi-touch displays and motion-capture, supports more efficient and flexible interactions that can overcome the challenges often encountered when attempting to navigate and manipulate in 3D environments.

Efforts this year focused on the research designed to enhance the display and understanding of bathymetric, and environmental (currents, waves, etc.) data, including uncertainty; innovative approaches for interacting with complex ocean mapping data sets; tools to help oceanographers, hydrographers, ocean engineers, biologists and others interpret complex data from a variety of sensors, models and data sets; and several tools created specifically to support our Super Storm Sandy efforts, including those designed to help identify marine debris, and several outreach tools.

Included in these efforts are human factor studies to determine the optimal mode of display to help viewers correctly perceive the shape of 3D terrain/bathymetry models. Earlier research concluded that contours are extremely effective, even in a 3D environment. Based on this, Tom Butkiewicz is experimenting with a novel dynamic contour line algorithm which intelligently subdivides contour lines to add more detail where needed, raising the question of whether it is possible to mix countable, fixed-interval contour lines with dynamically spaced contour lines in the same presentation. This work is being further extended to determine the optimal methods to illustrate dynamically changing bathymetry surfaces within 4D visualizations.

The Center continues to work on the portrayal of meteorological and environmental data for the navigator, including currents from operational flow models, sea state from the Wavewatch III model, and weather from NOAA Mesoscale operational forecast models. This work has been bolstered by a substantial grant from ONR to make these sorts of data available in compact form to the submarine community. Again, human perception research is being combined with appropriate navigational constraints to generate displays that transmit the most appropriate information in easily comprehensible forms (Figure ES-26).

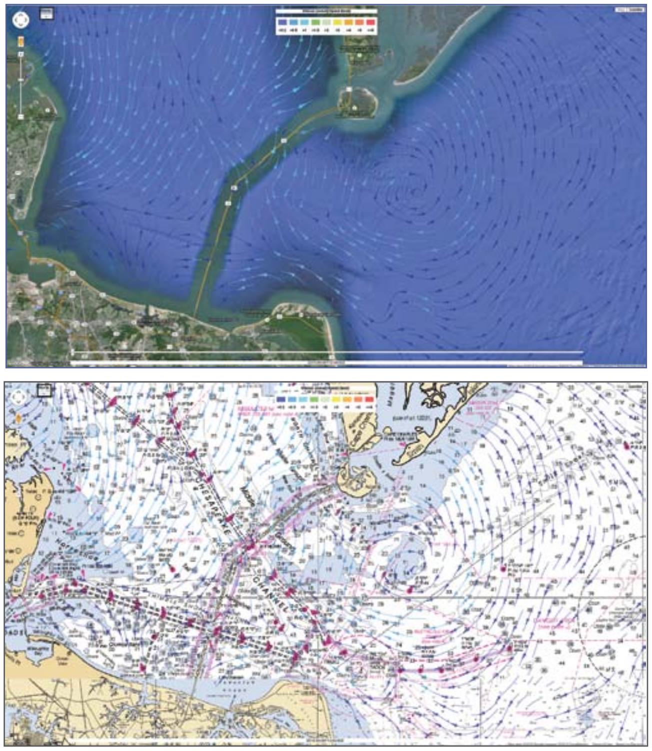


Figure ES-26. (Top) Currents from the CBOFS forecast model displayed as streamlines over Google Maps. (Bottom) Currents from the CBOFS forecast model displayed as streamlines over a WMS layer of nautical charts from OCS's ENC Direct service.

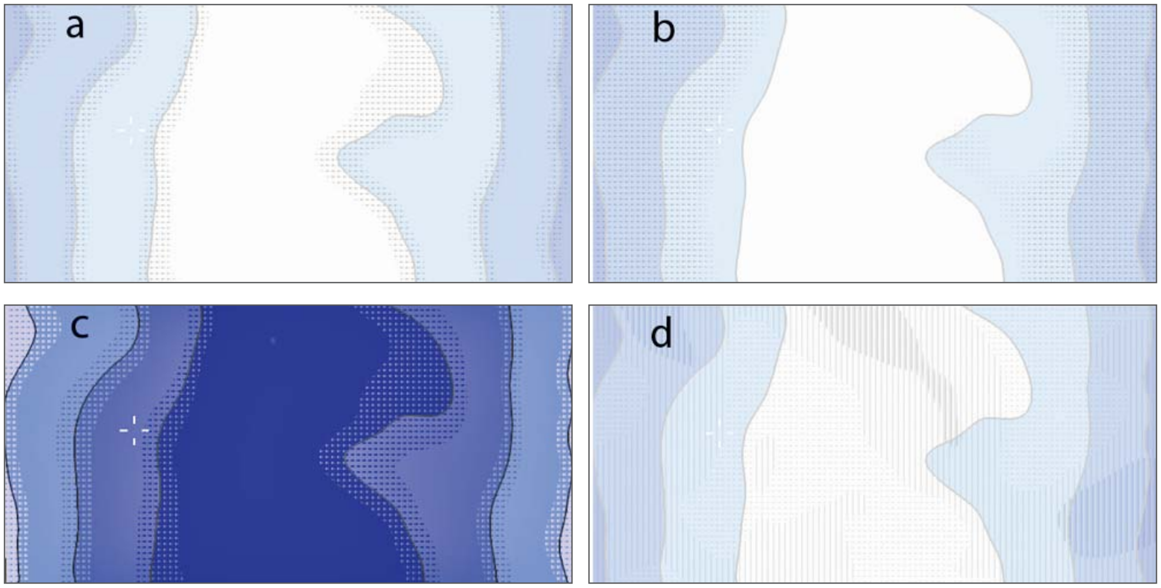


Figure ES-27. Four methods for representing bathymetric uncertainty. (a and c) Texture shows uncetainty ranges around contours. (b) Texture is used to designate no-go areas. (d) A sequence of textures is used to represent the degree of depth uncertainty over the entire chart.

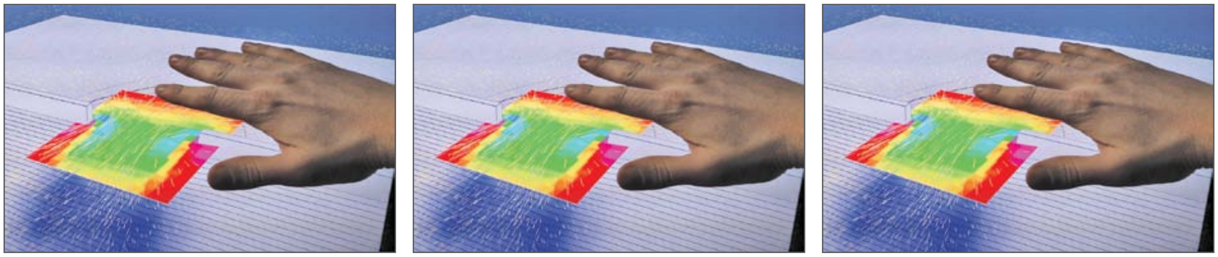


Figure ES-28. Hand-based positioning and orientation of a cutting plane within a 4D flow model, with colors indicating flow velocity.

Colin Ware and Brian Calder have begun a collaboration to investigate methods for portraying bathymetric uncertainty or risk. Ideally, mariners should be able to view both best estimates of bathymetry and any uncertainties and risks associated with it. However, portrayals of uncertainty should not overly interfere with the representation of other chart information. For this reason, we are exploring the use of transparent textures to convey uncertainty and are conducting a study of optimal methods to use transparent textures to display uncertainty (Figure ES-27).

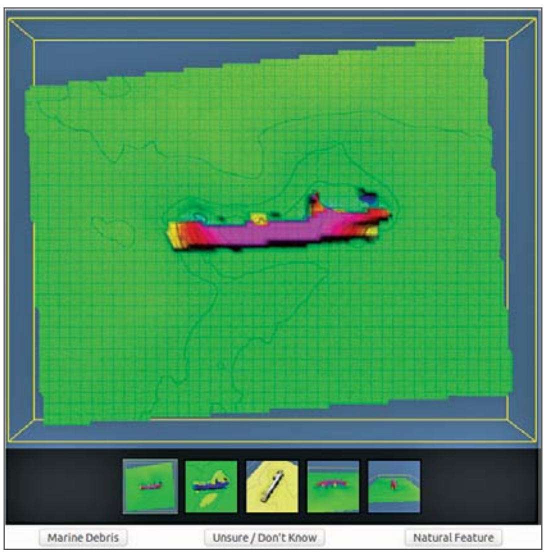


Figure ES-29. A screenshot of the web-based crowd-sourcing interface. Users see a single zoomed-in image, and can scroll through or click on the thumbnail images at the bottom to view each of them as many times as needed.

We continue to experiment with new human interface technologies for hydrographic visualization, integrating the Leap Motion device into our research visualization environment. This interface allows intuitive hand motions for interacting with complex data sets—for example, using one's hand as an interactive cutting plane through volumetric 4D datasets (Figure ES-28).

Our visualization team has actively supported the work of the Super Storm Sandy Grant team, developing tools to aid both researchers and the public in the location and identification of marine debris and to help visualize the impact of Super Storm Sandy. The Marine Debris Rapid Decision Tool automatically presents multiple optimized views of potential debris objects to help the viewer quickly decide if the object is debris. If these views are not sufficient, each can be manipulated as necessary, as they are fully-interactive instances of our Virtual Test Tank 4D software. A web-based version of this tool allows the "crowd" to aid in the search and identification of marine debris. Our studies have demonstrated an accuracy rate of between 80% and 84% for the crowd, when compared to expert observers (Figure ES-29).

In further in support of our Super Storm Sandy efforts, Butkiewicz developed an HTML5/WebGL-based version of the visualization technique known as the "Magic Lens" (trademarked by Xerox). This tool takes multiple overlapping images and presents them to the user with an interactive "lens" tools that allow them to peer between layers simultaneously (Figure ES-30).

Figure ES-30. The WebLens tool on the Center's Super Storm Sandy website, showing pre- and post-storm data from Great Kills Harbor, NY.

Chart of the Future

Inherent in the Center's data-processing philosophy is our long-held belief that the "products" of hydrographic data processing can also serve a variety of applications and constituencies well beyond hydrography. Another long-held tenet of the Center is that the standard navigation charts produced by the world's hydrographic authorities do not do justice to the information content of high-resolution multibeam and sidescan-sonar data. We also believe that the mode of delivery of these products will inevitably be electronic—and thus the initiation of the Chart of the Future project. This effort draws upon our visualization team, our signal and image processors, our hydrographers, and our mariners. In doing so, it epitomizes the strength of our Center—the ability to bring together talented people with a range of skills to focus on problems that are important to NOAA and the nation. The effort has had two paths—an "evolutionary" path that tries to work within existing electronic charting standards (which are very restrictive), and a "revolutionary" path that lifts the constraint of current standards and explores new approaches the may lead to the establishment of new standards.

Within the evolutionary track, we have worked with electronic chart manufacturers on approaches for including high-density hydrographic survey data and in particular, the concept of a tide-aware ENC that can vary the display with the state of the tide.

The evolutionary track also includes our work to take advantage of the Automatic Identification System (AIS) carried by many vessels to transmit and receive data from the vessels. Our AIS efforts have led to the visualization of the behavior of the *Cosco Busan* after the San Francisco Bay spill incident, evidence for a fishing trawler violating Canadian fishing regulations and damaging Canada's Ocean Observatory (Neptune) equipment, and the creation of the vessel traffic layer in ERMA, the response application used by Unified Command during the Deepwater Horizon Spill. This application was a finalist for the Homeland Security Medal. A very successful application of our AIS work has been its use in monitoring right whales in an LNG shipping route approaching Boston Harbor. This application (WhaleALERT) can be run on iPads, iPhones, and other hand-held devices. There is a web-based version of the application with the ability to generate KML files so that WhaleAlert data can be viewed dynamically in GoogleEarth. The system became fully operational in 2014 and has been operating autonomously without intervention.

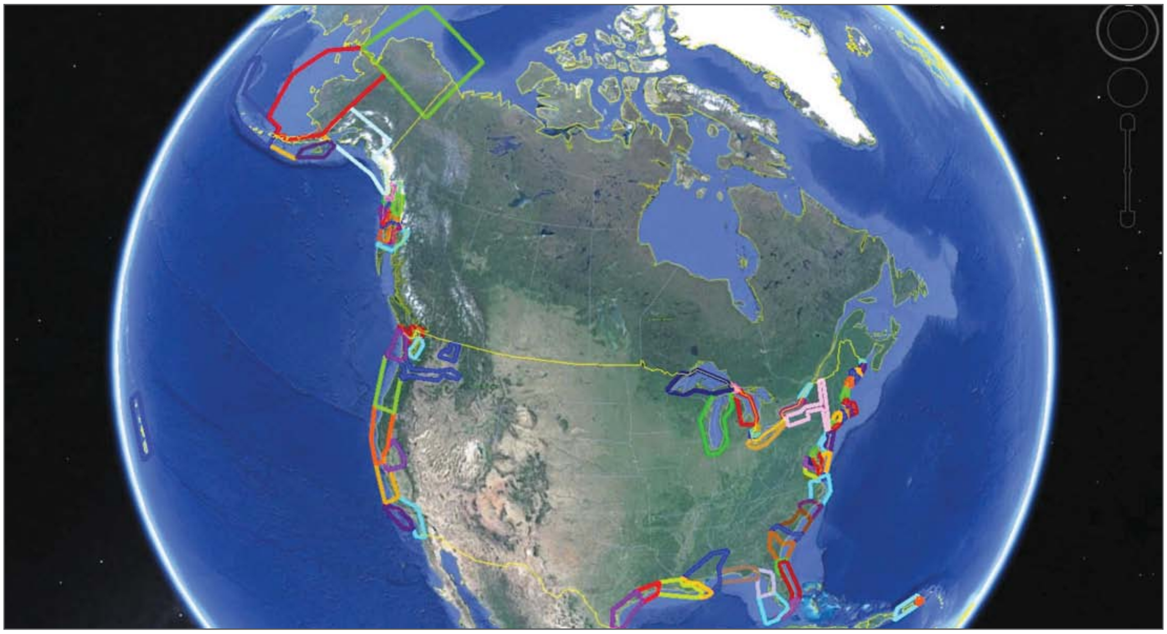


Figure ES-31. Coast Pilot® chapter boundaries added by the Center to the Coast Pilot database.

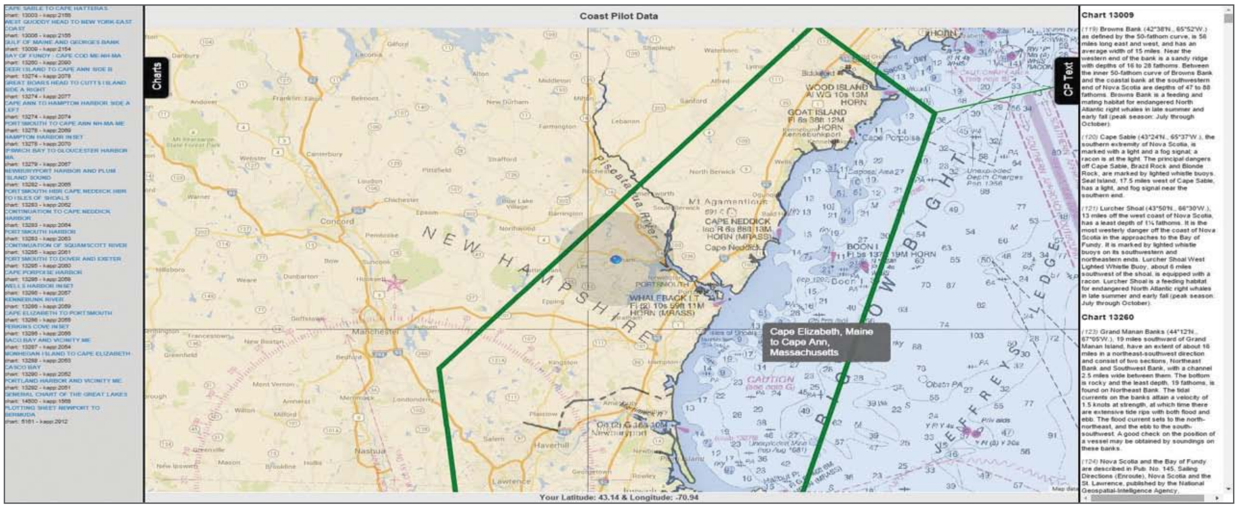


Figure ES-32. Coast Pilot® data in a georeferenced environment.

The revolutionary track for the Chart of the Future involves 3D and 4D displays and much more interactivity (see VISUALIZATION Theme). In the last few years, another focus of this effort has been the development of GeoCoastPilot, a research software application built to explore techniques to simplify access to the navigation information that a mariner needs prior to entering or leaving port. GeoCoastPilot is not intended to be used directly for navigation purposes but, instead, is intended to demonstrate what is possible with current technology and to facilitate technology transfer. With such a digital product, a mariner could, in real-time on the vessel or before entering a harbor, explore, with the click of a mouse, any object identified in the text and see a pictorial representation (in 2D or 3D) of the object in a geospatial context. Conversely, a click on a picture of an object will directly link to the full description of the object, as well as other relevant information. GeoCoastPilot turns the NOAA Coast Pilot manual into an interactive document linked to a 3D map environment that provides connections between the written text; 2D and 3D views; web content; and other primary sources such as charts, maps, and related federal regulations. This visualization technique helps the mariner become familiar with the relative location of critical navigation-related features within a port before ever going there.

Our efforts in 2015 focused on going beyond the prototype and working directly with OCS-derived Coastal Pilot data. In collaboration with the OCS Coast Pilot team, Briana Sullivan is now working with the OCS Coast Pilot database, mapping out the relationships between the tables so that the next iteration of the Digital Coast Pilot will work directly on NOAA data. Sullivan's work on the prototype has begun with adding new tables to the database, the goal being to give everything a geographic reference (Figure ES-31).

Sullivan created an initial web-based prototype that sets up the Coast Pilot data from the database using jQuery mobile's fluid layout to demonstrate how things can be ready for any device or any platform using the same code. Another part of the prototype involves a more efficient way to navigate within the text-based layout, as well as accessing the Coast Pilot data in a georeferenced environment with user location geo-enabled (blue dot in Figure ES-32). The data, when tagged with chart numbers, will only be available when the associated chart boundary is within the viewport of the screen.

The boundaries between the evolutionary and revolutionary components of our Chart of the Future work are slowly dissipating. Many of the visualization team's innovations are gradually being incorporated into ECS standards. Examples of this include Sullivan's participation in the S-111 product specification for surface current information and her work with the Nautical Information Provision Working Group to ensure that data are more discoverable, usable, shareable, and interoperable.

Law of the Sea

Recognizing that the implemention the United Nations Convention on the Law of the Sea (UNCLOS) could confer sovereign rights and management authority over large—and potentially resource-rich—areas of the seabed beyond our current 200 nautical mile limit, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding our Exclusive Economic Zone, or EEZ (**www.ccom.unh.edu/unclos**). Following up on the recommendations made in the UNH study, Congress has funded the Center through NOAA to collect new multibeam sonar data in support of a potential submission for an Extended Continental Shelf (ECS) under UNCLOS Article 76.

Since 2003, Center staff have participated in 28 cruises, surveying regions of the Bering Sea, the Gulf of Alaska, the Atlantic margin, the ice-covered Arctic, the Gulf of Mexico, and the eastern, central and western Pacific Ocean. We have collected 2,450,000 km^2 of bathymetry and backscatter data that provide an unprecedented high-resolution view of the seafloor. These data are revolutionizing our understanding of many geological processes on the margins and will result in significant additions to a potential U.S. ECS under UNCLOS, particularly in the Arctic.

Two ECS cruises were competed in 2015—a 30-day cruise in the Atlantic aboard the R/V *Langseth* and a 30-day expedition in the Kingman/Palmyra region of the Pacific aboard the R/V *Kilo Moana*. The Atlantic cruise, led by Brian Calder, was the fifth UNH cruise to this area, collecting 157,166 km^2 of high-resolution multibeam bathymetry and backscatter data and completing the needed coverage of the Atlantic for ECS purposes (Figure ES-33). Post-cruise, Jim Gardner and Paul Johnson archived data (at both the Center and NCEI in Boulder), generated metadata, and created derivative products from the data.

The second 2015 ECS cruise to the Kingman Reef-Palmyra Atoll area of the central Equatorial Pacific, again led by Brian Calder, collected 164,200 km^2 of high-resolution multibeam sonar and backscatter with the objective of mapping the northern extent of the Line Islands platform, a broad feature that rises as much as 1000 m above the adjacent deep-sea floor

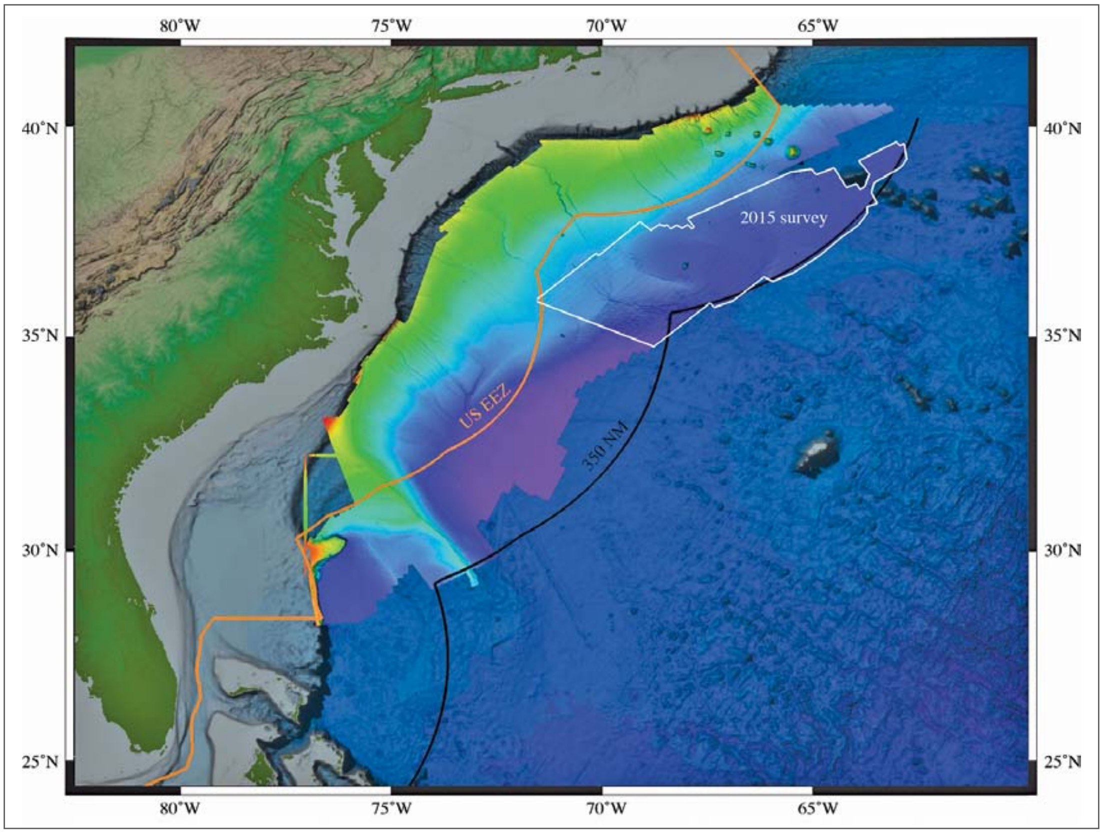


Figure ES-33. 2015 *Langseth* survey added on to previous ECS data.

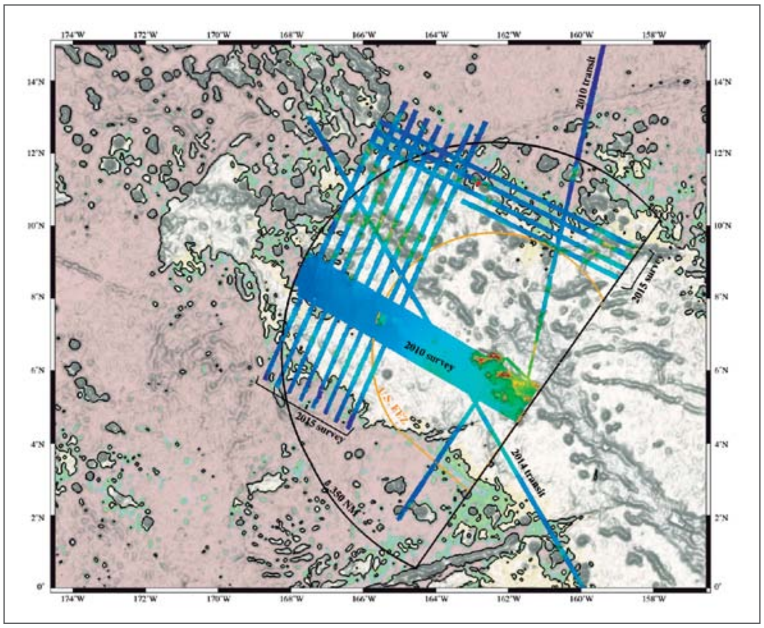


Figure ES-34. Base map of bathymetry of Kingman Reef-Palmyra Atoll area (GMRT, 2015) with overlay of legacy multibeam bathymetry (blue NNE-SSW lines) and CCOM-JHC 2010 and 2015 multibeam data (large blue NW-SE area and blue NE-SW lines). Black contour is 5150 m isobath.

(Figure ES-34). This was the second cruise to this region; more will be necessary in the future to fully understand the ECS potential of this area. Both cruises were very successful, collecting high-quality data that has already been made available to the national data repositories.

In 2015, a new faculty member, David Mosher, joined the Center faculty and has become an important member of our ECS team. He is starting to fill in for Jim Gardner as Gardner moves towards retirement. Since arriving, David has procured software packages for seismic data processing and seismic data interpretation. These are necessary for establishing sediment thickness and sediment continuity as supporting evidence in establishing the base of the continental slope and the foot of the continental slope.

The Center ECS Team (Armstrong, Gardner, Mayer, and Mosher) have spent much time analyzing ECS data and participating in ECS meetings and reviews, including meetings of Integrated Regional Teams (IRTs). There was also a week-long review session for all IRTs in Boulder, and two meetings with external experts—one in Breckenridge and one in San Francisco. Paul Johnson has done much to upgrade our database capabilities and, working with Jim Gardner, has added data and capabilities to our Law of the Sea database and website. Along with the ongoing process of entering all new data into the database and assuring metadata standards are met, during the spring and fall of 2015, Jim and Paul began the process of regenerating the bathymetry and backscatter grids for each of the Center's Law of the Sea survey sites. This large undertaking was driven by the desire to improve and validate each site's grids, as well as to validate each grid. Three separate downloadable products were then generated for each new grid—a Fledermaus SD grid file, an ESRI ArcGIS grid file, and an ASCII file. These files were bundled with the metadata file for the grid and then zipped into a single file for distribution. Final ESRI grid files are currently being loaded on to the Center's GIS server for use by users within the lab or by those interacting with the Center's dynamic map webpages (Figure ES-35).

Demonstrating the value of the ECS multibeam sonar data beyond the establishment of an extended continental shelf, Jim Gardner and the rest of the Center Law of the Sea team have been involved in writing peer-reviewed journal articles and we have begun a new research effort aimed specifically at looking at the potential of ECS data to be used for regional habitat studies. In 2015, two peer-review papers

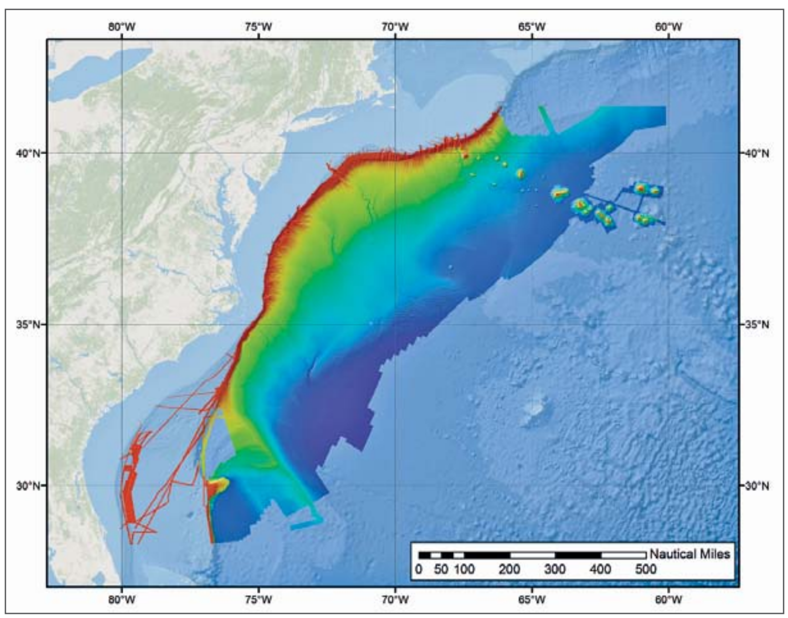


Figure ES-35. Atlantic Extended Continental Shelf bathymetry grid. This grid is a synthesis of the Center's ECS surveys fused with bathymetry collected by the NOAA Ship *Okeanos Explorer.*

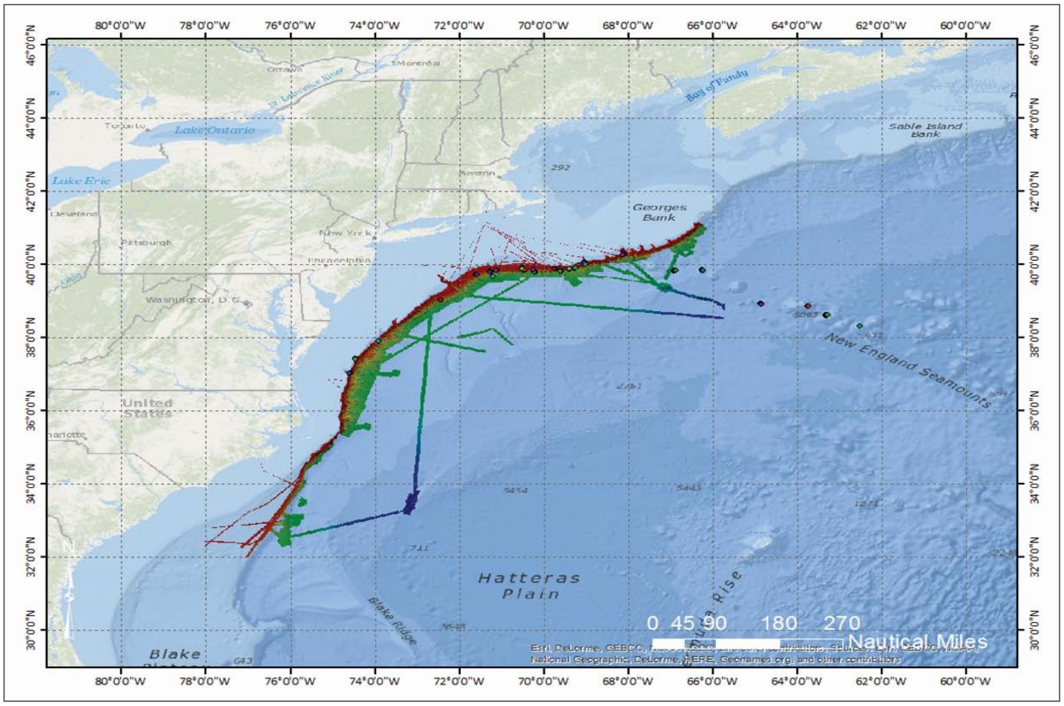


Figure ES-36. Map of deep sea sites used for analysis.

were published on ECS data: Gardner, Armstrong and Calder, 2015, "Hatteras Transverse Canyon, Hatteras Outer Ridge and Environs of the U.S. Atlantic margin: A View from Multibeam Bathymetry and Backscatter," *Marine Geology*, v. 371, p. 18-32, documenting the geomorphology of a unique feature of the U.S.; and, Armstrong, Mayer and Gardner, 2015, "Seamounts, Submarine Channels, and New Discoveries: Benefits of Continental Shelf Surveys Extend Beyond Defining the Limits of the Shelf," *Journal of Ocean Technology*, v. 10, p. 114, providing a brief review of all the areas the Center Law of the Sea team has mapped in the 12 years of the project.

We have also explored deriving "value-added" products from the ECS data. Graduate student Derek Sowers, working with Jenn Dijkstra and Kristen Mello, has been investigating the potential of using the data collected in support of ECS studies for broad-scale habitat mapping. His initial focus has been the ECS data collected along the Atlantic Margin, where large amounts of ancillary data (images, core samples, ecological studies) already exist. While Sowers is interpreting acoustic data, Dijkstra and Mello are analyzing video data as ground-truth where it exists (Figures ES-36 and ES-37).

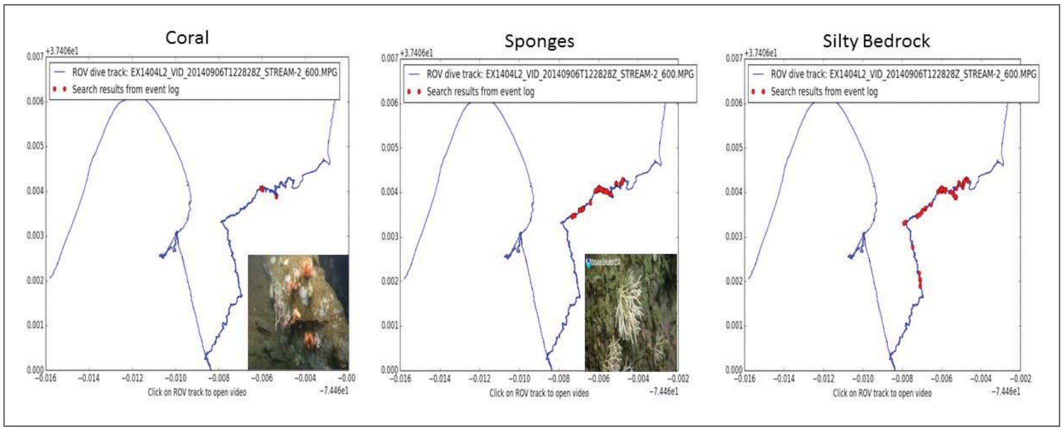


Figure ES-37. Distribution of coral, sponges, and sediments along the ROV track.

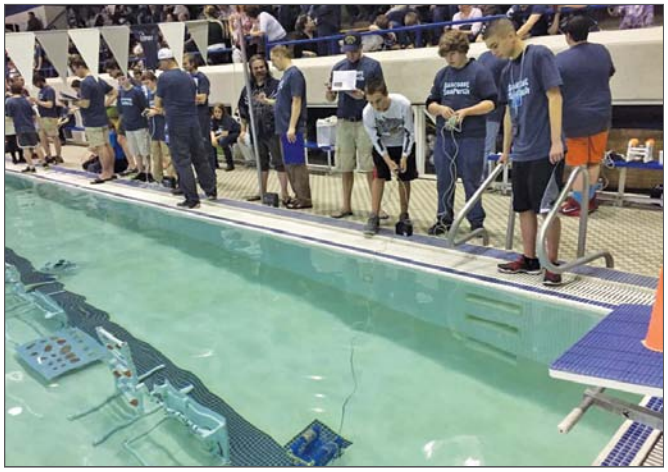



Figure ES-38. April 2015 SeaPerch competition. Teams with their ROVs in the water (left) and making last minute adjustments (right).

Outreach and Education

In addition to our research efforts, education and outreach are also fundamental components of our program. Our educational objectives are to produce a generation of highly trained students—critical thinkers able to fill positions in government, industry and academia and become leaders in the development of new approaches to ocean mapping. Thirty-five students were enrolled in the Ocean Mapping program in 2015, including six GEBCO students, two NOAA Corps officers and three NOAA physical scientists (three as part-time Ph.D. students). This year, we graduated nine master's students and one Ph.D. student, while six GEBCO students received Certificates in Ocean Mapping.

We also recognize the interest that the public takes in our work and realize our responsibility to explain the importance of what we do to those who ultimately bear the cost of our work. One of the primary methods of this communication is our website. We had 43,232 visits to the site in 2015 with a spike in hits associated with the Super Storm Sandy Citizen Science Project (see above). We also recognize the importance of engaging young people in our activities to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have upgraded other aspects of our web presence including a Flickr stream, a Vimeo site, a Twitter feed, a Pinterest page, and a Facebook presence. Our Flickr stream currently has 2,033 photos with over 232,084 views since 2009 and our more than 80 videos were viewed 7,631 times in 2015, with Jim Gardner's fly-through of the Mariana Trench receiving 5,479 plays. Our seminar series is widely advertised and

Figure ES-39. April 2015 SeaPerch competition before a full house at the UNH pool.

webcast, allowing NOAA employees and our Industrial Partners around the world to listen and participate in the seminars. Our seminars are also recorded and uploaded to Vimeo. We have actively expanded our outreach activities and now have a dedicated outreach staffer (Tara Hicks Johnson). This past year, Tara hosted tours of the Center for thousands of school children and many community groups.

Several large and specialized events were organized by the Center outreach team, including numerous Sea-Perch ROV events and the annual UNH Ocean Discovery Days. The SeaPerch ROV events are coordinated with the Portsmouth Naval Shipyard (PNS). Students build ROVs, then bring them to the Center to test them in our deep tank and tour the Center and the engineering facilities on campus. In this year's annual SeaPerch Competition, 48 teams from New Hampshire, Maine, and Massachusetts schools, after-school programs and community groups competed in this challenge, using ROVs that they built themselves (Figures ES-38 and ES-39). Although there is a basic ROV design, the participants have the freedom to innovate and create new designs that might be better suited for that specific challenge. This year's competition included challenges such as an obstacle course where pilots had to navigate their ROV through five submerged hoops, and a finesse course where they had to manipulate three challenges including pressing target buttons to raise a flag, lifting submerged rods and placing them in vertical tubes, and sliding movable collars on a submerged ladder, like an abacus. There was also a poster session where they presented posters and explained their building process to a panel of judges.

The Seacoast SeaPerch program held educator ROV workshops at the Center twice in 2015. These training programs are open to formal and informal educators, 4-H leaders, after-school providers, community partners and homeschool parents. The trainings included building a SeaPerch ROV, a discussion about starting Sea Perch ROV teams, and ways to incorporate ROVs into learning experiences. Each educator was able to take a SeaPerch kit back to their institution.

Ocean Discovery Day is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, October 16, more than 1,300 students from school groups and homeschool associations from all over New Hampshire, Maine and Massachusetts came to visit our facilities and learn about the exciting research happening here at the Center (Figure ES-40). Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, ASVs, ROVs, ocean engineering, coastal ecology, lidar, and ocean visualization. The event was then opened to the public on Saturday, October 17, when close to 700 more children and adults got to learn about the exciting research at the Center.

Center activities have also been featured in many international, national, and local media outlets including, CBS News, *Huffington Post*, *National Geographic*, CNN, *Irish Times*, *60 Minutes*, *Marine Technology News*, NASA Earth Observatory, *Marine Log*, *Vox*, *Foster's Daily Democrat*, and *Subsea World News*.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2015; more detailed discussions of these and other activities of the Center can found in the full progress report.

Figure ES-40. More than 1300 students visited the Center during Ocean Discovery Day.

On 4 June 1999, the Administrator of NOAA and the President of the University of New Hampshire signed a memorandum of understanding that established a Joint Hydrographic Center (JHC) at the University of New Hampshire. On 1 July 1999, a cooperative agreement was awarded to the University of New Hampshire that provided the initial funding for the establishment of the Joint Hydrographic Center. This Center, the first of its kind to be established in the United States, was formed as a national resource for the advancement of research and education in the hydrographic and ocean-mapping sciences. In the broadest sense, the activities of the Center are focused on two major themes: a research theme aimed at the development and evaluation of a wide range of state-of-the-art hydrographic and ocean-mapping technologies and applications, and an educational theme aimed at the establishment of a learning center that promotes and fosters the education of a new generation of hydrographers and ocean-mapping scientists to meet the growing needs of both government agencies and the private sector. In concert with the Joint Hydrographic Center, the Center for Coastal and Ocean Mapping was also formed in order to provide a mechanism whereby a broader base of support (from the private sector and other government agencies) could be established for ocean-mapping activities.

The Joint Hydrographic Center was funded by annual cooperative agreements from July 1999 until 31 December 2005. In 2005, a five-year cooperative agreement was awarded with an ending date of 31 December 2010. In January 2010, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2010. After a national competition, the University of New Hampshire was selected as the recipient of a five-year award, funding the Center for the period of 1 July 2010 until December 2015.

This report is the twentieth in a series of what were, until December 2002, semi-annual progress reports. Since December 2002, the written reports have been produced annually; this report provides an overview of the activities of the Joint Hydrographic Center, highlighting the period between 1 January and 31 December 2015. As such, it represents the sixth written progress report for the current grant (NA10NOS4000073). Copies of previous reports and more detailed information about the Center can be found on the Center's website **www.ccom.unh.edu**. More detailed descriptions of many of the research efforts described herein can be found in the individual progress reports of Center researchers that are available on request.

Infrastructure

Personnel

The Center has grown, over the past 15 years, from an original complement of 18 people to more than 95 faculty, staff and students. Our faculty and staff have been remarkably stable but as with any large organization, inevitably, there are changes. In 2015, Maureen Claussen was promoted to a role in the business office that supports our Center leaving an opening in our admin staff that we are seeking to fill. 2015 was an important year of growth for the Center. John Hughes-Clarke, formerly the Chair in Ocean Mapping at the University of New Brunswick, joined our faculty with a tenured position split between the departments of Earth Science and Mechanical Engineering and David Mosher, formerly a senior geoscientist working on Law of the Sea issues with the Geological Survey of Canada joined our faculty with a tenured position in the Earth Science Department. Additionally, Anthony Lyons, an internationally known acoustician, joined the Center as a Research Professor. We also welcomed two new post-doctoral scholars to our program in 2015—Christian Stranne comes from the University of Stockholm and is funded entirely by Swedish sources, and Firat Eren returns after completing his Ph.D. at UNH to serve as the Tyco Postdoctoral Scholar. Lee Alexander, who retired last year, was brought back to supervise the final construction and delivery of our new survey vessel. Jennifer Crosby was brought on board as a web developer to support our expanding web presence, and Renee Blinn joined our administrative staff.

Faculty

Lee Alexander is a Research Associate Professor at the Center for Coastal and Ocean Mapping and Joint Hydrographic Center at the University of New Hampshire, and an Adjunct Professor at both the University of New Brunswick and Memorial University of Newfoundland, Canada. Previously a Research Scientist with the U.S. Coast Guard, he was also a Visiting Scientist with the Canadian Hydrographic Service. His area of expertise is applied Research, Development, Test and Evaluation (RDT&E) on e-Navigation related technologies, international standards development, and the use of electronic charts for safety-of-navigation and marine environmental protection. He serves on several international committees and working groups dealing with electronic charting and e-Navigation, including the International Hydrographic Organization, International Maritime Organization, and the International Association of Lighthouse Authorities. Dr. Alexander has published over 150 papers and reports on electronic chart-related technologies, and is the co-author of a textbook on Electronic Charting, now in Third Edition. Dr. Alexander received his M.S. from the University of New Hampshire, and Ph.D. from Yale University in Natural Resource Management. He is also a Captain (now retired) in the U.S. Navy Reserve. Lee formally retired as a Research Associate Professor at the end of 2014 but was brought back in 2015 to supervise the final construction and delivery of our new research vessel.

Thomas Butkiewicz received a Bachelor of Science degree in Computer Science in 2005 from Ithaca College where he focused on computer graphics and virtual reality research. During his graduate studies at The University of North Carolina at Charlotte, he designed and developed new interactive geospatial visualization techniques, receiving a Masters in Computer Science in 2007 and a Ph.D. in Computer Science in 2010. After a year as a research scientist at The Charlotte Visualization Center, he joined CCOM as a post-doctoral research fellow in 2011. In 2012, he joined the faculty as a Research Assistant Professor.

Dr. Butkiewicz specializes in creating highly interactive visualizations that allow users to perform complex visual analysis on geospatial datasets through unique, intuitive exploratory techniques. His research interests also include multi-touch and natural interfaces, virtual reality, stereoscopic displays, and image processing/computer vision. His current research projects include visual analysis of 4D dynamic ocean simulations, using Microsoft's Kinect device to enhance multi-touch screens and provide new interaction methods, multi-touch gesture research, and developing new interface approaches for sonar data cleaning.

Brian Calder graduated with an M.Eng (Merit) and a Ph.D in Electrical and Electronic Engineering in 1994 and 1997 respectively, from Heriot-Watt University, Scotland. His doctoral research was in Bayesian statistical methods applied to processing of sidescan sonar and other data sources, and his post-doctoral research included investigation of high-resolution seismic reconstruction, infrared data simulation, high-resolution acoustic propagation modeling and real-time assessment of pebble size distributions for mining potential assessment. Brian joined CCOM as a founding member in 2000, where his research has focused mainly on understanding, utilizing and portraying the uncertainty inherent in bathymetric data, and in efficient semi-automatic processing of high-density multibeam echosounder data. He is a Research Associate Professor, and Associate Director of CCOM, the Chair of the Open Navigation Surface Working Group, and a past Associate Editor of IEEE Journal of Oceanic Engineering.

Jenn Dijkstra received her Ph.D. in Zoology in 2007 at the University of New Hampshire, has a B.A. from the University of New Brunswick (Canada), and a M.S. in Marine Biology from the University of Bremen (Germany). She has conducted research in a variety of geographical areas and habitats, from polar to tropical and from intertidal to deep-water. Her research incorporates observation and experimental approaches to address questions centered around the ecological causes and consequences of human-mediated effects on benthic and coastal communities. Her research at CCOM focuses on the use of remote sensing (video and multibeam) to detect and characterize benthic communities.

Semme Dijkstra is a hydrographer from the Netherlands who has several years of hydrographic experience with both the Dutch Navy and industry. Semme earned his Ph.D. In Geodesy and Geodetic Engineering from the University of New Brunswick in Canada. His thesis work involved artifact removal from multibeam-sonar data and development of an echosounder processing and sediment classification system. From 1996 to 1999, Semme worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam-sonar data acquisition and processing. Semme's current research focuses on applications of single-beam sonars for seafloor characterization, small object detection and fisheries habitat mapping. In 2008, Semme was appointed a full-time instructor and he has taken a much larger role in evaluating the overall CCOM curriculum, the development of courses and teaching.

Jim Gardner is a marine geologist focused on seafloor mapping, marine sedimentology, and paleoceanography. He received his Ph.D. in Marine Geology from the Lamont Doherty Earth Observatory of Columbia University in 1973. He worked for 30 years with the Branch of Pacific Marine Geology at the U.S. Geological Survey in Menlo Park, CA where he studied a wide variety of marine sedimentological and paleoceanographic problems in the Bering Sea, North and South Pacific Ocean, northeast Atlantic Ocean, Gulf of Mexico, Caribbean and Mediterranean Seas, and the Coral Sea. He conceived, organized, and directed the eight-year EEZ-SCAN mapping of the U.S. Exclusive Economic Zone using GLORIA long-range sidescan sonar in the 1980s; participated in four Deep Sea Drilling Project cruises, one as co-chief scientist; participated in more than 50 research cruises, and was Chief of Pacific Seafloor Mapping from 1995 to 2003, a project that used high-resolution multibeam echosounders to map portions of the U.S. continental shelves and margins. He also mapped Lake Tahoe in California and Crater Lake in Oregon. Jim was the first USGS Mendenhall Lecturer, received the Department of Interior Meritorious Service Award and received two USGS Shoemaker Awards. He has published more than 200 scientific papers and given an untold number of talks and presentations all over the world. Jim retired from the U.S. Geological Survey in 2003 to join the Center.

Jim was an Adjunct Professor at CCOM/UNH from its inception until he moved to UNH in 2003 when he became a Research Professor affiliated with the Earth Science Dept. At JHC/CCOM, Jim is in charge of all non-Arctic U.S. Law of the Sea bathymetry mapping cruises and is involved in research methods to extract meaningful geological information from multibeam acoustic backscatter through ground truth and advanced image analysis methods. Jim was awarded the 2012 Francis P. Shepard Medal for Sustained Excellence in Marine Geology by the SEPM Society of Sedimentary Geology. Jim has taught Geological Oceanography—ESCI 759/859 and the Geological Oceanography module of Fundamentals of Ocean Mapping—ESCI 874/OE 874.01. In 2013, Jim reduced his effort to half-time.

John Hughes Clarke is a Professor jointly appointed in the departments of Earth Sciences and Mechanical Engineering. For the past 15 years, John was the Chair in Ocean Mapping at the University of New Brunswick in Canada and a Professor in the department of Geodesy and Geomatics Engineering. During that period, he also ran the scientific seabed mapping program on board the CCGS Amundsen, undertaking seabed surveys of the Canadian Arctic Archipelago. As a compliment to his research and teaching he has acted as a consultant, formally assessing the capability of the hydrographic survey vessels of the New Zealand, Australian, British and Dutch Navies as well as the U.S. Naval Oceanographic Office TAGS fleet. For the past 21 years John, together with Larry Mayer, Tom Weber and Dave Wells, has delivered the Multibeam Training Course that is presented globally three times per year. This is the world's leading training course in seabed survey and is widely attended by international government and commercial offshore survey personnel as well as academics. John was formally trained in geology and oceanography in the UK and Canada (Oxford, Southampton and Dalhousie). He's spent the last 27 years, however, focusing on ocean mapping methods. His underlying interest lies in resolving seabed sediment transport mechanisms.

Jim Irish received his Ph.D. from Scripps Institution of Oceanography in 1971 and worked many years at the Woods Hole Oceanographic Institution where he is still an Oceanographer Emeritus. He is currently a Research Professor of Ocean Engineering at UNH and has also joined the Center team. Jim's research focuses on: ocean instruments, their calibration, response and the methodology of their use; buoys, moorings and modeling of moored observing systems; physical oceanography of the coastal ocean, including waves, tides, currents and water-mass property observations and analysis; and acoustic instrumentation for bottom sediment and bedload transport, for remote observations of sediment and for fish surveys.

Tom Lippmann is an Associate Professor with affiliation in the Department of Earth Sciences, Marine Program, and Ocean Engineering Graduate Program, and is currently the Director of the Oceanography Graduate Program. He received a B.A. in Mathematics and Biology from Linfield College (1985), and an M.S. (1989) and Ph.D. (1992) in Oceanography at Oregon State University. His dissertation research conducted within the Geological Oceanography Department was on shallow water physical oceanography and large-scale coastal behavior. He went on to do a Post Doc at the Naval Postgraduate School (1992-1995) in Physical Oceanography. He worked as a Research Oceanographer at Scripps Institution of Oceanography (1995-2003) in the Center for Coastal Studies. He was then a Research Scientist at Ohio State University (1999-2008) jointly in the Byrd Polar Research Center and the Department of Civil and Environmental Engineering & Geodetic Science. Dr. Lippmann's research is focused on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning inner continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 20 nearshore field experiments and spent more than two years in the field.

Anthony P. Lyons received the B.S. degree (summa cum laude) in physics from the Henderson State University, Arkadelphia, AR, in 1988 and the M.S. and Ph.D. degrees in oceanography from Texas A&M University, College Station, TX, in 1991 and 1995, respectively. He was a Scientist at the SACLANT Undersea Research Centre, La Spezia, Italy, from 1995 to 2000, where he was involved in a variety of projects in the area of environmental acoustics. Dr. Lyons was awarded, with the recommendation of the Acoustical Society of America, the Institute of Acoustics' (U.K.) A.B. Wood Medal in 2003. He is a Fellow of the Acoustical Society of America and a member of the IEEE Oceanic Engineering Society. He is also currently an Associate Editor for the Journal of the Acoustical Society of America and is on the Editorial Board for the international journal Methods in Oceanography. Dr. Lyons conducts research in the field of underwater acoustics and acoustical oceanography. His current areas of interest include high-frequency acoustic propagation and scattering in the ocean environment, acoustic characterization of the seafloor, and quantitative studies using synthetic aperture sonar.

Larry Mayer is the founding Director of the Center for Coastal and Ocean Mapping and Co-Director of the Joint Hydrographic Center. Larry's faculty position is split between the Ocean Engineering and Earth Science Departments. His Ph.D. is from the Scripps Institution of Oceanography (1979) and he has a background in marine geology and geophysics with an emphasis on seafloor mapping, innovative use of visualization techniques, and the remote identification of seafloor properties from acoustic data. Before coming to New Hampshire, he was the NSERC Chair of Ocean Mapping at the University of New Brunswick where he led a team that developed a worldwide reputation for innovative approaches to ocean mapping problems.

David Mosher is a Professor in the Dept. of Earth Sciences and the Center for Coastal and Ocean Mapping. He graduated with a Ph.D. in Geophysics from the Oceanography Department at Dalhousie University in 1993, following an M.Sc. in Earth Sciences from Memorial University of Newfoundland in 1987 and a B.Sc. at Acadia in 1983. In 1993, he commenced work on Canada's West Coast at the Institute of Ocean Sciences, in Sidney on Vancouver Island, studying marine geology and neotectonics in the inland waters of British Columbia. In 2000, he took a posting at Bedford Institute of Oceanography. His research focus was studying the geology of Canada's deep water margins, focusing on marine geohazards using geophysical and geotechinical techniques. From 2008 to 2015, he was involved in preparing Canada's submission for an extended continental shelf under the Law of the Sea (UNCLOS) and, in this capacity, he led four expeditions to the high Arctic. In 2011, he became manager of this program and was acting Director from 2014. In 2015, he joined UNH to conduct research in all aspects of ocean mapping, focusing on marine geohazards and marine geoscience applications in Law of the Sea. He has participated in over 45 sea-going expeditions and was chief scientists on 27 of these.

Shachak Pe'eri received his Ph.D. degree in Geophysics from the Tel Aviv University, Israel. In 2005, he started his post-doctoral work at the Center with a Tyco post-doctoral fellowship award. He is currently working as a Research Assistant Professor at the Center His research interests are in optical remote sensing in the littoral zone with a focus on experimental and theoretical studies of lidar remote sensing (airborne lidar bathymetry, topographic lidar, and terrestrial laser scanning), hyperspectral remote sensing, and sensor fusion. Shachak is a member of the American Geophysical Union (AGU) and the Ocean Engineering (OE) and Geoscience and Remote Sensing (GRS) societies of the IEEE, and of The Hydrographic Society of America (THSOA).

Yuri Rzhanov, a Research Professor, has a Ph.D. in Physics and Mathematics from the Russian Academy of Sciences. He completed his thesis on nonlinear phenomena in solid state semiconductors in 1983. Since joining the Center in 2000 he has worked on a number of signal processing problems, including construction of large-scale mosaics from underwater imagery, automatic segmentation of acoustic backscatter mosaics, and accurate measurements of underwater objects from stereo imagery. His research interests include development of algorithms and their implementation in software for 3D reconstruction of underwater scenes, and automatic detection and abundance estimation of various marine species from imagery acquired from ROVs, AUVs, and aerial platforms.

Larry Ward has an M.S. (1974) and a Ph. D. (1978) from the University of South Carolina in Geology. He has over 30 years' experience conducting research in shallow water marine systems. Primary interests include estuarine, coastal, and inner shelf morphology and sedimentology. His most recent research focuses on seafloor characterization and the sedimentology, stratigraphy and Holocene evolution of nearshore marine systems. Present teaching includes a course in Nearshore Processes and a Geological Oceanography module.

Colin Ware is a leading scientific authority on the creative invention, and the scientifically sound, correct use of visual expressions for information visualization. Ware's research is focused on applying an understanding of human perception to interaction and information display. He is author of *Visual Thinking for Design* (2008) which discusses the science of visualization and has published more than 120 research articles on this subject. His other book, *Information Visualization: Perception for Design* (2004) has become the standard reference in the field. He also designs, builds and experiments with visualization applications. One of his main current interests is interpreting the space-time trajectories of tagged foraging humpback whales and to support this he has developed TrackPlot an interactive 3D software tool for interpreting both acoustic and kinematic data from tagged marine mammals. TrackPlot shows interactive 3D tracks of whales with whale behavioral properties visually encoded on the tracks. This has resulted in a number of scientific discoveries, including a new classification of bubble-net feeding by humpbacks. Fledermaus, a visualization package initially developed by him and his students, is now the leading 3D visualization package used in ocean mapping applications. GeoZui4D is an experimental package developed by his team in an initiative to explore techniques for interacting with time-varying geospatial data. It is the basis for the CCOM Chart of the Future project and work on real-time visualization of undersea sonar data. In recent work with BBN he invented a patented technique for using motion cues in the exploration of large social networks. He has worked on the problem of visualizing uncertainty for sonar target detection. He is Professor of Computer Science and Director of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping, University of New Hampshire. He has advanced degrees in both computer science (M.Math, University of Waterloo) and psychology (Ph.D., University of Toronto).

Tom Weber received his Ph.D. in Acoustics at The Pennsylvania State University in 2006 and has B.S. (1997) and M.S. (2000) degrees in Ocean Engineering from the University of Rhode Island. He joined the Center in 2006 and the Mechanical Engineering Department, as an Assistant Professor, in 2012. Dr. Weber conducts research in the field of underwater acoustics and acoustical oceanography. His specific areas of interest include acoustic propagation and scattering in fluids containing gas bubbles, the application of acoustic technologies to fisheries science, high-frequency acoustic characterization of the seafloor, and sonar engineering.

Research Scientists and Staff

Roland Arsenault received a bachelor's degree in Computer Science and worked as a research assistant with the Human Computer Interaction Lab at the Department of Computer Science, University of New Brunswick. As a member of the Data Visualization Research Lab, he combines his expertise with interactive 3D graphics and his experience working with various mapping related technologies to help provide a unique perspective on some of the challenges undertaken at the Center.

Jordan Chadwick is the Systems Manager at JHC/CCOM. He is responsible for the day-to-day operation of the information systems and network as well as the planning and implementation of new systems and services. Jordan has a B.A. in History from the University of New Hampshire. He previously worked as a Student Engineer at UNH's InterOperability Lab and, most recently, as a Network Administrator in the credit card industry.

Jennifer Crosby is the Web Developer at JHC/CCOM. As the Web Developer, Jennifer is responsible for the maintenance and development of the CCOM external and internal websites. Jennifer has more than seven years of experience in technology and computing in various areas of concentration (DBA with system/network admin duties, QA/Testing, Configuration Management, Web Development). Jennifer holds the CompTIA Security+ certification, and is working towards Oracle PL/SQL Developer Certified Associate Certification. She has a B.A. in Biology from the University of Colorado with an emphasis in Marine Biology/Ecology. She has a single engine private pilot's license and a NAUI SCUBA license.

Will Fessenden is a Systems Administrator for JHC/CCOM, and has provided workstation, server, and backup support to the Center since 2005. Will has a B.A. in Political Science from the University of New Hampshire, and has over 15 years of experience in information technology.

Tara Hicks Johnson has a B.S. in Geophysics from the University of Western Ontario, and an M.S. in Geology and Geophysics from the University of Hawaii at Manoa where she studied meteorites. In June of 2011, Tara moved to New Hampshire from Honolulu, Hawaii, where she was the Outreach Specialist for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. While there she organized educational and community events for the school, including the biennial Open House event, and ran the Hawaii Ocean Sciences Bowl, the Aloha Bowl. She also handled media relations for the School and coordinated television production projects. Tara also worked with the Bishop Museum in Honolulu developing science exhibits, and at the Canadian Broadcasting Corporation in Toronto (where she was born and raised).

Tianhang Hou was a Research Associate with the University of New Brunswick Ocean Mapping for six years before coming to UNH. He has significant experience with the UNB/OMG multibeam processing tools and has taken part in several offshore surveys. In addition to his work as a research scientist Mr. Hou has also begun a Ph.D. in which he is looking at the application of wavelets for artifact removal and seafloor classification in multibeam sonar records. He is currently working with Tom Weber and Jonathan Beaudoin developing plug-in software modules for seafloor characterization and mid-water data processing.

Jon Hunt is a UNH alumnus who studied economics and oceanography while a student at the university. Jon is now a Research Technician at the Center. Working under the supervision of Tom Lippmann, Jon has built a survey vessel which is capable of undertaking both multibeam sonar surveys and measurements of currents. Jon is a certified research scuba diver and has been a part of many field work projects for JHC/CCOM.

Paul Johnson has an M.S. in Geology and Geophysics from the University of Hawaii at Manoa where he studied the tectonics and kinematics of the fastest spreading section of the East Pacific Rise. Since finishing his masters, he has spent time in the remote sensing industry processing, managing, and visualizing hyperspectral data associated with coral reefs, forestry, and research applications. More recently, he was the interim director of the Hawaii Mapping Research Group at the University of Hawaii where he specialized in the acquisition, processing, and visualization of data from both multibeam mapping systems and towed near bottom mapping systems. Paul started at the Center in June of 2011 as the data manager. When not working on data related issues for the Joint Hydrographic Center, he is aiding in the support of multibeam acquisition for the US academic fleet through the National Science Foundation's Multibeam Advisory Committee.

Carlo Lanzoni received a Masters degree in Ocean Engineering from the University of New Hampshire. His masters research was the design of a methodology for field calibration of multibeam echo sounders using a split-beam sonar system and a standard target. He also has an M.S. and B.S. in Electrical Engineering from the University of New Hampshire. Carlo has worked with different calibration methodologies applied to different sonar systems. He is responsible for the operation, maintenance, and development of test equipment used in acoustic calibrations of echo sounders at the acoustic tank of Chase Ocean Engineering Lab. His research focuses on the field calibration methodology for multibeam echo sounders.

Brian Madore graduated from the University of New Hampshire in 2013 with a B.S. in Geology and is working as a GIS analyst under Shachak Pe'eri and Christopher Parrish. His work focuses on satellite derived bathymetry and lidar bathymetry.

Giuseppe Masetti received an M.Eng. degree in ocean engineering (ocean mapping option) UNH in 2012, and a Masters in Marine Geomatics (with honors) and a Ph.D. degrees in System Monitoring and Environmental Risk Management from the University of Genoa, Italy, in 2008 and 2013, respectively. In addition, he graduated (with honors) in Political Sciences from the University of Pisa, Italy, in 2003 and in Diplomatic and International Sciences from the University of Trieste, Italy, in 2004. Dr. Masetti achieved the FIG/IHO Category A certification in 2010, and he is member of IEEE and THSOA.

He has served with Italian Navy since 1999, and he has been Operation Officer aboard the hydrographic vessels ITN Aretusa and ITN Magnaghi. Since August 2013, he has been the Tyco Post-Doctoral Fellow with the Center, where he is focusing on signal processing for marine target detection.

Zachary McAvoy received a B.S. in Geology from the University of New Hampshire in 2011. His background is in geochemistry, geology, and GIS. Since graduating, he has worked on various environmental and geoscience related projects for the Earths Systems Research Center and Ocean Process Analysis Laboratory at UNH; as well as the New Hampshire DOT and Geological Survey. Zach is currently a research technician working for Dr. Larry Ward. As part of a BOEM beach nourishment study, he is using geologic and geospatial datasets for synthesis in GIS and mapping the geomorphology of the New Hampshire inner continental shelf. He also assists Dr. Ward with maintaining the Coastal Geology Lab at Jackson Estuarine Laboratory.

Andy McLeod received his B.S. in Ocean Studies from Maine Maritime Academy in 1998. His duties at the Center include managing projects from conception through pre-production to completion, providing technical support to the Center and wider regional projects, managing project budgets and keeping costs down, overseeing the maintenance and operations of projects after initiation, responsibility for the completion of all documentation, producing test plans and reports, preparing contract documentation for procurement services and materials, carrying out effective client liaison for all projects undertaken, as well as liaising with manufacturers, development interests and customers on a regular basis to ensure the successful design and manufacture of products to agreed budgets and time frames.

Colleen Mitchell has a B.A. in English from Nyack College in Nyack, NY and a Masters in Education from the State University of New York at Plattsburgh. She began working for the Environmental Research Group (ERG) at UNH in 1999. In July 2009, Colleen joined JHC/CCOM as the Center's graphic designer. She is responsible for the graphic identity of the Center and, in this capacity, creates ways to visually communicate the Center's message in print and electronic media.

Erin Nagel worked as a Physical Scientist for the U.S. Army Corps of Engineers and with NOAA's Atlantic Hydrographic Branch for the Office of Coast Survey before joining the Center in 2014. She has supported USACE and FEMA in emergency operations during Hurricane Sandy and Irene with emergency response mapping and pre- and post-storm analysis of Bathymetry and lidar. Erin focused her undergraduate studies at the University of Colorado at Boulder on Geographic Information Systems and Atmospheric and Oceanic Sciences.

Abby Pagan-Allis is the administrative manager at JHC/CCOM. She has worked at the Center since 2002, overseeing the day-to-day operations at the Center and supervising the administrative staff. She earned her B.S. in Management and Leadership from Granite State College. In 2006, she completed the Managing at UNH program and, in 2009, she received her Human Resources Management certificate at the University of New Hampshire.

Victoria Price began working on the IOCM Super Storm Sandy project in 2014. She is focused on investigating effective uses of hydroacoustics for rapid post-storm response surveys, as well as developing efficient methods for acoustic data analysis. She is also focusing on pre- and post-Sandy lidar data to investigate the use of topo-bathy data for modeling habitat and shoreline changes in the wake of major weather events. Victoria received her B.S. and M.S. in Oceanography from the University of Connecticut, where she focused on the development of ecological survey methods using high-resolution imaging sonars. Her previous work includes investigating methods for quantifying predation over broad time scales using DIDSON sonar, as well as developing effective algorithms for large-batch acoustic data processing and analysis.

Val Schmidt received his Bachelors degree in Physics from the University of the South, Sewanee, TN in 1994. During his junior undergraduate year he joined the Navy and served as an officer in the submarine fleet aboard the USS *Hawkbill* from 1994 to 1999. In 1998 and 1999 the USS *Hawkbill* participated in two National Science Foundation sponsored "SCICEX" missions to conduct seafloor mapping from the submarine under the Arctic ice sheet. Val served as Sonar and Science Liaison Officer during these missions. Val left the Navy in 1999 and worked for Qwest Communications as a telecommunications and Voice over IP engineer from 2000 to 2002. Val began work in 2002 as a research engineer for the Lamont Doherty Earth Observatory of Columbia University where he provided science-engineering support both on campus and to several research vessels in the U.S. academic research fleet. Val acted as a technical lead aboard the U.S. Coast Guard Icebreaker Healy for several summer cruises in this role. Val completed his Masters degree in Ocean Engineering in 2008 at the Center for Coastal and Ocean Mapping. His thesis involved development of an underwater acoustic positioning system for whales that had been tagged with an acoustic recording sensor package. Val continues to work as an engineer for the Center where his research focuses on seafloor and water column mapping from autonomous underwater vehicles, sensor development, and sonar signal processing and calibration.

Ben Smith is the Captain of the JHC/CCOM research vessel *Coastal Surveyor*, and a research technician specializing in programming languages and UNIX-like operating systems and services. He has years of both programming and marine experience. He designed, built, and captained his own 45-foot blue water steel ketch, S/V *Mother of Perl*. He has been master of *Coastal Surveyor* for over ten years. He holds a USCG 100 ton near coastal license with endorsements for sail and rescue towing.

Briana Sullivan received a B.S. in Computer Science at UMASS, Lowell and an M.S. in Computer Science at UNH, under the supervision of Dr. Colin Ware. Her Masters thesis involved linking audio and visual information in a virtual underwater kiosk display that resulted in an interactive museum exhibit at the Seacoast Science Center. Briana was hired in July 2005 as a Research Scientist for the Center. She works on the Chart of the Future project which involves things such as the Local Notice to Mariners, ship sensors, the Coast Pilot, other marine related topics. Her focus is on web technologies and mobile environments.

Emily Terry joined the Center as Relief Captain in 2009, and was promoted to Research Vessel Captain in 2014. She came to the Center from the NOAA Ship *Fairweather* where she worked for three years as a member of the deck department, separating from the ship as a Seaman Surveyor. Prior to working for NOAA, she spent five years working aboard traditional sailing vessels. Emily holds a USCG 100 ton near coastal license.

Rochelle Wigley has a mixed hard rock/soft rock background with an M.Sc. in Igneous Geochemistry (focusing on dolerite dyke swarms) and a Ph.D. in sedimentology/sediment chemistry, where she integrated geochemistry and geochronology into marine sequence stratigraphic studies of a condensed sediment record in order to improve the understanding of continental shelf evolution along the western margin of southern Africa. Phosphorites and glauconite have remained as a research interest where these marine authigenic minerals are increasingly the focus of offshore mineral exploration programs. She was awarded a Graduate Certificate in Ocean Mapping from UNH in 2008. Rochelle concentrated largely on understanding the needs and requirements of all end-users within the South African marine sectors on her return home, as she developed a plan for a national offshore mapping program from 2009 through 2012. As Project Director of the GEBCO Nippon Foundation Indian Ocean Project, she is involved in the development of an updated bathymetric grid for the Indian Ocean and management of a project working to train other Nippon Foundation GEBCO scholars. In 2014, Rochelle took on the responsibility of the Director of the Nippon Foundation GEBCO training program at the Center.

In addition to the academic, research and technical staff, our administrative support staff, Linda Prescott and Renee Blinn ensure the smooth running of the organization.

NOAA Employees

NOAA has demonstrated its commitment to the Center by assigning sixteen NOAA employees (or contractors) to the Center.

Capt. Andrew Armstrong, founding Co-Director of the JHC, retired as an officer in the National Ocean and Atmospheric Administration Commissioned Officer Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. Captain Armstrong has specialized in hydrographic surveying and served on several NOAA hydrographic ships, including the NOAA Ship *Whiting* where he was Commanding Officer and Chief Hydrographer. Before his appointment as Co-Director of the NOAA/UNH Joint Hydrographic Center, Captain Armstrong was the Chief of NOAA's Hydrographic Surveys Division, directing all of the agency's hydrographic survey activities. Captain Armstrong has a B.S. in Geology from Tulane University and an M.S. in Technical Management from the Johns Hopkins University. Capt. Armstrong is overseeing the hydrographic training program at UNH and organized our successful Cat. A certification submission to the International Hydrographic Organization in 2011.

Michael Bogonko is currently working on Super Storm Sandy post-disaster research work, mostly providing support to NOAA's ICOM/JHC group in operational planning, processing practices for massive amounts of lidar and acoustic data to establish the best possible operational methods. Before joining ICOM/JHC, Michael worked as a consultant in engineering and environmental firms applying expertise in GIS/geospatial applications, hydrological modeling and data processing. He has been an R.A. and a T.A. in the Department of Civil and Environmental Engineering at UNH. Michael has an M.S. in Civil Engineering from San Diego State University, CA. He holds a B.S. focusing on GIS and geography with a minor in Mathematics from University of Nairobi. He also holds an M.S. in Physical Land resources in Engineering Geology from VUB, Brussels, Belgium.

John G.W. Kelley is a research meteorologist and coastal modeler with NOAA/National Ocean Service's Marine Modeling and Analysis Programs within the Coast Survey Development Lab. John has a Ph.D. in Atmospheric Sciences from Ohio State University. He is involved in the development and implementation of NOS's operational numerical ocean forecast models for estuaries, the coastal ocean and the Great Lakes. He is also PI for a NOAA web mapping portal to real-time coastal observations and forecasts. John is working with JHC/CCOM personnel on developing the capability to incorporate NOAA's real-time gridded digital atmospheric and oceanographic forecast into the next generation of NOS nautical charts.

Juliet Kinney is working on the Super Storm Sandy Project with the IOCM group. She graduated with a B.S. in Earth Systems Science from the UMass-Amherst Geosciences Department and received her Ph.D. in Marine and Atmospheric Sciences from Stony Brook University where her dissertation focused on *The Evolution of the Peconic Estuary 'Oyster Terrain,' Long Island, NY*. Her study included high-resolution mapping using a combination of geophysical techniques: multibeam sonar, chirp seismic profiles, and sidescan sonar. She is interested in paleoclimate/paleoceanography and her expertise is as a geological oceanographer is in high resolution sea floor mapping. Before joining the Center, Juliet was a temporary full-time faculty member in the Department of Geological Sciences at Bridgewater State University in Bridgewater, MA for one year. Prior to graduate school, she worked at the USGS as an ECO intern for two years in Menlo Park, CA with the Coastal and Marine Geology Program, working primarily with physical oceanographic and sediment transport data.

Cassie Bongiovanni received her B.S. in Geology at the University of Washington in Seattle with a focus in Oceanography. There she spent time aboard both U.W. research vessels working with multibeam data. She is now working with NOAA's IOCM group on processing lidar and acoustic data for the Super Storm Sandy research effort.

Sam Greenaway graduated from Brown University with a Sc.B. in Physics in 1998. He was initially commissioned into the NOAA Corps in 2004 and has served on the NOAA Ships *Rainier* and *Ferdinand R. Hassler.* In 2010, he graduated from the University of New Hampshire with an M.S. in Ocean Engineering.

Megan Greenaway is a Physical Scientist with the NOAA Office of Coast Survey (OCS) and is stationed in the Integrated Ocean and Coastal Mapping (IOCM) center. Megan previously worked at the Atlantic and Pacific Hydrographic Branches, and the Operations Branch where she sailed on multiple NOAA hydrographic vessels. Megan has a B.S. in Geography and a M.S. in Hydrographic Surveying from the University of Southern Mississippi.

Jason Greenlaw is a software developer for ERT, Inc. working as a contractor for NOAA/National Ocean Service's Coast Survey Development Laboratory in the Marine Modeling and Analysis Programs (MMAP) branch. Jason works primarily on the development of NOAA's nowCOAST project (**http://nowcoast.noaa.gov**), but also works closely with MMAP modelers to assist in the development of oceanographic forecast systems and the visualization of model output. Jason is a native of Madbury, NH and graduated in May 2006 from the University of New Hampshire with a B.S. in Computer Science.

Carl Kammerer is an oceanographer with the National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS), now seconded to the Center. He is a specialist in estuarine and near-shore currents and has been project manager for current surveys throughout the United Stated and its territories. His present project is a two-year survey of currents in the San Francisco Bay region. Working out of the Joint Hydrographic Center, he acts as a liaison between CO-OPS and the JHC, and provides expertise and assistance in the analysis and collection of tides. He has a B.Sc. in Oceanography from the University of Washington and an MBA from the University of Maryland University College.

Elizabeth "Meme" Lobecker is a Physical Scientist for the *Okeanos Explorer* program within the NOAA Office of Ocean Exploration and Research (OER). She organizes and leads mapping exploration cruises aboard the NOAA Ship *Okeanos Explorer*. She has spent the last ten years mapping the global ocean floor for an array of purposes, ranging from shallow water hydrography for NOAA charting and habitat management purposes in U.S. waters from Alaska to the Gulf of Maine, cable and pipeline inspection and pre-lay surveys in the Eastern Atlantic Ocean, the North Sea and Mediterranean Sea, and most recently as a Physical Scientist for OER sailing on *Okeanos Explorer* as it explores U.S. and international waters around the world. So far this has included Indonesia, Guam, Hawaii, California, the Galapagos Spreading Center, the Mid-Cayman Rise, the Gulf of Mexico, and the U.S. Atlantic continental margin. Meme obtained a Master of Marine Affairs degree from the University of Rhode Island in 2008, and a Bachelor of Arts in Environmental Studies from The George Washington University in 2000. Her interests in her current position include maximizing offshore operational efficiency in order to provide large amounts of high quality data to the public to enable further exploration, focused research, and wise management of U.S. and global ocean resources.

Mashkoor Malik received his M.S. degree from the University of New Hampshire in 2005. Since 2008 he has been working for NOAA as a physical scientist. His current assignment is with NOAA Office of Ocean Exploration and Research (OER). In this capacity, Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the OER supported hydrographic surveys. When not serving on the survey vessels, Mashkoor works at NOAA HQ in Silver Spring. Mashkoor also continues to be a Ph.D. student at the Center, his research focusing on understanding the uncertainty associated with backscatter measurements.

Lindsay McKenna is a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER), where she supports mapping operations aboard the NOAA Ship *Okeanos Explorer.* On shore, Lindsay works out of the Integrated Ocean and Coastal Mapping (IOCM) center, contributing to expeditions through data processing and archiving, operational planning, and mapping product development. Lindsay earned her Sc.B. in Geological Sciences from Brown University in 2007, and her M.S. in Earth Science—Ocean Mapping from the University of New Hampshire in 2013. Prior to her position with OER, Lindsay worked at CCOM as a Project Director for a Super Storm Sandy research project. Before graduate school, Lindsay was employed as a geologist at Malcolm Pirnie, Inc. in New Jersey, where she worked on a variety of water resource projects.

Glen Rice started with the Center as a Lieutenant (Junior Grade) in the NOAA Corps stationed with at the Joint Hydrographic Center as Team Lead of the Integrated Ocean and Coastal Mapping Center. He had previously served aboard the NOAA Hydrographic Ships *Rude* and *Fairweather* along the coasts of Virginia and Alaska after receiving a M.Sc. in Ocean Engineering at the University of New Hampshire. In 2013, Glen left the NOAA Corps and became a civilian contractor to NOAA. In 2014 Glen became a permanent physical scientist with NOAA. He maintains his position as Team Lead of the ICOM Center at UNH.

Derek Sowers works as a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER) supporting ocean mapping efforts of the NOAA Ship *Okeanos Explorer.* This work involves overseeing other sonar scientists shore-side at JHC/CCOM. Derek is also a part-time Oceanography Ph.D. student at JHC/CCOM with interests in seafloor characterization data collection at sea during ocean exploration expeditions, managing data, ocean habitat mapping, and marine conservation. He has a B.S. in Environmental Science from the University of New Hampshire (1995), and holds an M.S. in Marine Resource Management from Oregon State University (2000) where he completed a NOAA-funded assessment of the, "Benefits of Geographic Information Systems for State and Regional Ocean Management." Derek has thirteen years of previous coastal research and management experience working for NOAA's National Estuarine Research Reserve network and EPA's National Estuary Program in both Oregon and New Hampshire. Derek has participated in ocean research expeditions in the Arctic Ocean, Gulf of Maine, and Pacific Northwest continental shelf.

Sarah Wolfskehl is a Hydrographic Data Analyst with NOAA's Super Storm Sandy contract at the IOCM Center. She is located at the Joint Hydrographic Center to utilize the Center's research to improve and diversify the use of hydrographic data across NOAA in support of Integrated Ocean and Coastal Mapping projects. Previously, Sarah worked as a Physical Scientist for NOAA's Office of Coast Survey in Seattle, WA. Sarah has a B.A. in Biology from The Colorado College.

Other Affiliated Faculty

Brad Barr received a B.S. from the University of Maine, an M.S. from the University of Massachusetts, and a Ph.D. from the University of Alaska. He is currently a Senior Policy Advisor in the NOAA Office of National Marine Sanctuaries, Affiliate Professor at the School of Marine Sciences and Ocean Engineering at the University of New Hampshire, and a Visiting Professor at the University Center of the Westfjords in Iceland. He is a member of the IUCN World Commission on Protected Areas, the International Committee on Marine Mammal Protected Areas/IUCN Marine Mammal Protected Areas Task Force. He has served on the Boards of Directors of the George Wright Society in the U.S., the Science and Management of Protected Areas Association (SAMPAA) in Canada, and, currently, on the Board of Directors of the Coastal Zone Canada Association (CZCA). He also serves on the Editorial Board of the World Maritime University Journal of Maritime Affairs. He has published extensively on marine protected areas science and management, whaling and maritime heritage preservation, with a primary research focus on the identification and management of ocean wilderness.

Jonathan Beaudoin earned his undergraduate degrees in Geomatics Engineering and Computer Science from the University of New Brunswick (UNB) in Fredericton, NB, Canada. He continued his studies at UNB under the supervision of Dr. John Hughes Clarke of the Ocean Mapping Group and after completing his Ph.D. studies in the field of refraction related echo sounding uncertainty, Jonathan took a research position at JHC/CCOM in 2010. While there, he carried on in the field of his Ph.D. research and joined the ongoing seabed imaging and characterization efforts. He also played a leading role in establishing the Multibeam Advisory Committee, an NSF-funded effort to provide technical support to seabed mapping vessels in the US academic fleet. Jonathan returned to Canada in late 2013 where he joined the Fredericton, NB office of QPS.

Margaret Boettcher received a Ph.D. in Geophysics from the MIT/WHOI Joint Program in Oceanography in 2005. She joined JHC/CCOM in 2008 as a post-doctoral scholar after completing a Mendenhall Postdoctoral Fellowship at the U.S. Geological Survey. Although she will continue to collaborate with scientists at JHC/CCOM indefinitely, Margaret also is, since 2009, a member of the faculty in the Earth Science Department at UNH. Margaret's research focuses on the physics of earthquakes and faulting and she approaches these topics from the perspectives of seismology, rock mechanics, and numerical modeling. Margaret seeks to better understand slip accommodation on oceanic transform faults. Recently she has been delving deeper into the details of earthquake source processes by looking at very small earthquakes in deep gold mines in South Africa.

Dale Chayes has been an active instrument developer, troubleshooter, and operator in the oceanographic community since 1973 and has participated in well over a hundred and fifty field events. He has worked on many projects including hull mounted multibeams, submarine (SCAMP) and deep-towed mapping sonars (SeaMARC I), real-time wireless data systems, database infrastructure for digital libraries (DLESE) and marine geoscience data (MDS), satellite IP connectivity solutions (SeaNet), GPS geodesy, trace gas water samplers, precision positioning systems and backpack mounted particle samplers. In his spare time he is a licensed amateur radio operator, Wilderness EMT/NREMT and is in training (with his dog Frodo) for K9 wilderness search and rescue.

John Hall spent his sabbatical from the Geological Survey of Israel with the Center. John has been a major influence in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

Martin Jakobsson joined the group in August of 2000 as a Post-Doctoral Fellow. Martin completed a Ph.D. at the University of Stockholm where he combined modern multibeam sonar data with historical single-beam and other data to produce an exciting new series of charts for the Arctic Ocean. Martin has been developing robust techniques for combining historical data sets and tracking uncertainty as well as working on developing approaches for distributed database management and Law of the Sea issues. Martin returned to a prestigious professorship in his native Sweden in April 2004 but remains associated with the Center.

Xavier Lurton graduated in Physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in Applied Acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as an R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989 he joined IFREMER (the French government agency for Oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (data transmission, fisheries sonar, ocean tomography, etc.). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (both in physical modeling and in sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson); in this context he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer), heavily based on his own experience as a teacher. He manages the IFREMER team specialized in underwater acoustics, and has been the Ph.D. advisor of about 15 students. He spent six months as a visiting scholar at UNH in 2012, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

Christopher Parrish holds a Ph.D. in Civil and Environmental Engineering with an emphasis in geospatial information engineering from the University of Wisconsin-Madison and an M.S. in Civil and Coastal Engineering with an emphasis in geomatics from the University of Florida. His research focuses on full-waveform lidar, topographic-bathymetric LIDAR, hyperspectral imagery, uncertainty modeling, and UAVs for coastal applications. Parrish is the Director of the American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Division and associate editor of the journal Marine Geodesy. Prior to joining Oregon State University, he served as lead physical scientist in the Remote Sensing Division of NOAA's National Geodetic Survey and affiliate professor at JHC/CCOM.

Kurt Schwehr received his Ph.D. from Scripps Institution of Oceanography studying Marine Geology and Geophysics. Before joining the Center, he worked at JPL, NASA Ames, the Field Robotics Center at Carnegie Mellon, and the USGS Menlo Park. His research has included components of computer science, geology, and geophysics. He looks to apply robotics, computer graphics, and real-time systems to solve problems in marine and space exploration environments. He has been on the mission control teams for the Mars Pathfinder, Mars Polar Lander, Mars Exploration Rovers and Mars Science Laboratory. He has designed computer vision, 3D visualization, and on-board driving software for NASA's Mars exploration program. Fieldwork has taken him from Yellowstone National Park to Antarctica. At the Center, he was working on a range of projects including the Chart of the Future, visualization techniques for underwater and space applications, and sedimentary geology. He has been particularly active in developing hydrographic applications of AIS data. Kurt is currently Head of Ocean Engineering at Google and an affiliate faculty in the Center.

Arthur Trembanis is the director of the Coastal Sediments, Hydrodynamics and Engineering Laboratory (CSHEL) in the College of Earth, Ocean, and Environment at the University of Delaware. The work of CSHEL involves the development and utilization of advanced oceanographic instrumentation, particularly autonomous underwater vehicles for seafloor mapping and benthic habitat characterization. He received a bachelor's degree in Geology from Duke University in 1998, a Fulbright Fellowship at the University of Sydney in 1999, and a Ph.D. in Marine Sciences from the Virginia Institute of Marine Sciences in 2004. He is presently a visiting professor at the University of Ferrara.

Lysandros Tsoulos is an Associate Professor of Cartography at the National Technical University of Athens. Lysandros is internationally known for his work in digital mapping, geoinformatics, expert systems in cartography, and the theory of error in cartographic databases. At the Center, Lysandros worked with NOAA student Nick Forfinski exploring new approaches to the generalization of dense bathymetric data sets.

Dave Wells is world-renowned in hydrographic circles. Dave is an expert in GPS and other aspects of positioning, providing geodetic science support to the Center. Along with his time at UNH, Dave also spends time at the University of New Brunswick and at the University of Southern Mississippi where he is participating in their hydrographic program. Dave also helps UNH in its continuing development of the curriculum in hydrographic training.

Visiting Scholars

Since the end of its first year, the Center has had a program of visiting scholars that allows us to bring some of the top people in various fields to interact with Center staff for periods of between several months and one year.

Jorgen Eeg (October–December 2000) is a senior researcher with the Royal Danish Administration of Navigation and Hydrography and was selected as our first visiting scholar. Jorgen brought a wealth of experience applying sophisticated statistical algorithms to problems of outlier detection and automated cleaning techniques for hydrographic data.

Donald House (January–July 2001) spent his sabbatical with our visualization group. He is a professor at Texas A&M University where he is part of the TAMU Visualization Laboratory. He is interested in many aspects of the field of computer graphics, both 3D graphics and 2D image manipulation. Recently his research has been in the area of physically based modeling. He is currently working on the use of transparent texture maps on surfaces.

Rolf Doerner (March–September 2002) worked on techniques for creating self-organizing data sets using methods from behavioral animation. The method, called “Analytic Stimulus Response Animation,” has objects operating according to simple behavioral rules that cause similar data objects to seek one another and dissimilar objects to avoid one another.

Ron Boyd (July–December 2003) spent his sabbatical at the Center. At the time, Ron was a Professor of Marine Geology at the University of Newcastle in Australia and an internationally recognized expert on coastal geology and processes. He is now an employee of Conoco-Phillips Petroleum in Houston. Ron’s efforts at the Center focused on helping us interpret the complex, high-resolution repeat survey data collected off Martha’s Vineyard as part of the ONR Mine Burial Experiment

John Hall (August 2003-October 2004) See Dr. Hall’s biography under Affiliate Faculty.

LCDR Anthony Withers (July–December 2005) was the Commanding Officer of the HMAS Ships *Leeuwin* and *Melville* after being officer in charge of the RAN Hydrographic School in Sydney, Australia. He also has a Masters of Science and Technology in GIS Technology and a Bachelor of Science from the University of New South Wales. LCDR Withers joined us at sea for the Law of the Sea Survey in the Gulf of Alaska and upon returning to the Center focused his efforts on developing uncertainty models for phase-comparison sonars.

Walter Smith (November 2005–July 2006) received his Ph.D. in Geophysics from Columbia University's Lamont-Doherty Earth Observatory in 1990. While at Lamont, he began development of the GMT data analysis and graphics software. From 1990-92 he held a post-doctoral scholarship at the University of California, San Diego's Scripps Institution of Oceanography in the Institute for Geophysics and Planetary Physics He joined NOAA in 1992 and has also been a lecturer at the Johns Hopkins University, teaching Data Analysis and Inverse Theory. Walter's research interests include the use of satellites to map the Earth's gravity field, and the use of gravity data to determine the structure of the sea floor and changes in the Earth's oceans and climate.

Lysandros Tsoulos (January-August 2007) See Dr. Tsoulos's biography under Affiliate Faculty.

Jean-Marie Augustin (2010) is a senior engineer at the Acoustics and Seismics Department of IFREMER focusing on data processing and software development for oceanographic applications and specializing in sonar image and bathymetry processing. His main interests include software development for signal, data and image processing applied to seafloor-mapping sonars, featuring bathymetry computation algorithms and backscatter reflectivity analysis. He is the architect, designer and main developer of the software suite, *SonarScope*.

Xabier Guinda (2010) is a Postdoctoral Research Fellow at the Environmental Hydraulics Institute of the University of Cantabria in Spain. He received a Ph.D. from the University of Cantabria. His main research topics are related to marine benthic ecology (especially macroalgae), water quality monitoring and environmental assessment of anthropogenically disturbed sites as well as the use of remote sensing hydroacoustic and visual techniques for mapping of the seafloor and associated communities. His stay at the Center was sponsored by the Spanish government.

Sanghyun Suh (2010) is a Senior Research Scientist at the Maritime and Ocean Engineering Research Institute (MOERI) at the Korea Ocean Research and Development Institute (KORDI) in Daejeon, Republic of Korea (South Korea). Dr. Suh received his Ph.D. from the University of Michigan in GIS and Remote Sensing. He worked with Dr. Lee Alexander on e-Navigation research and development (R&D) related to real-time and forecast tidal information that can be broadcast via AIS binary application-specific messages to shipborne and shore-based users for situational awareness and decision-support.

Xavier Lurton (August 2010–March 2012) See Dr. Lurton's biography under Affiliate Faculty.

Seojeong Lee (April 2012–April 2013) received her Ph.D. in Computer Science with an emphasis on Software Engineering from Sookmyung Women's University in South Korea. She completed an expert course on Software Quality at Carnegie Mellon University. With this software engineering background, she has worked at the Korea Maritime University as an Associate Professor since 2005 where her research has been focused on software engineering and software quality issues in the maritime area. As a Korean delegate of the IMO NAV sub-committee and IALA e-NAV committee, she is contributing to the development of e-navigation. Her current research topic is software quality assessment of e-navigation, and development of e-navigation portrayal guidelines. Also, she is interested in AIS ASM and improvement of NAVTEX message.

Gideon Tibor (April 2012–November 2012) Gideon Tibor was a visiting scholar from the Israel Oceanographic & Limnological Research Institute and the Leon H. Charney School of Marine Sciences in the University of Haifa. Gideon received his Ph.D. in Geophysics & Planetary Sciences from Tel-Aviv University. His main research interest is the development and application of high-resolution marine geophysics and remote sensing using innovative methods in the study of phenomena that influence the marine environment and natural resources. By means of international and local competitive research grants, he uses a multi-disciplinary approach for studying the Holocene evolution of the Levant margin, the Sea of Galilee, and the northern Gulf of Eilat/Aqaba.

Facilities, IT and Equipment

Office and Teaching Space

The Joint Hydrographic Center at UNH has been fortunate to have equipment and facilities that are unsurpassed in the academic hydrographic community. Upon the initial establishment of the Center at UNH, the University constructed an 8,000-square-foot building dedicated to the JHC/CCOM and attached to the unique Ocean Engineering high-bay and tank facilities already at UNH. Since that time, a 10,000-square-foot addition has been constructed (through NOAA funding), resulting in 18,000 square feet of space dedicated to JHC/CCOM research, instruction, education, and outreach activities (Figure 1-1).

Figure 1-1. Aerial view of Chase Ocean Engineering Lab and the NOAA/UNH Joint Hydrographic Center.

Of this 18,000 square feet of space, approximately 4,000 square feet are dedicated to teaching purposes and 11,000 square feet to research and outreach, including office space. Our teaching classroom can seat 45 students and has two high-resolution LCD projectors capable of widescreen display. There are 34 offices for faculty or staff. With the influx of NOAA OER, IOCM and Super Storm Sandy personnel, the Center is now providing office space for 16 NOAA personnel. The Center has 27 student cubicles (seven of which are for GEBCO students) and we typically have two or three NOAA students. Two additional NOAA cubicles are available for NOAA Marine Operations Center employees at the pier support facility in New Castle (see below).

Laboratory Facilities

Laboratory facilities within the Center include a map room with light tables and map-storage units. The Center has a full suite of printers and plotters including two 60-inch, large format color plotters. Users have the ability to scan documents and charts up to 54 inches using our wide format, continuous feed, high-resolution scanner. The Center has begun to phase out single-function laser printers in favor of fewer, more efficient multi-function printers capable of printing, scanning, copying, and faxing documents. A UNH-contracted vendor provides all maintenance and supplies for the printers, reducing overall costs.

The Center's Presentation Room houses the Telepresence Console (Figure 1-2) as well as the Geowall, a high-resolution multi-display system. The IT Group upgraded the Geowall in early 2013, replacing a seven-node Linux cluster with a single Windows 7 system capable of driving all twelve displays. Previously, the Geowall could only be utilized for a single application. In its present form, it can be utilized for multiple purposes, including, but not limited to, the display of additional video streams from Telepresence-equipped UNOLS vessels, as well as educational and outreach purposes. The hardware for the Telepresence Console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video, three 42-inch LG HDTV displays through which the streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints (Figure 1-2). The multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Presentation Room are connected to an Eaton Powerware UPS to protect against power surges and outages. Over the last several field seasons, JHC/CCOM has joined forces with the NOAA vessel *Okeanos Explorer* and the Ocean Exploration Trust's vessel *Nautilus* on their respective research cruises. Both vessels have had successful field seasons each year since 2010 utilizing the Telepresence technology to process data and collaborate with scientists and educators ashore. The success has led to increased interest in deploying the technology to other vessels in the UNOLS fleet in 2016–2017. The Center IT Group expects to utilize both the Telepresence Console and the Geowall to support these additional initiatives.

Figure 1-2. The Telepresence Console in action.

The Center's Computer Classroom consists of 15 Dell workstations, upgraded in the summer of 2014 (Figure 1-3). A ceiling-mounted NEC high-resolution projector is used to provide classroom instruction. All training that requires the use of a computer system is conducted in this room. Students also frequently use the classroom for individual study and collaborative projects. In addition to these purposes, a high-resolution camera allows for web conferencing and remote teaching.

The Center Video Classroom also provides for web conferencing, remote teaching, and the hosting of webinars via Citrix GoToMeeting. The IT Group collaborates with the Center seminar organizers to provide both live webinar versions of the Center Seminar Series, as well as video and audio archives available through the web after each event. Building on the success of the 2011 through 2015 seminar series, the IT Group continues to make improvements to both the quality and accessibility of these seminars through better video and audio hardware, as well as distribution of the finished product through the Center website, Vimeo, and YouTube.

The Center's Visualization Lab includes a new immersive display that was inspired by, and expands upon, Google's Liquid Galaxy system. The display is made up of five 60-inch, vertically mounted LED monitors that are arranged in a 120-degree arc (Figure 1-4). This new display and its applications will be discussed further in the Visualization section of the report. The Visualization Lab also has a custom multi-touch stereoscopic viewing environment for visualizing oceanographic flow model output, force-feedback and six-degree-of-freedom tracking devices, and a Minolta LS-100 luminance meter.

We have also built a Lidar Simulator Lab, providing a secure and safe environment in which to perform experiments with our newly constructed Lidar Simulator. The Center also maintains a full suite of survey, testing, electronic, and positioning equipment.

The Center is co-located with the Chase Ocean Engineering Lab. The Lab contains a high-bay facility that includes extensive storage and workspace in a warehouse-like environment. The high bay consists of two interior work bays and one exterior work bay with power, lights, and data feeds available throughout. A 5000-lb. capacity forklift is available.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 10 ft. deep. It provides a 90-foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geo-textile construction that has an average 92% efficiency in the specified frequency range. The wave-maker software allows tank users to develop regular or random seas using a variety of spectra. A user interface, written in LabView, resides on

Figure 1-3. CCOM Computer Teaching Lab was equipped with new computers and displays in 2014.

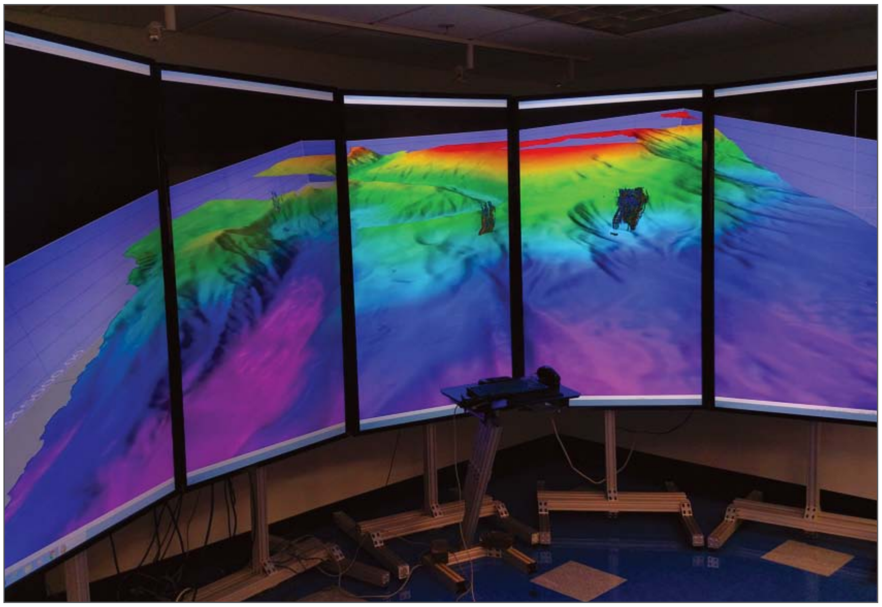


Figure 1-4. Semi-immersive, large-format tiled display.

the main control station PC and a wireless LAN network allows for communication between instrumentation and data acquisition systems. Data acquisition has been vastly improved with 32 channels of analog input, 4 channels of strain measurement, and Ethernet and serial connectivity all routed through shielded cabling to the main control computer. Power is available on the carriage in 120 or 240 VAC. In 2015, the wave-maker was repaired and the wave-tank saw 114 days of use of which 20% was Center-specific work.

The engineering tank is a freshwater test tank 60 ft. long by 40 ft. wide with a nominal depth of 20 ft. The 380,000 gallons that fill the tank are filtered through a 10-micron sand filter twice per day providing an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH SCUBA course, many of the OE classes in acoustics and buoy dynamics, as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20-foot span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmitting voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1 degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2015, the engineering tank saw 136 days of use of which 58% were dedicated to Center activities.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 750 sq. ft., fully equipped electronics lab provides a controlled environment for the design, building, testing, and repair of electronic hardware. A separate student electronics laboratory is available to support student research. A 720 square foot machine shop equipped with a milling machine, a tool-room lathe, a heavy-duty drill press, large vertical and horizontal band saws, sheet metal shear and standard and arc welding capability are available for students and researchers. A secure facility for the development and construction of a state-of-the-art ROV system has been constructed for our collaboration with NOAA's Ocean Exploration Program. A 12 ft. x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist/engineer is on staff to support fabrication activities. This past year we have repurposed the “ROV Lab” for support of autonomous vehicles.

Pier Facilities

In support of the Center and other UNH and NOAA vessels, the University recently constructed a new pier facility in New Castle, NH. The new pier is a 328-foot long, 25-foot wide concrete structure with approximately 15 feet of water alongside. The pier can accommodate UNH vessels and, in 2013, became the homeport for the new NOAA Ship *Ferdinand R. Hassler*, a 124-foot LOA, 60-foot breadth, Small Waterplane Area Twin Hull (SWATH) Coastal Mapping Vessel (CMV)—the first of its kind to be constructed for NOAA. Services provided on the new pier include 480V-400A and 208V- 50A power with TV and telecommunications panel, potable water and sewerage connections. In addition to the new pier, the University constructed a new pier support facility—approximately 4,500 square feet of air-conditioned interior space including offices, a dive locker, a workshop, and storage. Two additional buildings (1,100 square feet and 1,300 square feet) are available for storage of the variety of equipment and supplies typically associated with marine operations.

Information Technology

The IT Group currently consists of three full-time staff members, a part-time web developer, and two part-time help desk staff. Jordan Chadwick fills the role of Systems Manager and deals primarily with the day-to-day administration of the Center network and server infrastructure. He is also responsible for leading the development of the Information Technology strategy for the Center. The Systems Administrator, William Fessenden, is responsible for the administration of all Center workstations and backup systems. In addition, William serves as Jordan's backup in all network and server administration tasks and contributes to the planning and implementation of new technologies at the Center. Paul Johnson, the Center's Data Manager, is responsible for organizing and cataloging the Center's vast data stores. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and Federal standards. Jennifer Crosby, the Center web developer, is responsible for developing and maintaining the external and internal websites maintained in the Center.

IT facilities within Chase Ocean Engineering Lab consist of two server rooms, a laboratory, the Presentation Room, Computer Classroom, and several staff offices. The server room in the south wing of the building is four times larger than its counterpart in the north wing, and has the capacity to house 14 server racks. This space, combined with the north-wing server room, give the Center's data centers the capacity to house 20 full-height server racks. Both server rooms are equipped with redundant air conditioning, temperature and humidity monitoring, security cameras, and FE-227 fire suppression systems. Additionally, the larger of the server rooms employs a natural gas generator to provide power in the event of a major outage. The IT lab provides ample workspace for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

All Center servers, storage systems, and network equipment are consolidated into nine full height cabinets with one or more Uninterruptible Power Supplies (UPS) per cabinet. At present, there are a total of 19 physical servers, 40 virtual servers, two NetApp storage systems fronting eight disk arrays, two compute clusters consisting of 15 nodes combined. A Palo Alto Networks PA-3020 next-generation firewall provides boundary protection for our 10-gigabit and gigabit Local Area Network (LAN). Center also hosts four dedicated servers for NOAA's nowCOAST Web Mapping Portal, which mirror the primary nowCOAST web and database servers, currently hosted in Silver Spring, MD.

At the heart of the Center's network lies its robust networking equipment. A Dell/Force10 C300 switch serves as the core routing and switching device on the network. It is currently configured with 192 gigabit Ethernet ports, all of which support Power over Ethernet (PoE), as well as 24 10-gigabit Ethernet ports. The 10-gigabit ports provide higher-throughput access to network storage and the Center's compute cluster. A Brocade ICX 6610 switch stack provides an aditional192 gigabit Ethernet ports for workstation connectivity and 32 10-gigabit Ethernet ports, to be used for access to the network backbone as well as for certain workstations needing high-speed access to storage resources. These core switching and routing systems are supplemented with several edge switches, consisting of a Dell PowerConnect 2924 switch, a Dell PowerConnect 2848, four Brocade 7131N wireless access points centrally managed with a Brocade RFS4000 management device, and a QLogic SANBox 5800 Fibre Channel switch. The PowerConnect switches handle edge applications such as the Center's Electronics Laboratory, and out-of-band management for servers and network equipment. The SANBox 5800 provides Fibre Channel connectivity to the Storage Area Network for backups and high-speed server access to storage resources. The C300 PoE ports power the wireless access points as well as the various Axis network cameras used to monitor physical security at Chase Lab. The Brocade wireless access points provide wireless network connectivity for both employees and guests. Access to the internal wireless network is secured through the use of the 802.1x protocol utilizing the Extensible Authentication Protocol (EAP) to identify wireless devices authorized to use the internal wireless network.

Increasing efficiency and utilization of server hardware at JHC/CCOM remains a top priority. The Center has set out to virtualize as many servers as possible, and to use a "virtualize-first" method of implementing new servers and services. To this end, the IT staff utilizes a three host VMware ESXi cluster managed as a single resource with VMware vSphere. The cluster utilizes VMware High Availability and vMotion to provide for a flexible platform for hosting virtual machines. All virtual machines in the cluster are stored in the Center's high-speed SAN storage system, which utilizes snapshots for data protection and deduplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems house 40 virtual servers at present, and plans are in place to virtualize more servers as current physical servers reach the end of their hardware lifecycle. Current virtual machines include the Center email server, email security appliance, CommVault Simpana management server, Visualization Lab web server, Certification Authority server, several Linux/Apache web servers, a Windows Server 2008 R2 domain controller, version control server, a JIRA project management server, a FTP server, Skype for Business 2015 real-time collaboration server, an Oracle database server, and two ESRI ArcGIS development/testing servers.

Figure 1-5. Center SAN and NAS infrastructure in the primary server room.

The Center's storage area network (SAN) systems currently consist of a NetApp FAS3240 cluster, and a NetApp FAS3140 storage appliance (Figure 1-5). The FAS3240 currently hosts 128 terabytes (TB) of raw storage and is capable of expanding to nearly 2 petabytes (PB). The FAS3240 also supports clustered operation for failover in the event of system failure, block-level de-duplication to augment efficiency of disk usage, and support for a number of data transfer protocols, including iSCSI, Fibre Channel, NFS, CIFS, and NDMP. Center IT staff also built, configured, and installed a custom-built locally-redundant NAS storage system in the first quarter of 2013. This storage system is used to supplement the NetApp SAN by moving less critical datasets onto a less expensive medium. In the three years this system has been in use, it has proven a popular and reliable option for large, static data sets and as such, the disk drives in the array were upgraded to increase the available storage to 75TB. The IT Staff utilizes Microsoft's Distributed File System (DFS) to organize all SAN and NAS data shares logically by type. In addition to DFS, a custom metadata cataloging web application was developed to make discovering and searching for data easier for both IT Staff and the Center as a whole.

Constantly increasing storage needs create an ever increasing demand on the Center's backup system. To meet these demands, the IT Group utilizes a CommVault Simpana backup solution which consists of two physical backup servers, three media libraries, and backup control and management software. The system provides comprehensive protection for workstation, server, and storage systems. The system utilizes deduplicated disk-to-disk backup in addition to magnetic tape backup, providing two layers of data security and allowing for more rapid backup and restore capabilities. For magnetic tape backup, the IT Group utilizes a Dell PowerVault TL4000 LTO6 tape library, capable of backing up 250TB of data without changing tapes. This library doubles the capacity and speed of the Quantum Scalar i40 tape library, which was previously used for NDMP backups, and has since been reallocated to back up the Center's server and workstation environments. The IT group completed a major version change migrating from Simpana 9 to Simpana 10 this spring, which adds support for the latest desktop and server operating systems and virtual server hypervisors.

The Center network is protected by a new Palo Alto Networks PA-3020 next-generation firewall. The firewall provides for high-performance packet filtering, intrusion prevention, malware detection, and malicious URL filtering. The former Cisco ASA 5520 firewall serves as a remote access gateway, providing SSL VPN access. With the remote access solution, users are able to join their local computer to the Center network from anywhere in the world, allowing them to use many of the Center's network-specific resources on their local computer.

The IT Group recently implemented a new eight-node compute cluster acquired from Dell, running Windows HPC Server 2012 (Figure 1-6). The new cluster utilizes eight enterprise-class servers with 20 CPU cores and 64 GB of RAM per system, totaling 160 CPU cores and 512 GB of RAM. The cluster is used for resource-intensive data processing, which frees up scientists' workstations while data is processed, allowing them to make more efficient use of their time and resources. The new cluster runs MATLAB DCS, and is used as the test-bed for developing a next-generation, parallel-processing software system with Industrial Consortium partners. The former cluster hardware, installed in 2008, sees continued use as a test environment for a variety of parallel processing applications.

The Center has continued to upgrade end users' primary workstations, as both computing power requirements, and the number of employees and students have increased. There are currently 253 high-end Windows and Linux desktops/laptops, as well as

Figure 1-6. Dell computer cluster in its rack; installed in 2014.

28 Apple Mac OSX computers that serve as faculty, staff, and student workstations. All Windows workstations at the Center are running 64-bit versions of Windows 7 Professional, Windows 8.1 Pro, or Windows 10 Pro. Apple Mac OSX versions 10.10 and 10.11 are widely used throughout the Center.

The Center also maintains a network at the Pier Support Building at UNH's Coastal Marine Lab facility in New Castle, NH. The Center network is extended through the use of a Cisco ASA VPN device. This allows for a permanent, secure network connection over public networks between the support building and the Center's main facility at Chase Lab on the UNH campus. The VPN connection allows the IT Group to easily manage the Center's systems at the facility using remote management and, conversely, systems at the facility have access to resources at Chase Lab. Both of the current Center research vessels are located at the pier adjacent to the Pier Support Building. The new Center research vessel, R/V Gulf Surveyor will also be moored at this location. The IT Group maintains computer systems and local networks on both the R/V *Coastal Surveyor* and the R/V *Cocheco*. Both launches also have access to wireless network connectivity through the Coastal Marine Lab. The *Cocheco*'s systems were upgraded for the 2014 field season, and the *Coastal Surveyor*'s systems were upgraded in time for the 2015 season. As with the Center's existing vessels, the IT Group will provision and support the computing and networking needs aboard the R/V Gulf Surveyor.

In September of 2013, UNH received a grant from the National Science Foundation intended to improve campus cyber infrastructure. The express intent of the grant was to improve bandwidth and access to Internet2 resources for scientific research. The Center was identified in the grant as a potential beneficiary of such improved access. The project is currently in the operational stage, providing a 20-gigabit connection to UNH's Science DMZ, and from there a 10-gigabit connection to Internet2. This improvement allows the researchers at the Center to collaborate with NOAA and other partners through the use of high-bandwidth data transfers, streaming high-definition video, and other bandwidth intensive applications. The Center IT Group will test data transfers to the regular UNH campus and to other educational and/or research institutions in early 2016.

Information security is of paramount importance for the IT Group. Members of the Center staff have been working with NOS and OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and Center systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. Recent measures taken to enhance security include the installation of a virtual appliance-based email security gateway, designed to reduce the amount of malicious and spam email reaching end users. A next-generation firewall/threat management appliance was installed in May of 2015 to replace the Center's former firewall/IPS hardware.

The Center utilizes Avira AntiVir antivirus software to provide virus and malware protection on individual servers and workstations. Avira server software allows for centralized monitoring and management of all Windows and Linux systems on the Center network. The AntiVir solution is supplemented by Microsoft ForeFront EndPoint Protection for systems dedicated to field work that do not have the ability to check-in with the management server on a periodic basis. Microsoft Windows Server Update Services (WSUS) is used to provide a central location for Center workstations and servers to download Microsoft updates. WSUS allows the IT staff to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems.

In an effort to tie many of these security measures together, the IT Group utilizes Nagios for general network and service monitoring. Nagios not only provides for enhanced availability of services for internal Center systems, but has been a boon for external systems that are critical pieces of several research projects, including AIS ship tracking for the U.S. Coast Guard. In the spring of 2015, the server formerly dedicated to Nagios service monitoring and log aggregation was replaced with a new Dell server offering larger and faster internal hard drives, a faster CPU, and increased memory. A new security event management system, utilizing Open Source Security (OSSEC) and Splunk, was implemented as part of the migration to the new server hardware. OSSEC performs threat identification, and log analysis. Splunk is used for data mining and event correlation across systems and platforms.

To ensure physical security, Chase Ocean Engineering Lab utilizes a biometric door access system, which provides 24/7 monitoring and alerting of external doors and sensitive IT areas within the facility. The primary data center utilizes two factor authentication to control physical access. Security cameras monitor the data center as well as the network closet in the building. Dual-redundant environment monitoring systems, managed internally at the Center and centrally through UNH Campus Energy, keep tabs on the temperature and humidity sensors in the data center and network closet.

The IT Group utilizes Request Tracker, a helpdesk ticket tracking software published by Best Practical. Center staff, students, and faculty have submitted over 10,000 Request Tracker tickets since its inception in mid-2009. Throughout 2015, the IT Staff was able to resolve 90% of tickets within three days. The software is also used for issue tracking by the Center administrative staff, lab and facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee project.

Center continues to operate within a Windows Active Directory domain environment, and in early 2012, migrated the majority of its domain services to 2008 R2 Active Directory running on Windows Server 2008 R2. A functional 2008 R2 domain allows the IT Group to take advantage of hundreds of new security and management features available on Windows 7 and Windows 8 operating systems. The Windows 2008 Active Directory servers also provide DHCP, DNS, and DFS services. Policies can be deployed via Active Directory objects to many computers at once, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, the JHC/CCOM IT Group maintains all NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the JHC with enhanced security and data protection.

The Center currently utilizes two separate version control mechanisms on its version control virtual server—Subversion (SVN) and Mercurial (Hg). The Mercurial system went online in 2011 and presently, the Center IT Group encourages developers to use Mercurial for new projects, while continuing to support Subversion for existing projects. Mercurial uses a decentralized architecture which is less reliant on a central server, and also permits updates to repositories without direct communication to that server. This allows users in the field to continue software development while still maintaining version history. The IT Group hosts a Jira software project management server to aid in tracking bugs and new features for software projects.

The Center also utilizes Bitbucket to facilitate software collaboration between its own members as well as industrial partners and other academic colleagues. Bitbucket is a source control management solution that hosts Mercurial and Git software repositories. Atlassian, the company behind Bitbucket, states that Bitbucket is SAS70 Type II compliant and is also compliant with the Safe Harbor Privacy Policy put forth by the U.S. Department of Commerce.

The Center website, re-launched in 2012, utilizes the Drupal content management system as its framework. Drupal allows for content providers within the Center to make changes and updates without the assistance of a web developer. The flexibility of the framework was utilized for the creation of a data content portal, which can dynamically serve any dataset hosted through JHC's ArcGIS Server. Additionally, the website offers a more robust platform of multimedia and other rich content, as well as a polished look and feel. The Center IT Group is planning to migrate from Drupal 7, the current website framework, to Drupal 8 in the next calendar year.

Figure 1-7. R/V *Coastal Surveyor* with bow ram.

Work continues on the development of Center-wide Intranet services using the Drupal content management software. The Intranet provides a centralized framework for a variety of information management tools, including the Center's wiki, purchase tracking, library, data catalog, and progress reporting systems. The progress reporting system is entering its fourth reporting period and has greatly improved the efficiency and completeness of the Center's annual report. Additionally, development continues on the Center's ArcGIS server. As this resource evolves, more Intranet services will be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services.

Research Vessels and Platforms

The Center operates two dedicated research vessels (Figures 1-7 and 1-8), the 40-foot R/V *Coastal Surveyor* (JHC/CCOM owned and operated) and the 34-foot R/V *Cocheco* (NOAA owned and JHC/CCOM maintained and operated). In 2015, the *Coastal Surveyor* operated seven months of the year with much of its operations supporting a range of lab-based experiments and focused on collecting data in support of the Summer Hydrography Field Course. The *Coastal Surveyor* is also often used by our industrial partners to test their sonar systems over the well-known Portsmouth Harbor Shallow Survey Common Data Set field area. As will be detailed below, the *Coastal Surveyor* is nearing the end of its useful service and, in 2015, we began the process of replacing it. The *Cocheco* operated for five months, focusing on over the side operations such as deploying buoys and bottom mounted instruments, bottom sampling, and towing instruments. The vessels are operated primarily in the area of Portsmouth, New Hampshire, but are capable of transiting and operating from Maine to Massachusetts. Neither vessel is designed for offshore operations; they are ideally suited to near-shore and shallow water (in as little as four meters depth).

The vessels are operated under all appropriate national and international maritime rules as well as the appropriate NOAA small boat rules and those of the University of New Hampshire. Both boats carry life rafts and EPIRBs (Emergency Position Indicating Radio Beacons), electronic navigation systems based on GPS, and radar. Safety briefings are given to all crew, students, and scientists. Random man-overboard and emergency towing exercises are performed throughout the operating season. The Center employs two permanent captains.

In addition to the two research vessels, the Center also has a personal watercraft equipped with differential GPS, single-beam 192-kHz acoustic altimeter, multibeam sonar system, ADCP, and onboard navigation system (CBASS—see SENSORS discussion below) and has partnered with the Blodgett Foundation to help equip a hovercraft (R/H *Sabvabba*) especially outfitted to work in the most extreme regions of the Arctic (see SENSORS discussion below).

R/V *Coastal Surveyor*
(40 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed of 9 knots)

The *Coastal Surveyor* (Figure 1-8) was built by C&C Technologies (Lafayette, LA) approximately thirty years ago on a fiberglass hull design that had been used for U.S. Navy launches. She was built specifically for the purpose of collecting multibeam sonar data, and has a bow ram for mounting sonar transducers without hauling the vessel. C&C operated the *Coastal Surveyor* for a decade and a half, and then made a gift of her to the Center in 2001. She has become a core tool for the Center's operations in New Hampshire and continues to be invaluable to the Center. Thanks to improved hydraulic stabilizers (in 2005), the high precision of boat offset surveys and the remarkably stable transducer mount, she remains one of the finest shallow-water survey vessels in the world. A marine survey was completed in 2008, acknowledging that the vessel is sound but beginning to show her age. The main engine, a 200 BHP Caterpillar diesel with over five thousand hours, although running reliably, does not run efficiently. Minor electrical and plumbing issues were identified in the survey and were addressed. In 2010, the ship's AIS transponder and a new Simrad AP28 autopilot was installed and the HVAC seawater pump and manifold and engine room bilge pump were also replaced. In 2011, the Isuzu-powered 20 kilowatt generator terminally failed and was replaced with a 12 kilowatt Northern Lights generator. Additionally, the degraded engine room soundproofing was replaced along with the hydraulic steering piston and several hydraulic hoses. In 2012, leaking hatches, caulking and gaskets were replaced, and in 2013, along with regular maintenance (e.g., painting, cleaning etc.), the POS/MV antennae were replaced and a new AIRMAR weather sensor, a new navigation transducer, and a pier-side webcam were installed.

In 2014, the seawater pump was replaced with a factory rebuilt pump, all injectors were replaced with factory rebuilt injectors, the seawater/coolant head exchanger was removed, cleaned and re-installed with new hoses, and the after cooler was removed, cleaned and reinstalled. Additionally, the *Coastal Surveyor's* networking capabilities were upgraded. The survey equipment (sonar, position, attitude, etc.) have been connected to a single network through high speed network switches and twenty cables running through the boat. This internal network is extended with an internal WiFi network router. A miniature WiFi -enabled computer (*DreamPlug*) is used to create an intelligent bridge which switches the boat's internal network to either the high speed UNH/NOAA pier WiFi network or the slower and more expensive Verizon MiFi network while out of range on the shore based WiFi. The boat's internal network is automatically connected to the Internet through the most appropriate service.

In anticipation of outfitting a replacement vessel for R/V *Coastal Surveyor* (see below), an extensive documentation project of all systems is underway. The documentation focuses on the design and rational for the configuration of all:

- Navigation devices
- Autopilot
- RADAR
- AIS
- POS/MV attitude and sensor
- Network devices
- Servers and workstations
- Computer video switching and sharing

R/V *Coastal Surveyor* Scheduled Research and Educational Operations for 2015

Month	Days	User
January	0	
January	0	
March	0	
April	1	Seamanship Class
May	1	Seamanship Class
May	7	Kelly Nifong Research Survey
June	15	Summer Hydro Class
July	4	John Kidd Research Survey
July	2	Maintenance
August	2	L3-Klein
September	1	L3-Klein
September	2	Maintenance
December	1	Maintenance
TOTAL	61	

R/V *Cocheco*

(34 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed of 16 knots)

Figure 1-8. R/V *Cocheco*.

R/V *Cocheco* (Figure 1-8) was designed for fast transits and for over-the-stern operations from her A-Frame. Several years ago, a hydraulic system and winch equipped with a multi-conductor cable were installed making the vessel suitable for deploying or towing a wide variety of samplers or sensors. She provides an additional vessel to support sampling and over-the-side operations necessary for our research programs and adds a critical component to our Hydrographic Field Camp.

In 2009, AIS was permanently installed on *Cocheco*, her fluxgate compass was replaced, and improvements made to her autopilot system. In addition, *Cocheco's* 12 VDC power system, hydraulic system wiring and communications wiring were updated. In 2010, a second VHF radio and antenna was installed and several battery banks were replaced and upgraded. In 2013 the *Cocheco* had an extended yard period that, in addition to the annual maintenance, included engine maintenance to improve performance and limit oily exhaust, repairs to the hydraulic steering system, and replacing the non-skid paint on the aft deck.

In 2015, routine preventative maintenance of R/V *Cocheco* was performed (e.g., replacing fluids and filters, cleaning the bilge, having the liferaft inspected, etc.) and unexpected problems were addressed (e.g., replacing the battery charging system, and completing a refit of the hydraulic system which powers her A-frame and winch). R/V *Cocheco* had annual maintenance performed at the boatyard this summer, including new bottom paint and zincs. Routine maintenance and winterization were completed in the fall of 2015.

In 2015, *Cocheco* operated over five months (March through July) and supported 23 days of research programs and the Hydrographic Field Camp. Usage of *Cocheco* was limited beyond July by problems with the hydraulic system.

R/V *Cocheco* Scheduled Research and Educational Operations for 2015

Month	Days	User
March	1	Weber sonar calibration
April	1	Mooring project
May	1	Seamanship Course—buoy operations
May	4	Nifong thesis sampling and video
June	15	Summer Hydro Field Course—SBES, MVP, and sidescan
July	1	Klein testing
TOTAL	55	

New Vessel: R/V *Gulf Surveyor*

It has become increasingly clear that our workhorse survey vessel, the R/V *Coastal Surveyor* is reaching the limit of its useable service and that our other vessel R/V *Cocheco* is not a suitable candidate to take over the role as a sonar-mapping platform. The *Coastal Surveyor's* fiberglass hull is starting to delaminate and a number of drivetrain failures have been encountered, some in hazardous areas with students aboard. The *Coastal Surveyor* has a very small aft deck on top of the cabin, offering very limited structural rigidity and poor access. This prohibits its use with systems such as moving vessel profilers, hindering the ability of the Center to keep abreast with the current state of the art.

Coastal Surveyor is also very limited in her capabilities as an educational platform due to the limited space in the cabin that houses the data acquisition and processing systems. R/V *Coastal Surveyor's* greatest strength is the versatile transducer strut that allows for the robust installation of many different instruments, albeit that the installation of these systems is cumbersome and not without risk. Given this situation, we have embarked on the acquisition of a new vessel that will offer the same versatility for instrument deployment (in a much easier fashion), while providing better cabin space to house students, researchers, and navigation crew.

The new vessel—the R/V *Gulf Surveyor*—has been designed specifically for coastal hydrography and is being constructed by All American Marine, Inc. (AAM) in Bellingham, WA. The overall design is based the success of the R/V *Auk* that AAM built for NOAA in 2006, and the 45-foot R/V *David Folger* built for Middlebury College in 2012. At an overall length of 48 feet and a beam of 18 feet, the catamaran vessel follows an advanced Teknicraft Design, Ltd. (Auckland, New Zealand) pattern (Figure 1-9). This includes a signature hull shape with symmetrical bow, asymmetrical tunnel, and integrated wave piercer. Main propulsion is provided by twin Cummins QSB 6.7 Tier 3 engines rated 250 mhp at 2600 rpm. Auxiliary power is supplied via a Cummins Onan 21.5kW generator. The suite of deck gear includes a hydraulic A-frame, davit, scientific winch, side mount sonar strut, and moon pool with deployable sonar strut.

The vessel is scheduled to be launched in late December 2015—two months ahead of the original plan! Following sea-trials/acceptance in mid-January 2016 at the AAM shipyard, the vessel will be sailed from Bellingham, WA to Victoria, BC (Canada) to await ocean transport to Miami, FL via the Panama Canal during February/March 2016. Afterwards, it will be motor-sailed up the Atlantic Coast via the Inter-Coastal

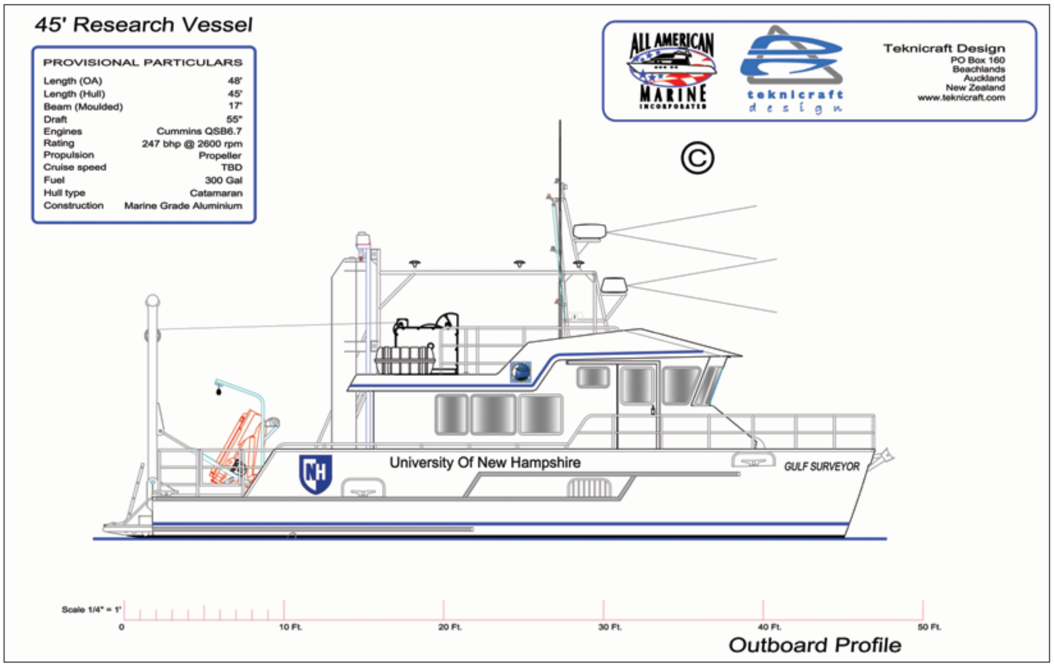


Figure 1-9. Drawing of the new Center research vessel.

Waterway to arrive in at the UNH pier facility in New Castle, NH in April 2016.

After final outfitting, it will join the University's existing fleet and will complement current capabilities by offering a highly-sophisticated, multi-mission platform that will enable the collection of detailed seafloor and water column mapping data. As a multi-mission platform, this includes bottom sampling and ground-truth data that are needed to better understand what sonar mapping systems reveal about the seafloor and ocean environment. Eventually, it is expected that the R/V *Gulf Surveyor* will replace both the R/V *Coastal Surveyor* and R/V *Cocheco*.

Figure 1-10. New Center vessel Gulf Surveyor under construction at All American Marine, Seattle.

CBASS – Very Shallow Water Mapping System

Difficulties working in shallow hazardous waters often preclude accurate measurement of water depth both within the river channel where high flows rapidly change the location of channels, ebb tide shoals, and sand bars, and around rocky shores where submerged outcrops are poorly mapped or uncharted. To address these issues, Tom Lippmann has developed the Coastal Bathymetry Survey System (CBASS; Figure 1-11). In 2012, numerous upgrades were made to the CBASS including the development of full-waveform capabilities for the 192 kHz single beam echosounder on board, the integration and field use of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) for observation of the vertical structure of mean currents in shallow water, particularly around inlets and river mouths where the flows are substantial, and most importantly, the addition of 240 kHz Imagenex Delta-T multibeam echosounder (MBES) with a state-of-the-art inertial measurement unit (IMU). The system was tested over a four week period in May 2012 at New River Inlet, NC, as part of the Office of Naval Research (ONR) sponsored Inlet and River Mouth Dynamics Experiment (RIVET) (Figure 1-12). During RIVET, bathymetric maps were produced at 10-20 cm resolution from multiple overlapping transects in water depths ranging from 1 to 12 m within the inlet. Ultimately, the noise floor of bathymetric maps obtained with the CBASS (after incorporating CUBE uncertainty analysis) was found to be between 2.5 and 5 cm, with the ability to resolve bedforms with wavelengths greater than 30 cm, typical of large ripples and megaripples. A leak and subsequent battery fire in the CBASS late in 2012 kept it out of the field for most of 2013, but it was brought back to operational status in 2014. Improvements include waterproof housings for the batteries, hull reinforcements, improved mountings for the sonars, and new display monitors. Research for a replacement craft has begun.

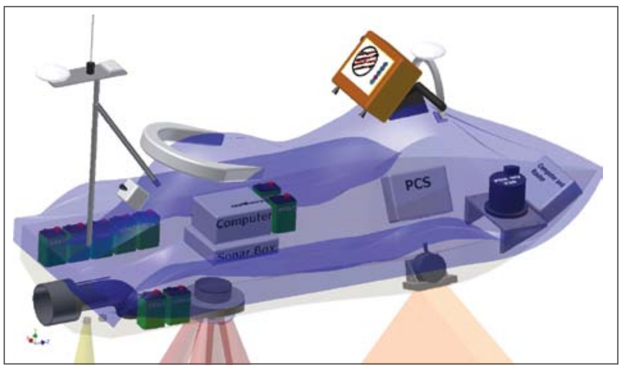


Figure 1-11. CAD drawing (right) showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery packs, GPS and RTK antennae, and navigational display monitor.

Figure 1-12. CBASS surveying in New River Inlet, NC.

Figure 1-12. R/H *Sabvabba*.

R/H *Sabvabaa (Blodgett Foundation)*

Dr. John K. Hall, visiting scholar at the Center in 2003 and 2004 was instrumental in the construction of a hovercraft designed to support mapping and other research in the most inaccessible regions of the high Arctic. The construction of the hovercraft, a 13-meter-long Griffon 2000T called the R/H *Sabvabaa* (Figure 1-12), was underwritten by Dr. Hall's family foundation, the Blodgett Foundation. The vessel has operated out of UNIS, a University Centre in Longyearbyen, Svalbard, since June 2008 under the supervision of Professor Yngve Kristoffersen of the University of Bergen. Through donations from the Blodgett Foundation, the Center provided a Knudsen 12-kHz echosounder, a four-element Knudsen CHIRP sub-bottom profiler and a six-channel streamer for the *Sabvabaa.* Using a 20 to 40 in^3 airgun sound source, the craft is capable of profiling the shallow and deep layers over some of the least studied and most interesting areas of the ice-covered Arctic—areas that are critical to understanding the origin and history of the Arctic Ocean.

In 2012, the *Sabvabaa* spent 10 weeks on the ice including more than five weeks monitoring some 300 earthquakes on the Gakkel Ridge. In 2013, Sabvabaa embarked on two expeditions. The first involved ten days on the ice on the Yermak Plateau between 80° N and 82°N measuring the damping of ocean swell with distance from the ice edge and collecting heat flow measurements using a 7-m long free-fall dart corer equipped with thermistor outriggers. The second expedition involved the deployment of the *Sabvabaa* from the Norwegian naval icebreaker K/V *Svalbard*. Operating as a satellite platform from the *Svalbard* the *Sabvabaa* took part in the UNDER-ICE-2013 experiment involving an international team deploying numerous ice buoys as well as making acoustic and CTD measurements (Figure 1-13). While a broken clutch eventually disabled the *Sabvabaa*, the successful deployments from the Svalbard demonstrated the value of the hovercraft as a support vehicle for larger ice-breakers. In 2014, the *Sabvabaa* was deployed on an ice drift station from the German icebreaker *Polarstern* in the central Arctic Ocean and a year later it returned to Svalbard after completing a remarkable drift of 1900 km and collecting a suite of seismic, oceanographic and hydrographic measurements.

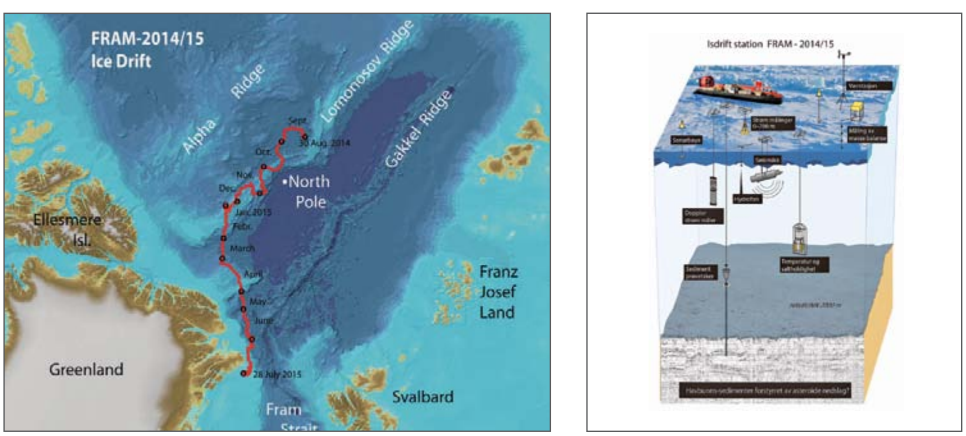


Figure 1-13. Drift of *Sabvabba* ice-drift (right). An overview of the scientific measurements to be made by Sabvabba during its operation as an ice-drift station during 2014/2015. Figure from **www.geo.uib.no/polarhovercraft/index.php?n=Main.FRAM-2014-15.**

Educational Program

Curriculum Development

At its inception, the Center, under the guidance of Capt. Armstrong, developed an ocean-mapping-specific curriculum that was approved by the University and certified (in May 2001) as a Category A program by the FIG/IHO/ICA International Advisory Board for Standards of Competence for Hydrographic Surveyors. We also established a post-graduate certificate program in Ocean Mapping. The certificate program has a minimum set of course requirements that can be completed in one year and allows post-graduate students who cannot spend the two years (at least) necessary to complete a Master's degree a means to upgrade their education and receive a certification of completion of the course work.

Although our students have a range of general science and engineering courses to take as part of the Ocean Mapping Program, the Center teaches several courses specifically designed to support the Ocean Mapping Program. In response to our concern about the varied backgrounds of the students entering our program, we have created, in collaboration with the Dean of the College of Engineering and Physical Sciences and the Dept. of Mathematics and Statistics a specialized math course, taught at the Center. This course is designed to provide Center students with a background in the math skills needed to complete the curriculum in Ocean Mapping. The content of this course has been designed by Semme Dijkstra and Brian Calder specifically to address the needs of our students and is being taught by professors from the UNH Math Dept. In 2008, in recognition of the importance of our educational program, we created the position of full-time instructor in hydrographic science. Semme Dijkstra, who led the effort to revamp our curriculum and renew our FIG/IHO/ICA Cat. A certification (see below), has filled this position.

The original FIG/IHO Certification received by the Center at its inception required renewal in 2011 and in light of the need for a new submission to the FIG/IHO/ICA, the extraordinary growth of the Center (and expansion of faculty expertise), and the recognition that certain aspects of our curriculum were leading to unrealistic demands on our students, the Center, under the leadership of Semme Dijkstra, re-designed the entire ocean mapping curriculum.

The goals of the new curriculum were to:

- Reduce the number of required credit hours for our certificate students,
- Create a keystone, two-semester "Fundamentals of Ocean Mapping" course that would cover all the fundamentals defined by the members of our faculty and the IHO/FIG/ICA,
- Take broad advantage of the expertise available at JHC/CCOM,
- Meet the standards required for FIG/IHO Category A certification, and
- Be modular so that components may be taught on their own at the Center or other locations.

This curriculum was presented to the FIG/IHO/ICA education board by Dijkstra and Capt. Armstrong and accepted (the board lauded the UNH submission as "outstanding"). Thus the Center maintains an IHO Category A Certification and continues to be one of only two Category A programs available in North America. The new curriculum (Appendix A) was subsequently accepted by the College of Engineering and Physical Sciences curriculum committee, approved by the graduate school, and was presented for the first time in 2012.

Initial feedback from students has been good, however, suggestions for improvements were made and in the academic year 2012-2013, Dijkstra focused on providing the students with a better understanding of the context and order of presentation for each of the teaching modules. A remaining challenge is to better integrate practical exercises within the curriculum. To achieve this goal, Dijkstra is working on two sets of practice exercises: 1) the continued development of the "Tools for Ocean Mapping Course" that was completely overhauled in academic year 2012-2013, and; 2) the development of a Virtual Ocean Mapping Assignment similar in nature to the existing Virtual GNSS assignment (which was also updated significantly this year).

Our "Tools for Ocean Mapping" course is now a 21-step practical assignment. As part of this assignment the students combine data for various data sources including bathymetry, DTMs, video, etc., into a single GIS database and learn to process and manipulate the data (e.g., changing datums) using a variety of software tools. As part of this process, the students need to evaluate various coordinate reference frames used for the data acquisition and QA/QC the data. This exercise involves extensive use of ArcGIS, data manipulation in Excel, programming in Matlab, creating Windows terminal scripts and Ubuntu Linux scripts. Finally the students have to use these data to plan future data collection using Hypack and present the data using the Generic Mapping Tools. Additionally in 2015, the Geodesy and Positioning for Ocean Mapping course was updated to keep the course abreast of current technical developments, particularly with respect to Kinematic GNSS networks and to keep the course more in alignment with the needs of our students and the requirements outlined by the IHO/CA/FIG educational board. Finally, with the arrival of John Hughes Clarke, we have begun to look at a major restructuring of our entire ocean mapping curriculum. This new curriculum development is in response to evolving requirements of the IHO/CA/FIG educational board, feedback from current and past students, and the recognition of the experience and skills that our new faculty members can bring to our curriculum.

We had 38 students enrolled in the Ocean Mapping program during 2014 (see below), including six GEBCO students, three NOAA Corps officers and four NOAA physical scientists (three in part-time Ph.D. programs). We have produced five Ph.D.s: Luciano Fonseca (2001), Anthony Hewitt (2002), Matt Plumlee (2004), Randy Cutter (2005), and Dan Pineo (2010). This past year, we graduated eight new Master's students and six Certificate students, bringing the total number of M.S. degrees completed at the Center to 53 and the total number of Certificates in Ocean Mapping to 60.

JHC – Originated Courses

COURSE	INSTRUCTORS
Applied Tools for Ocean Mapping	Dijkstra, Wigley
Fundamentals of Ocean Mapping I	Armstrong, Calder, Dijkstra, Gardner, Mayer, Lippmann,Weber, Ward
Fundamentals of Ocean Mapping II	Armstrong, Dijkstra, Mayer, Alexander, Pe'eri
Geodesy and Positioning for OM	Dijkstra
Hydrographic Field Course	Dijkstra, Armstrong
Interactive Data Visualization	Ware
Mathematics for Geodesy	Wineberg (Math Dept.)
Nearshore Processes	Ward, Gardner
Seafloor Characterization	Mayer, Calder
Seamanship and Marine Weather	Armstrong, Kelley
Seminars in Ocean Mapping	All
Special Topics: Bathy-Spatial Analysis	Wigley, Monahan
Special Topics: Law of the Sea	Monahan
Special Topics: Ocean. Data Analysis	Weber
Time Series Analysis	Lippmann
Underwater Acoustics	Weber

GEBCO Certificate Program

The Joint Hydrographic Center/Center for Coastal and Ocean Mapping was selected to host the Nippon Foundation/GEBCO Bathymetric Training Program in 2004 through an international competition that included most of the leading hydrographic education centers in the world. UNH was awarded $0.9 M from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate level training program for seven international students. Fifty-seven students from thirty-two nations applied and, in just four months (through the tremendous cooperation of the UNH Graduate School and the Foreign Students Office), seven students were selected, admitted, received visas and began their studies. This first class of seven students graduated (receiving a "Graduate Certificate in Ocean Mapping") in 2005. The second class of five graduated in 2006, and the program has continued to graduate six students per year since the 2007 academic years, such that 66 scholars have already graduated with the Graduate Certificate in Ocean Mapping.

Funding for the 12th year of this GEBCO training program was received from the Nippon Foundation in 2015 and the selection process followed the new guidelines including input from the home organizations of prospective students.

This year the recruiting process was further refined by adding a former GEBCO Scholar to the selection committee to continue scholar interactions. The 2015 class of six was selected from forty-nine applications from twenty-eight countries, attesting to the on-going demand for this course. The current 12th class of 2015/2016 includes six students from Japan, Barbados, Pakistan, Russian Federation, Malaysia and Peru (Figure 2-1).

The Nippon Foundation GEBCO students have added a tremendous dynamic to the Center both academically and culturally. Funding from the Nippon Foundation has allowed us to add Rochelle Wigley to our faculty in the position of Program Director for the Nippon Foundation/GEBCO training program. One of the important aspects included in the Nippon Foundation/GEBCO training program at UNH is the visit to an international laboratory and/or opportunity to take part in a deep-ocean cruise to round out the students training, to help them build networks and to deepen some of their newly-acquired theoretical knowledge. This internship allows students to become familiarized with the programs that the visited organization is engaged in, as well as to undertake some directed research under supervision. The Nippon Foundation/GEBCO training program students of Year 11 all attended the 1st NOAA-GEBCO Chart Adequacy Workshop at NOAA headquarters in Silver Spring, MD, after which four students stayed on for an extended two-week visit where they worked on a satellite-derived bathymetry project in an area relevant to their home organization. In addition, students worked with the NOAA Office of Ocean Exploration and Research (OER), supporting product development from data collected by the NOAA Ship *Okeanos Explorer*, visited the British Oceanographic Data Centre for an introduction to the open-source software GMT and worked on seafloor characterization and assessment of marine mineral resources on the continental shelf. Three students were onboard the R/V *Marcus G. Langseth* Extended Continental Shelf cruise of the Atlantic margin from 29th July to 30th August 2015 and another student participated on the R/V *Maria S. Merian* geohazard mapping cruise to study, by means of multibeam, parasound and multichannel seismics data, the 1929 Grand Banks landslide area from 30 September to 30 October 2015.

In addition, the 11th Nippon Foundation/GEBCO class attended an intense two day training session at NOAA's National Geophysical Data Center (NGDC) and co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO in January. During this visit, the students were introduced to the Marine Geology and Geophysics Division research team and the projects being undertaken in terms of data management and stewardship.

The Indian Ocean Bathymetric Compilation (IOBC) project is ongoing with the establishment of a database comprised of >700 available single beam, multibeam data and compilation grids. This project has proved

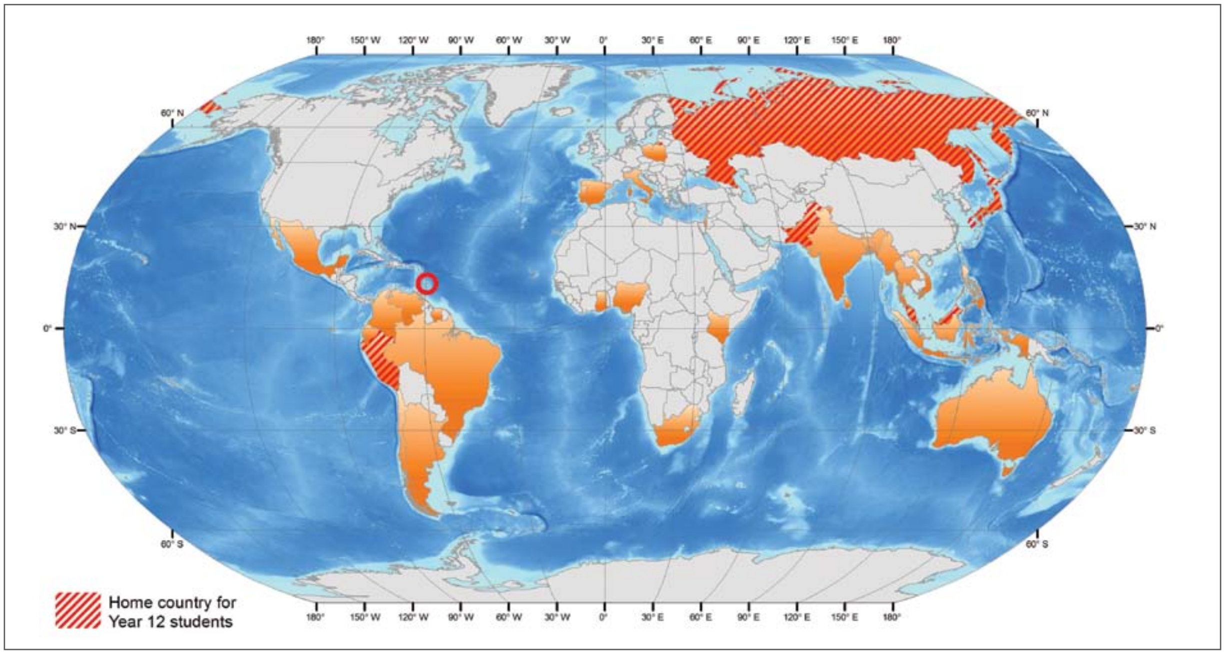


Figure 2-1. Distribution of countries from which GEBCO scholars have come (orange) and home countries of Year 12 GEBCO scholars (red).

to be an excellent working case study for the Nippon Foundation/GEBCO students to understand the complexities of downloading and working with publically-available bathymetric datasets. The Nippon Foundation/GEBCO Crowd-Sourced Bathymetry (CSB) initiative for a data assessment pilot project was initiated in Malaysia from 18-24 January 2015 with the deployment of three Sea-ID data loggers on board vessels through a collaboration with the Royal Malaysian Hydrographic Office.

Figure 2-2. The GEBCO Year 11 class visiting NOAA's National Centers for Environmental Information in Boulder, CO in January 2015. From left: Jaya Roperez, Nilupa Samarakoon, Maxlimer Vallee, Amon Kimeli, Indra Prasetyawan, and Hirokazu Kurita.

The first phase of the Nippon Foundation/GEBCO Short Video Series, "GEBCO: Standing on the Shoulders of Giants," has been completed, with interviews of selected members of the GEBCO community in attendance at the GEBCO Guiding Committee (GGC), the Technical Sub-Committee on Ocean Mapping (TSCOM), and the Sub-Committee on Regional Under-sea Mapping (SCRUM) meetings in Kuala Lumpur, Malaysia in October 2015. The first short video should be available by the end of January and will focus on the training program at the Center and its impact on alumni.

The Nippon Foundation awarded additional funds for the Future of the Ocean Floor Forum to be held in the Principality of Monaco in June 2016. Planning for this event is well underway and the logistics and program team are busy with organization. The outcomes of the Future of the Ocean Floor Forum will be an increased understanding of the importance of the ocean floor to sustainable development and environmental sustainability of the oceans; thereby enabling GEBCO to better service the needs of the ocean community into the future. Currently the program has HSH Prince Albert II of Monaco invited to open the forum, where he can acknowledge the legacy of his great-great grandfather HSH Albert I in founding GEBCO, and he will describe his own commitment to the oceans and outline how he can best support improved understanding of the ocean floor over the coming 10 years and into the future. Following the Prince's declaration, the Chairman of the Nippon Foundation will highlight achievements of the NF-GEBCO Scholar program to date and describe how the Nippon Foundation is going to expand its program of ocean-related activity to realize the Prince's declaration. Invited collaborators and panelists from major ocean-related organizations and academic institutions will also discuss critical ocean issues and their view of the future. In addition, Center alumni will explain how their training experience has enhanced ocean mapping in their home country.

Year 12 GEBCO Students

STUDENT	INSTITUTION	COUNTRY
Bazhenova, Evgenia	St. Petersburg State University	Russia
Maingot, Brandon	University of the West Indies	Barbados
Menacho, Renzo	Peruvian Navy	Peru
Wasim, Muhammad	Pakistan Navy	Pakistan
Rosedee, Azmi	Royal Malaysian Navy	Malaysia
Tsuchiya, Chikara	Hydrographic and Oceanographic Department, Japan Coast Guard	Japan

Hydrographic Field Course

The 2015 Summer Hydrographic Field Course brought the R/V *Coastal Surveyor*, R/V *Cocheco*, R/V *Galen J*, 11 JHC/CCOM students, and several technical staff under the supervision of Semme Dijkstra to the near-shore waters between Northampton and Rye, NH. The primary objective was to extend southwards the survey area covered by the same course in 2014. Additionally a small area of Salisbury Beach, MA was mapped.

One hundred and fifty-two nautical miles of main scheme lines were collected, with an additional 16 miles of cross lines in water depths ranging from 22 m to 1 m below MLLW for a total areal coverage of 3.2 nm^2 (Figure 2-3). Additionally, 11 video stations were occupied, with grab samples were recovered at four. Data were collected using a Kongsberg EM2040 multibeam sonar and a Klein 3900 sidescan sonar. The data were processed using SIS, HYPACK, Qimera, SonarWiz and HIPS. A comparison with Charts 13274, 13278 and 13282 was performed and the observed depths generally matched the charted depths, but close to several rocky outcrops shoaler depths were observed resulting in two DTONS (affecting eight charts). The charted contours generally align well with the automatically generated contours from the dense MBES data.

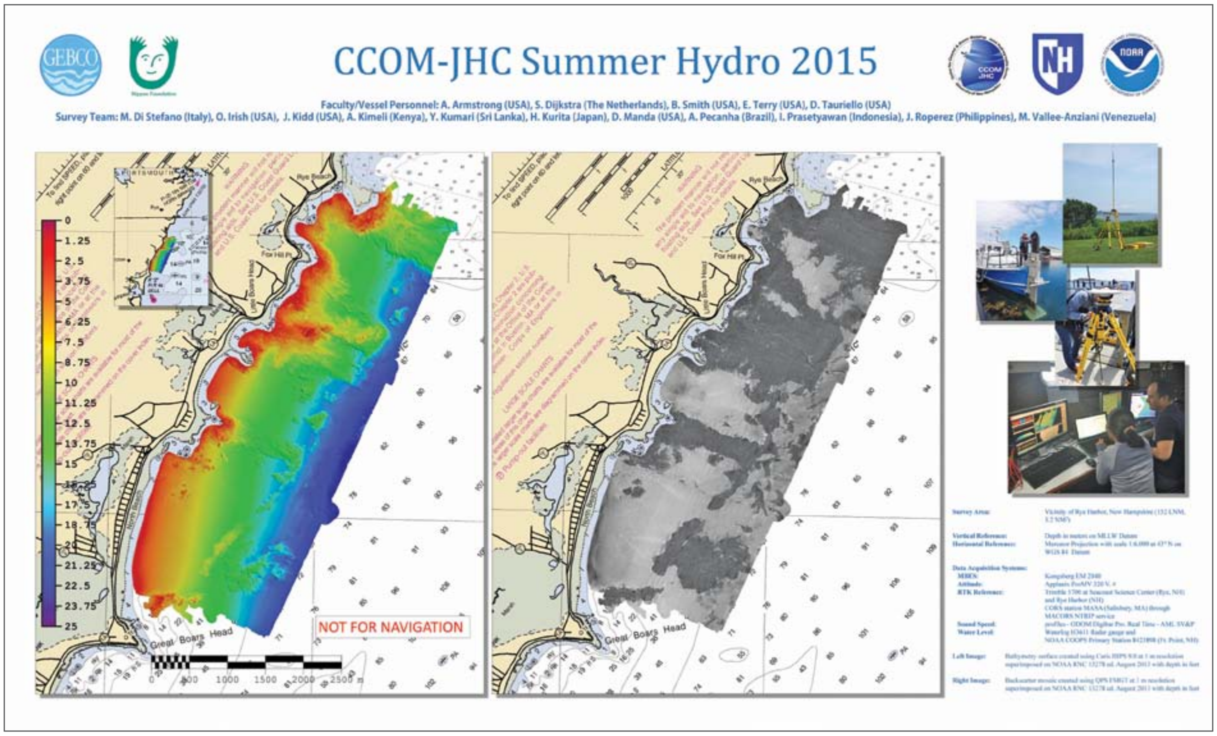


Figure 2-3. Poster showing 2015 Hydrographic Field Course data collected between Northampton and Rye, NH.

Extended Training

With our fundamental education programs in place, we are expanding our efforts to design programs that can serve undergraduates, as well as government and industry employees. We have started a formal summer undergraduate intern program we call SURF (Summer Undergraduate Research Fellowship—see below), are now hosting NOAA Hollings Scholars (see below), and continue to offer the Center as a venue for industry and government training courses and meetings (e.g., CARIS, Triton-Elics, SAIC, Geoacoustics, Reson, R2Sonics, IVS/QPS, ESRI, GEBCO, HYPACK, Chesapeake Technologies, ATLIS, IBCAO, SAIC, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, NPS, ECS Workshops, USGS, Deepwater Horizon Subsurface Monitoring Unit, and others). In 2015, we hosted short courses from CARIS, ESRI, QPS, HYPACK, and MATLAB. These meetings and courses have proven very useful because our students can attend them and are thus exposed to a range of state-of-the-art systems and important issues. Particularly important have been visits to the Center by a number of members of NOAA's Coast Survey Development Lab and National Geodetic Service in order to explore research paths of mutual interest.

Center staff are also involved in training programs at venues outside of the Center. Shachak Pe'eri was an instructor at an Airborne Lidar Bathymetry training course in Norfolk, VA, a Chart Adequacy Workshop in Silver Spring, and training for USGS employees in Satellite Derived Bathymetry, also in Silver Spring. Additionally, John Hughes Clarke, Larry Mayer and Tom Weber continue to teach (along with David Wells) the internationally renowned Multibeam Training Course; in 2015, courses were taught in New Orleans, Lisbon and Brisbane, Australia.

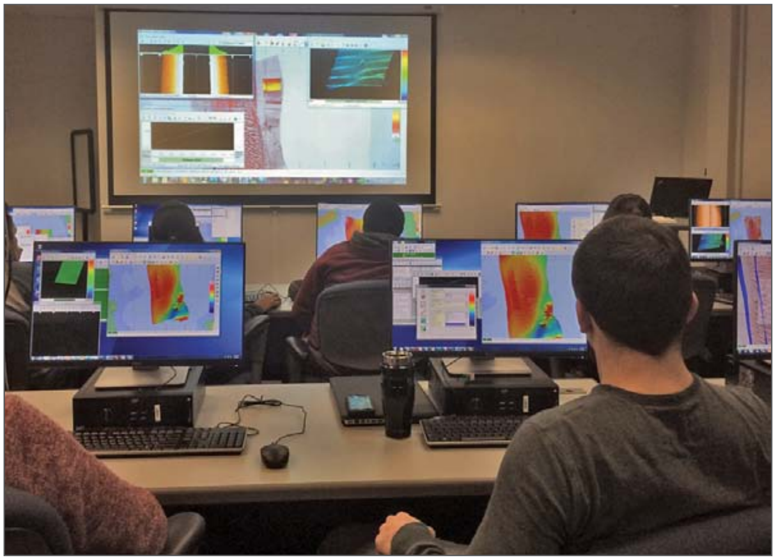


Figure 2-4. Students in an IVS/QPS training sesson in the Center's computer classroom.

SURF Program and Hollings Scholars

The Summer Undergraduate Research Fellowship (SURF) program was initiated in 2012. SURF is designed to create research experiences for undergraduate students who are interested in pursuing graduate work and is aimed primarily at students who are working toward a degree in science, engineering, or math, and are completing their junior year. Students accepted into the program spend up to ten intensive weeks (normally early-June to mid-August) working under the guidance of a faculty member. They conduct research related to acoustics, bathymetric mapping, habitat mapping, lidar, marine geology and geophysics, optical imaging, sonar signal processing, or data visualization. Research activities include laboratory experiments, field work, a research cruise, data analysis, model development, or instrument development. The research conducted by the fellows is presented to Center faculty and staff at the end of the summer and summarized in a written report.

2015 SURF Fellows and Projects

Fellow: Diamond Tachera, University of Hawaii
Advisor: Larry Ward
Project: Beach Profiling: Methods Comparison Report

Undergraduate Mentoring

While most of the Center's efforts are focused on graduate students, many of the Center faculty are also involved with mentoring undergraduates through the employment of students on an hourly or work-study basis. Over the past two years, we have had an exceptional example of the value that the Center can play to undergraduate training as well as an excellent example of selflessness and commitment on the part of one of our graduate students. NOAA Corps. Officer, LTJG Damian Manda volunteered to be the graduate advisor to a group of UNH senior engineering and computer science students developing an autonomous boat for their capstone project (UNH Autonomous Surface Vehicle (ASV) Team). In addition to leading weekly progress meetings, Manda offered advice and guidance to members of the team on selection of electronics, programming, and concepts of positioning systems including GPS and acoustics. The project used the deep tank at the Center for testing and had a workspace in the high bay, with funding for materials provided through a grant from the Naval Engineering Education Center (NEEC).

Academic Year 2015 Graduate Students

STUDENT	PROGRAM	ADVISOR
Bajor, Eric	M.S. Mech. Eng	Weber
Birkebak, Mathew	MS OE Mapping	Pe'eri
Bolan, Daniel	MS Comp. Sci.	Ware
Borba, Caesar	MS E. Sci. Ocean Mapping	Armstrong
Di Stefano, Massimo	Ph.D. OE	Mayer
Freire, Ricardo	Ph.D. OE Mapping	Alexander
Heffron, Erin	MS E. Sci. Ocean Mapping	Mayer
Hoy, Shannon	MS E. Sci. Ocean Mapping	Calder
Hu, Han	MS OE Mapping	Rzhanov
Humberston, Josh	MS E. Sci. Ocean Mapping	Lippmann
Irish, Onni	MS E. Sci. Ocean Mapping	Mayer
Kidd, John (NOAA)	MS E. Sci. Ocean Mapping	Armstrong
Kozlov, Igor	MS Comp. Sci.	Rzhanov
Loranger, Scott	Ph.D. E. Sci. Oceanography	Weber
Malik, Mashkoor (NOAA)*	Ph.D. Ocean Engineering	Mayer
Manda, Damian (NOAA)	MS OE Mapping	Armstrong
Munene, Tiziana	MS OE Mapping	Armstrong
Nifong, Kelly	MS E. Sci. Ocean Mapping	Ward
Norton, Ashley	Ph.D. NRESS	Mayer
Padilla, Alexandra	Ph.D. OE Mapping	Weber
Pencanha, Anderson	MS E. Sci. Ocean Mapping	Armstrong
Pillsbury, Liam	MS OE Mapping	Weber
Reed, Samuel	MS EE Mapping	Armstrong
Rice, Glen (NOAA)*	Ph.D. OE Mapping	Weber
Rychert, Kevin	MS OE Mapping	Weber
Sowers, Derek (NOAA)*	Ph.D. NRESS	Mayer

* Part-time

Status of Research: January–December 2015

When the Center was established in 1999, four primary research directions were identified:

1. Innovative sensor design—understanding capabilities and limitations;
2. New approaches to multibeam and sidescan sonar data processing;
3. New approaches to data visualization, fusion, and presentation;
4. Tools and approaches for seafloor characterization.

Within each of these themes, projects were chosen with long-range research goals designed to make fundamental contributions to the fields of hydrography and ocean and coastal mapping, and with short-term objectives designed to address immediate concerns of the hydrographic community in the United States. Over the years, in response to the needs of NOAA and others, several new research themes were added:

5. Electronic Chart of the Future;
6. Water-column mapping;
7. Capabilities and limitations of lidar for bathymetry, seafloor characterization and shoreline mapping;
8. Coastal process studies—very shallow water mapping;
9. Understanding the capabilities and limitations of AUVs as hydrographic tools;
10. Developing innovative approaches for mapping in support of Law of the Sea.

As our research progressed and evolved, the boundaries between these themes became more blurred. For example, from an initial focus on sonar sensors we expanded our efforts to include lidar and recently, satellite-derived bathymetry. Our data-processing efforts merged into our data-fusion and Chart of the Future efforts. The data-fusion and visualization projects have blended with our seafloor characterization and Chart of the Future efforts as we began to define new sets of "non-traditional" products. This is a natural (and desirable) evolution that slowly changes the nature of the programs and the thrust of our efforts.

With the transition to the new cooperative agreement (2011-2015), the research themes have been re-defined. The request for proposals for the new cooperative agreement prescribed seven thematic headings:

1. Improving the sensors used for hydrographic, ocean and coastal mapping (sonar, lidar, AUVs, etc.) with emphasis on increasing accuracy, resolution, and efficiency, especially in shallow water; (SENSORS)
2. Improving and developing new approaches to hydrographic, ocean and coastal mapping data processing with emphasis on increasing efficiency while understanding, quantifying, and reducing uncertainty; (PROCESSING)
3. Developing tools and approaches for the adaptation of hydrographic, coastal and ocean mapping technologies for the mapping of benthic habitat and exploring the broad potential of mapping features in the water-column; (HABITAT AND WATER COLUMN MAPPING)
4. Developing tools, protocols, non-standard products, and approaches that support the concept of "map once – use many times," i.e., integrated coastal and ocean mapping; (IOCM)
5. Developing new and innovative approaches for 3D and 4D visualization of hydrographic and ocean mapping datasets, including better representation of uncertainty, and complex time- and space-varying oceanographic, biological, and geological phenomena; (VISUALIZATION)
6. Developing innovative approaches and concepts for the electronic chart of the future and e-navigation, and; (CHART OF THE FUTURE)
7. Being national leaders in the planning, acquisition, processing, analysis and interpretation of bathymetric data collected in support of a potential submission by the U.S. for an extended continental shelf under Article 76 of the United Nations Convention on the Law of the Sea. (LAW OF THE SEA)

These new thematic headings do not represent a significant departure from our previous research endeavors. However, inasmuch as our efforts since 2011 have been conducted under these new thematic headings, our 2015 research efforts will be described in the context of these seven themes. As with the earlier themes, many of the projects areas overlap several themes. This is particularly true for HABITAT, IOCM, and PROCESSING efforts. In this context, distribution of projects among the themes is sometimes quite "fuzzy."

Theme 1 – Sensors

Improving the Sensors Used for Hydrographic, Ocean and Coastal Mapping (Sonar, Lidar, AUVs, etc.) with Emphasis on Increasing Accuracy, Resolution, and Efficiency, Especially in Shallow Water

The Center's work in understanding and improving ocean mapping sensors has steadily grown and encompassed new dimensions. A key component of many of these efforts is our access to, and continued development of, state-of-the-art sonar (and lidar) calibration facilities that allow us to better understand the performance of systems and to develop new approaches to their calibration. Included in our discussion of sensors are our efforts to better understand the behavior of several new sonar systems (both traditional multibeam and phase measuring bathymetric sonars) being offered by our industrial partners, to better understand the performance of lidar and satellite sensing systems for shoreline mapping, bathymetry and seafloor characterization studies, to explore the potential of AUVs and ASVs as platforms for bathymetric and other measurements, and to make better measurements of the temporal and spatial variability of sound speed in the areas where we are working.

Sonars

Sonar Calibration Facility

Developing Approaches to Calibrate MBES in the Field

We continue to make progress upgrading the Center's sonar calibration facility (originally funded in part by NSF), which is now one of the best of its kind in New England. The facility is equipped with a rigid (x, y)-positioning system, computer controlled transducer rotor (with resolution of 0.025 degree) and a custom-built data-acquisition system. Measurements that can now be made include transducer impedance (magnitude and phase) as a function of frequency, beam patterns (transmit and receive), open circuit voltage response (receive sensitivity), and transmit voltage response (transmit sensitivity). In addition, the A/D channel inputs have been optimized as a function of beam angle and the cross-correlation and r.m.s. levels of the transmitted and received channels can be computed in real-time. In 2014 the acoustic tank instrumentation was upgraded to include an automated mechanism to perform complete three-dimensional combined transmit/receive beam pattern measurements of electro-acoustic transducers in just one run. This mechanism controls the vertical position of a standard target in the acoustic tank and has been incorporated into the high-resolution Yuasa rotor of the tank, providing angular resolution of less than 0.1o for the two directions during beam-pattern measurements and optimized operation time.

In 2015, a sound speed measurement device for fresh water was designed and built for use in the acoustic tank facility at Chase Engineering Lab. The system is comprised of a pair of radio transceivers: a transmitter module to read the water temperature, calculate the sound speed, and send the measured/calculated values to a receiver module connected to the tank computer via USB interface. The temperature values are used to calculate the sound speed. The performance of the system was evaluated by comparing its computed sound speed to the sound speed values from a Digi-bar Pro. The temperature sensor and Digi-bar probe were put inside a water bucket and data was collected at different water temperatures. The tests results show that the sound speed measurements from both systems agree with differences below 0.09% of the "true" value determined with the Digi-bar (Figure 3-1). Additionally a humidity sensor network was designed and built for the acoustic tank facility to monitor the humidity level in the tank area. High humidity levels may compromise the life span of electronic equipment stored in the tank area. We hope to address this problem by adding a solution to the water in the tank that decreases humidity levels by creating a thin layer on the water surface, decreasing evaporation rate. The humidity sensor network will help monitoring the humidity levels at different points in the tank area before and after the solution is applied to the water.

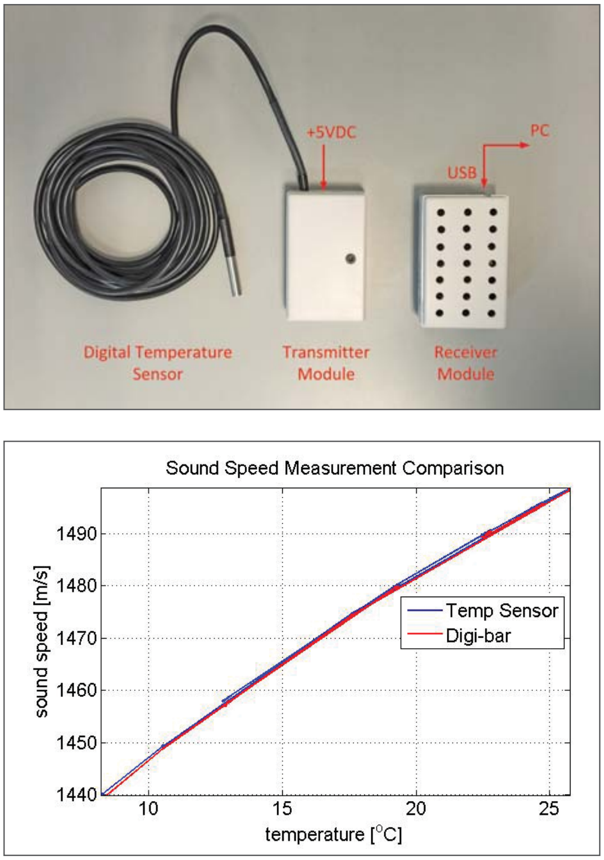


Figure 3-1. Sound speed monitoring system for acoustic test tank (top) and calibration against Digi-bar (bottom).

The system is comprised of four sensor nodes which send sensor data (humidity and temperature) wirelessly to a base station. The base station receives data from the sensor nodes (identifying the corresponding sending node) and transmits to the tank computer via USB interface.

Calibration of Sonar Systems

Along with supporting our own research projects, the Center's acoustic calibration facility is also available to NOAA, our industrial partners, and others for use in quantifying the behavior of new or existing sonar systems. In 2015, a number of systems and sonars were tested or calibrated in our facility or in the field so as to better understand their performance and capabilities (Figure 3-2). These calibrations include measurements of radiation beam pattern, impedance, transmit voltage response (TVR) and receive sensitivity (RS):

1. A new wide-band transceiver provided by industrial sponsor Kongsberg to Tom Weber that has great potential for better target discrimination and classification, particularly associated with our water column work (see HABITAT and WATER COLUMN MAPPING themes). In this particular application we used a Linear Frequency Modulation (LFM).

2. MSI constant beamwidth transducer was tested by Tom Weber as part of his efforts to more precisely locate and characterize small midwater targets (in particular oil droplets and gas bubbles). This work is discussed further in the section on the WATER COLUMN MAPPING theme.

3. A Simrad EK60 was tested to evaluate target detection capability close to the seafloor.

4. A DIDSON imaging system, to better understand the capabilities of the system for habitat mapping applications),

5. A Garmin GD-81 prototype transducer (impedance and radiation beam pattern measurements) to better understand the performance of this sonar and its potential to collect hydrographic quality data.

Beyond the Tank: *In-Situ* Calibration of MBES

2015 saw continued progress on the work begun with Carlo Lanzoni's M.S. thesis aimed at the development of field-calibration procedures for multibeam echosounders (MBES) using a Simrad EK-60 split-beam echosounder and a target calibration sphere. The idea of this approach is that the split-beam echosounder

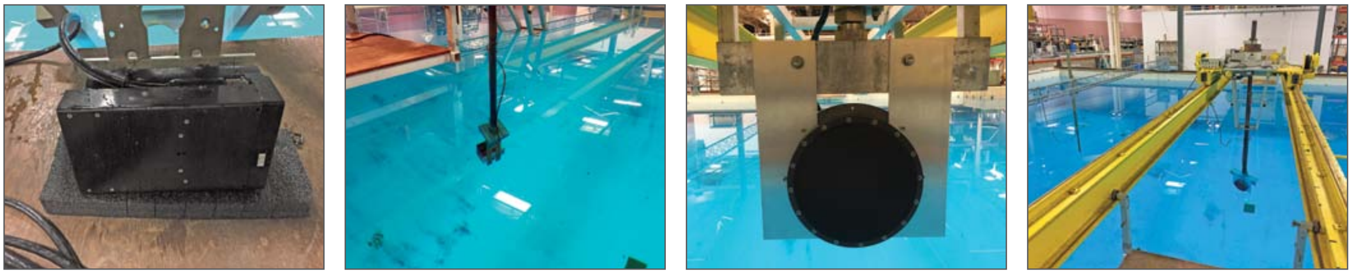


Figure 3-2. Some of the transducers tested in the acoustic tank in 2015 top row: DIDSON, bottom row: MSI Constant Beamwidth Transducer.

Figure 3-3. Top images: Deployment of a calibrated target sphere on the R/V *Coastal Surveyor*

provides precise information about the target sphere position allowing beam pattern and other calibration measurements to be made on the MBES in the field while it is mounted on the vessel (Figure 3-3). This procedure can reduce the time necessary for a MBES calibration compared to the standard indoor tank methods and allows systems already installed on the vessel to be calibrated in place.

The calibration methodology uses a high-resolution rotation mechanism on the split-beam EK60 system mount to provide coverage of the whole range of beams of the MBES under calibration. The rotation mechanism utilizes a high-resolution stepper motor that allows the positioning of the split-beam transducer with an angular resolution of 0.1o. The methodology was tested in the field using a Teledyne Reson T20-P multibeam system (Figure 3-4) as the system to be calibrated, providing measurements of beam pattern data (Figure 3-5).

Even though the calibration procedure was delayed due to the interference of seaweeds/leaves, it was possible to collect measurement data corresponding to athwartship angular range from -5° to +45° in 3.5 hours of measurement time. This methodology provides a way to calibrate a multibeam sonar system in the field in a significantly reduced operation time when compared to tank calibrations.

EK80 Wideband Transceiver

We have also begun a collaborative effort with industrial partner Kongsberg, NOAA fisheries scientists, and scientists at the Woods Hole Oceanographic Institution to look at the capabilities of Kongsberg's new wideband transceiver (WBT), the EK80. Wideband acoustic echo- sounders offer great promise for characterizing several phenomena (e.g., the seafloor, marine organisms, gas bubbles), as well as very high precision range measurements using pulse compression techniques. A handful of wideband acoustic systems have been previously built, but have not been readily available on the commercial market. This has changed with the introduction of the new Kongsberg EK80 wideband transceiver, which is intended to interface to Kongsberg's

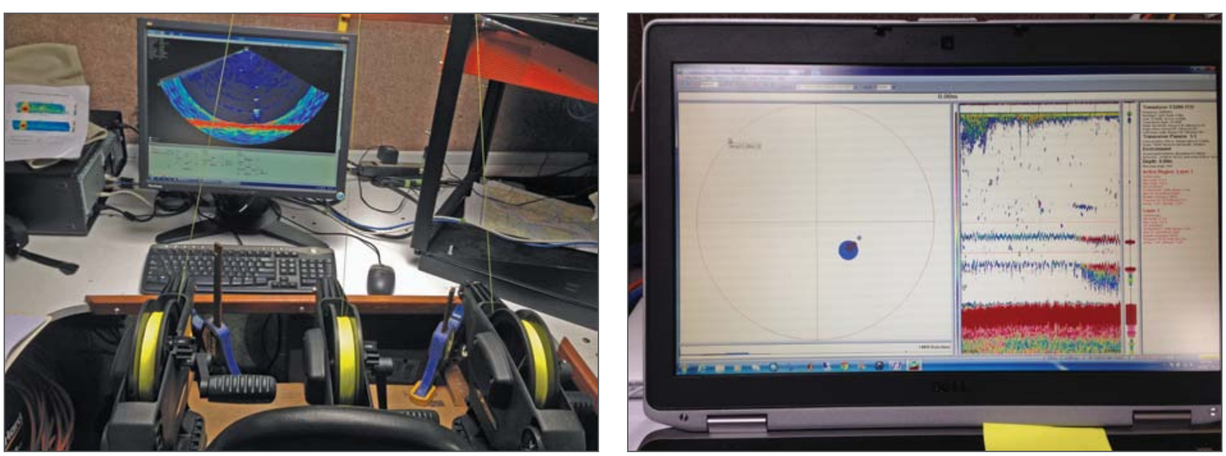


Figure 3-4. Field measurements with the Reson T20-P. aboard the *Coastal Surveyor.*

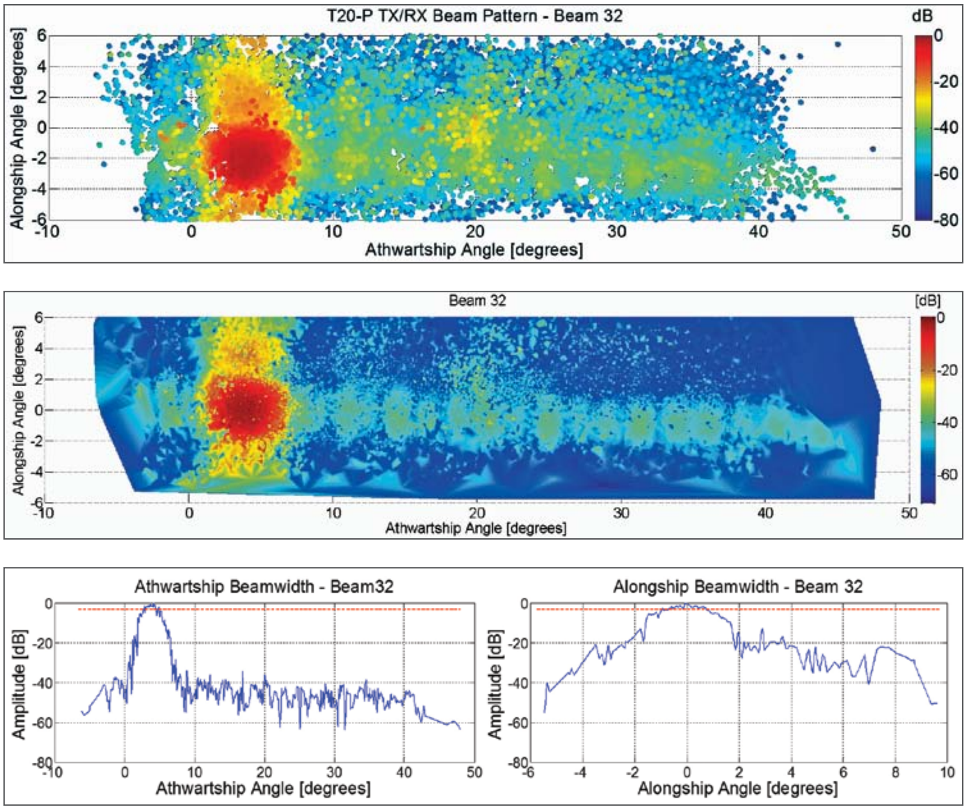


Figure 3-5. Beam pattern results from field measurements with the Reson T20-P.

fisheries echo- sounder transducers (one of which the Center is using on the NEWBEX project).

Following up on initial calibrations, in the summer of 2014, Mayer and Jerram deployed an EK80 on board the Icebreaker *Oden* as part of the Swedish and NSF-funded SWERUS-C3 field program in the Eastern Siberian Arctic Ocean, and Weber deployed an EK80 on board the R/V *Endeavor* as part a DOE-sponsored program to map gas seeps in the vicinity of Hudson Canyon. In preparation for these field programs a Simrad ES-18 (18kHz) transducer similar to that used aboard the *Oden* was calibrated in the Center's acoustic test tank using the EK-80 WBT. The prototype WBT was interfaced to an ES18-11 transducer in the Center's test tanks and used to transmit linear frequency-modulated acoustic pulses between 10-30 kHz as the ES18-11 was rotated from -90° to +90° along its equator. The tests demonstrated that the main beam behaves as designed, with a one-way -3 dB beamwidth that varies smoothly from 6° near 30 kHz to 19° at 10 kHz, with maximum sidelobe levels of -18 dB near the design frequency (close to a theoretically predicted value of -17 dB). Above 22 kHz, increased sidelobes (or suppressed grating lobes) appear that are likely due to the echosounder construction (44 individual Tonpilz transducer elements), but these sidelobe levels are still lower than -15 dB (1-way). The tests also revealed that the frequency-dependent figure of merit (combined transmit and receiving response, (Figure 3-6) for the ES18-11 varies less than 4 dB between 16-22 kHz. Field trials conducted by Weber, Mayer and Jerram on the R/V *Cocheco* just before the departure for the Arctic revealed that the WBT was capable of producing a response from a target sphere between approximately 15 and 30 kHz.

The EK80 on board the *Oden* was calibrated in the Arctic using calibration spheres and a complex setup of outriggers to maneuver the spheres beneath the acoustic center of the EK80 transducer (Figure 3-7).

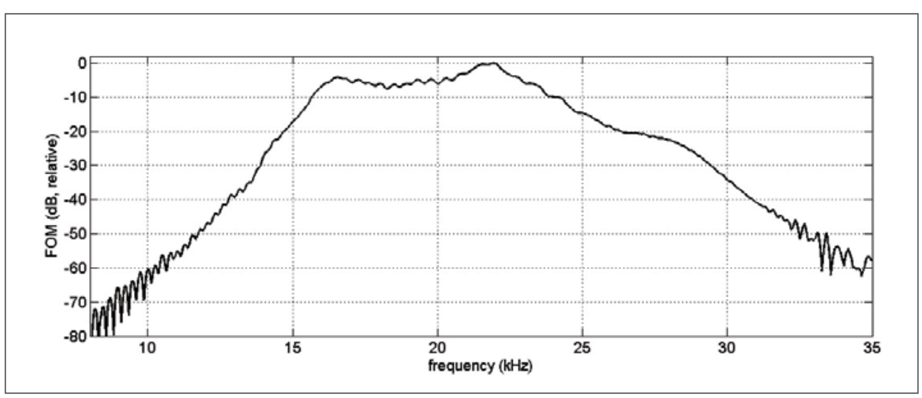


Figure 3-6. Figure of merit (combined transmit/receive response) of ES18 using WBT in decibels, relative to its peak value.

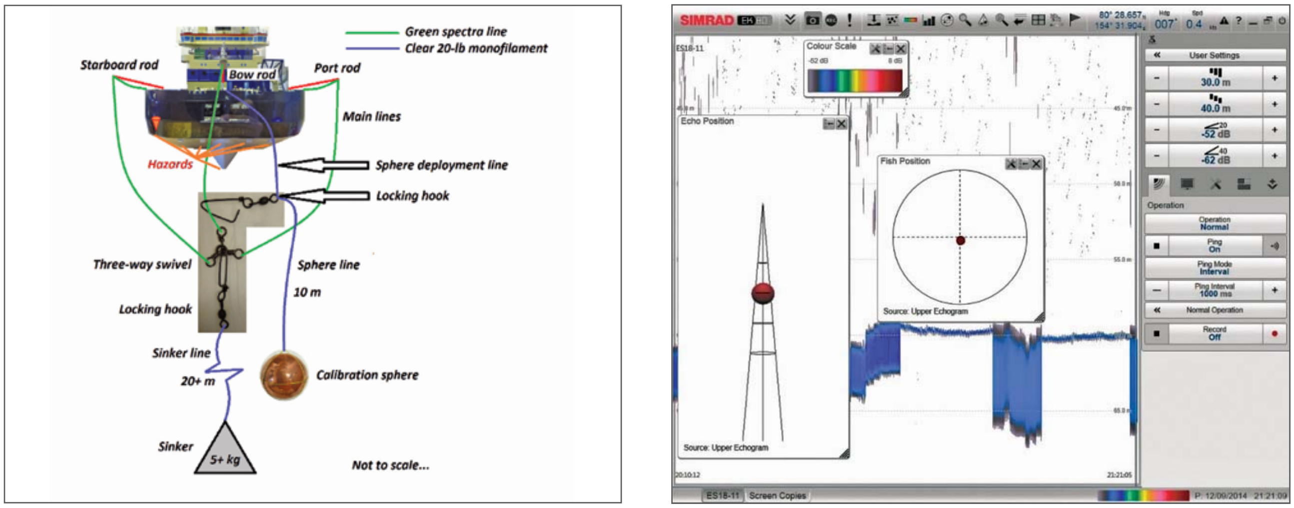


Figure 3-7. Schematic of field calibration for EK80 with ES18-11 transducer (left) and location of calibration sphere at acoustic center of transducer during calibration on board Icebreaker *Oden* (right).

Mayer and Jerram were able to use the EK80 on the *Oden* again in 2015 as part of an NSF-funded experiment in the Petermann Fjord in northern Greenland. Along with the calibration of the EK-80, we were also able to use a far-field hydrophone to capture the far-field source signatures of the EK80, the EM122 multibeam echosounder, and the SBP120 multibeam subbottom profiler. These measurements will allow us to interpret EK80, EM122 and SBP120 data in a much more quantitative manner than previously possible. Applications of this work will be discussed under the WATER COLUMN MAPPING theme.

New Broadband Sonar

For Information—funded by non-NOAA sources

This NSF Career Award-funded project (awarded to Weber) is focused on the development of a broadband system to help assess the fate of methane gas bubbles exiting the seabed. Two important milestones for this project were reached in the last six months. This included deliver of a modified low-frequency (1-10 kHz) Kongsberg wideband transceiver along with a visit by Kongsberg for initial testing, and an opportunity to test the high-frequency (10-100 kHz) component of the project on the NOAA Ship *Oscar Dyson* in the Gulf of Alaska during a three-week cruise in June. During this cruise, there was an opportunity to calibrate the high-frequency system and to collect data over seeps. The high-frequency system is also being used in collaboration with Chris Wilson and Chris Bassett (NOAA AFSC) and Peter Dahl (Univ. of Washington, ARL and ME Dept.) to examine broadband scattering from fish.

Sea Acceptance Trials Multibeam Advisory Committee

For Information—funded by non-NOAA sources

The expertise of the researchers at the Center has been sought of late to help ensure that that new multibeam sonar systems being installed by the U.S. academic fleet are working properly. In 2010, Jonathan Beaudoin, Val Schmidt, and Jim Gardner participated in acceptance trials of two multibeam systems. Beaudoin participated in the sea acceptance trials (SAT) for the USCGC *Healy's* new EM122 multibeam sonar, testing achievable swath coverage, accuracy and precision of the system. Beaudoin and Val Schmidt also participated in the SAT for the University of Washington's EM302 on the R/V *Thomas Thompson*. Jim Gardner participated in the sea acceptance trial of the Kongsberg EM122 newly installed on the University of Hawaii's R/V *Kilo Moana*, testing noise levels and swath-width issues. In all cases, Center researchers were able to offer valuable advice on the operational status of the systems.

This role of the Center in evaluating the performance of the academic communities MBES systems was formalized in 2011 with funding from the National Science Foundation to Paul Johnson and Jonathan Beaudoin (along with Vicki Ferrini at LDEO) for the establishment of a Multibeam Advisory Committee (MAC). The goal of the MAC is to ensure that consistently high-quality multibeam data are collected across the U.S. academic research fleet (UNOLS vessels). The strategy is to create a community of stakeholders that includes representatives from operating institutions, funding agencies, and key outside experts from the user and technical/ engineering communities that can assist in providing guidance on a broad array of multibeam issues. A part of the MAC effort is the development and dissemination of best-practice documentation and quality assurance software as well as collaboration on maintenance agreements and a spare parts pool. The best-practice documents, software guides and reports on the status of the multibeam systems in the UNOLS fleet can be found at the MAC website: **http://mac.unols.org**.

With the departure of Jonathan Beaudoin to work for QPS, his involvement with the MAC has greatly diminished. This has meant that Paul Johnson has taken on more of the responsibility of the management and operations of the MAC, acting as the point person for questions submitted to the MAC's help desk from multibeam operators across the U.S. academic fleet. These questions tend to deal with best practices for multibeam acquisition, technical questions on multibeam performance, questions about patch tests, and requests for data review of problematic datasets. Kevin Jerram and Erin Nagel have come aboard this project to help Paul out, particularly with sea-going efforts.

In 2014, Paul and research scientist Kevin Jerram sailed as representatives of the MAC to conduct a Shipboard Acceptance Test (SAT) of a new EM122 installed on the RVIB *Nathaniel B. Palmer* and, in August of 2014, Paul Johnson, former Center graduate student Ashton Flinders, and LCDR Samuel Greenaway from NOAA's Office of Coast Survey performed a full Shipboard Acceptance Test of a newly installed EM302 and EM710 MBES aboard the University of Alaska's R/V *Sikuliaq*. LCDR Greenaway's participation was designed to inform NOAA of the scope of MAC activities and to familiarize LCDR Greenaway with MAC procedures in support of NOAA's Sonar Acceptance Project.

The first shipboard Quality Assessment Test (QAT) that Paul and Kevin undertook for the MAC in 2015 was on the R/V *Kilo Moana* at the end of April. As part of this visit, Paul and Kevin had originally planned on conducting patch tests, accuracy tests, self-noise tests, and swath performance tests on the ship's EM122 and EM710 multibeam echosounder systems. While the EM710 performed very well during the QAT, the EM122 system was severely compromised due to acoustic noise problems with the ship. Figure 3-8 shows a sample of extremely low quality swath data collected during the tests. Self-noise tests conducted using the RX BIST function in SIS showed that the ship's self-noise had changed from RX values around 42 dB to 60 to 70+ dB. This change severely hampered the EM122's ability to map the seafloor.

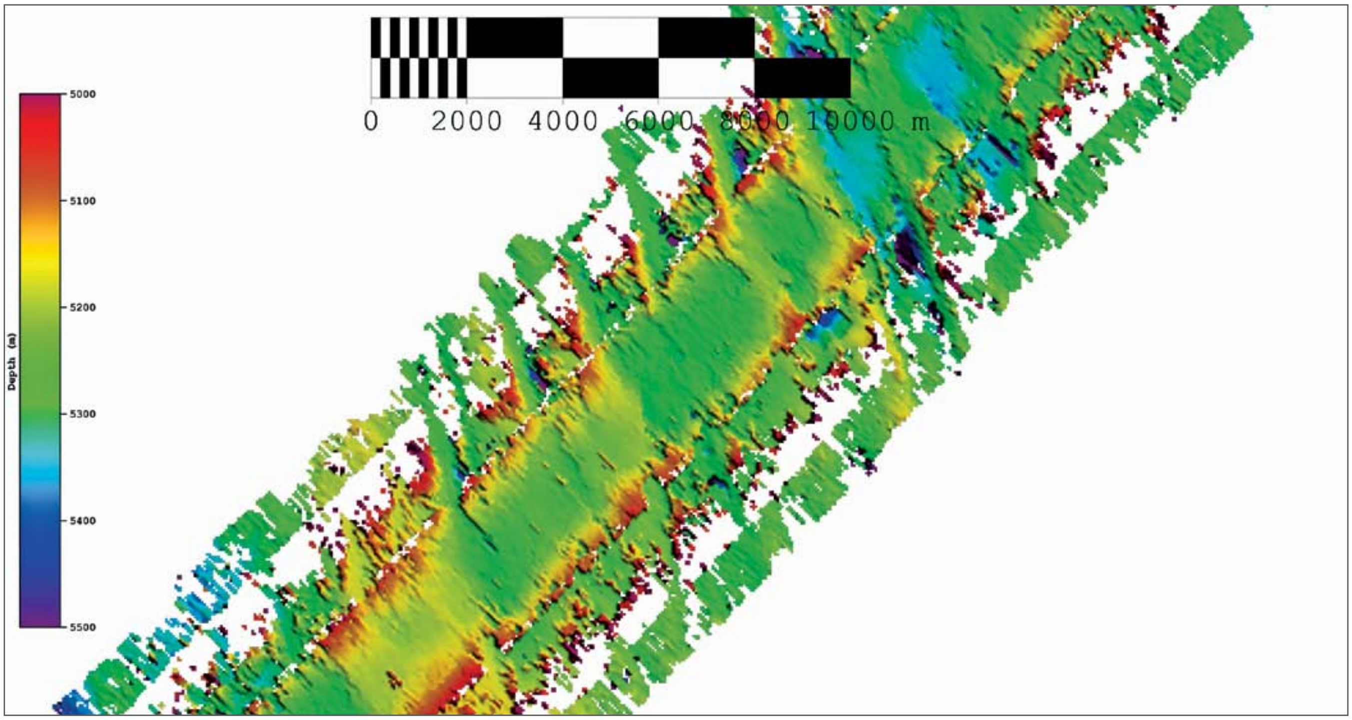


Figure 3-8. Data collected during by the *Kilo Moana's* EM122 system during a MAC Quality Assurance visit. Data quality was extremely poor due to apparent noise from the ship.

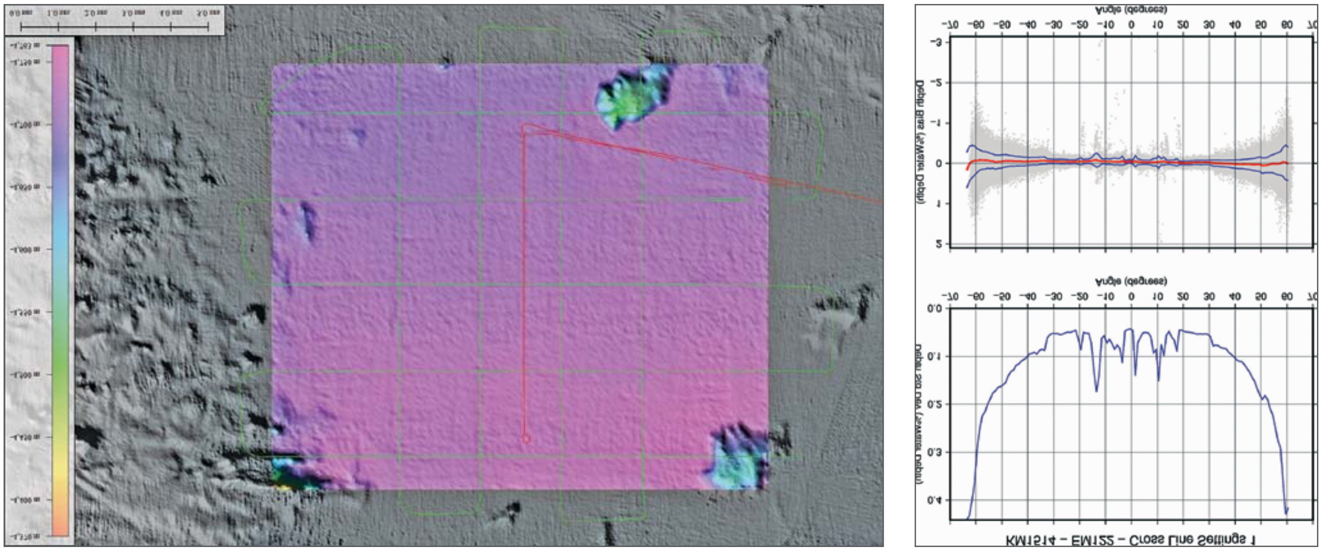


Figure 3-9. Accuracy testing on the R/V *Kilo Moana* during September 2015. The leftmost figure shows the deep water reference surface located southwest of Oahu. Green lines show the survey lines used to collect the reference surface, red lines show the KM1514 cross lines (North-South) over the reference surface. Rightmost figure shows the results of the accuracy testing conducted during KM1514.

Following the April visit, the Hawaii technical staff queried the ship's chief engineer and determined that during the spring 2015 dry dock period, the shipyard had changed the mount points for the ship's main generators. Further inspection revealed that the mount points had been installed incorrectly. The *Kilo Moana* then reinstalled the mount points and sought help with a follow-up QAT visit in August. For the second ship visit, Paul and Vicki Ferrini represented the MAC, Tim Gates and Marisa Yearta representing Gates Acoustic Services, and Chuck Hohing and Travis Eliason representing Kongsberg Maritime. The follow-up visit revealed that although the reinstallation of the generator mounts had succeeded in lowering the ship's self-noise, the quality of the EM122 multibeam data was still compromised. After exhaustive system testing, it was revealed that an EM122 receive array (RX) module which had been changed during the 2015 shipyard period had been wired at the factory with reverse phase. When a wiring adapter was constructed to correct this phase reversal, the data across the entire swath improved dramatically. With the little time remaining during the cruise, a quick accuracy test (Figure 3-9) and extinction test were run to verify that the system was operational.

After a drydock period to replace faulty components found in 2014, Kevin and Paul returned to the *Nathanial B. Palmer* to once again conduct an SAT of the ship's EM122. Similar to the 2014 tests, the 2015 tests were conducted during a transit from Talcahuano to Puerto Montt, Chile. However, unlike the 2014 test, this year's tests were conducted in the water depths they were planned for.

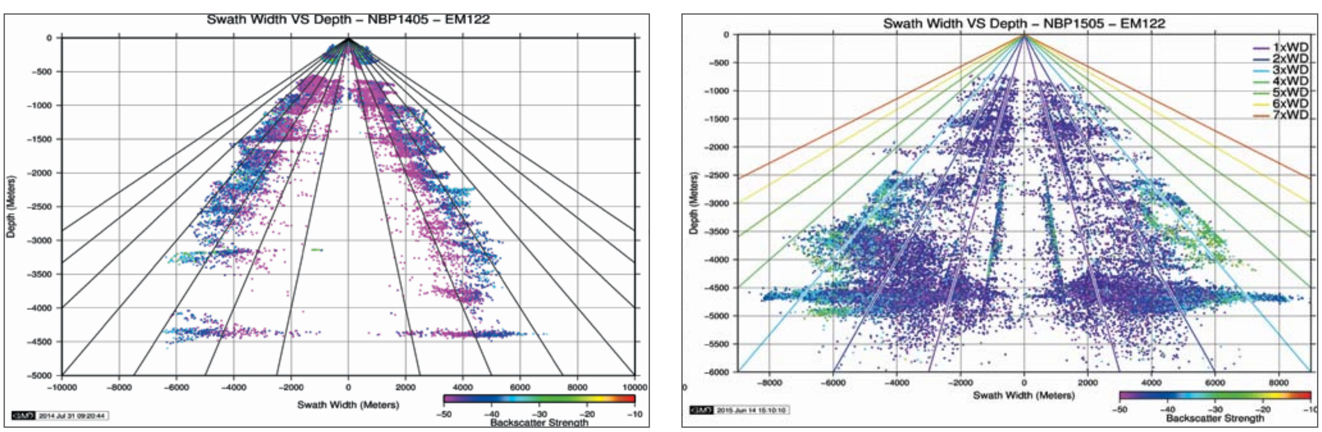


Figure 3-10. Plot of swath performance as a function of depth from the 2014 SAT (left) and 2015 SAT (right).

Analysis of the data collected during the SAT show an improved swath width from the upgraded arrays. Figure 3-10 shows the 2014 swath performance as a function of depth (left), as well as the results from the data collected in 2015 (right). It can be seen in this plot that the 2014 swath width was not even 3x water depth in 4500 meters of water, while in 2015 the swath width was 3.5x water depth, even with consistently worse seas than those experienced in 2014.

Institutions outside of UNOLS fleet have also come to us for assistance with their MBES systems. The Center, in collaboration with colleagues from IFREMER in France, assisted the Schmidt Ocean Institute (SOI) with the harbor and sea acceptance trials of all acoustic systems on their newly refitted vessel R/V *Falkor* and has entered an agreement with SOI for long-term assistance in maintaining technician skill sets, monitoring of acoustic system health, etc. The Center has a similar arrangement with Dr. Robert Ballard's Ocean Exploration Trust and their vessel E/V *Nautilus*. In 2015, Paul and Kevin conducted multibeam Quality Assurance visits on board the E/V *Nautilus* and the R/V *Falkor*. During these cruises, which were conducted off the west coast of Florida for the *Nautilus* and Hawaii for the *Falkor*, Paul and Kevin were able to fully validate the installation and quality of data from each ship's multibeams. This included verifying each ship's MBES installation geometries, checking the impedance values of the arrays, conducting patch tests in order to determine static offset values, running swath performance tests (Figure 3-11), determining self-noise vs. speed and sea direction, and conducting accuracy tests. As was the case observed during last year's QAT visits, both the *Nautilus*'s EM302 multibeam and the Falkor's EM302 and EM710 multibeams were still performing very well and do not show any signs of degradation.

By scheduling these types of Quality Assurance checkups on a yearly basis, Paul and Kevin are able to evaluate potential changes in the performance and give OET and SOI some prior warning if their systems are not collecting the highest quality multibeam data possible. These cruises also gave Paul and Kevin an opportunity to improve the tools and techniques they utilize for multibeam echosounder evaluation for the Multibeam Advisory Committee.

We are working hard to coordinate and share our MAC experiences with our NOAA colleagues.

The Hydrographic Systems and Technology Branch (HSTB) continues to be the primary NOAA resource for the acceptance and support of mapping echosounders. NOAA colleagues have participated in UNOLS SATs and Center personnel will participated in future NOAA SATs. Planning for the installation and testing of a new EM710 MKII and EM2040 for the NOAA Ship *Thomas Jefferson* is ongoing, with likely involvement of John Hughes Clarke. HSTB has been supporting preparation of the Extended Continental Shelf cruise aboard the NOAA Ship *Ronald H. Brown*. Both Center personnel and HSTB members will be aboard for the test and evaluation cruise in the beginning of January 2016. Finally, HSTB also plans to be part of the acoustic testing cruise for the R/V *Neil Armstrong* (AGOR 27) that will be conducted by the MAC team in February 2016.

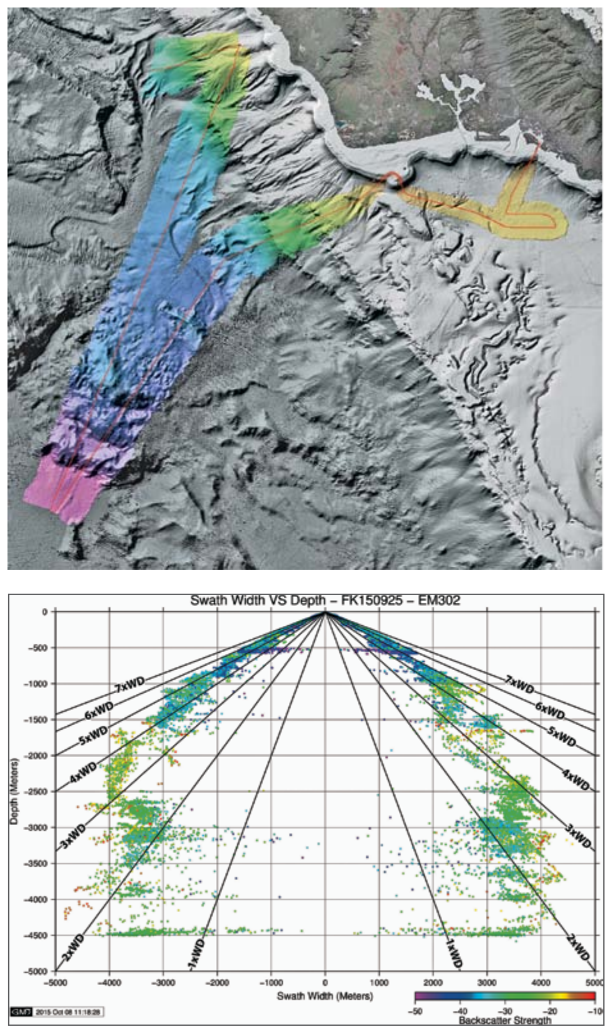


Figure 3-11. EM302 extinction testing from the 2015 R/V *Falkor* Quality Assurance Visit. Upper figure shows the data contributing to the extinction calculation (colored). Lower figure shows the results, plotting swath width vs. depth.

Phase Measuring Bathymetric Sonar Systems (PMBS)

Under the leadership of Val Schmidt and Tom Weber, the Center has invested a significant effort in trying to understand the potential of phase-measuring bathymetric sonars (PMBS—multiple-row sidescan sonars that use phase differences from the multiple rows to determine depth as well as backscatter) for hydrographic use. With the arrival of Tony Lyons, our ability to explore the efficacy of PMBS sonars for hydrographic and other applications has greatly expanded. While this is clearly a "SENSOR" issue, our efforts have been focused on the processing aspects of the problem rather than hardware aspects. Thus our efforts involving PMBS will be discussed under the DATA PROCESSING theme rather than the SENSOR theme.

Lidar

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric lidar systems offer the possibility to rapidly collect bathymetric (and other) data in these very shallow regions but there still remains great uncertainty about the accuracy and resolution of these systems. Additionally lidar (both bathymetric and terrestrial) offer the opportunity to extract other critical information about the coastal zone including seafloor characterization and shoreline mapping data. We have thus invested heavily in lidar-based research (led by Shachak Pe'eri and Chris Parrish) and will report on most of this effort under the HABITAT theme later in the report.

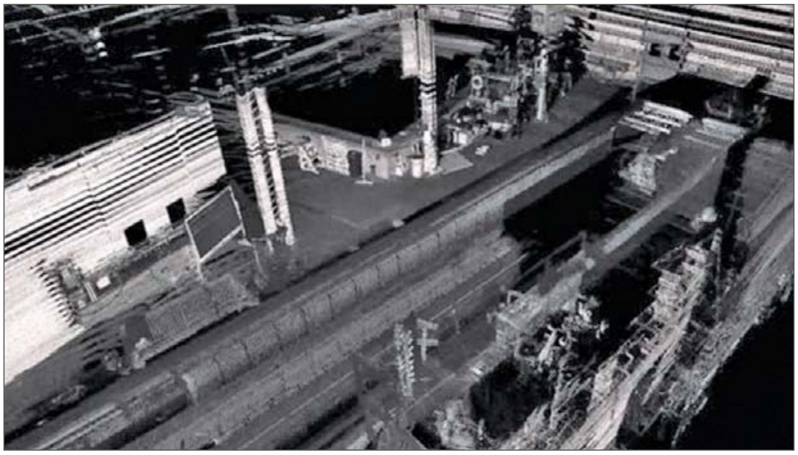


Figure 3-12. Point cloud of the Chase Ocean Engineering Facility using the VLP-16 Velodyne system.

Mobile Laser Scanner Integration

Within the context of the SENSOR theme we report on a new laser-based effort begun in 2014 by Shachak Pe'eri in collaboration with graduate student/NOAA Corps officer John Kidd, NOAA CSDL and NSD, and Vitad Pradith of Hypack. The navigational response teams (NRTs) of OCS/NSD are responsible for mapping hydrographic surveys to support chart update for 175 major U.S. ports that include mapping the bathymetry and features that may be a danger to navigation. In addition, the NRTs are on call to respond in emergencies to ensure the resumption of shipping after storms, protecting life and property from underwater dangers to navigation. In addition to natural features (e.g., shoals and boulders), there are also man-made features that pose danger to navigation (e.g., piers, piles). Previous work conducted by HSD has shown that survey-grade 3D laser scanners can be used to remotely map above-water danger-to-navigation features. However, it is hard to justify the purchase of a system that costs on the order of several hundred thousand dollars. An alternative solution is the use of an industrial safety 2D laser scanner. These systems require integration with auxiliary systems yet their cost is substantially less ($5k to $20k) than the survey grade 3D scanners.

After a market survey comparing different manufacturers, a HDL-32E Velodyne system was evaluated. The system was evaluated in laboratory conditions (in the Chase Ocean Engineering high bay) and in the field (at the UNH Coastal Marine Laboratory) mounted to the R/V *Coastal Surveyor*. Data was collected using both Hypack HYSWEEP® and VeloView, an open source software package. Based on these trials, the center purchased a Velodyne system that is currently being tested (Figure 3-12). Most of the work is being conducted by John Kidd with the support of Postdoctoral Researcher Firat Eren and graduate student Matt Birkebak. Initial efforts are underway to quantify the uncertainty of the Velodyne HDL-16 with respect to target detection. A variety of targets including wood, sand, concrete and aluminum were mounted at one end of the UNH Wave and Tow Tank. The laser scanner was then mounted to the tow carriage and measurements were taken over many ranges and incidence angles (Figure 3-13). The ability of the laser scanner to detect these objects is currently being analyzed.

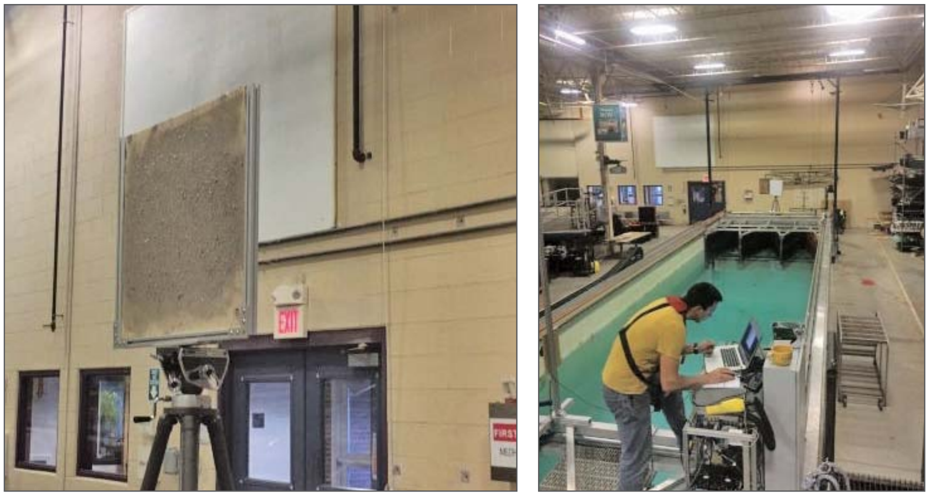


Figure 3-13. Target detection experiments: a sand covered target (left) and a laser scanner mounted on the tow carriage (right).

Lidar Simulator: ALB Uncertainty Derivation Using a Detector Array

Large uncertainty still remains as to the influence of the water column, surface wave conditions and bottom type on an incident Airborne Laser Bathymetry pulse. Unless these uncertainties can be reduced the usefulness of ALB for hydrographic purposes will remain in question. To address these questions, Shachak Pe'eri, working with postdoctoral researcher Firat Eren and graduate student Matthew Birkebak, has continued his efforts with the lidar simulator—a device designed to emulate an airborne lidar system in the laboratory. As part of the lidar Simulator project, we are investigating the effect of variation on the water surface, in the water column and the bottom return on the laser pulse measurements in an ALB system. Each of these environmental conditions introduce an uncertainty factor which potentially biases depth measurements and the seafloor characterization process. To do this, laser pulse intensity is measured by a planar optical detector array that was designed by Eren under Pe'eri's supervision during his Ph.D.work.

The optical detector array consists of 36 silicon photodiodes that are evenly spaced in a 6x6m planar array configuration. The modularity of the detector array makes it a suitable instrument for water surface and water column scattering measurements. With 80/20 Aluminum frames, the detector array can be deployed easily for both water surface and water column measurements. With the current design, it is possible to measure down-welling laser beam intensity, i.e., water surface and water column measurements. For upwelling signals such as bottom return, another detector array design is being constructed.

Water surface: The laser pulse interaction with the surface waves was investigated as part of Matt Birkebak's master's research. Here, the effect of wave periods and amplitudes on the laser footprint location are of interest. The system is deployed in the Center's wave tank where a wide range of wave conditions can be created. The amplitude and wavelength of the waves are measured using a Velodyne HDL-16 lidar unit. The spatial location of the laser footprint under different wave inputs were compared to calm conditions, i.e., when there are no waves. When there is a wave input, the location of the laser pulse incident on the optical detector array changes. By implementing image pro-

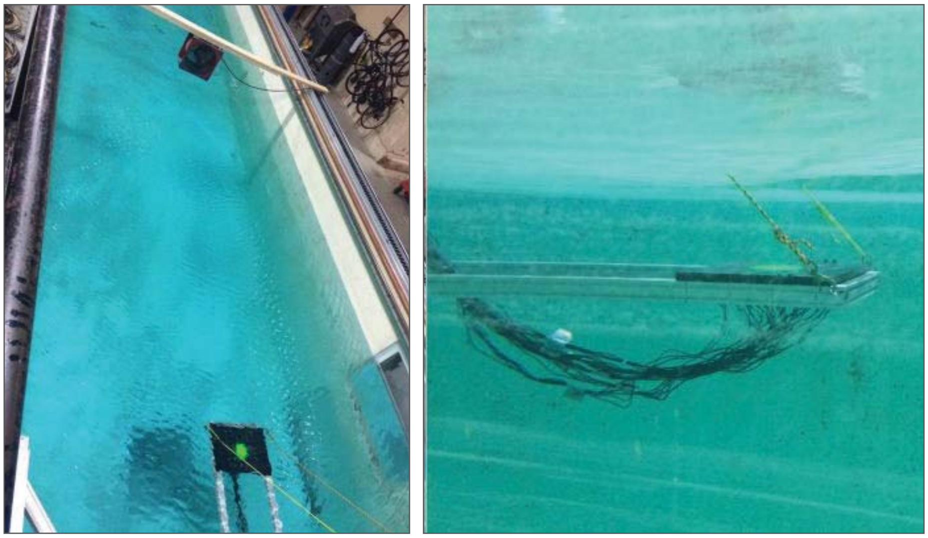


Figure 3-14. Water surface measurements. Laser pulse foot print under fan-generated wind conditions. (Left) The fan mounted on the tow tank generates the capillary waves. (Right) Side view of the optical detector array submerged into the water.

cessing techniques, namely image moment invariants, it is possible to derive the centroid of the image formed on the optical detector array. The experiments were conducted in the wave/tow tank. The optical detector array was submerged into the water and a continuous laser pulse was mounted in a configuration that results in a 20° incidence angle (Figure 3-14).

Water column: The laser pulse propagating underwater expands in a cone due to scattering in the water. The scattering induces an uncertainty factor in the laser pulse measurements that is recorded by the optical detector. Initial data sets have been collected for future analysis.

Bottom return: The hypothesis being tested is that pulse returns from different materials result in different waveform shape and amplitude. To test this, returns from a variety of materials have been recorded using a pulsed laser (Minilite solid state laser unit) at 532 nm as the source and an Avalanche Photodiode (APD) to collect bottom returns (Figure 3-15). Materials under test were plywood, white plastic, dark plastic and cardboard. Future work will include the evaluation of the bottom returns underwater in the tow tank. The utilization of the optical detector array for bottom returns is still being investigated.

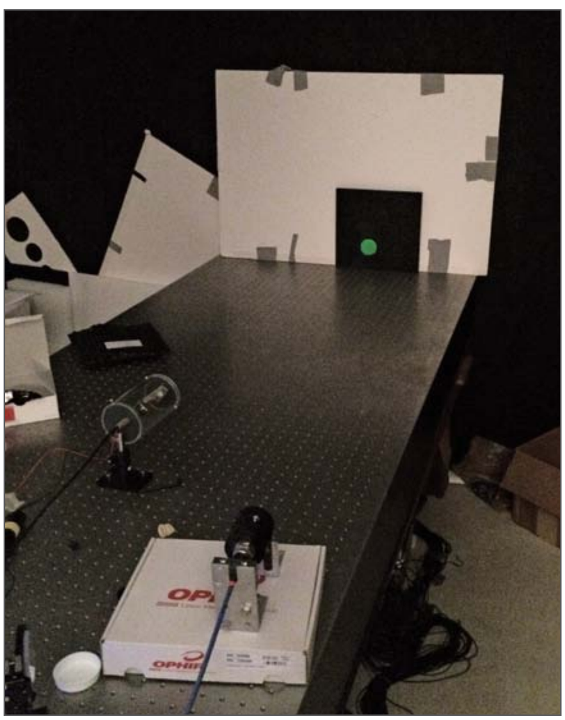


Figure 3-15. Bottom return experimental setup. The material under test here is black delrin. The APD is connected to the oscilloscope to record the bottom return waveforms resulting from different materials.

AUV/ASV Activities

AUVs

In 2006, the Center began an effort to explore the applicability of using a small Autonomous Underwater Vehicle (AUV) to collect critical bathymetric and other data. We teamed with Art Trembanis of the University of Delaware to obtain use of his *Fetch 3* vehicle. We purchased, calibrated and integrated a small multibeam sonar (an Imagenex Delta-T) into this AUV and over the course of 2007 began to explore its applicability for collecting both hydrographic quality bathymetric data and seafloor characterization data. Unfortunately, the Fetch 3 vehicle suffered a catastrophic failure during a mission in the Black Sea. Fortunately, the system was fully insured and we were able to replace the *Fetch* and Delta-T with a *Gavia* AUV and a 500 kHz GeoAcoustics GeoSwath phase-measuring bathymetric sidescan and a Kearfott inertial navigation system. Additional capabilities include sensors for temperature, sound speed, (derived) salinity, dissolved oxygen, chlorophyll and turbidity, a downward-looking camera and a Marine Sonics 900 kHz/1800 kHz sidescan sonar. The new system is a much more mature AUV than was the *Fetch*, with imagery, bathymetry, and particularly positioning capabilities far beyond the original vehicle. We have also purchased a WHOI acoustic modem for the new vehicle that allows enhanced positioning and two-way communication.

Val Schmidt is providing support to both the Center and the University of Delaware AUV operations. He has established a series of Standard Procedures and checklists for AUV operations and has written a considerable amount of software to monitor and support the Gavia, including code to explore an alternative, and hopefully improved and more deterministic, pipeline for processing phase-measuring bathymetric sonar data. Additionally, Schmidt and Trembanis have hosted a series of very popular "AUV Bootcamps," the latest of which took place in the summer of 2014. AUV Bootcamp is an engineering and development workshop focused on advancing the art of the use of AUVs for hydrographic survey. The 2014 bootcamp provided a special opportunity to operate NOAA's REMUS 600 AUV with experienced operators and hydrographers from the public, private and military sectors, and to scrutinize every detail of operations, data collection and processing in a hydrographic context. There were 44 attendees at the bootcamp, including 19 from industry, four from the US Navy, 11 academics, two from the UK Ministry of Defence and eight from NOAA. An issue identified at the last bootcamp was the failure of standard

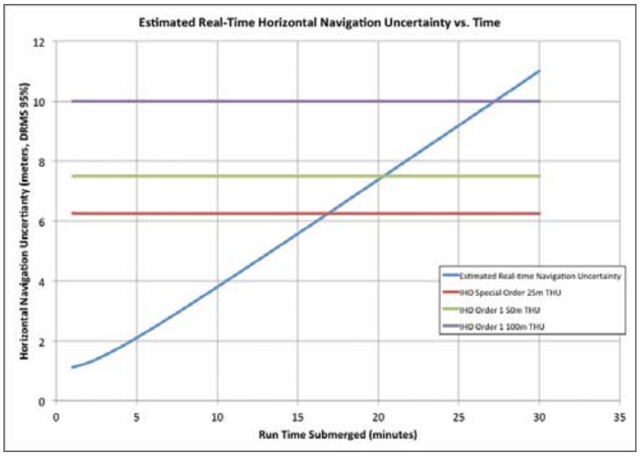


Figure 3-16. Modeled horizontal AUV position uncertainty as a function of time after submergence for a straight trajectory, is plotted at the 95% DRMS level and compared with various International Hydrographic Organization uncertainty requirements. The model predicts that with no post-processing, the AUV's navigation uncertainty estimate will exceed IHO specifications in as little as 17 minutes.

AUV post-processing to compensate for atmospheric pressure and actual density characteristics of the water column.

During the workshop, specific attention was paid to minimizing the uncertainty in vehicle navigation. In January and February 2015, Schmidt and Shannon Byrne, from industrial partner Leidos Inc., quantified the results of these investigations, presenting them in a 2015 U.S. Hydrographic Conference paper. Figure 3-16 illustrates the challenge of AUV-based survey, showing, for example, that after just 17 minutes of operation, the requirement for an IHO S.44 5ed. Special Order survey is likely to be exceeded. When navigation

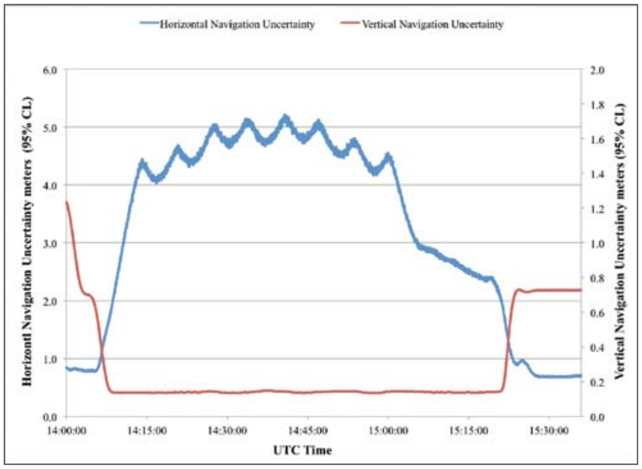


Figure 3-17. Post-processed position uncertainty for a mission run in Portsmouth Harbor.

post-processing is included however, the uncertainty increase seen in the model is mitigated by constraining the position estimates with solutions computed both forward and backward in time. The effect is seen in Figure 3-17, depicting post-processed position uncertainty for a mission run in Portsmouth Harbor.

The initial analysis also identified methods for correcting for biases in the vehicle's pressure sensor due to installation orientation, changes in barometric pressure, variations in water density from nominal conditions, and even local gravitational anomalies. These biases directly contribute to biases in the vehicle's own depth estimate, and subsequently the system's estimate of seafloor bathymetry. When fully accounted for, Schmidt and Byrne showed the AUV capable of generating a surface whose point-for-point differences from a ship-navigated reference were less than 0.19 meters 95% of the time, with a mean difference of just 0.08 meters. [NB. These metrics are obtained over a flat seafloor and demonstrate the vertical positioning capability rather than the horizontal capability.]

Significantly, the only commercial sonar data post-processing application currently capable of incorporating these corrections and ingesting real-time uncertainty from the vehicle was Leidos' SABER. The Center's corporate partnership with Leidos and personal relationships developed over several years facilitated the close collaboration in this work.

ASVs

In late 2014, we began a new effort designed to explore the feasibility of using Autonomous Surface Vehicles (ASVs) as a platform for the collection of hydrographic data. The initial focus of our efforts have revolved around the work of graduate student and NOAA Corps Officer LTJG Damian Manda whose thesis work focuses on development of small autonomous surface vehicles with hydrographic surveying-targeted behaviors. The platform uses a Raspberry Pi 2 embedded Linux computer, which controls the vessel in conjunction with an Arduino microcontroller. The Linux computer runs the open source MOOS-IvP autonomy platform, which receives commands from a remote station via a long range WiFi link. A human radio control override is also available. Feedback to the autonomy system comes from a CHRobotics GP9 position and attitude reference system, shaft speed sensors and a speed through the water wheel sensor. Attitude is filtered using pre-existing algorithms in the Robotics Operating System (ROS) software. This control system is intended to be flexible for installation on platforms of

Figure 3-18. Screenshot of EMILY during testing at Swains Lake. Entire video can be viewed at **https://youtu.be/hiJdUtHbYaY**.

opportunity and for this research was implemented on an existing NOAA EMILY small autonomous boat, and boats constructed by an undergraduate senior project team. During this reporting period, the EMILY vehicle was tested in lakes around the UNH campus for tuning of the control system and testing of interaction with other vessels (Figure 3-18).

Algorithms were developed for use in hydrographic surveying applications. These behaviors allow a craft to start from a given line and complete a survey area without previous knowledge of the bathymetry. Paths adapt based on detected hazards and are spaced dynamically depending on the depth for applicability to varying width multibeam swaths (Figure 3-19). These algorithms and an associated operational routine were implemented into the MOOS-IvP autonomy system and field tested both with single beam sonar using a simulated swath and the Teledyne Odom MB-1 multibeam system. Developments on the hardware and software have been presented at the MOOS-DAWG conference at MIT, IEEE/MTS Oceans '15 and shared with other participants of the Alliance for Coastal Technologies ASV Workshop.

Manda also tested his software on Teledyne Z-Boats that are now in operation on the NOAA Ship *Thomas Jefferson* and loaned to the Center by industrial partner Teledyne OceanScience (Figure 3-20). In order to test his survey related autonomous behaviors and add autonomous control to the vessel without a supplied module, Manda adapted his low cost system for operation with the Z-Boat, including writing necessary drivers for the positioning, sonar and motor interface systems and designing a simpler hardware module. Three copies of the simplified module were purchased for continued use on the ship.

The autonomy behaviors and integration with the Z-Boat were first tested in August 2015 in Newport, RI and used to conduct single beam surveys from preplanned patterns and adapting to measured depths. Additional testing was performed on a multibeam equipped Z-Boat at the JHC in November, followed by a field demonstration at the ACT ASV workshop in Solomons, MD where a selected region was surveyed for full coverage using the autonomy system. Further testing with the NOAA Ship *Thomas Jefferson* is ongoing, including remote operation tests for control and monitoring of the boats over a cell network. A boat in Virginia has successfully completed survey acquisition while being managed by Manda in New Hampshire.

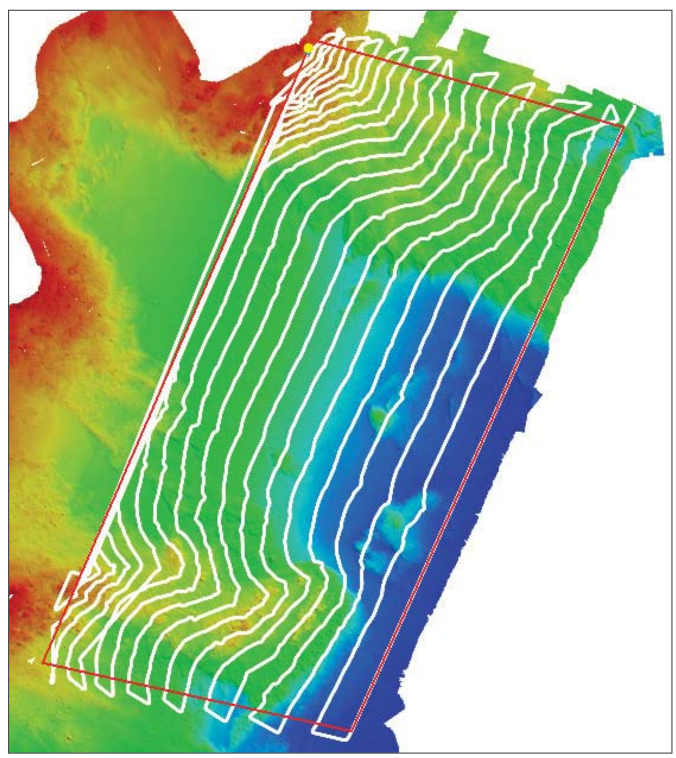


Figure 3-19: Adaptive path planning for bathymetric data collection from simulation using previously collected bathymetry.

Figure 3-20. Teledyne OceanScience Z-Boat for NOAA Ship *Thomas Jefferson.*

In order to better understand current ASV capabilities and how they relate to hydrographic needs, in January 2015, the Center began a survey of the state-of-the-art ASVs that are commercially available, evaluating them in the context of the mission objectives of NOAA and the ability of our own researchers to quickly integrate new sensors and behaviors into existing systems. Three of the systems evaluated are shown in Figure 3-21.

Although many ASV research programs exist in academic and government labs, commercially supported systems are advantageous in that they provide a faster means of getting operational systems into the hands of NOAA for production operation. The systems evaluated were generally found to be thoughtfully designed, and while they each were meeting the requirements of a target customer set, none of those requirements matched that of sea-going production hydrographic survey. These requirements include seaworthiness suitable for open ocean navigation, electrical payload capability to support sonar and navigation systems, and full work-day endurance. Nonetheless, many manufacturers have expressed interest in collaboration and partnerships are underway to build and co-develop systems that will allow real testing of the feasibility of production hydrography from ASVs.

In an effort to develop rapidly develop ASV capabilities for safe navigation at sea and production hydrographic work the Center has partnered with ASV Global Ltd and Teledyne Oceansciences, Inc. The Center will likely purchase and co-develop a four-meter vessel from ASV Global, with payload and endurance capabilities suitable for production hydrographic survey similar to that of a standard NOAA launch. The Center will also take possession of a Teledyne Oceansciences "Z-Boat," graciously provided under the corporate partnership program with an aim to rapid deployment and survey of shallow areas unsuitable for larger vessels.

Clearpath Robotics "Kingfisher"	Teledyne Oceansciences "Z-Boat"	Hydronalix "EMILY Boat"	ASV Global "C-Worker"

Figure 3-21. Autonomous surface vessels recently evaluated for their suitability for production hydrographic survey work.

Other Sensors

Low-Cost Coastal Mapping and Surface Tracking With a Kinect Device

Thomas Butkiewicz has been investigating novel usage of Microsoft's Kinect v2 device (which uses time-of-flight measurements as opposed to the less accurate structured light approach of the earlier generation of Kinect devices) to perform low-cost small-scale mapping of coastal environments (Figure 3-22). Capturing high-resolution 3D data is generally expensive, and the prohibitive cost of acquiring up-to-date data through traditional methods often limits the applications. At a cost of ~$200, a Kinect v2 is affordable for even low-budget research projects, and has the potential to allow a single user to capture highly accurate 3D maps of coastal environments.

Butkiewicz's experiments with the device have identified its limitations and error characteristics in outdoor and underwater usage, which are detailed in the publication, "Low-Cost Coastal Mapping using Kinect v2 Time-of-Flight Cameras," (IEEE OCEANS 2014).

In 2015, he continued to develop and maintain the "Kinect2 Map Kit" software based on feedback from actual users outside the Center. It is available for free on the Center's website. In addition to better time-lapse surface tracking, the tool now allows for the live capture and direct export of 3D meshes into common, standardized file formats which can be loaded, manipulated, and measured in free open source software such as MeshLab. These features are useful to an extremely broad range of scientific fields. For example, Kinect2 Map Kit is actively being used by anthropologists to capture data inside lava tubes and at other dig sites.

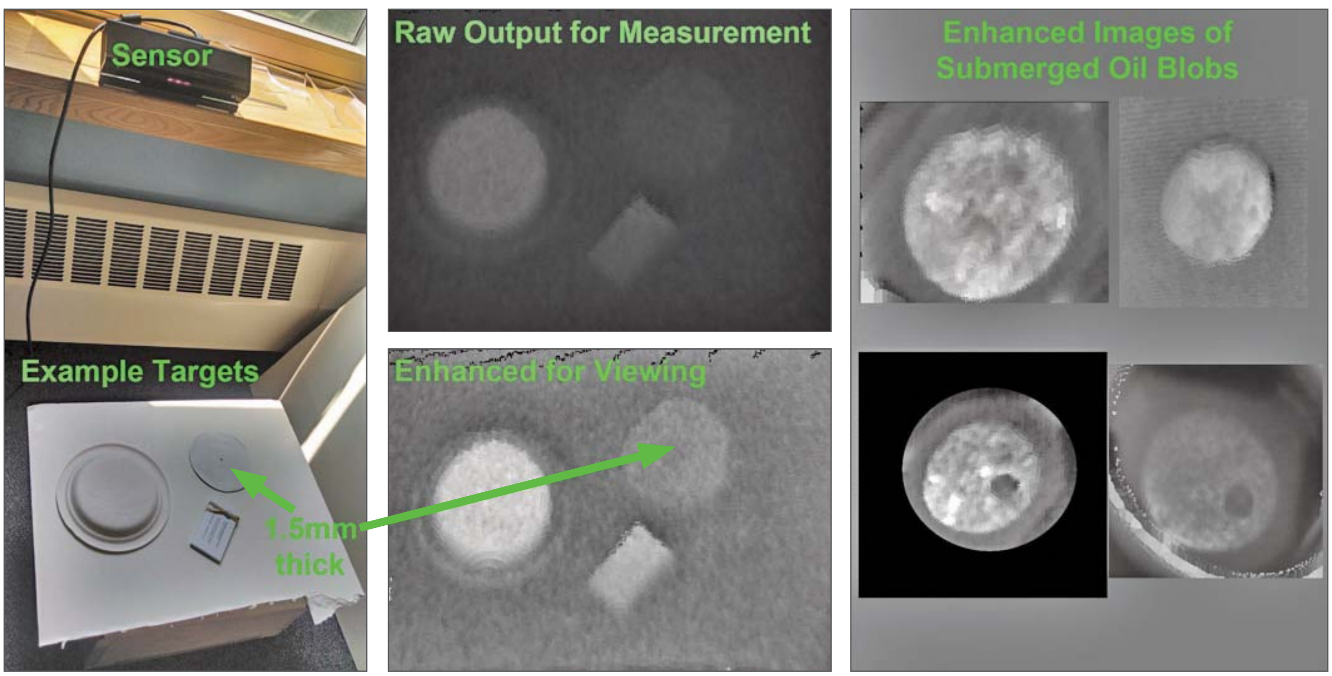


Figure 3-22. Kinect 2 being used to measure thin targets (left) and oil slicks on water surface (right).

Theme 2 – Processing

Improving and Developing New Approaches to Hydrographic, Ocean and Coastal Mapping Data Processing with Emphasis on Increasing Efficiency While Understanding, Quantifying, and Reducing Uncertainty

The development of better and more efficient means to process hydrographic data has been a long-term goal of Center activities. As the number and type of sensors with which we are involved, and the scope of ocean mapping expands, so does the range of processing challenges we face. In this section we begin with our "bread and butter," a discussion of bathymetric processing tools that we have developed and are developing for both traditional multibeam echo sounders and phase measuring bathymetric sonars. We then look at the concept of "trusted community" or "crowd-sourced" data collection and explore the usefulness of existing datasets and suggest new directions that might be taken. We also look at processing tools being developed to extract bathymetric, shoreline and other data from satellite and other imagery. In parallel with our work on bathymetric data processing we are also investigating approaches to understanding the uncertainty associated with the backscatter that is provided by swath mapping systems and applying this understanding to efforts to characterize the seafloor. We also introduce a new processing effort that began with our efforts associated with Super Storm Sandy—a project aimed to develop tools for the automated detection of marine debris. Finally, we recognize our critical responsibility to manage and deliver the data that we collect in an appropriate fashion and thus discuss our efforts to develop state-of-the-art data management and delivery systems.

Improved Bathymetric Processing

Limitations to Wide Swath Bottom Tracking Due to Dynamic Oceanography

The arrival of John Hughes Clarke at the Center greatly expands our expertise in understanding the factors that impact the quality of the swath mapping data we collect. NOAA, along with many hydrographic organizations, continually investigates the feasibility of working with ever wider angular sectors. This potentially allows higher productivity in shallow coastal waters but also exacerbates the position and integration issues that are compounded by obliquity. It also particularly exacerbates a source of uncertainly that has received much attention—unstable near-surface sound speed fluctuations that can provide a practical limit on achieved coverage. Hughes Clarke has been exploring this issue in a long-standing collaboration with the U.S. Naval Oceanographic Office.

NavO is in the process of upgrading all its hydrographic survey launches with the EM2040D. The dual receiver version of the EM2040 has a number of potential benefits in resolution over the single receiver model. Most notably, swath widths up to +/-82° are feasible, involving receiver beam-widths much narrower than available from the single flat receiver. To take advantage of those narrower, lower grazing angle beams, however, requires that the challenges of motion, refraction and bottom tracking be adequately addressed.

A major operational finding of the NavO trials has been that there are significant environmental limitations of working in areas where there are strong near-surface sound speed gradients. Using both rapidly dipping underway profilers and built-in water column imaging, the correlation between the oceanographic stability and the quality of the outer swath bottom detection is apparent. A particular concern is small oscillations in the velocline that appear to correspond to short wavelength internal waves. These can be made much worse by repeated passage of vessels that trigger these internal waves in a manner similar to wakes. This would impact operation in heavily trafficked waters (Figure 4-1a and b).

A second concern noted with these wide swath trials is the limited angular sector within which object detection can be confidently achieved. Using calibrated targets, the small object detection capability of the

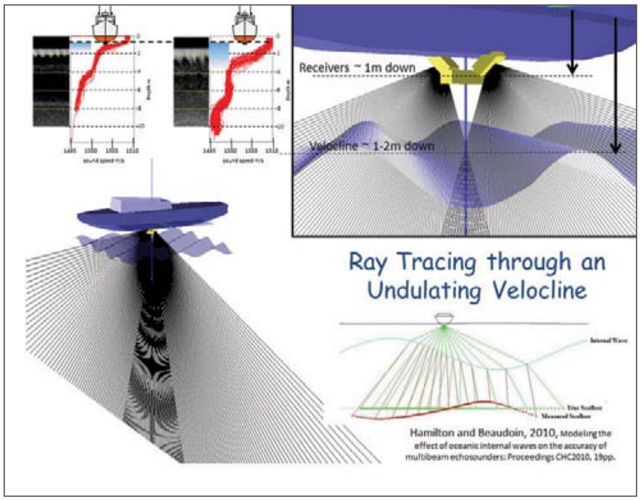


Figure 4-1a. Showing the sound speed environment in which bottom tracking instability occurred and the geometry of the internal wave activity.

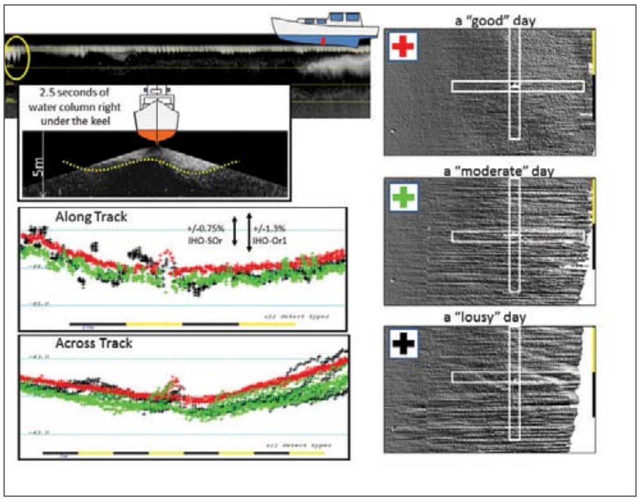


Figure 4-1b. Showing the varying quality of outer swath bottom tracking (along and across track) as the vessel passed over crests and troughs of internal waves on the velocline (as revealed in the water column).

2040D was shown to be limited within about 60° incidence. Although, the height of the targets was not correctly tracked, they were apparent at larger incidence angles through a gap in the coverage. To address this deficiency, an updated Bearing Direction Indicator (BDI) algorithm was recently implemented using the logged water column data, and is shown to be capable of recovering these targets. Even with BDI capability, however, the recovered targets may be at or below the level of pseudo-random sounding noise introduced by velocline instabilities.

The ongoing NavO collaboration involving field trials of their EM2040D systems will be continuing in July/August 2016 in Canadian waters near British Columbia. Additionally, the new Center research vessel will be stationed briefly in Victoria, BC in February 2016 while awaiting shipment to the east coast. On an opportunistic basis, tests may be undertaken using the NavO target infrastructure there to experiment with other sonar systems on their standard range of targets. Once the new Center research vessel arrives on the east coast, comparable low grazing angle sensor trials are envisaged in New Hampshire waters, further examining these oceanographic phenomena and their impact on bottom tracking.

CUBE and Improved Uncertainty Management

One of the major efforts of the Center has been to develop improved data-processing methods that can provide hydrographers with the ability to very rapidly and accurately process the massive amounts of data collected with modern multibeam systems. Data-processing is one of the most serious bottlenecks in the hydrographic "data-processing pipeline" at NOAA, NAVO, and hydrographic agencies and survey companies worldwide. After evaluating a number of approaches, our efforts have focused on a technique developed by Brian Calder that is both very fast (10s to 100s of times faster than then contemporary processing approaches) and statistically robust. The technique, known as CUBE (Combined Uncertainty and Bathymetric Estimator), is an uncertainty model-based system that estimates the depth plus a confidence interval on each node point of a (generalized) bathymetric grid. In doing this, the approach provides a mechanism for automatically processing most of the data and, most importantly, the technique produces an estimate of uncertainty associated with each grid node. When the algorithm fails to make a statistically conclusive decision, it will generate multiple hypotheses, then attempt to quantify the relative merit of each hypothesis and present them to the operator for a subjective decision. The key is that the operator needs to interact only with that small subset of data for which there is some ambiguity rather than going through the conventional, very time-consuming process of subjectively examining all data points.

CUBE was subjected to detailed verification studies in 2003 as part of a cooperative research effort with NOAA that compared the automated output of CUBE to equivalent products (smooth sheets) produced through the standard NOAA processing pipeline.

Verification studies were done in three very different environments (Snow Passage, AK; Woods Hole, MA; and Valdez, AK) involving surveys in various states of completion and comparisons done by NOAA cartographers. The CUBE-processed data agreed in each case, with the NOAA processed data within IHO limits. CUBE processing took from 30 to 50 times less time than the standard NOAA procedures in use at the time.

Based on these verification trials and careful evaluation, Capt. Roger Parsons, then director of NOAA's Office of Coast Survey, notified NOAA employees as well as other major hydrographic organizations in the U.S. (NAVO and NGA) of NOAA's intent to implement CUBE as part of standard NOAA data processing protocols. As described by Capt. Parsons in his letter to NAVO and NGA, CUBE and its sister development, The Navigation Surface:

> *"…promise considerable efficiencies in processing and managing large data sets that result from the use of modern surveying technologies such as multibeam sonar and bathymetric lidar. The expected efficiency gains will reduce cost, improve quality by providing processing consistency and quantification of error, and allow us to put products in the hands of our customers faster."*

In light of NOAA's acceptance of CUBE, most providers of hydrographic software have now implemented CUBE into their software packages (CARIS, IVS/QPS, SAIC (now Leidos), Kongsberg Maritime, Triton-Imaging, Reson, Fugro, GeoAcoustics, HyPack, and IFREMER). Dr. Calder continues to work with these vendors to ensure a proper implementation of the algorithms as well as working on new implementations and improvements. The progress made in 2015 is described below.

Multiresolution Grids—CHRT

Calder's efforts with respect to CUBE in 2015 have focused on the CHRT (CUBE with Hierarchical Resolution Techniques) algorithm. CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of estimates of depth generated. The architecture is also designed to be efficient, parallelizable, and distributable over a network. As part of the on-going development of CHRT, Calder has been conducting work in three primary areas: development of better internal resolution estimation and uncertainty propagation algorithms, support for variable resolution BAG surfaces (including development of the variable resolution BAG specification), and testing protocols for vendor implementations.

The CHRT project implements a multi-resolution, data-adaptive estimation layer on top of the core CUBE hydrographic data processing algorithm. This allows for better control over many of the parameters in CUBE that otherwise have to be specified by the user, and eases many of the issues with variant implementations of the CUBE algorithm in the industrial sector. In the current reporting period, Calder has continued to adjust features of CHRT that are associated with the resolution assessment algorithm in order to support implementers and stabilize the estimates generated. These modifications allow the user to specify directly which algorithm should be used to compute the estimation resolution based on statistics estimated from the data being processed, and allow for calibration of the resolution computation algorithm, which improves stability of estimation. In addition, an interface to generate variable-resolution BAG files (using the experimental, proposed specification for BAG V1.6) has been added and demonstrated using the BAGViewer application (see discussion under IMPROVED DATA PROCESSING FLOW discussion) and the BAG extension of HDF Compass (see discussion of later in this section).

As vendor implementations of CHRT start of be readied for release, however, we face questions of how to implement the certification process mandated by CHRT software licenses, which require that vendors show that their CHRT implementation matches the reference version maintained by the Center, and allow end-users to do the same.

In the current reporting period, therefore, Calder has focused on testing issues, working with a number of industrial co-developers, and NOAA representatives, to establish a test suite that would allow for CHRT 1.0 validation. The structure for the initial test suite has been defined, and will consist of a lightweight C-language API that can exercise all of the commands used by the CHRT network protocol, exercised by a set of standard test scripts that verify both positive and negative behaviors. A working group of interested industrial co-developers is being established in order to support this effort, with target representation initially from CARIS, Leidos, QPS, and NOAA.

Additionally, Calder has collaborated with Paul Elmore (NRL Stennis) on an alternative uncertainty propagation equation for use in CUBE and CHRT. Based on a development of the core uncertainty propagation equation, the modified version uses the mean distance propagated by a sounding, rather than a somewhat arbitrary scale factor applied to horizontal uncertainty, and a separate scale factor that controls the magnitude of uncertainty magnification at one unit grid distance in a manner that makes it much easier for the user to understand and control the uncertainty being used. This modification will reduce over-emphasis of uncertainty due to the effects of horizontal uncertainty in the input observations while providing better control over the magnitude of the uncertainty being propagated. A paper is in preparation, and the new algorithm has now been implemented in CHRT.

Development of Theoretical and Computational Methods for Single-Source Bathymetric Data

For Information – funded by other sources

Most hydrographic agencies are now, have been, or are planning on, attempting to generate a single-source bathymetric database from which to derive the bathymetric components of the charts being produced. Although much effort has been expended on this subject, there are still fundamental gaps in both theoretical and computational techniques associated with this problem. Supported by a research grant from the Office of Naval Research, Calder and Ware have started investigating this issue, with a focus on being able to predict, given heterogeneous data sources, a composite output product element, along with its associated uncertainty, and then communicate it to the end-user with an appropriate visualization technique. In practice, a bathymetric safety contour has been selected as the simplest useful product for which to develop a methodology.

Working with researchers at Navy Research Labs/Stennis, and the Naval Oceanographic Office, the work considers the relatively well understood issues of dense data, the less well understood issues of sparse data, and the almost completely unknown issues of incomplete and ill-specified data. In this first year of the project, the objective is to catalogue the various sources of uncertainty, and to establish methods by which the disparate forms of uncertainty could be combined, or at least manipulated, towards the common goal of a knowledge-based statement of uncertainty in a product recognizable by the end user. An additional objective is to be able to readily explain the process by which the uncertainty estimate was constructed.

Trusted Community and Crowd Source Bathymetry

A current trend in hydrographic practice is the increasing interest in 'crowd sourced' bathymetric measurements (also known as 'volunteered geospatial information,' or VGI). Although there are a number of projects underway to collect bathymetric data with the ostensible intent of creating or updating charts, most (if not all) hydrographic offices are reluctant to accept non-professional survey data for chart update due to the liability issues involved.

In order to address these issues, Calder and Dijkstra have initiated a new project to investigate an alternative approach to the problem where instead of gathering data of uncertain provenance and then attempting to make it suitable for charting through some sophisticated processing, a more sophisticated data collection system is developed that by design gathers data that is of demonstrable quality, and preferably of sufficient quality to be used for chart update (Trusted Community Bathymetry—TCB). The system (Figure 4-2) provides a dedicated data capture device (using a small embedded processor) along with a PPP-capable GNSS receiver and low-cost imaging sonar (combined VBES and side imaging sonar). This, in theory, allows sufficient data to be collected to apply post-processed GNSS positioning techniques and estimate depths to the ellipsoid autonomously of ship operations. The associated data flow path allows for rapid publication of data in national archives with full metadata, and for value-added data aggregators (VADAs) to build services on top of the raw data. The idea of TCB is that instead of collecting unreliable data from the public crowd (which gener-

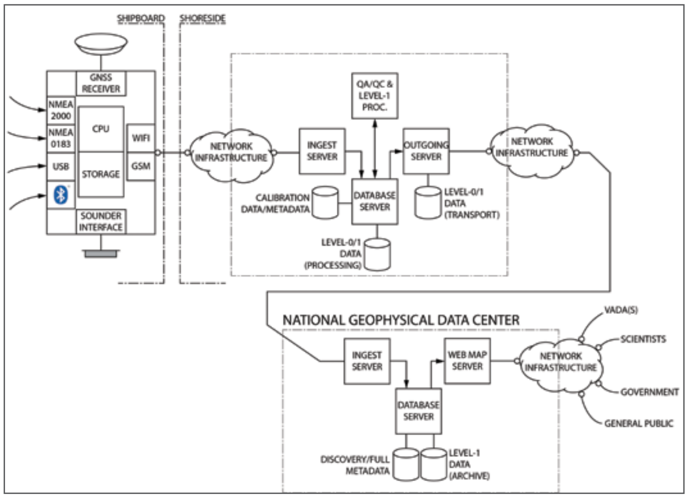


Figure 4-2. Design of a Trusted Community Bathymetry collection system, and associated data flow paths.

Figure 4-3. Garmin GT-30 sidescan/downscan transducer (left) and GCV-10 black-box sonar module (right), being tested for Trusted Community Bathymetry applications at the UNH pier in New Castle, NH on June 8.

ally does not satisfy the requirements of a "crowd" in the sense normally used) and then trying to sanitize it, or relying on some "trusted partners" that are specially trained to collect putatively better data, it makes more sense to provide a (relatively) low-cost system, or system add-on, that would collect data that by design is of sufficiently high quality to be used directly by a hydrographic agency in their consideration of charting updates.

In 2015, Calder, with the assistance of summer intern Fruth, started testing equipment that could be used for a Trusted Community Bathymetry (TCB) system. The first stage of this project is to determine the capabilities of potential component parts of such a system, and to thereby develop the requirements for a system design. To that end, Calder and Fruth have been testing an inexpensive (~$500) Garmin GT-30/GCV-10 sidescan system (Figure 4-3) that is designed primarily for recreational fishermen, as a means to capture useful data that might be used for hazard assessment. The system can generate conventional high-frequency sidescan, and also a downward-looking "sidescan" beam (Figure 4-4) which could potentially be turned on automatically if the system recognizes that it is in the vicinity of a target of interest to the hydrographic office (as supplied by the hydrographic office on the capture media provided for the system). Calder and Fruth are currently working on understanding the data generated by the sidescan system, primarily to determine control strategies and capture protocols.

Our efforts in Crowd Sourced Bathymetry are further supported by the participation of Brian Calder in the recently formed IHO working group on Crowd Sourced Bathymetry (CSB). The working group has terms of reference to investigate the requirements for CSB, including the business model, hardware requirements, software support, data formats, archival, uncertainty estimation, and data processing. As part of the initial working group, Calder has been involved in early discussions on requirements, with a particular interest in uncertainty issues, information estimation, decision thresholds, data processing, and formats for archival. He is also leader of the Correspondence Group for uncertainty estimation and management. The working group presented an initial proposal at the GEBCO meeting in Kuala Lumpur in October 2015, and will have a second international meeting in Boulder, CO, February 10-11, 2016.

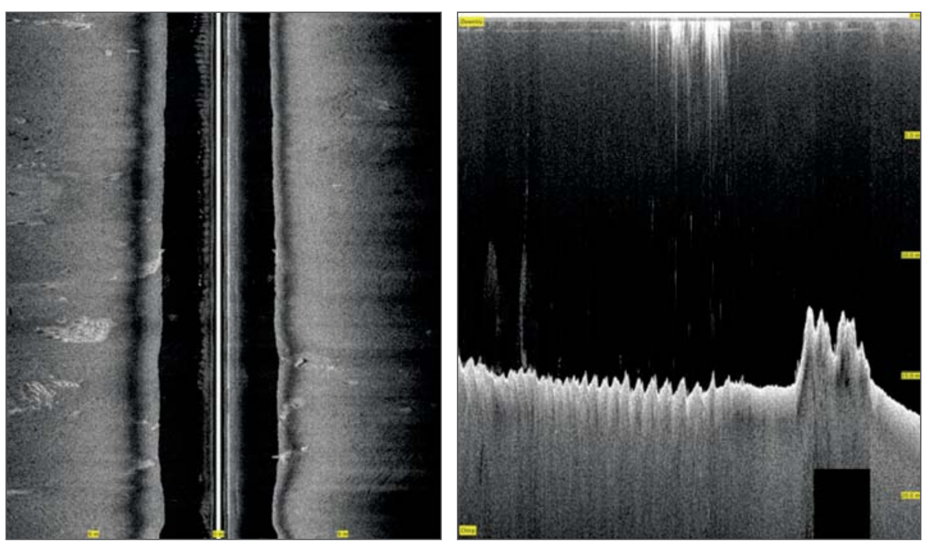


Figure 4-4. Example of Garmin GT-30 sidescan (left, in Pepperel Cove) and downscan (right, in the harbor sandwave field) in Portsmouth Harbor, NH, collected from the *Galen J* on June 19.

Improved Processing for Phase-Measuring Bathymetric Sonars

Phase-measuring bathymetric sonars (PMBS) (multi-row sidescan sonars that look at the phase differences of the acoustic signals between the rows to derive a bathymetric solution) have the potential of offering much wider coverage in shallow water than conventional beam-forming multibeam sonars. NOAA and other mapping agencies have recognized this potential benefit and have begun to explore the feasibility of using PMBS as a hydrographic tool. One of the immediate results of this is the realization that current hydrographic processing software approaches and tools are cumbersome to use with the very dense, but inherently noisy, data produced by a PMBS. The Center has committed itself to explore new approaches to processing PMBS data and, in support of this commitment, has teamed with the University of Delaware in the operation of a 500-kHz GeoSwath PMBS that is mounted on a *Gavia* Autonomous Underwater Vehicle. This has provided us the opportunity to collect PMBS data and begin to explore the problems associated with PMBS data (as well as AUV-derived data). Our experience in recent years with PMBS expanded to include work with the Klein HydroChart 5000 and the EdgeTech 4600 and also included involvement with Xavier Lurton of IFREMER.

Val Schmidt has taken the lead in exploring problems with (and new approaches to) processing PMBS bathymetric data. Val has been working with manufacturers for better hardware designs and with software developers of post-processing packages for better handling of PMBS data such that it is more readily suitable for hydrographic work. As a direct result, Edgetech and Klein systems now provide real-time bathymetric uncertainty estimates with their data (Figure 4-5). Geoacoutics and Bathyswath have yet to do the same, but it is clear from lengthy discussions that they understand the need for hydrographic processing. In addition, Klein has redesigned their bathy processing engine to produce nearly full coverage at nadir in water depths shallower than approximately 20 m, where previous systems left a 60 degree gap. The lack of data at nadir had been a major challenge for patch-test calibration procedures, as the effects of biases in pitch, roll, and heading could not be suitably isolated during the calibration. Further, Caris and Hypack now support ingestion of uncertainty from Edgetech and Klein systems. The Center has also been working with Caris to reduce confusion in their interfaces for these systems, particularly with regard to how uncertainty is handled.

Schmidt has been working closely with NOAA contractors Cassandra Bongiovanni, Juliet Kinney and Sarah Wolfskehl, who are co-located at the Center, to help discern if recent post Super Storm Sandy surveys by the USGS with the SeaSwath system are suitable for nautical charting. The kinds of questions we are posing are illustrated in Figure 4-6, where the upper images shows

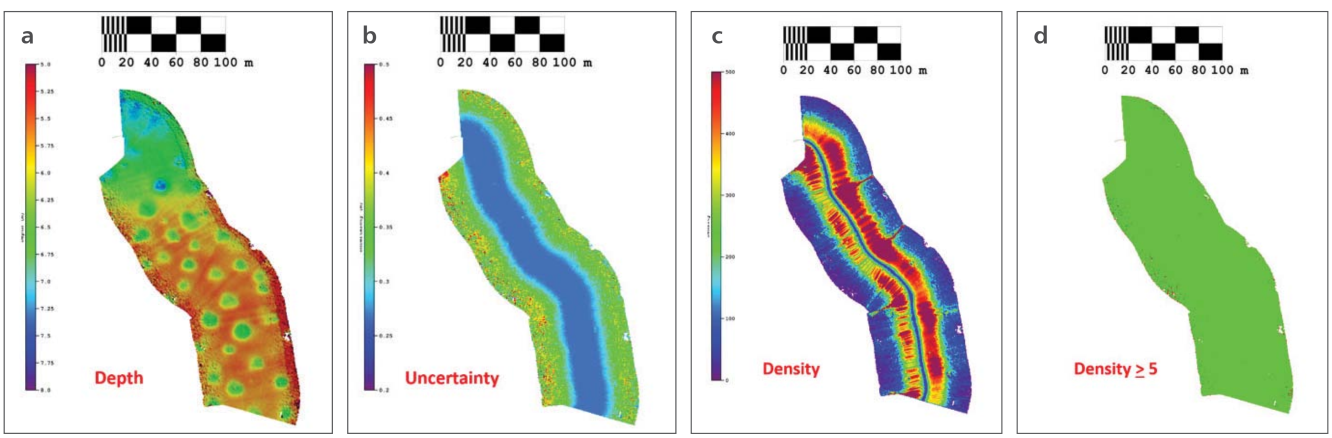


Figure 4-5. An example EdgeTech 6205 survey line over a mooring field in Portsmouth Harbor meets NOAA requirements for sounding density and vertical total propagated uncertainty (TPU, 95% confidence) across a large portion of the swath. The raw data were processed without binning in Discover Bathymetric version 34.0.1.110 using a Quality Filter of 50%. Processed data were then gridded at 50 cm, the finest grid resolution required by NOAA in this depth range, using the CUBE algorithm in CARIS HIPS 9.0. No manual editing has been performed. Bathymetry (a, color scale of 5 m to 8 m) appears generally free of artifacts out to 8-9 times water depth, beyond which a shoal bias of unknown origin is evident. Grid cells with uncertainty exceeding the maximum TVU (50-51 cm in this depth range for IHO Order 1) appear as purple in the uncertainty plot (b). Sounding density below the minimum of five soundings per grid cell appear as red in the density criterion plot (c).

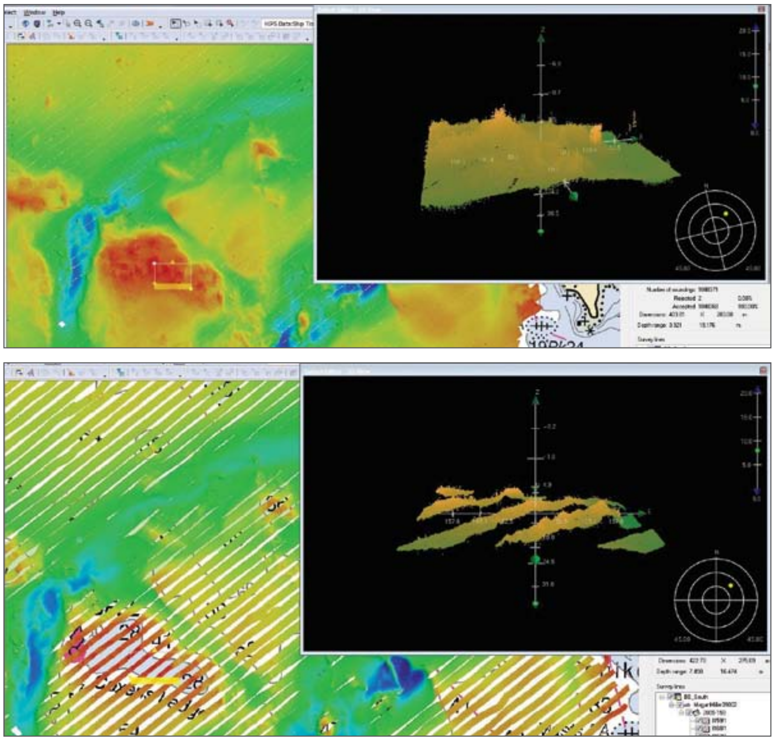


Figure 4-6. Subsets of full-swath SwathPlus PMBS data (above) and the same data limited to +/-60 degrees (below), illustrate the tradeoffs of PMBS data sets, namely noise, holidays, target detection and measurement.

a selection from the complete data set and the lower image shows a selection from a subset of the data in which the swath angle is limited to +/- 60 degrees commensurate with standard practice for MBES surveys.

The reduced-swath angle data set has a lower standard deviation on average with fewer outliers, but has large holidays between adjacent lines. The full swath data set would have taken less than half the time required to survey for full seafloor coverage than the reduced-swath angle data set. Both would meet IHO Order 1 uncertainty requirements. Is it preferable to have full coverage even if the uncertainty in the result is significantly higher (but still meeting spec)? How difficult is it to estimate least depths over hazards to navigation from the full-swath data set? The group will be working through these issues as we progress.

In addition, as part of our work under the IOCM Super Storm Sandy Disaster Relief cooperative agreement (NA14NOS4830001), PMBS data sets have been evaluated by Schmidt and Jerram for their effectiveness in post-storm survey. From these findings a series of recommendations have been produced for effective object detection from the bathymetry of PMBS systems. These include careful interpretation of the bathymetry data in the context of the sidescan imagery (Figure 4-7), scanning data in real time to ensure hazards to navigation are captured in the most favorable survey geometries, utilizing systems that produce real-time uncertainty with their measurements as well as bin and average data to reduce noise and thoughtful outlier rejection to ensure true outliers and not the tails of a noisy measurement distribution are omitted.

For example, the 'Show Cursor On All' option helps the user to identify the same location (red crosshairs) in the gridded bathymetry and the sidescan imagery from multiple passes for better context and correlation among targets. With the 'Show Range Ring' option selected, the range to a high-amplitude target selected in one sidescan image (green cursor, middle right) is depicted in the 3-D subset (green range ring, lower left); this option helps to confirm the relationship between shallow soundings in survey line 2 (light green soundings) and the corresponding shallow sidescan feature.

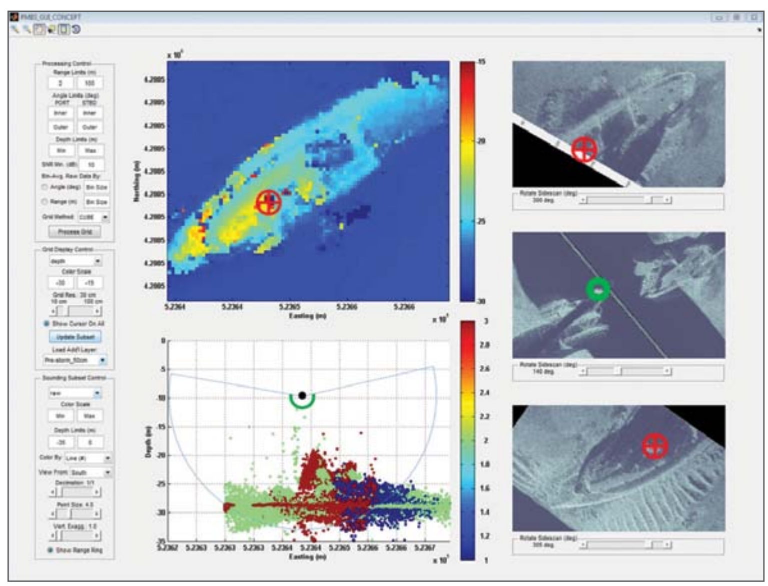


Figure 4-7. In this conceptual graphical user interface for PMBS sonar data, the raw soundings, gridded bathymetry, and all available sidescan imagery collected over a shipwreck are presented simultaneously to facilitate correlation of features across all data streams and improve detection of least depths over hazards.

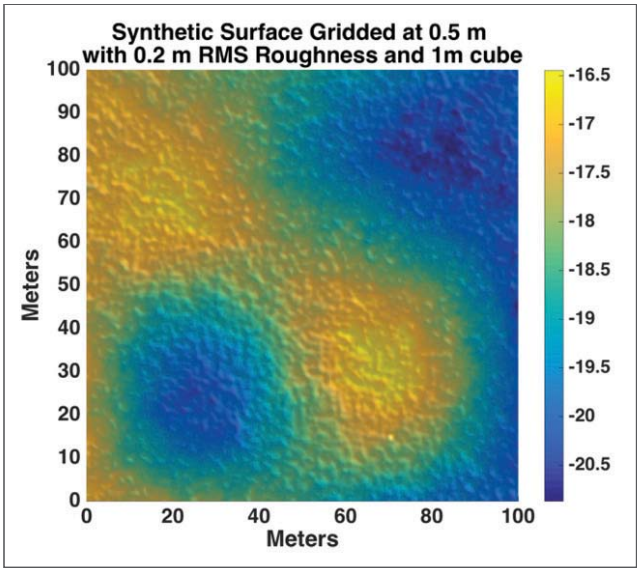


Figure 4-8. A synthetic seafloor with 20 cm RMS roughness with a barely visible 1 m cube object (at 73,13)). Preliminary investigation suggestions this roughness level, whether due to seafloor variation or measurement uncertainty, is near the practical limit to detecting 1 m objects in gridded surfaces.

Because older model PMBS systems do not bin and average data within each ping, they tend to produce noisier measurements than new systems or multibeam echo sounders that average many measurements as part of the bottom detection algorithm. The question naturally arises, "What is the maximum sounding uncertainty required to meet standard hydrographic requirements for object detection?" This proves to be an extremely complex topic, dependent on the type of object, the ambient seafloor roughness, the method by which the data is presented and the resolving capability of the sonar itself. Investigation of this topic is far from over, but to gain some understanding of the problem Schmidt and Jerram built synthetic seafloors of various spectral roughness and processed these as though sampled by a bathymetric sounder, gridded at 0.5 m grid cell size and presented to a user in a plan-view graphical user interface. An example of such a surface is presented in Figure 4-8, in which a 1 m cube has been inserted into a surface having an r.m.s. spectral roughness of 20 cm. Informal testing indicates that this roughness level, resulting from a combination of seafloor variation and measurement uncertainty, approaches the limit of what is required to reliably detect a 1 m object as specified by IHO survey requirements.

Finally, our efforts to understand the limitations and capabilities of PMBS have been greatly enhanced by the arrival of Dr. Tony Lyons. Dr. Lyons, supported mostly by the Office of Naval Research, brings a rich history of expertise in PMBS and Synthetic Aperture Sonar (SAS) design and processing to the Center; his Navy work has immediate applicability to the questions faced by NOAA and others regarding the efficacy of PMBS and SAS for hydrographic applications. The introduction of stable, commercially available autonomous underwater vehicles (AUVs) and improved micronavigation methods have made interferometric SAS and interferometric sidescan (or phase measuring) bathymetric sonar systems increasingly viable solutions for increasing areal coverage rates in shallow water. Both of these technologies

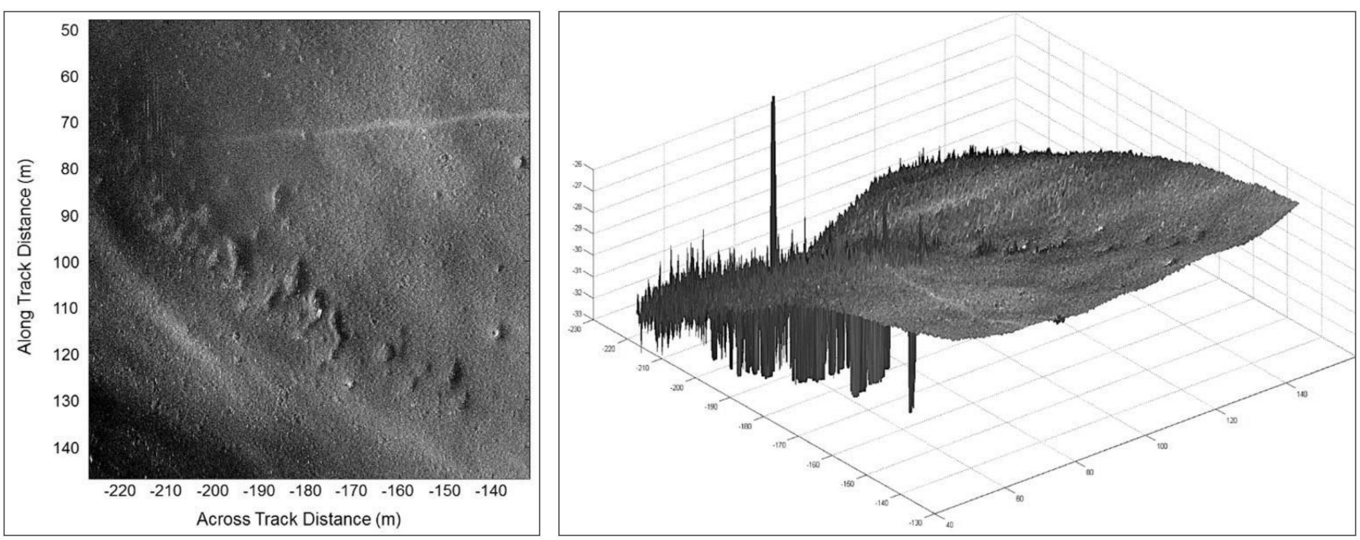


Figure 4-9. APL-SAS_LowSNR_Intensity, APL-SAS_LowSNR_Bathy_Original: Original SAS intensity (left) and bathymetry (right) images showing areas of low SNR and consequent depth errors. HISAS data provided by Roy Hansen of the Norwegian Defense Establishment (FFI).

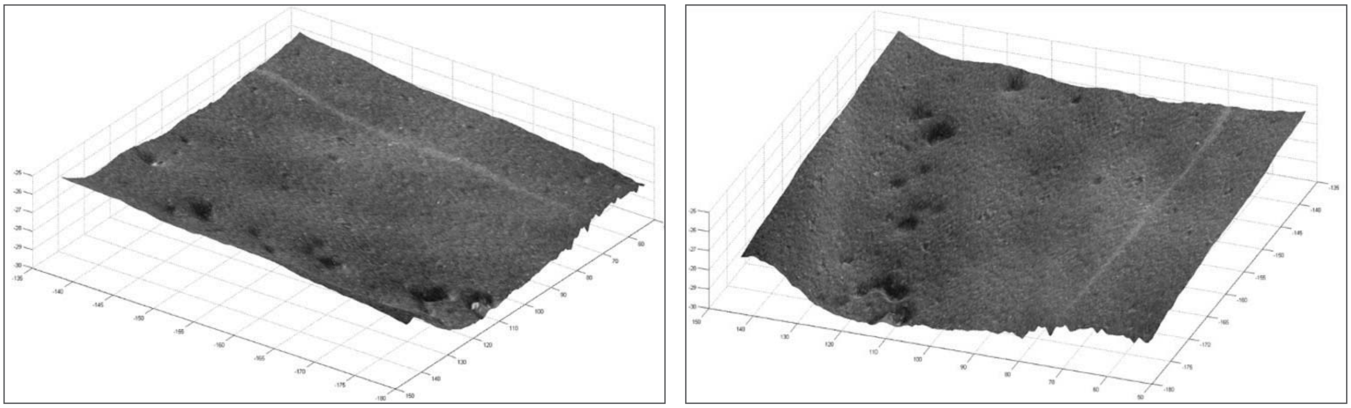


Figure 4-10. APL-SAS_LowSNR_Bathy_Clean_1, APL-SAS_LowSNR_Bathy_Clean_2: Cleaned bathymetry with depth errors in previous figure replaced with estimates obtained via the SFS technique. HISAS data provided by Roy Hansen of the Norwegian Defense Establishment (FFI).

present a number of challenges, however, including platform stability, acoustic multipath interference, low signal-to-noise ratio (SNR), and water column sound speed variation. The advantages of SAS interferometry may outweigh its problems when resolution and area-coverage rate is of concern as SAS interferometry outperforms multibeam echosounders in terms of bathymetry measurement density while also providing co-registered intensity imagery, useful for mapping of habitat or sediment types.

Lyons, in conjunction with Roy Hansen of the Norwegian Defense Research Establishment (FFI), examined SAS bathymetry data containing low-SNR phase estimation errors and also explored several possible mitigation techniques for these low SNR situations. The data used in this study were collected near Larvik, Norway, using FFI's 100 kHz HISAS system. One mitigation method explored as part of this study consisted of replacing areas where the interferometric solution for relative depth was corrupted by low-SNR errors with estimates obtained using techniques such as stereogrammetry and shape from shading (SFS). Stereogrammetry uses two different images of an area obtained from different perspectives to invert for height. SFS makes use of the fact that intensity shading encodes shape for areas where the albedo (or surface scattering) is constant over a region. Examples of original low-SNR interferometric SAS bathymetric data taken over a low-scattering mud and data augmented with SFS estimates in areas with bad phase measurements are given in the Figures 4-9 and 4-10.

Evaluation of Uncertainty in Bathymetry, Navigation and Shoreline Data from Lidar, Photogrammetry or Satellite Imagery

Also covered within the PROCESSING theme are various efforts aimed at developing better ways to extract information about bathymetry, navigation and shorelines from lidar, photogrammetry or satellite imagery. Much of our effort during the current reporting period has been focused on understanding the impact of Super Storm Sandy; some of the Super Storm Sandy efforts have been funded by another NOAA grant (Brian Calder–PI) although they also draw on personnel and efforts supported under this grant. We briefly report on these efforts here and refer the reader to **sandy.ccom.unh.edu** and references therein for more detailed descriptions of the work done under the Super Storm Sandy grant. Efforts related to Super Storm Sandy are also reported on under the HABITAT and IOCM themes.

Uncertainty Estimation of Outside Sourced Lidar Data

The USACE administers federal laws enacted for the protection and preservation of navigable waters of the United States. The USACE jurisdiction includes all ocean and coastal waters within a zone three nautical miles seaward from the coastline (see 33 CFR 329.12-14 for more details). Although channel depth data and boundaries are already ingested into the charts, USACE Airborne Lidar Bathymetry (ALB) datasets have not yet been certified by OCS to be ingested into a charting workflow. Shachack Pe'eri, in collaboration with NOAA colleagues Gretchen Imahori and Josh Witmer, is working on finding a simplified maximum allowable uncertainty for NOAA's bathymetric surveys (considering only bathymetry, and ignoring the potential for removal/change of obstructions or other similar dangers for navigation). Current efforts are focused on the USACE National Coastal Mapping Program (NCMP) that collects bathymetry mainly with Optech's SHOALS-1000 and CZMIL systems. Based on the processing workflow, an uncertainty is evaluated using uncertainties derived from calibration parameters and vertical transformations.

Morphological Change After Super Storm Sandy

(For information – funded by another NOAA grant)

As part of the Center's effort to support post-Super Storm Sandy relief activities, members of the Super Storm Sandy grant team (Price, Nagel, Pe'eri and Madore) under the supervision of Calder are developing processing approaches for establishing pre- and post-storm shoreline and erosion maps along the New Jersey coast using EAARL-B topo-bathy lidar collected by the U.S. Geological Survey (USGS). The processing work flow uses open source software to merge and grid the data, and ArcGIS to extract the shoreline and create maps of erosion, shoaling, and debris deposits that may pose navigational hazards. Erin Nagel has explored methods and best practices to grid bathymetric lidar surfaces from raw LAS files including an analysis of different software programs and modeling techniques that include Fledermaus, ArcGIS, LP360, Global Mapper, LAStools, and LIBLAS.

To investigate the magnitude of the event on coastal features and impacts to the seafloor, an area of significant breaks and overwash was analyzed (Figure 4-11) near Mantoloking, NJ, a region that suffered the largest barrier island breach during the storm. The breach was filled in within a couple days post storm to prevent further erosion and damage to the bridge, roads, and the community. While this area was analyzed to close the breach, the back-bay area where the sand was deposited could not be surveyed. Using pre- and post-storm lidar, an area of 120,600 square meters covering the back bay shoreline was assessed to have a total volume of 34900 cubic meters of change, resulting in a volume of 33300 cubic meters deposited in the back bay nearshore environment and 1600 cubic meters of sediment eroded.

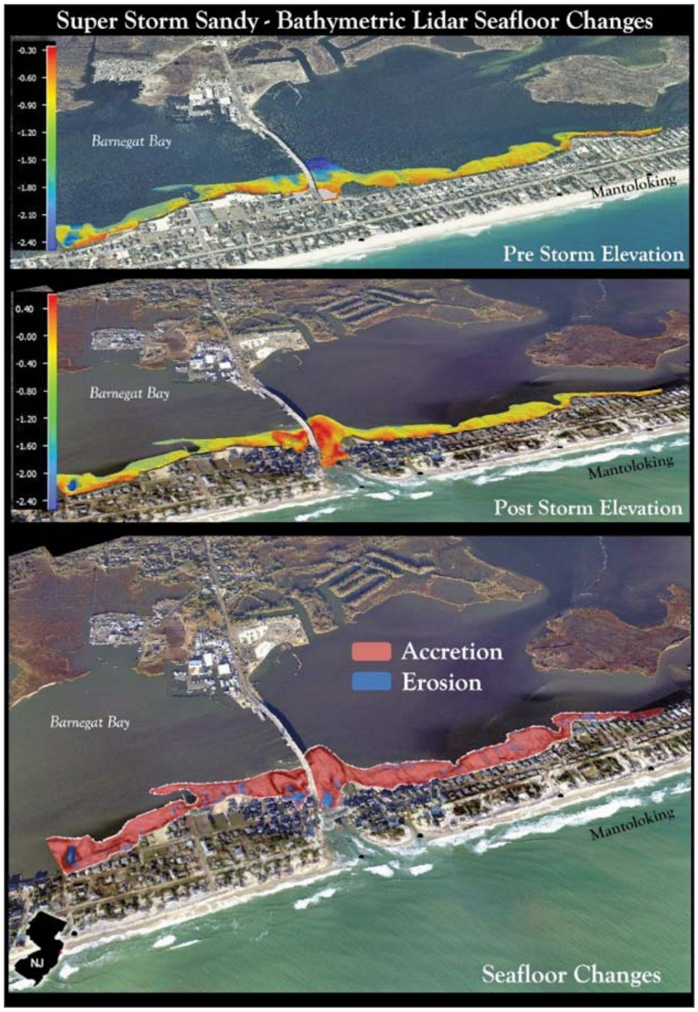


Figure 4-11. Super Storm Sandy seafloor changes from breaches and overwash in Mantoloking, New Jersey derived from Pre and Post bathymetric lidar. The storm deposited 33321.05 cubic meters in the area highlighted.

Bathymetry from Imagery

The ability to derive bathymetry from satellite imagery is of increasing interest to a number of government agencies and private sector firms, due, in part, to the reported capabilities of a number of new algorithms and satellite sensors. For example, Landsat 8, WorldView-2, and the planned WorldView-3 have all been reported to provide enhanced capabilities for coastal bathymetric mapping. A Center team, headed by Shachak Pe'eri, is developing and evaluating approaches to extracting bathymetry from satellite imagery (Satellite Derived Bathymetry—SDB) as well as exploring the applicability of SDB for change analysis, benthic habitat mapping, depth retrieval in remote regions, and hydrographic survey planning (Pe'eri et al., 2013). In the first stage of this research effort, the potential use of Landsat satellite imagery to map and portray shallow-water bathymetry was investigated at three study sites: U.S., Nigeria, and Belize. Publicly-available, multi-spectral satellite imagery and published algorithms were used to derive estimates of the bathymetry in shallow water. The study determined the most appropriate algorithms based on their performance using different combinations of frequency bands and spatial filters. The accuracy of the results was also modeled using a Monte Carlo simulation and validated empirically using a reference dataset. Based on the success of this first stage, the procedure has been published in a GEBCO "cookbook" for the use of hydrographic offices world-wide.

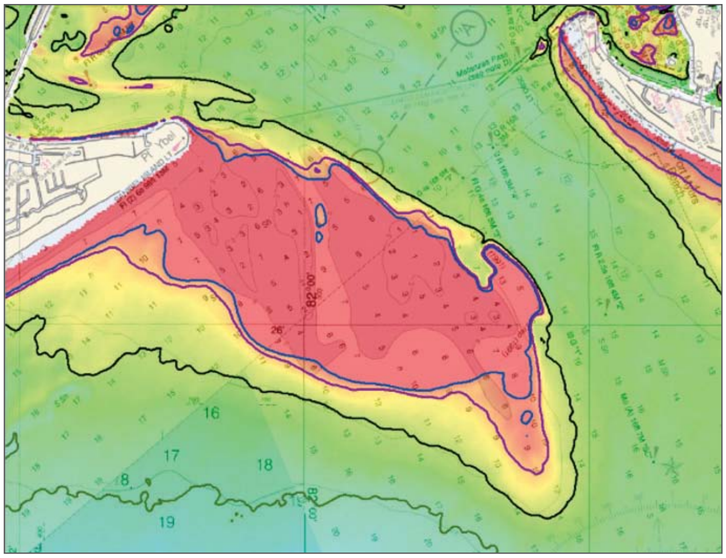


Figure 4-12. Bathymetric Difference class: SDB results with depth curves overlaid on a NOAA Chart (Fort Myers, FL).

The great potential for Satellite Derived Bathymetry has led to its testing and application in a number of regions. In the 2013 Progress Report we described approaches for deriving bathymetry from very clear waters around Haiti (an easier case). We also demon-strated an approach for deriving bathymetry from regions where water clarity is very variable (using the North Slope of Alaska as the example). In these regions we use multiple satellite images and define areas that are "clear" by comparison (i.e., minimum water clarity change between two satellite images). In 2014 we described the application of SDB for the location of navigation channels in Bechevin Bay, AK and changes in the Intercoastal Waterway in South Carolina.

Following the US-Canada Hydrographic Commission (USCHC) meeting in March 2015, OCS has decided to outline an internal NOAA policy regarding the use of SDB as a supplementary information that can support the hydrographer/cartographer with decision making with regards to the need of updating a chart. Shachak Pe'eri have been consulting with MCD on the policy (written and managed by John Barber and Anthony Klemm) that should be publicly available soon.

Chart Adequacy Using Publicly Available Data

Researchers at the Center have been looking at the use of satellite derived bathymetry as a tool for evaluating that adequacy of nautical charts. Working in collaboration with NOAA/NOS/OCS/MCD, we have been evaluating the potential use of automatic-identification system (AIS) data, satellite-derived bathymetry (SDB), and airborne-lidar bathymetry (ALB) for evaluating the adequacy and completeness of information on NOAA charts. Working with NOAA, a new chart adequacy approach was developed using publicly-available information and ENC IHO S-57 format symbols in a commercial-of-the-shelf (COTS) Geographic Information System (GIS) environment. The goal of the approach is to develop a standardized chart adequacy procedure that can be transferable to different sites around the world. The scope of work focused only on the quality of the chart and not on potential consequences to different users (i.e., risk assessment). National Oceanic and Atmospheric Administration (NOAA) charts were used as model cases.

A reference surface and four source layers were used to evaluate the chart. The reference surface was generated using the smooth sheet data or depth soundings (SOUNDG). The source layers include:

- *Bathymetric Difference* – A current reconnaissance bathymetric dataset generated based on the available non-hydrographic acoustic or lidar surveys of opportunity, supplemented with SDB in coastal and shallow-water areas. Depth contours extracted from the reconnaissance bathymetric datasets are compared to the charted depth curves (Figure 4-12).

- *Vessel Traffic* – From a navigational perspective, the most important areas in the chart are along the traffic routes. The coverage of the traffic route areas for this procedure is defined based on vessel traffic density from AIS datasets (Figure 4-13).

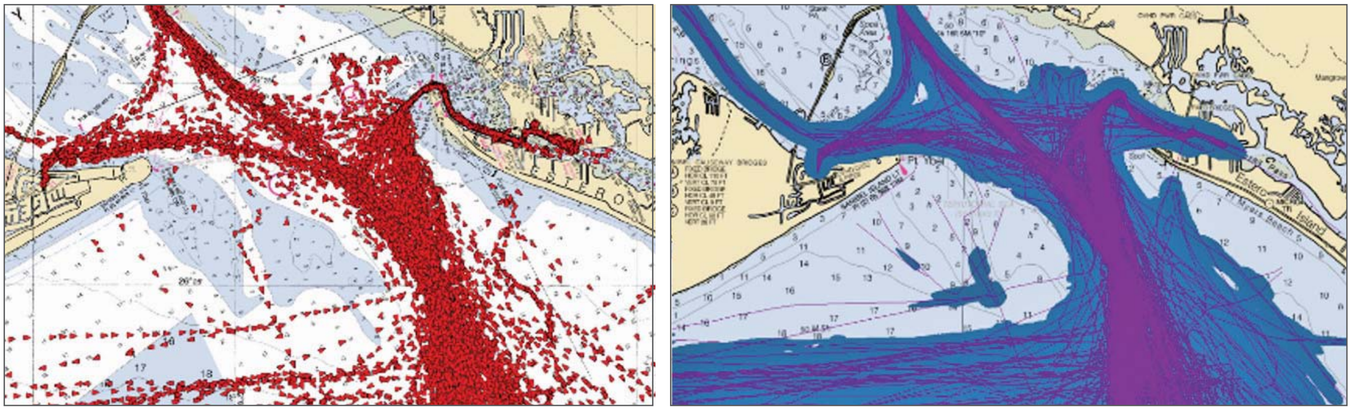


Figure 4-13. Vessel Traffic overlaid on a NOAA Chart (Fort Myers, FL): Left: Point features of AIS positions; Right: Polylines of the AIS tracks overlaid on a rasterized 300 m buffered class.

- *Hydrographic Characteristics (HC)* – It is possible to classify the charted areas based on the survey dates and survey technology provided by the source diagram or the metadata associated with the CATZOC.

- *Geographic Significant Areas (GSA)* – Areas that are not navigational routes but may support economic activities (e.g., ports, harbors, and anchorage areas), cultural and natural importance (e.g., marine protected areas), military restricted areas, or areas for exploration and exploitation of natural resources.

Carrying this work several steps further, Calder (2014) outlined an objective assessment of the risk involved in taking a ship through a given area, which takes into account environmental effects, the nature of the seafloor, and potentially the age of the prior survey and its technology. Combined with information on shipping traffic in the area (Calder and Schwehr, 2009), for example from AIS messages, an assessment of risk can be used to assess the knowledge contributed by a modern survey and therefore the relative return on investment of a survey being conducted. In principle, the area with the highest return should be the highest on the resurvey priority list.

In the 2104 reporting period, Calder, in conjunction with colleagues in NOAA, the UK Hydrographic Office, and UK Maritime and Coastguard Agency, initiated a project to investigate these ideas, with a target of applying them to the resurvey priority list of the UK Civil Hydrography Programme (which is significantly smaller in scope than the problem applied to the US entire). As an initial step towards this, however, the current reporting period has been used to develop the computational structures for this project, and to test the initial version of the algorithm on the Port of Hampton Roads/Norfolk, VA as an example.

The algorithm developed evaluates the basic underkeel clearance risk model in a Monte Carlo simulation loop so that the effects of winds, currents, astronomical tides, and shipping can be taken into account.

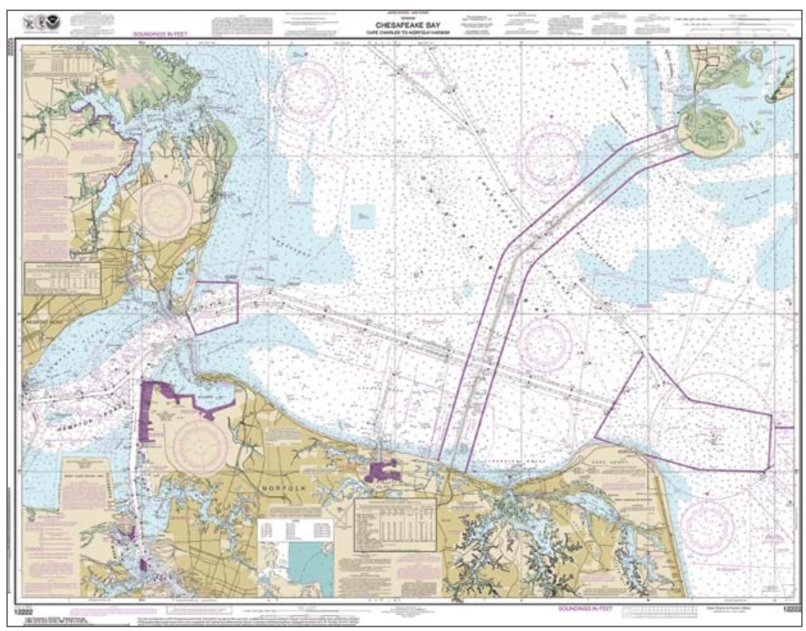


Figure 4-14. NOAA Chart 12222 for the area of the resurvey priority estimation experiments. This covers the Chesapeake Bay entrance, along with the deep draft channel to Hampton Roads and the approach route to Baltimore, MD.

The simulation area covers approximately the area of NOAA Chart 12222 (Figure 4-14). The algorithm is data driven, but Norfolk has a wide variety of environmental information available, including wind fields and tidal constituents from the Chesapeake Bay Bridge-Tunnel, and current fields from the York Spit station, further up the bay. A year of observations for wind and current fields were used to estimate synoptic fields as a function of time of day; a full 19-year tidal epoch was used to evaluate the distribution of low water points in the tidal signal. AIS traffic for the area is available in anonymized form, and a year of observations were analyzed by the method of Calder & Schwehr (2009) to provide estimates of shipping density, sizes, and types for the entire area (e.g., Figure 4-15), which in turn allows for simulation of nominal ships from the various traffic categories as part of the Monte Carlo process. (The algorithms have been re-implemented in C++ in order to provide faster performance and independence from MATLAB licensing requirements.) A land area mask was generated from the current ENC for the area, while a composite DTM for the area was assembled from a mixture of spot soundings, NOAA re-digititized survey archives, and modern NOAA BAG files. Motion dynamics are estimated from wave spectra predicted from wind field estimates, and dynamic draft effects were estimated using Barras' method.

Once calibrated, the model can predict risk associated with transits within any cell of the analysis area with, or without, the effects of unknowns such as the potential for unobserved rocks or other obstructions in the water, or uncertainties in the estimated bathymetry of the area. The difference between these estimates, Figure 4-16, is the reduction in risk associated with a modern survey, and therefore can be used as a proxy for the relative benefit in different places of conducting a survey, and therefore for prioritization.

It is not, currently, clear which metric will be most useful for relative analysis of the benefits of the survey, and therefore for setting the priority. It can be argued, for example, that the simple difference of Figure 4-16 does not reflect the relative benefit of the reduction in risk, and that a relative measure that rewards more highly the same level of reduction when the initial risk is higher. Alternatively, it could be argued that reduction of risk in areas where ships do not go is not particularly useful and therefore areas that are densely trafficked should be emphasized. These issues will be considered in the context of a wider trial of the algorithm in future reporting periods.

A potential criticism of the model is that it can only predict where traffic is observed in AIS data, and that this could just mean that traffic did not occupy the analysis cell in the period of observation, not that traffic never goes there. Of course, since the traffic model is based on a year's worth of observation, it is trivial to set an upper bound on observation density.

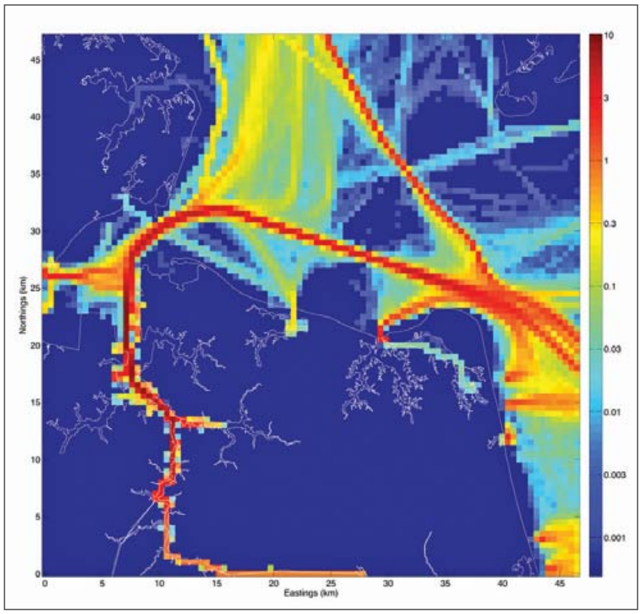


Figure 4-15. AIS-estimated traffic density for all traffic in the Norfolk, VA area for 2013 (transits per day, logarithmic scale). Sub-divisions of this by traffic class are also generated to allow for simulated ships to be generated for Monte Carlo analysis of the underkeel clearance risk.

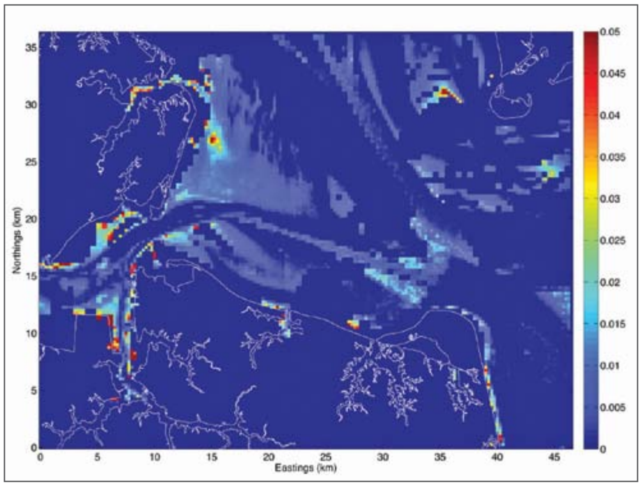


Figure 4-16. Simple difference between estimated risk without and with predicted unobserved objects and other uncertainties. Higher values indicate larger potential for reducing the estimated risk, and therefore are more persuasive targets for investment of survey resources.

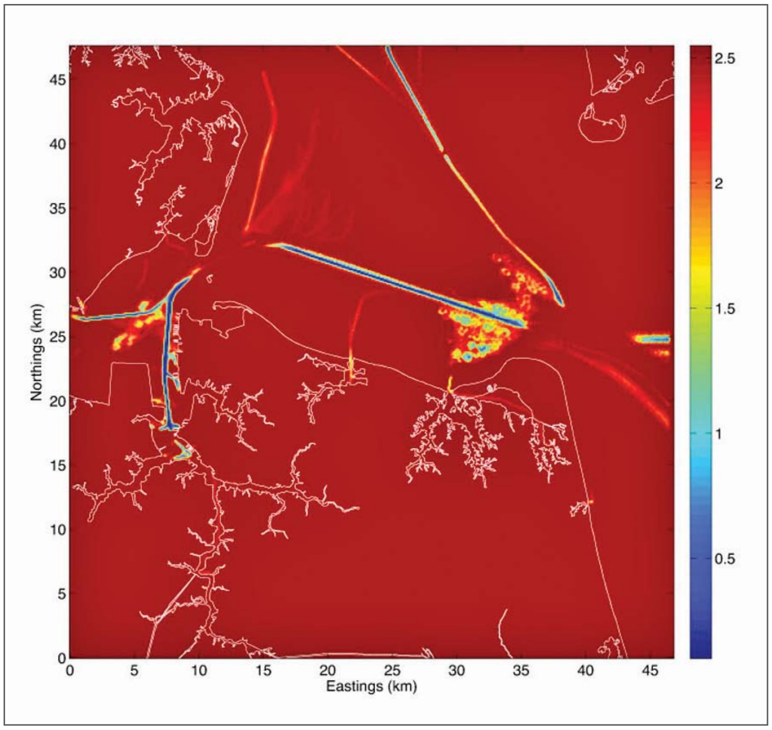


Figure 4-17. Estimated empirical prior mean of height distribution of anthropogenic unobserved objects (used as a summary for the underlying distribution), after update by the AIS traffic observations for 2013. Areas where traffic has proved that low underkeel clearance does not lead to an elision show (dramatically) lower estimates. Areas with default estimates either have no observations, or have traffic that never gets very close to the minimal underkeel clearance, in which case the effect of unobserved objects is inconsequential.

However, it is not immediately evident that this means there is no risk in such an area: the consequences of traffic straying into that area (either by design, or by mistake, which would not be in the "normal behavior" observation data either) could be very high. In addition, it is unsafe to assume that traffic will always follow its "normal" pattern; problems often occur when ships deviate, or are forced to deviate, from their planned routes and normal behaviors.

To compensate for this issue, Calder has extended the model to estimate, for each traffic category, the behaviors (e.g., of speed, relative density of traffic) likely to be observed as a function of depth, which can then be extrapolated into the areas where there are not direct observations of traffic by AIS. Using this prior information allows the Monte Carlo simulation to be adjust to accommodate for areas where there is no direct traffic observation. This highlights a number of areas that would otherwise not have raised concern.

Another potential criticism of the model is that the estimates of unobserved object prevalence (i.e., the number of objects expected to be in the area that were not observed on sparse lead-line or single-beam surveys, and which are therefore not represented in the digital archive, or any resulting DTM) is essentially arbitrary. The simulation model includes a probability distribution for potential height of objects, and a density of occurrence, so an inappropriately expansive choice of probability distribution could severely bias the resulting estimates, and make the area appear to be of higher priority than is warranted.

To address this, Calder has extended the model to allow for the use of AIS traffic to adjust the unobserved model calibration. Simply put, each observation of a ship transiting over an area constitutes a de facto wire drag of the area at the keel depth of the ship: if the ship passed without incident, then it is likely that there is nothing there sticking up off the seafloor higher than the predicted underkeel clearance of the ship. Each observation does not eliminate the possibility, but it does make it significantly less likely, an observation which can be formalized mathematically. By running a significant time period of AIS data through the model and conducting the distribution update step (which is usually used to determine the benefit that each ship gains from its own observations) it is therefore possible to adjust the initially arbitrary unobserved object distributions so that they are consistent with what is known about underkeel clearances in the area. The resulting estimate fields using a year's AIS data, Figure 4-17, can then be fed into the basic risk model as prior information, minimizing any calibration issues.

A presentation on the current work was given at Shallow Survey 2015, and will be converted into a journal publication in a subsequent reporting period.

There are obvious synergies between these ideas and the assessment of current chart adequacy. For example, the adequacy of the information on a chart might be assessed by conducting a risk analysis for any given transit through the area given knowledge of the traffic in the area. Consequently, Calder and Pe'eri have begun a collaboration with NOAA's Marine Chart Division to assess whether, and how, such ideas might be integrated with the on-going work being conducted there in assessing their chart portfolio.

Enhancing Satellite Imagery Using a Multiple-Image SDB Approach

As we continue to explore the potential of satellite-derived bathymetry we are also looking at methods to enhance the resolution of satellite imagery. As part of his graduate studies of Ricardo Freire, under the supervision of Shachak Pe'eri, is investigating the enhancement of satellite imagery ground resolution using super-resolution techniques. If successful, this may allow the production of hydrographic products (e.g., shoreline and satellite-derived bathymetry) at a higher resolution that the original satellite imagery. A practical approach is currently developed using a multi-temporal analysis of Landsat 8 imagery. A time-series analysis was conducted on two sites: Barnegat Bay Inlet, NJ and Martha's Vineyard, MA. Based on initial study results, it is possible to identify and monitor both stable and dynamic seafloor areas.

Freire has developed an uncertainty model for different single-image SDB models (affine and polynomial forms derived for Heidi Dierssen's and Richard Stumpf's algorithms, respectively) using linear and non-linear regression for vertical referencing. Current efforts are focused on multiple-images to detect shifts of crests and troughs in the bathymetry. In addition, Freire and Pe'eri are collaborating with OCS/MCD (John Nyberg), NGS/RSD (Mike Aslaksen) and NCCOS (Richard Stumpf) for the production of a global SDB model using Landsat 8 and the Sentinel-2 imagery.

Improved Backscatter Processing

In parallel with our efforts to improve bathymetry processing techniques several processing efforts are aimed at improving our ability to extract high quality, and hopefully quantitative, backscatter data from our sonar systems that can be used for seafloor characterization, habitat and many other applications. Although these efforts are discussed under the **PROCESSING** theme, they are clearly closely related to our **HABITAT** and **IOCM** themes.

Uncertainty of Backscatter Measurements: NEWBEX

As the use of backscatter data becomes more common (and particularly as we begin to use backscatter for seafloor characterization), we must face the same questions we have previously asked about bathymetric data and now need to understand the uncertainty associated with backscatter measurements. Most simply put, when we see a difference occur in the backscatter displayed in a sonar mosaic, does this difference truly represent a change in seafloor characteristics or can it be the result of changes in instrument behavior or the ocean environment? Mashkoor Malik is completing a Ph.D. aimed at addressing the very difficult question of identifying and quantifying the uncertainty sources of multibeam echosounder (MBES) backscatter surveys. An evaluation of MBES backscatter uncertainty is essential for quantitative analysis of backscatter data and should improve the collection of backscatter data and processing methodologies. Malik has examined sources of error both theoretically and empirically. The empirical component requires that the effect of each uncertainty source be isolated and observed independently. These efforts began in 2008 as part of Malik's thesis (see the 2008 Annual Report for full descriptions of these experiments and update below) but have seen renewed focus prompted by the visits of Xavier Lurton in 2012 and 2013 and a lab-wide decision to refocus on backscatter issues in the light of the needs of NOAA's IOCM program (see below).

This effort has manifested itself in the "New Castle Backscatter Experiment" (NEWBEX) a new (or renewed, from the laboratory perspective) effort aimed at testing our ability to properly collect and interpret seafloor backscatter data collected with hydrographic multibeam echosounders. The project is a collaboration of many Center and NOAA participants including Tom Weber, Jonathan Beaudoin, Glen Rice (NOAA), Briana Welton (NOAA), Val Schmidt, Brian Calder, Yuri Rzhanov, Larry Mayer, Larry Ward, and Carlo Lanzoni. With respect to seafloor backscatter, it is important to note that the term "calibrated" takes on multiple meanings in the context of this work, ranging from the calibration of settings to ensure we understand the real effect of a system setting change to a full absolute calibration where the output of the multibeam echo sounder can be used as estimates of the true seafloor scattering strength. This project brings together several different existing lab efforts: Malik's thesis work, Carlo Lanzoni's work toward an absolute backscatter calibration for MBES, former student and NOAA Corps officer Sam Greenaway and Glen Rice's efforts toward field procedures for proper backscatter data collection, backscatter mosaicing (Fonseca's GeoCoder), backscatter inversion (Fonseca's ARA algorithms), and backscatter ground truth (e.g., optical imagery, bottom sampling, high accuracy positioning). In bringing together scientists with disparate backgrounds to address a common problem, the NEWBEX project epitomizes the strength of the Center. As problems arise, we can call upon local expertise (be it signal processing, image processing, geology, acoustics, etc.) to quickly and collaboratively seek solutions.

Many details of the NEWBEX experiment were presented in earlier progress reports. In late December 2013, we finished an 8-month field campaign that established a 'standard backscatter line' conveniently located near the UNH pier in New Castle, NH. In developing this line, we collected weekly 200 kHz calibrated EK60 data, weekly sediment samples at two locations, and conducted several seasonal sampling trips where more sediment samples and bottom images were collected at several locations along the line. These data will serve as the basis for many future studies.

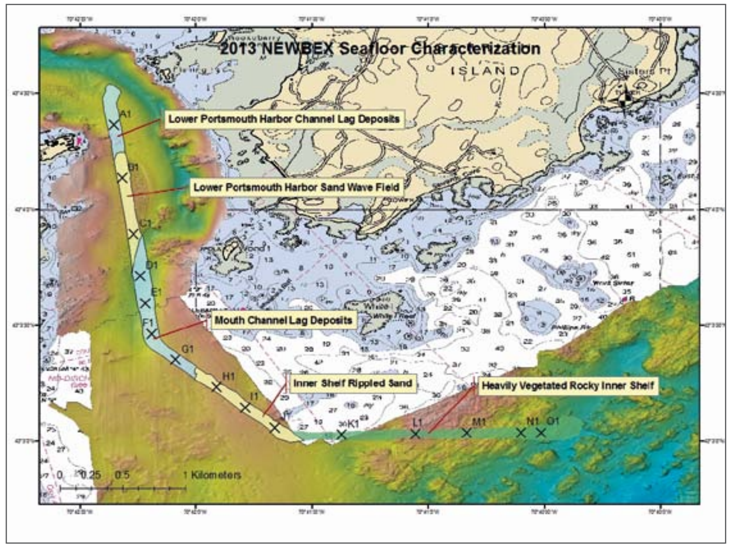


Figure 4-18. Location map of the NEWBEX transect, the 2013 sampling stations (targets), and an initial division of seafloor types.

The focus of the NEWBEX project during 2015 has been the analysis of Eric Bajor's field experiment, in which he collected stereo camera data and sediment samples within the Portsmouth Harbor sandwave field (Figure 4-19) while collecting broadband seafloor backscatter data. Bajor has led this effort with guidance from Weber, based in part on the work described in Weber and Ward (2015 [in revision]). The main empirical result is shown in Figure 4-20 which shows broadband seafloor backscatter over frequencies ranging from approximately 100-200 kHz.

These observations show two distinct trends: a relatively steep rise in backscatter strength with increasing frequency between 100-150 kHz, and then a frequency dependence about approximately 175 kHz that is nearly absent. The main challenge is to identify the mechanisms that control this frequency response and the backscatter levels themselves, so that backscatter mosaics collected with MBES at similar frequencies can be properly interpreted. So far, the identification of these mechanisms has remained elusive, with no clear signature of a backscattering regime controlled by

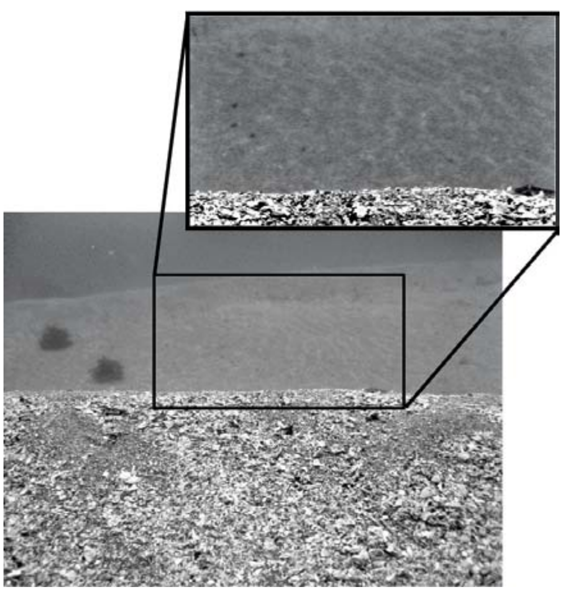


Figure 4-19. Diver photographs of the Portsmouth sandwave field.

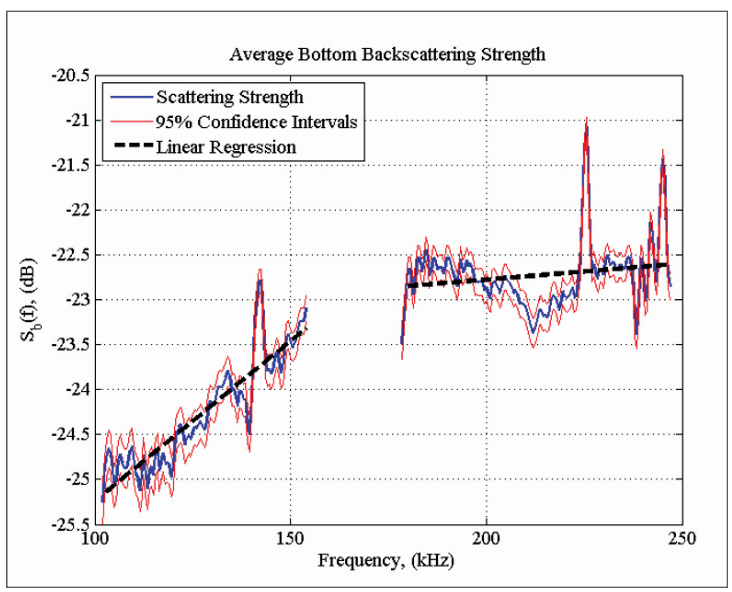


Figure 4-20. Observations of seafloor backscatter in the Portsmouth sandwave field.

either roughness or the sediment grains themselves. Efforts are still underway to refine the processing and compare the empirical observations against model predictions.

The NEWBEX experiment has built upon Mashkor Malik's thesis work attempting to identify and quantify the uncertainty sources associated with MBES backscatter survey (Tables 4-1 to 4-4). Malik's project has been reported upon in detail in earlier progress reports, and in 2013 Malik benefited from an extended visit to IFREMER to work with Xavier Lurton on aspects of this problem. As a result of this visit Malik has produced an analytical treatment of the sonar equation with the purpose of deriving backscatter uncertainty equations. This past year he has applied his model to real sonar systems operating under realistic conditions to estimate the effects of various components of the uncertainty and their propagation to the final backscatter result.

Table 4-1. Uncertainty sources for seafloor incidence angle.

Main Component	... depends on (subcomponents)	Subcomponent Uncertainty	Significant or Not
Beam steering angle	Sound speed at sonar head	< 0.1 m/s	No
	Ship attitude	$< 0.1°$	No
Bottom detection	Method of bottom detection	Case dependent	No
Refraction	SVP	Up to 12° in extreme cases	Case dependent
Seafloor slope	Across -track slope	Bathymetric data dependent; up to 10 % of slope	Case dependent
	Along-track slope	Negligible effect	No
	Unresolved seafloor slope	System dependent/ Signal footprint scale	Case dependent

Table 4-2. Uncertainty sources for transmission losses.

Main Component	... depends on (subcomponents)	Subcomponent Uncertainty	Significant or Not
Range to Seafloor	Ship attitude	$< 0.1°$ (from IMU)	No
	Sound speed at sonar head	Better than 1 %	No
	Sound speed profile	$\sim$ 2 % of range	No
	Bottom detection	Ignored	No
	Beam steering angle	Ignored	No
Absorption coefficient	Model accuracy	Up to 5%	Yes
	Frequency	System dependent	Case dependent
	Temperature	$<1°$	No
	Salinity	<1	No

	Pressure (depth)	< 1 %	No
	Micro thermal structure	Unknown	Unknown
Spreading Loss form / shape	SVP	SVP dependent	Case dependent
Water column anomalies	Bubbles Water column scattering	Unknown	Case dependent

Table 4-3. Uncertainty sources for seafloor ensonified area.

Main Component	... depends on (subcomponents)	Subcomponent Uncertainty	Significant or Not
Area integration bias	Bias between actual area and approximation used	Not negligible for near nadir region	Yes for near nadir
Beamwidth	Frequency	System dependent	Not known
	Ship attitude	System dependent	Not known
	Sound speed	System dependent	Yes
Pulse length	Pulse length calibration	System dependent	Not known
	Band width	System dependent	Not known
Seafloor incidence angle	See Table 3.2	See Table 3.2	Case dependent
Method errors	Flat seafloor assumption	Case dependent	Case dependent
Unresolved seafloor slope	Unresolved seafloor slope	Seafloor topography dependent	Not known
	Seafloor topography		Not known
Bottom sound speed		< 0.1%	No

Table 4-4. Uncertainty sources for multibeam response including transmit and receive characteristics.

Main Component	... depends on (subcomponents)	Subcomponent Uncertainty	Significant or Not
Receive sensitivity	Element sensitivity	System dependent	Yes, System dependent
	Amplifier gain	System dependent	Yes, System dependent
	Electronics / sonar head temperature	Unknown	Unknown
	ADC resolution	Typically < 0.5 dB	No
Signal to Noise Ratio	Ambient noise, self-noise, transmitted source level	Ignored if better than 10 dB	No
TVG	Saturation, noise floor, Nonlinearity (deviation from the model-imperfect electronics)	No effect if TVG is properly accounted for	No

Rx Beam Patterns	Intrinsic static directivity	System dependent	Case dependent
	Ship motion	How well the Rx beam patterns are known to account for the ship motion	No, if vessel motion $<10°$
	Element failure	System dependent	No
	Beam former	System dependent	Unknown
Pulse length	Ramping up	What is the actual transmit pulse length compared to its nominal value	No (for most cases)
Spectrum mismatch	Doppler System dependent	System dependent	Unknown (typically $<$ 1 dB)
Source level	Age, Biofouling, settings, element failure, temperature	Typically less than 1 d	System dependent
	Electric power input (electronics temperature)	System dependent	No
	Nonlinear gains	System dependent	System dependent
Tx Beam Patterns	Intrinsic static directivity	System dependent	No – if properly accounted for
	Ship motion	How well the Tx beam patterns are known to account for the ship motion	No, if vessel motion $<$ 10°

While the tables above do not represent all the possible sources of uncertainty, they do represent the major backscatter uncertainty sources and offer a framework for estimating the uncertainty associated with seafloor backscatter data.

Table 4-5. Uncertainty parameters used as an example to build uncertainty propagation model.

Parameter	**Mean**	**1 σ**	**Parameter**	**Mean**	**1 σ**
Water depth at nadir	10-1000 m	-	Frequency	30 kHz	0
Temperature ° (surface)	15	0.0005	Pulse length	5 ms	1 %
Temperature ° (bottom)	15	0.0005	Bean width-Across	1°	1 %
Salinity (Surface)	30	0.4	Bean width -Along	0.5°	1 %
Salinity (bottom)	30	0.4	Source level	216 dB re 1 μPa @ 1m	0.5
pH surface	7.7	1%	Sound speed	1500 m/s	0.1 %
pH bottom	7.7	1%	Slope across-track	0	1°
Absorption loss coefficient (surface)	29.3 dB/km	5%	Slope along-track	0	0°
Spreading loss parameter	20 log (Range)	-			

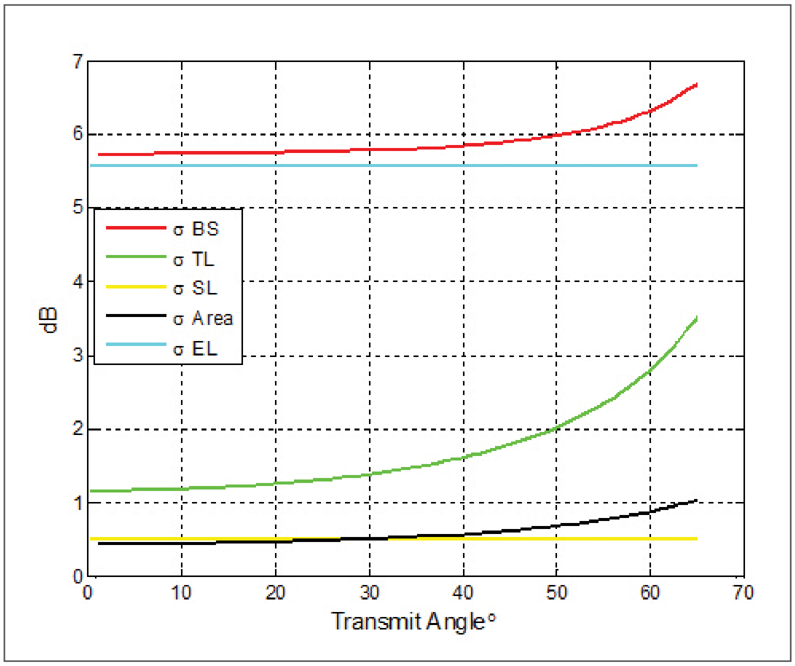


Figure 4-21. An example of backscatter uncertainty estimation using 30 kHz EM 302 in water depth of 500 m in nominal operating conditions. Individual uncertainty sources (provided in table above) were propagated to estimate uncertainty in ensonified area (Area), source level (SL), transmission loss (TL), echo level (EL) and final backscatter measurement (BS) for a single backscatter measurement.

An approach for propagating these uncertainty sources to the final backscatter measurement and applied correctors has been developed that can be applied to many systems. For example using the inputs in Table 4-5, the uncertainty in measured echo level, transmission loss, area ensonified and source level at 500m water depth are presented in Figure 4-21.

Marine Target Detection and Object Recognition

As we continue to improve the quality and resolution of the bathymetry and backscatter data we collect, the ability to detect small objects on the seafloor is enhanced. While the military has faced this challenge for many years, the hydrographic community has become acutely aware of the need to detect and identify small objects on the seafloor in the wake of the devastation caused by events like Super Storm Sandy. Much of the coastal infrastructure destroyed by the storm was carried offshore, creating hazards to navigation and grave threats to the health of the ecosystem. We have thus embarked on a new effort to develop tools for the detection and identification of submerged marine debris. Expanding on work started during his master's thesis, Guiseppe Masetti, who returned to the Center as a Research Scientist, has been working on this task in collaboration with Brian Calder. In the past year, aspects of this effort have evolved into a Super Storm Sandy-specific project funded by separate NOAA funds.

Typically, submerged marine debris has been identified through the subjective evaluation of sidescan sonar records by a human operator. The project explores the use of automated approaches to identification and classification of submerged marine debris, using the techniques developed for the detection of mines, unexploded ordinance and pipelines with the significant complication of a much wider range of potential targets. In order to address this additional complexity, an adaptive algorithm has been developed to appropriately respond to changes in the environment, context, and human skills.

The study can be divided into three subtopics—the creation of a predictive model, the development of a detection model, and the study of a reliable data exchange mechanism (Figure 22).

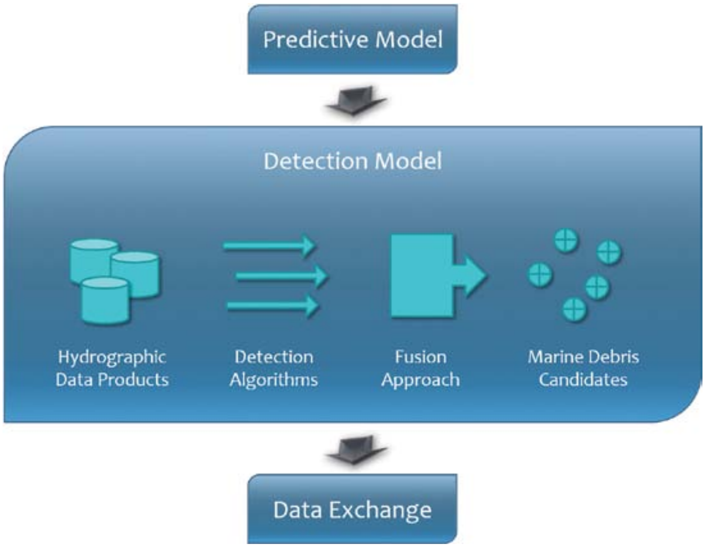


Figure 4-22. The three connected sub-fields that have been investigated for the marine debris analysis theme. The core topic of the research is represented by the detection model. It takes hydrographic data products as input and provides a list of marine debris candidates based on the fusion of the outcomes of several detection algorithms.

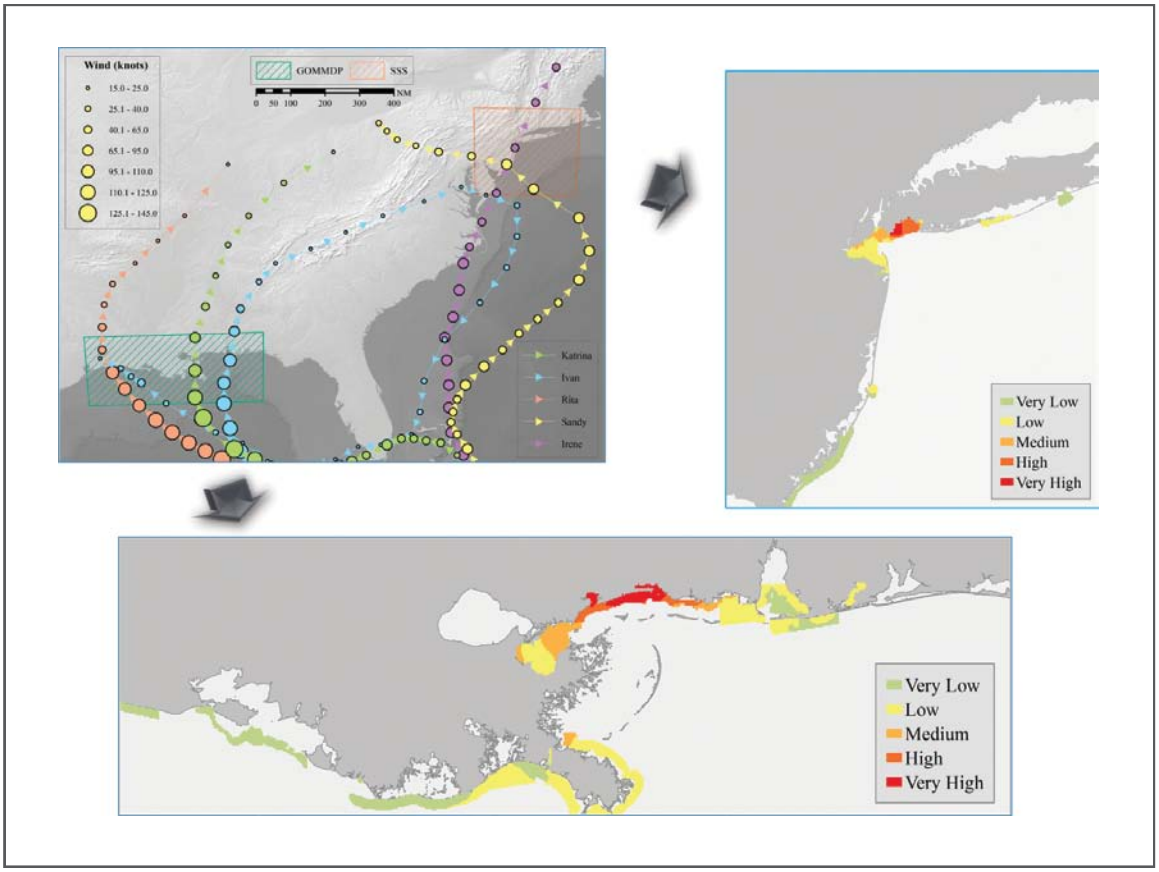


Figure 4-23. Top-left pane: study areas, and the best tracks (associated with peak winds) of the five hurricanes of interest. Predicted distribution density of marine debris in the Super Storm Sandy (top-right pane) and in the Gulf of Mexico (bottom pane) study areas.

The work on a predictive model has focused on understanding the types of data already available, or likely to be available, that can be used to determine estimates of where marine debris is likely to occur in the event of a storm. Given the complex nature of the problem, having some level of a priori knowledge of areas of marine debris accumulation can be a very powerful means to constrain the detection problem, particularly when combined with the new evidence from remediation surveys in an appropriate evidentiary framework; in the work here, a Bayesian framework for combination of prior evidence and observations is utilized. To provide a priori information on spatial clustering, the distribution of marine debris in recently available data sets were analyzed. For the Sandy area, the NOAA Marine Debris Program intertidal dataset (SSS-ID) and the preliminary NOAA Office of Coastal Survey subtidal dataset (SSS-SD) were used; these were augmented by the data set collected by the Gulf of Mexico Marine Debris Project (GOMMDP). These data sets are related to five hurricanes (Sandy, Irene, Ivan, Rita, and Katrina), each of them with particular properties driven by the storm track. Since these case studies showed statistically significant patterns, marine debris density warrants study since it can be used, e.g., to identify hot spots that can be used by posthurricane survey planners to prioritize and target data. An exploratory regression analysis based on several predictors showed that storm surge, population density index, and distance from urban areas are the most useful predictors of marine debris presence. The addition of other available predictors (e.g., max wind peaks) does not provide significant contributions. Using the regression coefficients, a prediction of debris distribution can be computed for the two study areas (Figure 4-23). The predictive step provides the initial state for a Bayesian spatial hierarchical model, but can also be used as a posthurricane survey planning tool.

The detection model has been developed around an adaptive fusion algorithm for effectively detecting the presence of marine debris (Figure 4-24); details of these

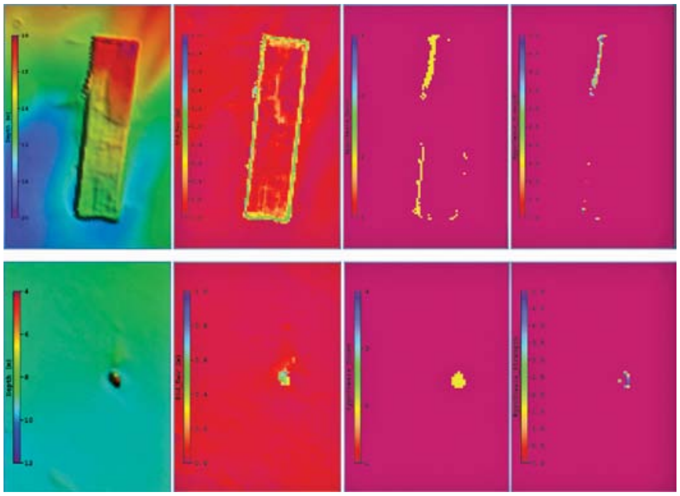


Figure 4-24. Example of DTM-based detection algorithm based on the additional CUBE statistic layers. The original inputs (showed on the first pane of the left) are analyzed using the CUBE standard deviation, the hypothesis count, and the hypothesis strength to recover information on the original soundings set (usually lost in pure XYZ surfaces.

approaches can be found in the Super Storm Sandy progress reports (**sandy.ccom.unh.edu**).

The algorithm has been tested on data from Jamaica Bay, NY where detailed data sets were collected after Super Storm Sandy including optical imagery, bathymetry, and sidescan, and ground truth object detections done by hand. Figure 25 is a comparison between the prediction of debris (hot spot map) and the manual identification of debris after the storm.

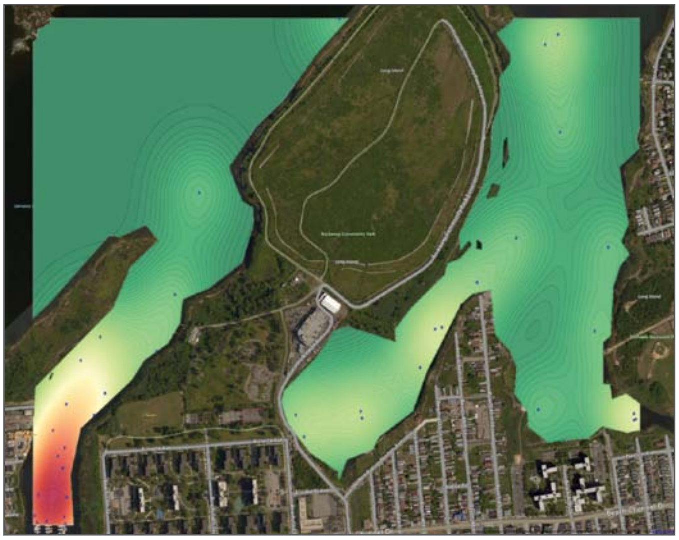


Figure 4-25. Results of the hot spot analysis in Jamaica Bay, New York, NY, with the ground-truth positions of the marine debris assigned by human analysts (blue dots).

Enhanced Data Processing Flow: HydrOffice

Ocean mapping procedures, like survey review and nautical chart compilation, are often characterized by the repeated execution of many operations that can be automated. When correctly implemented, automated tools can safely reduce the time from data acquisition to chart publication/updates (or database update) providing data analysts the time to focus their energy on specific problem issues (e.g., bathymetric blunders, anomalies in sound speed profiles, etc.) rather than repeated tasks. The automation of some processing steps may also enhance the consistency, accuracy and traceability of the final products. For these reasons, Masetti and Calder, in close collaboration with Matt Wilson, (NOAA OCS AHB physical scientist and Center alumnus), have begun an effort to define the requirements (by a whitepaper written in April 2015) and to start the implementation of a new software environment (called HydrOffice) designed to create a mechanism whereby processing algorithms can be quickly developed and tested within the current data processing pipeline and, if proven effective, quickly go into operation through implementation by industrial partners.

One of the main requirements for HydrOffice is ease of extension. This is achieved through the support of a plugin architecture that consists of a base framework package and GUI with common code and the ability to create task-specific "hydro-packages," algorithms that address specific problems but can access the common code from the base package. HydrOffice has an open license and encourages third-party contributions within the existing infrastructure and interface. Individual tools within HydrOffice are modularized so they can be easily updated and maintained. The current implementation can use Pydro (so that it easily fits in the NOAA processing stream) or can be run in a stand-alone environment for those that do not use Pydro.

The HydrOffice environment currently contains four projects in the advanced development phase: HCellScan, SARScan, SSP Manager, and BAG Tools and Explorer.

SARscan and HCellScan

With increasing data volumes, the time required and level of effort necessary to properly review hydrographic data is increasing. That is, ping-to-chart times are growing, while data quality may be waning. For this reason, Calder and Masetti in collaboration with Matthew Wilson (NOAA OCS AHB physical scientist and Center alumnus) have been developing a suite of tools to improve data quality issues, to reduce review and acceptance times, and ultimately to reduce ping-to-chart times.

Calder and Masetti have helped Wilson in the adaption of his SARScan and HCellScan code to the HydrOffice environment as well as to improve some aspects of the code organization (e.g., error checking, minimization of code duplication, several processing optimizations). Since this early phase work, several advantages of the HydrOffice framework have become evident including freedom in development (whereas commercial "off-the-shelf" software have limits originating in the need to meet several diverse customer requirements); direct customization to NOAA specifications and best practices, and quick delivery to the branches/field for testing and evaluation. Included in this initial development are the following hydro-packages:

- The "Flier finder" algorithm, designed to identify presence of anomalous data in the finalized gridded bathymetry delivered to the hydrographic branches (aka "fliers"). This represents a major concern since, when fliers are found, considerable time and effort is required to remove them, often requiring the re-computation and re-finalization of the grids, which can take several days (or longer) to accomplish with the additional disadvantage that the output is no longer the authentic field submission. "Flier finder" detects fliers as early as possible in the quality control process. Its initial implementation scans gridded bathymetry and flags abrupt depth changes using user-set criteria, (Figure 4-26—white "lassos" encircle the anomalous grid data). Several algorithm modifications will be tested in the coming months (e.g., by including the evaluation of additional statistic layers provided by a CUBE DTM).
- The "VALSOU to grid check" and "feature scan" algorithms focus on the required agreement between gridded bathymetry and submitted feature files, as well as the adherence of those feature files to current specifications. Wrecks, rocks, and obstructions should have appropriate representation in the gridded bathymetry with regard to position and least depth. It is a common situation at the hydrographic branches to receive surveys with hundreds (or even thousands) of features that need to be manually checked against the grid to ensure agreement, and also to ensure proper attribution. This process can be a massive time sink but is well suited for automation. The developed algorithms scan the

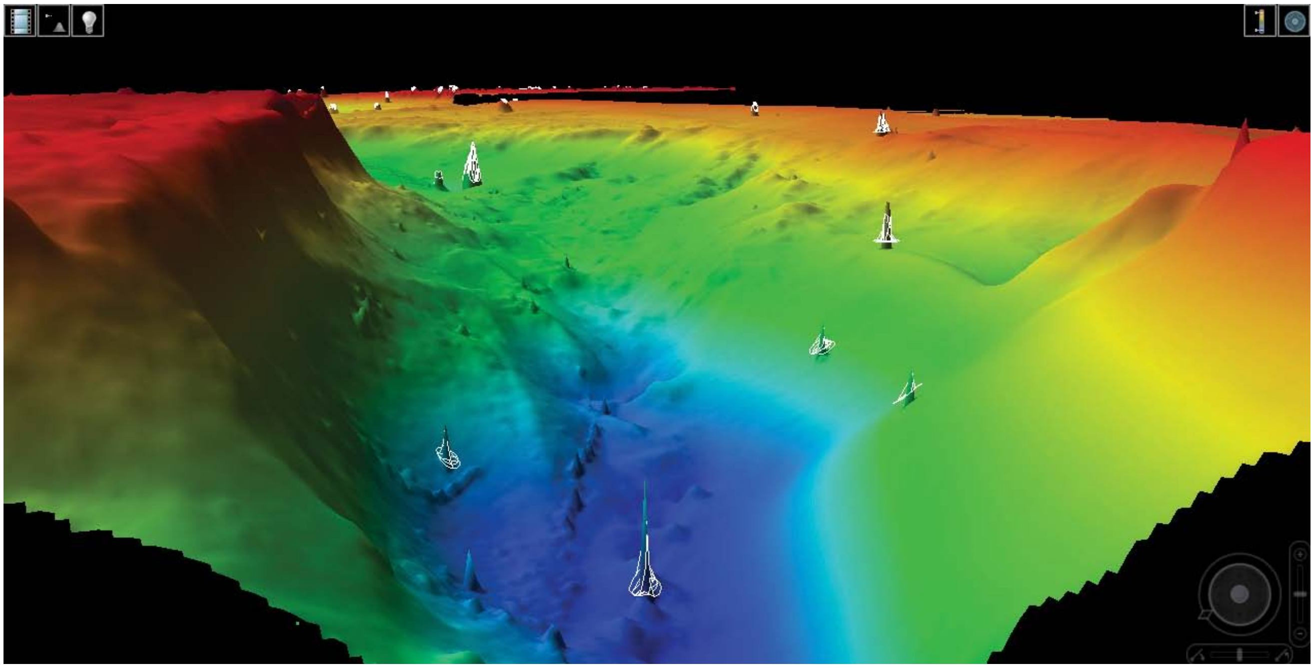


Figure 4-26. Anomalous grid data (aka fliers) detected by flier finder are shown in 3D view. The anomalous spikes are "lassoed" with a position stamp to facilitate prompt detection and removal.

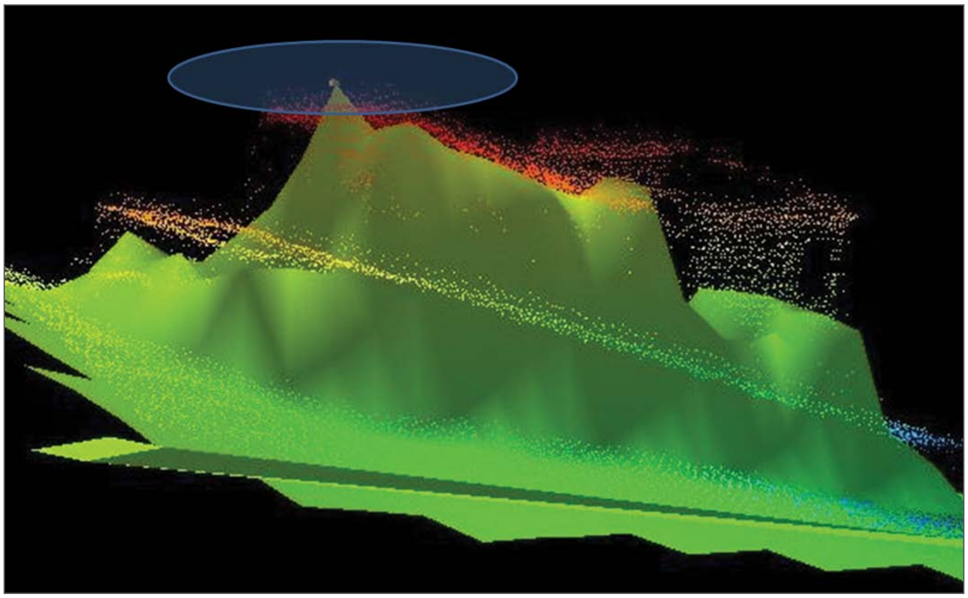


Figure 4-27. A wreck submitted in survey deliverables is represented by 1) a chosen least depth sounding, 2) gridded bathymetry, and 3) an S-57 feature. 1, 2, and 3 must be in agreement for all features submitted to HB. This is often not the case, so the developed algorithms scan these items and flag discrepancies for the hundreds (or sometimes thousands) of features submitted.

gridded bathymetry and feature files to ensure this agreement and that the attributes of the feature are as required by the current version of the NOAA Hydrographic Survey Specifications and Deliverables (HSSD) manual (SARScan tool), or the current NOAA HCell Specifications (depending on which phase of the ping-to-chart process that the survey is in) (HCellScan tool). An example of the agreement we wish to observe is shown in Figure 4-27.

- The "Sounding scan" algorithm is aimed at reducing survey data volumes of hundreds of gigabytes (or even terabytes) to a final product that is generally only a couple of megabytes, so that it can be applied to a nautical chart such that the display is optimal for safety. The algorithm automates a long-time best practice at Hydrographic Branches known as the "triangle rule" in which a TIN is created from the selected soundings at the chart scale. Then the dense, survey scale soundings (from which the chart soundings are a subset) are analyzed and flagged if they represent a sounding shoaler than the three vertices of the surrounding triangle (Figure 4-28). Those flagged soundings should be considered for selection, or for representation in some way (perhaps as a feature, or by contour). The same algorithm, created primarily for chart sounding evaluation, can also be useful in the field when performing a comparison between survey soundings and the existing charted soundings, a requirement for the Descriptive Report of Survey. Furthermore, the procedure can highlight potential dangers to navigation otherwise overlooked.

SSP Manager

The SSP Manager is an application based on the HydrOffice SSP library to simplify the exchange of data between sound speed profilers and multibeam echo-sounders (MBES) and the subsequent editing and manipulation of these data. The application, which is derived from the SVP Editor developed by Jonathan Beaudoin when he was at the Center, supports several data formats as file and network inputs (Castaway, Digibar, Idronaut, Seabird, Sippican, Turo, UNB, MVP). Once successfully imported, the application provides tools and functionalities to edit, improve (e.g., by using oceanographic atlases) and extend the collected raw samples (Figure 4-29, left). The resulting SSP can be then exported to files or

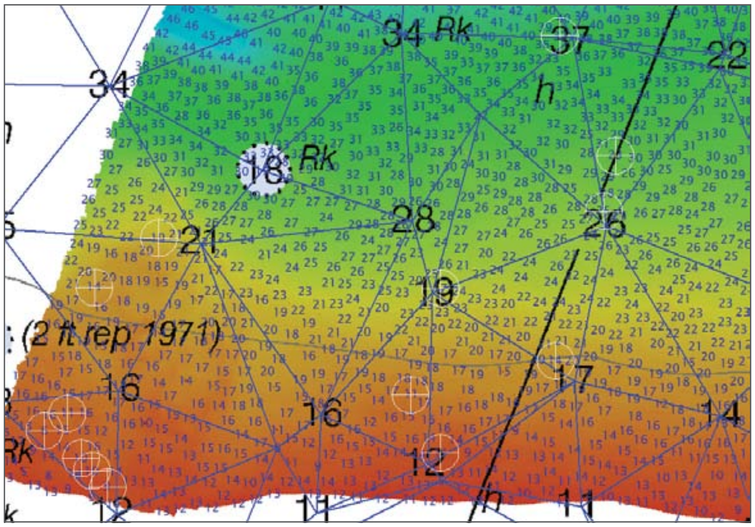


Figure 4-28. A TIN (blue) is created at the chart scale soundings. Any survey scale sounding that is shoal of the three vertices of the triangle within which it falls is flagged and should be ensured proper chart representation.

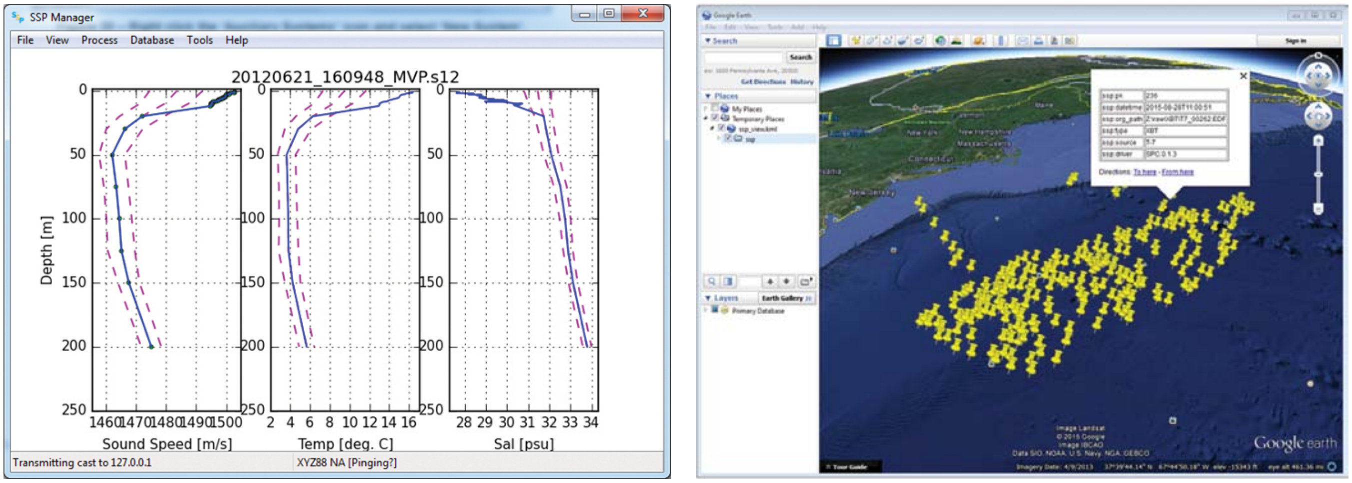


Figure 4-29. (left) Screenshot of SSP Manager in action: a sound speed profile was received from a moving vessel profiler (MVP), cleaned, and extended using the NOAA NODC World Ocean Atlas 2009. (Right) An SSP dataset stored into the SSP Manager database is exported with metadata to KML format for being visualized on Google Earth.

be directly sent to hydrographic data acquisition software (e.g., Hypack, Kongsberg SIS, QPS Qinsy, Reson). SSP Manager also provides a mechanism to store the raw, processed, and transmitted data samples in a database so that additional analyses can be applied to the SSPs collected during the whole survey or exported to other well-known geographic data formats for further analysis and visualization (Error! Reference source not found.).

BAG Tool and Explorer

The Bathymetric Attributed Grid (BAG) is an open hydrographic data exchange format developed and maintained by the ONS-WG (Open Navigation Surface Working Group), led by the Center. There is currently a lack of tools available to manage BAG files, particularly as the BAG structure grows in complexity to handle variable resolution grids. BAG Tool and Explorer provides freely available tools for this purpose:

- BAG library provides access to BAG-specific features, as well as a collection of tools to verify and manipulate BAG data files.
- BAG Explorer is an application, based on HDF Compass and the HydrOffice BAG library tools, to explore BAG data files and in particular providing a mechanism to explore the tree-like structure of a BAG file, to visualize and validate the XML metadata content to inspect the tracking list, and to plot the elevation and the uncertainty layers.

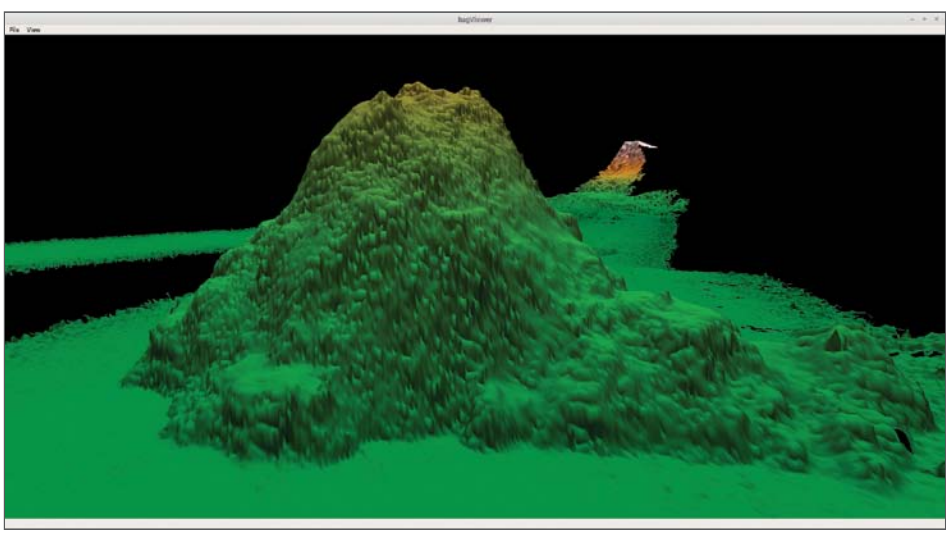


Figure 4-30. Patch test area for the KM1520 cruise scene in BAGViewer.

The most recent addition to the BAG Tool and Explorer library, BAGViewer is being developed by Roland Arsenault to interactively display BAG files (Figure 4-30). A primary goal of the BAGViewer is to allow the exploration of BAG's variable resolution extension. BAGViewer is targeted towards multiple platforms with modern graphics GPUs. Cross platform capability is achieved using C++

augmented with the Qt cross platform framework and the OpenGL graphics API. The build process is controlled by CMake which can target multiple platforms and development environments. Reading of BAG files is through the Open Navigation Surface's BAG library.

OpenGL (version 3.2, core profile) is being used to navigate large, multi-gigabyte BAG files interactively. Data transfer between the CPU and GPU, which may become an I/O bottleneck, is minimized by storing elevation and normals (used for lighting) as texture maps in GPU memory. Shaders are used to look up depths from the elevation texture and to distort the vertices of a predefined unit grid tile for a specific display tile. This approach saves on memory by only saving a height per vertex, and calculating the x and y components based on tile position. This tiling also is used to perform view frustum culling to speed up rendering. Standard tiles have been designed to allow multiple level of details (LOD) based on powers of two simplifications of the tile to achieve interactive rendering speeds.

Data Management

We were delighted to report in 2011 that we filled the position for a Data Manager for the Center with the very capable Paul Johnson who came to us from the University of Hawaii's Mapping Research Group. Paul has made tremendous progress in ensuring that our data holding are protected, documented, organized and easily accessible to our researchers and to any others who need them. Working with Johnson, Tianhang Hou has been focusing on creating appropriate metadata and areal coverage polygons for two our largest databases—the eight seasons of Arctic multibeam sonar data collection (see LAW OF THE SEA theme), as well as 15 years of hydrographic field camp surveys. Hou has also been working with Johnson in developing automated ways of bringing our multibeam data into the Arc Geodatabase.

ArcGIS Data Server

During the spring and summer of 2015, Paul Johnson and Jordan Chadwick began the process of integrating a new GIS Portal server into the Center's network. This portal is meant to work hand-in-hand with the Center's already existing GIS server to ease the process of discovery and interaction with the Center's data holdings, much like ESRI's ArcGIS.com service does. At present, the portal is only available for users at the Center, as Johnson and Chadwick are still testing the configuration and computational load on the portal hardware. Figure 4-31 shows the Portal's web homepage (left), where featured datasets, maps, and applications are shown. Figure 4-31 (right) shows an example of a content listing for the Law of the Sea's Gulf of Alaska survey.

By clicking on a dataset linked from the portal's homepage or through the portal's content listing, the user is provided with a fully documented description for that dataset. This information is pulled directly from the metadata served from the Center's GIS server, and is designed to provide basic information on the acquisition of the data, access use and constraints, contact information, etc. The description page also provides links for the user to open up the dataset within an interactive webpage or directly into the ArcGIS desktop application. Services such as this should greatly increase the ability of both users at the Center and outside of it, to discover and interact with the Center's data.

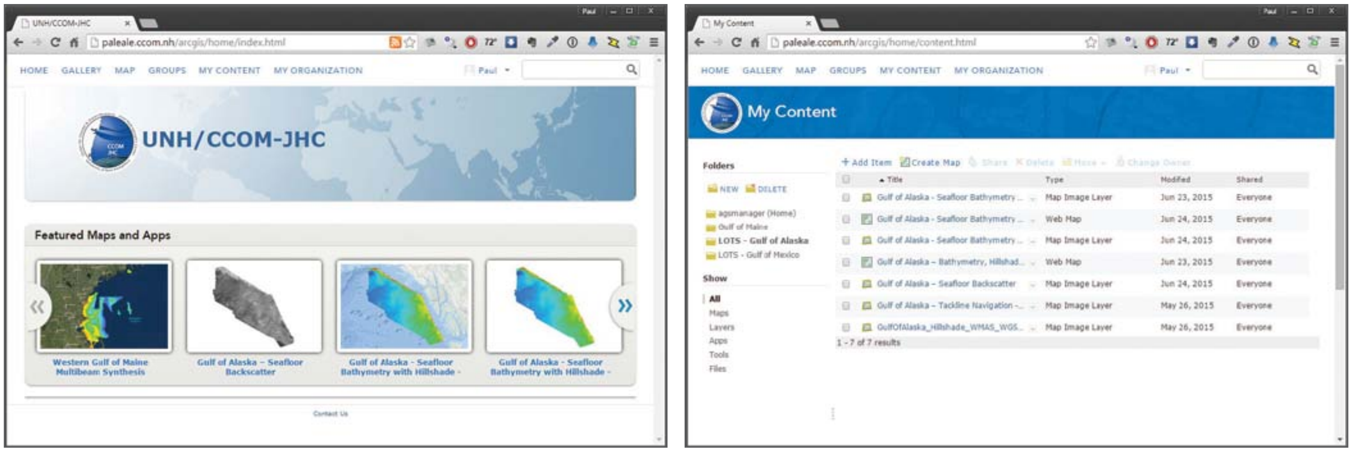


Figure 4-31. Home screen (left) for the Center's new GIS portal and an example of a content listing (right) for the Gulf of Alaska Law of the Sea survey area.

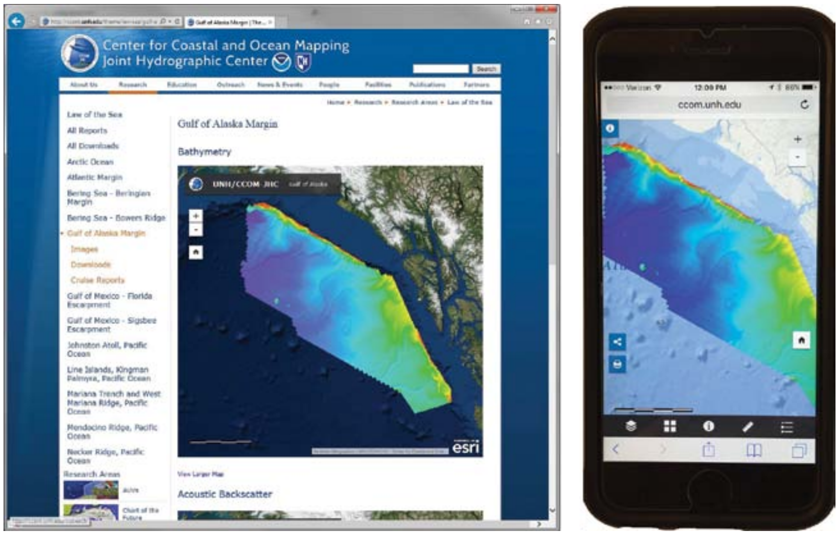


Figure 4-32. Interactive dynamic map of the Gulf of Alaska bathymetry available through the Center's website at (http://ccom.unh.edu/theme/law-sea/gulf-alaska-margin) through a desktop web browser (left) or through a mobile web browser (right).

The new GIS Portal also allows for the rapid development of web served dynamic interactive maps written in JavaScript. Development has already commenced along these lines with dynamic maps being served through the Center's webpages of some of the Law of the Sea data products (Figure 4-32 or **http://ccom.unh.edu/theme/law-sea/gulf-alaska-margin**) as well as the Western Gulf of Maine bathymetry and backscatter synthesis (see section below).

The Law of the Sea dynamic maps allow users to interact with the data in a wide variety of ways. This includes toggling layers on and off, adjusting the transparency of a layer, measuring distances, changing basemaps, sharing stored views with other users, printing, and querying information on the map. Currently only the Law of the Sea Gulf of Alaska bathymetry and backscatter data are being served through the Center's webserver and GIS portal, but further areas will be enabled in early spring 2016.

Organization, Visualization, and Distribution of Bathymetry and Backscatter Data from Portsmouth Harbor, Great Bay Estuary and the Gulf of Maine

Many of the field activities of the Center are focused on the local waters of Portsmouth Harbor, Great Bay, and the Gulf of Maine, resulting in the collection of much data from the region, and numerous requests for these data. Fifteen years of collection have resulted in multiple data sets, in various forms, that are scattered throughout our data storage systems. This has made it a challenge at times when faculty, students, staff, or people from outside the Center have sought to determine what data is available for different areas and the quality of that particular dataset. In order to streamline this process and make it easier for both the users and for the Data Manager, Johnson began organizing these datasets into geodatabases, which were in turn linked to a GIS project and mapping services.

During the spring of 2015, Paul continued to work on the Western Gulf of Maine (WGOM) Bathymetric Synthesis. This led to the first release of a WGOM multibeam-only synthesis and a regional bathymetry synthesis containing the multibeam data combined with the low resolution regional bathymetry (Figure 4-33).

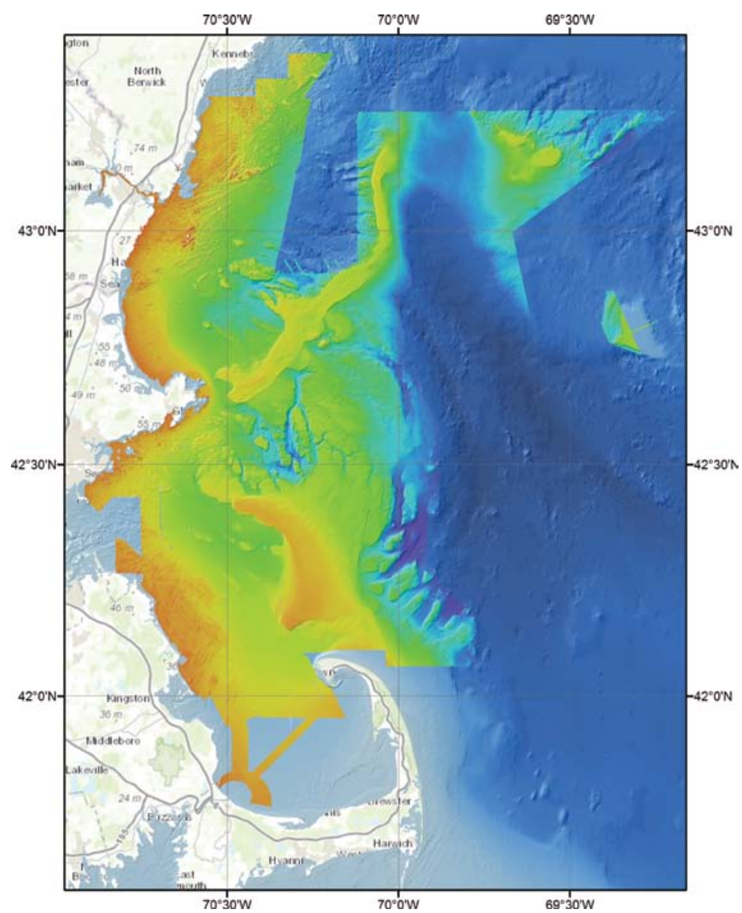


Figure 4-33. Map showing the Western Gulf of Maine Multibeam Synthesis (multi-colored bathymetry) overlaid on the Western Gulf of Maine Bathymetry Synthesis (blue colored bathymetry).

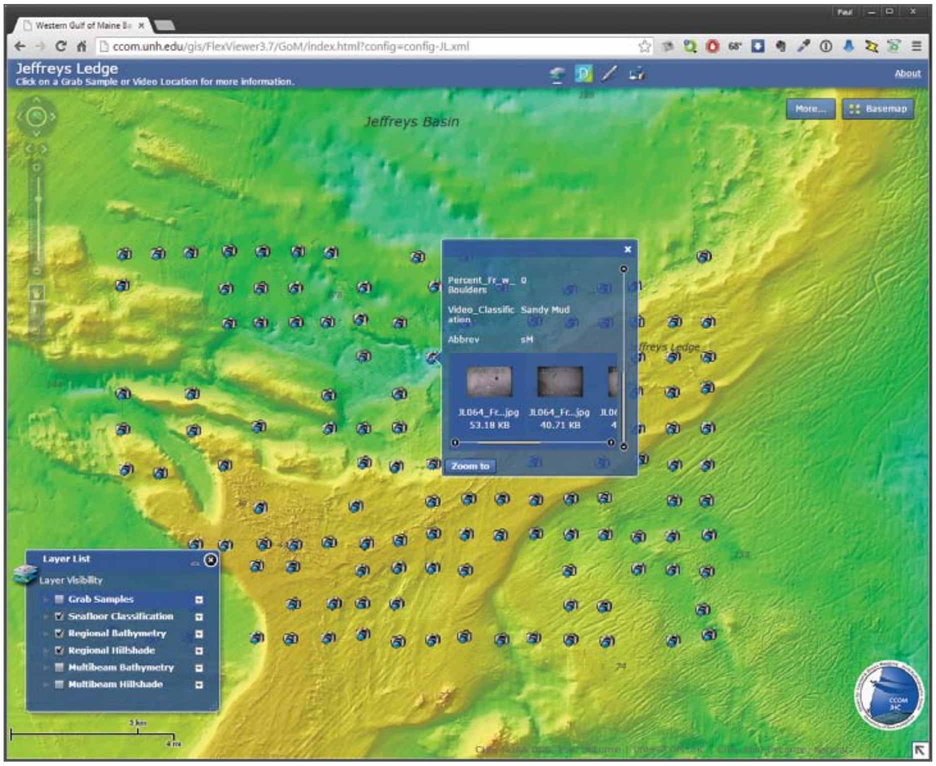


Figure 4-34. Jeffreys Ledge interactive webpage showing version 1 of the Western Gulf of Maine Bathymetry Synthesis, grab sample locations, and seafloor classification sites.

With the release of these two datasets, Johnson, working with Larry Ward and Erin Nagel, followed up with the release of a new dynamic map webpage (Figure 4-34 or **http://bit.ly/1Hl1xaq**) focused on the Jeffreys Ledge site in the Gulf of Maine. For this webpage, Ward supplied Johnson with grab sample locations, seafloor classification locations, and screen captures of the seafloor classification spots. Using the center's GIS server and ESRI's Flash API, Johnson developed the web interface so that users could query particular sample locations or classification sites and then see the associated video captures from those sites. Unfortunately, this website was designed prior to the implementation of the Center's GIS portal and was therefore developed using Adobe Flash, meaning the website is not currently compatible with many mobile devices. Johnson will be converting this site to JavaScript in the near future.

During the spring and fall of 2015, Johnson continued to work with Nagel, Ward, and Glen Rice on developing the backscatter synthesis for the Western Gulf of Maine. Nagel has handled a majority of the data integration and processing, while Johnson and Rice advised on the workflow and helped with troubleshooting when the processing broke down. This effort resulted in a delivery of a WGOM backscatter synthesis by Nagel during the Fall of 2015, which Johnson then translated into a new interactive webpage, that also included a new release of the WGOM bathymetry synthesis.

The new webpages, which are currently being served from the Center's website at http://**ccom.unh.edu/gis/maps/WGOM_4m/**, are based on the interactive JavaScript webpages developed as part of the Law of the Sea program. As was the case for the LOTs webpages, the interactive maps can display the gridded bathymetry (Figure 4-35a), zoom and pan through the datasets, display the backscatter synthesis (Figure 4-35b), change basemaps, measure distance, and query information on each of the surveys or grids (Figure 4-35c).

A Hydrographic Universal Data Description Language (HUDDL)

A fundamental operation in any data-processing environment is the management of the binary file formats of the acquired, processed, and archived data. Changes to these formats are often not well documented and writing the format library code to read and write data is tedious and error prone. Previous work by Calder has resulted in a simple data format compiler that translates an ASCII description of typical hydrographic data formats into C-code to read the data, but this code is aging, and does not take advantage of newer description languages, such as XML, which allow for more expressive description of data structures with better error checking, better distribution mechanisms and improved visibility.

Masetti and Calder have therefore started a project to upgrade and significantly extend the previous methods, using XML schemas to describe core and extended data objects in the sorts of binary data files used in hydrographic practice (a Hydrographic Universal Data Description Language—HUDDL). The intent of HUDDL is to provide a simple means to document clearly the contents of a binary data file in such a way that it can

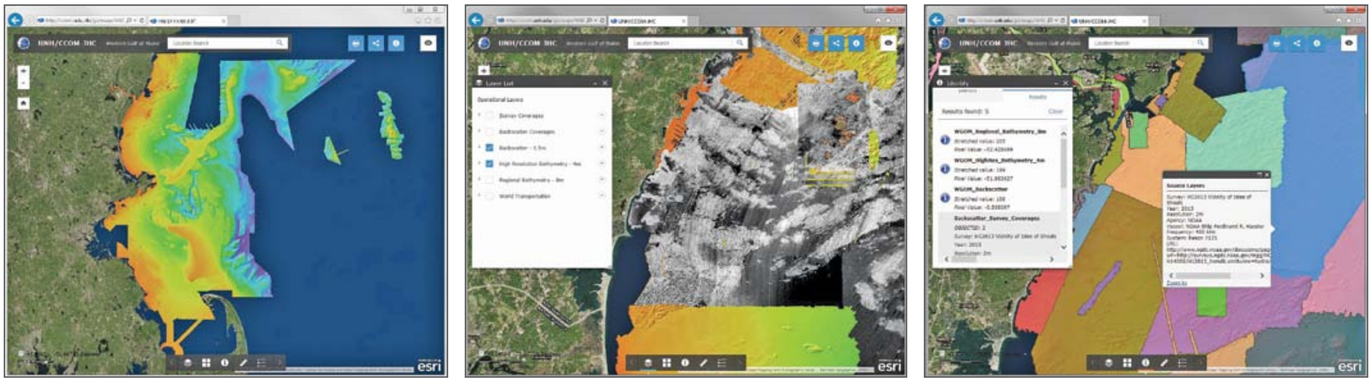


Figure 4-35. New release of the Western Gulf of Maine Bathymetry and Backscatter Synthesis. Figure 4-35a shows the 4m multibeam only bathymetry grid. Figure 4-35b shows the backscatter synthesis overlaying the bathymetry data. Figure 4-35c shows the webpages ability to query information such as survey, depth, system type, etc.

be used to generate, among other things, source code to read/write the file, and human-readable documentation of the file format. If adopted fully, this would significantly simplify the process of reading and writing new data formats, and provide hardware and software vendors an efficient and standard method to document their data files for all users. This approach would also allow an on-line repository of data formats to be developed, and enable easy push notification of format changes so that users and software developers are always aware of changes.

A Web repository for HUDDL Format Descriptions (HFD) was created at the Center to provide an initial safe and easy-to-check common point for data format specifications. Widely used systems (e.g., RSS, or an open-subscription mailing list) assist in staying current with the last release of data formats for all interested parties. The repository is part of a community-oriented website (using the Drupal content management software) to access, catalogue, and disseminate hydrographic data formats resources; HUDDL-specific information has been developed and is now publicly available (Figure 4-36).

Calder and Masetti have also developed an XML interface for HUDDL and constructed a code generator application in C++ that allows multiple language back-ends, so that the output code can be generated in different computer languages. Currently, code in C and C++ is generated directly, and Python modules are made available by SWIG bindings. IPython notebooks have been created (and published as blog posts on the project website) that demonstrate the language for current and historical binary files, and a current ASCII file, showing both the automatically-generated source-code for the formats described, and the use of high-level (Python) code to access them in a user-friendly manner (Figure 4-37).

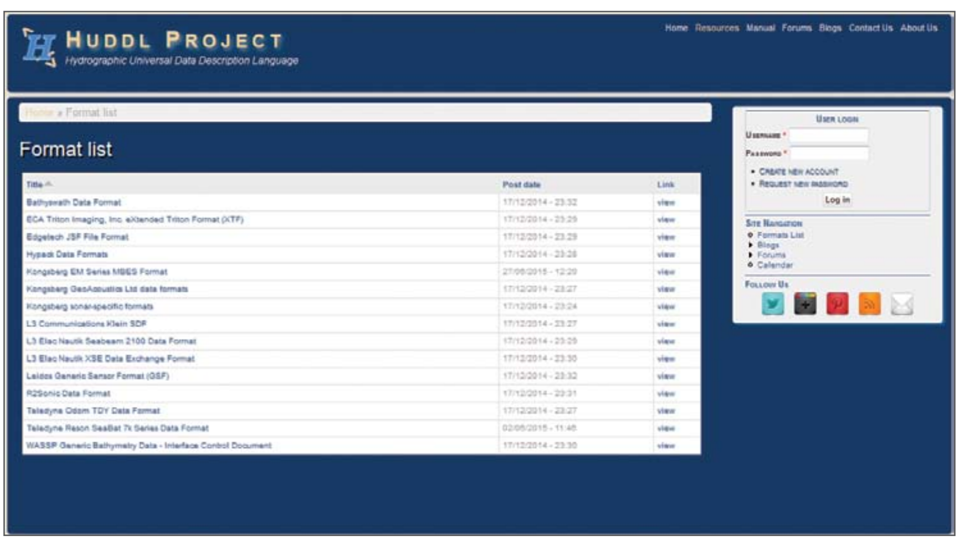


Figure 4-36. The "Format list" page of the Huddl Project website (https://huddl.ccom.unh.edu), made available to the public January 2015.

HUDDL is intended to be an open, community-led initiative aimed at simplifying the issues involved in hydrographic data access. The project was presented at the hydrographic community with an article published in the May issue of the International Hydrographic Review and the latest development of the HUDDLER compiler was presented at the US Hydro 2015 conference. A scientific paper about the open-source engineering code solutions used in the project is in preparation.

```
#!/usr/local/bin/python
import kongsberg_em_series as kng
import numpy as np
import matplotlib

class KngData:
    """ container for Kongsberg attitude data """
    roll = np.zeros(0, dtype=np.float)
    [… create all the required empty numpy arrays …]

def read_attitude(data_header, data_content, kng_data):
    """ read and store a Kongsberg attitude datagram """
    nr_entries = data_content.attitude.numentries
    loc_roll = np.zeros(nr_entries, dtype=np.float)

    for i in range(nr_entries):
        loc_att = kng.em96att_getitem(data_content.attitude.att, i)
        loc_roll[i] = loc_att.roll / 100.0
        [… read the other attitude measures: pitch, heave, etc. …]

    kng_data.roll = np.append(kng_data.roll, loc_roll)

def plot_attitude(kng_data):
    """ plot and save the read Kongsberg attitude data """
    fig, (ax0, ax1, ax2, ax3) = plt.subplots(ncols=1, nrows=4)
    plot0 = ax0.fill_between(kng_data.time, kng_data.roll,
                             linewidth=0.3, facecolor='green')
    ax0.set_title('Roll')
    [… use Matplotlib to plot all the attitude arrays …]

def main():
   kng_data = KngData()
   testfile_path = '0001_20120606_175918_ShipName.all'
   ip = kng.fopen(testfile_path, 'rb')
   [… check if the file was successfully open …]

   abort = False
   while not abort:
      rc, n_read = kng.read_kng_revR(ip, data, n_read,
                                     kng.validate_em96)
      if rc == kng.HUDDLER_TOPBLOCK_OK:
         if data.header.type == kng.KNG_REVR_ATTITUDE:
            read_attitude(data.header, data.datagram, kng_data)
      else:
         abort = True

   plot_attitude(kng_data)
```

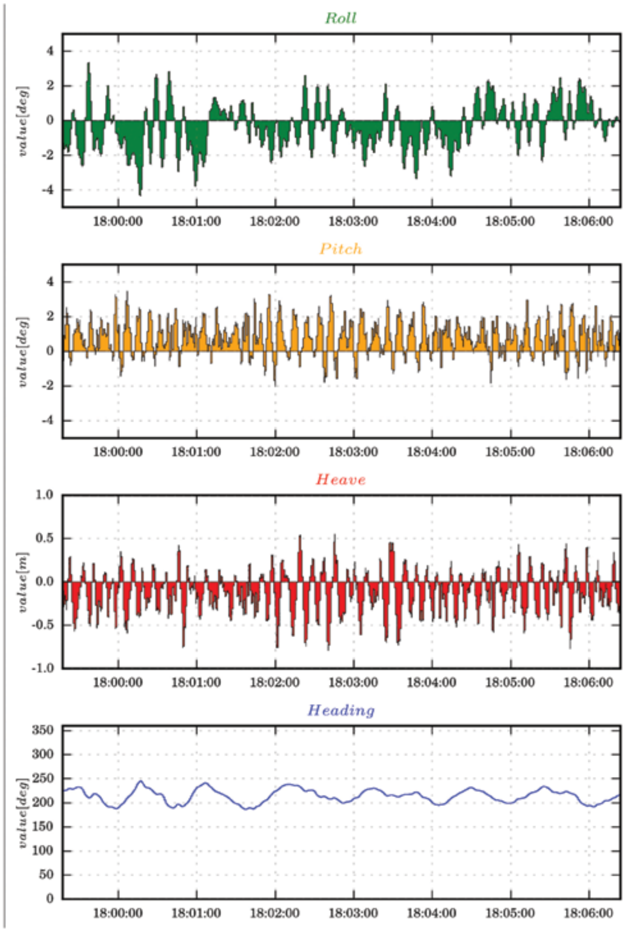


Figure 4-37. In the left pane, a simple script that imports the HUDDLER-generated library that provides all the methods to open and access the attitude data. In the right pane, the output generated by the Python script that can be used to quickly inspect the attitude data before manipulation and/or using it in processing algorithms. The full code for this example is accessible online at: **https://huddl.ccom.unh.edu/?q=blogs/gmas/plotting-attitude-data-kongsberg-file-python**.

Theme 3 – Habitat and Water Column Mapping

Developing Tools and Approaches for the Adaptation of Hydrographic, Coastal and Ocean Mapping Technologies for the Mapping of Benthic Habitat and Exploring the Broad Potential of Mapping Features in the Water Column

The initial focus of early multibeam echo sounder development was the collection of dense, high-resolution bathymetry in support of chart-making and other aspects of safe navigation. With the evolution of these sonars came the simultaneous collection of backscatter (amplitude) information, initially from the seafloor and, most recently, from both the seafloor and the water column. This backscatter information offers a wealth of additional information beyond the depth data initially provided by the time-of-flight measurements of the multibeam echo sounder. The Center has long pursued research focused on trying to better understand and calibrate the backscatter measurements provided by the various sonar systems available (see Backscatter section of PROCESSING theme). Understanding the nature of the backscatter produced by the sonar systems is an essential component of any seafloor characterization research. In parallel with these efforts, we are also developing approaches to apply backscatter measurements to problems of benthic habitat determination and the mapping of water column targets. All of these applications also have direct relevance to our IOCM Theme.

Habitat Mapping

While "habitat mapping" is a desired end product of many seafloor mapping efforts, just what habitat mapping means has often been ill-defined. Our response to this difficulty is to focus on the development of approaches for characterizing the seafloor through the analysis of data we can derive from the sensors with which we work (sonar, lidar, satellite imagery and hyperspectral scanners). As we perfect these techniques (which are currently far from perfect), we work closely with biologists and fisheries scientists to see how the data we provide can be used to answer the critical questions they face. From a seafloor perspective, the key parameter that offers the best chance for quantitative characterization of the seafloor is acoustic backscatter. However, if sonar backscatter data are to be used to correctly characterize seafloor properties, then the measured backscatter must represent changes in the seafloor rather than instrumental or environmental changes. Although many system and geometric corrections are applied by the manufacturers in their data collection process, some corrections are not applied (e.g., local slope), and for others, many questions remain about how and where the corrections are applied. As described under the SENSORS theme and in the Backscatter Processing section of the DATA PROCESSING theme, we have been working closely with NOAA and the manufacturers to fully and quantitatively understand the nature of the collected backscatter data and to develop tools (e.g., GeoCoder) that can properly make the needed adjustments to the data. At the core of this effort are the NEWBEX experiment and Mashkor Malik's research into backscatter uncertainty (described under the DATA PROCESSING theme). Once proper corrections are made, the resulting backscatter values should be much more representative of true seafloor variability and can then provide an important component of efforts to remotely characterize the seafloor.

Seafloor Characterization and Habitat Studies and Resource Studies Offshore New Hampshire

Seafloor Characterization and Marine Mineral Resources

The continental shelf of New Hampshire and vicinity provides an excellent setting to further our ability to characterize the seafloor utilizing high resolution MBES surveys and archived geophysical databases. During 2015 our work on seafloor characterization and evaluation of marine mineral resources (sand and gravel) was expanded due to external funding by the Bureau of Ocean Energy Management (BOEM) Marine Minerals Service (MMS) to conduct an evaluation of the sand and gravel resources on the New Hampshire shelf. In addition to the BOEM project, a primary goal was to explore best practices and workflow to take advantage of data collected for other purposes in support of seafloor characterization.

Seafloor Characterization of the New Hampshire and Vicinity Inner Continental Shelf

The relatively recent availability of high resolution multibeam echosounder (MBES) bathymetry and associated backscatter by NOAA NOS and the Center, along with previously developed geophysical databases, covering the continental shelf off New Hampshire (NH) provides an opportunity to further develop our capabilities to describe and characterize the seafloor. Therefore, a significant effort was put forth to locate and obtain all available (to our knowledge) MBES bathymetry and backscatter in the region. The development of this database was led by JHC Data Management personnel (Paul Johnson and Erin Nagel—see DATA MANAGEMENT section). The database and synthesis is now complete and is available via the JHC website (Western Gulf of Maine Bathymetry and Backscatter Synthesis—see **ccom.unh.edu/project/wgom-bathymetry-and-backscatter**). Complementing the MBES surveys is an extensive database consisting of surficial sediment data, subbottom seismic profiles, vibracores and video developed in the past for the NH shelf and vicinity that has been compiled at the Center.

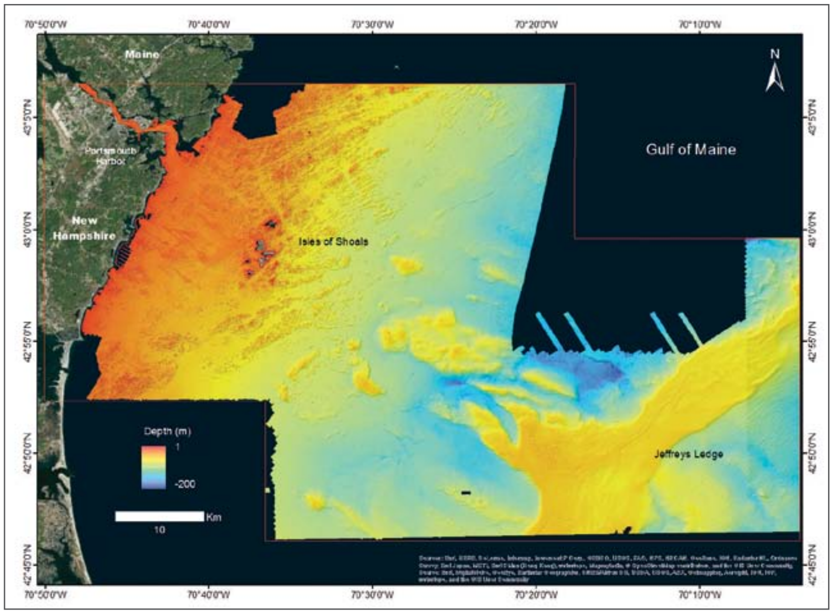


Figure 5-1. Location map of the study area (outlined in red) and MBES bathymetry. The bathymetry is draped over the shaded-relief surface and was produced by JHC Data Management personnel. Depths are relative to Mean Lower Low Water (MLLW) datum.

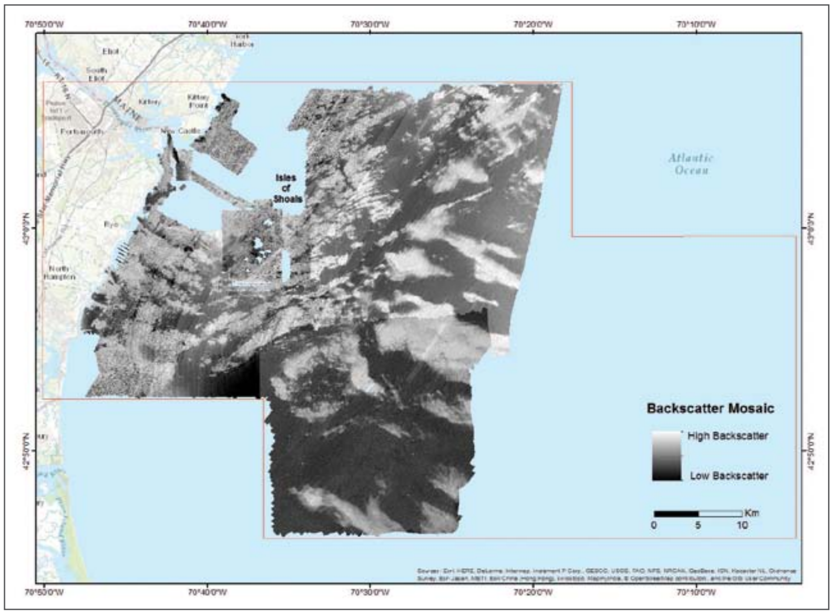


Figure 5-2. Backscatter mosaic for the study area. The mosaic was produced by JHC Data Management personnel.

The MBES bathymetry for the WGOM synthesis provides exceptional detail of the seafloor morphology for much of the study area which extends from the NH coast to Jeffreys Ledge (Figure 5-1). In addition, backscatter of varying quality is available for most of the MBES surveys (Figure 5-2). The bathymetry, along with several of its primary derivatives, were used to help segment the seafloor into geomorphic features (geoforms) as described following. The primary derivatives, which were computed from the WGOM Bathymetry Synthesis, were developed in ArcGIS 10 using the Geomorphometric and Gradient Metrics toolbox (Roughness), Benthic Terrain Modeler toolbox (Bathymetric Position Index, BPI) and Spatial Analyst toolbox (Slope, Aspect, Hillshade).

The purpose of the seafloor segmentation was to define distinctive morphologic features and evaluate their composition and origin. The geoforms were identified and isolated with polygons based on visual identification and expert opinion using, primarily, hillshade, BPI, and roughness (viewed independently). The geoforms or morphologic features were then classified based on their interpreted mode of formation, which also has implications to their geologic-textural characteristics. The main geoforms identified in the study area include: bedrock outcrops; sediment draped bedrock; marine modified glacial features; and marine formed features or shoals (Figure 5–3).

The geoforms identified and classified on the NH shelf show very clear trends. From several kilometers seaward of the Isles of Shoals to past (and including) Jeffreys Ledge, the geoforms are very large and dominated by marine modified glacial features. Some of these features may be slumps, or formed subglacially. Extending northeast and southwest of the Isles of Shoals are extensive bedrock outcrops, often with swales and surrounding veneers of coarse sediment. Landward of the Isles of Shoals to the coast the seafloor is extremely complex. The bedrock that dominates the seafloor north of the entrance to Portsmouth Harbor transitions into sediment draped bedrock as the sediment cover becomes more prevalent. The sediment draped bedrock category tends to have modified glacial features intermixed in some of the inner shelf areas. Landward of the Isles of Shoals to the coast are extensive marine modified (eroded) glacial features, marine formed shoals, and general (flat) seafloor in between. The largest sandy shoal in the study area is located just landward of the Isles of Shoals (the northern sand body).

The limited use of the backscatter and potential derivatives to date during the mapping and classification of geoforms is largely because advanced processing and further evaluation is needed to extract useful information. This is presently underway. The primary sources of the backscatter for this study include the JHC Summer Hydro surveys and recent NOAA Ship *Ferdinand R. Hassler* surveys. Collectively, these surveys provide relatively good coverage from northern Massachusetts to the Maine-New Hampshire border and seaward well past the Isles of Shoals.

A major goal of the work on seafloor classification is to better automate the processes and take advantage of what is becoming a field laboratory: the NH shelf. An extensive database has been created that includes considerable acoustic, geophysical, and ground-truth information. The geoforms that were developed will be added to this database. This database can be further used to ground-truth remote classifications based on bathymetry and its derivatives and backscatter.

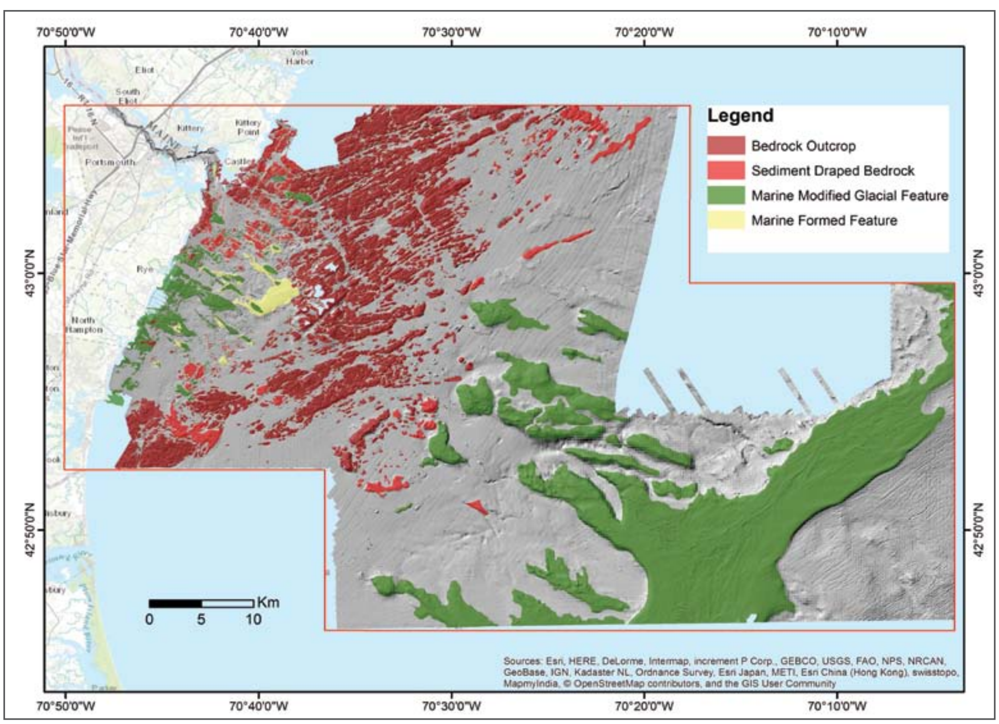


Figure 5-3. Major morphologic features (geoforms) on the New Hampshire and vicinity continental shelf draped over a shaded-relief raster surface of the bathymetry (10x vertical exaggeration).

The initial effort using an automated classification for bottom morphology utilized a multi-criteria analysis carry out using the Weighted Overlay tool in ArcGIS 10.3. The tool

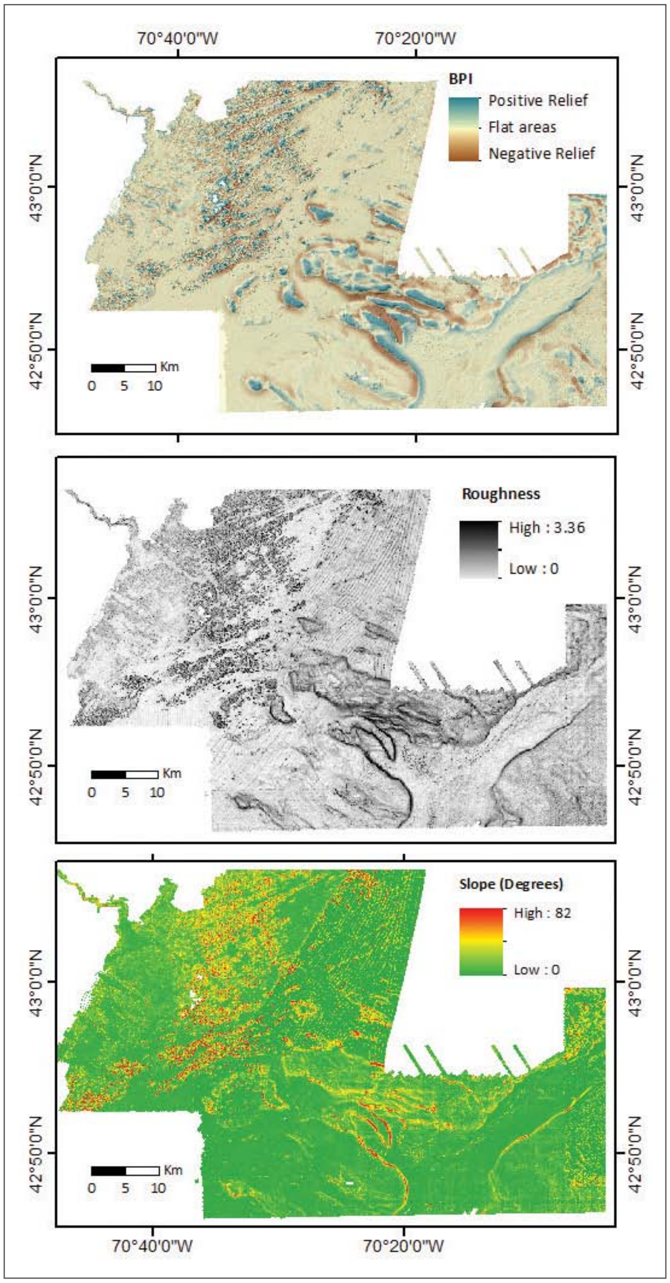


Figure 5-4. Major bathymetric derivatives used to identify morphologic features (geoforms) on the New Hampshire and vicinity continental shelf. BPI (top panel) is Bathymetric Position Index.

performs a supervised classification by combining several raster surfaces taking into consideration the level of importance that each variable might have in the final classification. For this study BPI, Slope, and Roughness (Figure 5-4) were chosen. The results are encouraging, but showed significant variation to the geoforms identified by expert opinion in some regions. The use of automated classifications will be further explored.

Assessment of Offshore Sand and Gravel Resources

For Information – funded by other sources

Demonstrating the value of the bathymetry and particularly the backscatter collected by NOAA and others, Larry Ward has been funded by the Bureau of Ocean Energy Management to conduct a two-year, intensive study of existing data to define the seafloor and sedimentary environments of the New Hampshire (NH) continental shelf and vicinity. The overarching goal of the project is to identify and characterize sand and gravel deposits that are suitable for beach nourishment and to help build coastal resiliency in New Hampshire, provide an analysis of existing geophysical and geological data delineating potential sand resources on the NH shelf, and determine areas that require future studies to better define potential sand resources. Associated with the overarching objectives is the development of new bathymetric maps based on existing surveys, utilization of acoustic backscatter to help identify seafloor features and boundaries, assessment of the use of backscatter as a mapping tool for sand and gravel deposits in the future, determination of the location and characteristics of previously identified sand and gravel deposits, and determination of the sediment textural characteristics of NH beaches. Therefore, the study has two focus areas: the NH continental shelf and the beaches. A further outcome of this work will be the development of best practices guidelines and documents describing the process of using multibeam sonar and other data to assess offshore sand and gravel resources.

Shelf Sand and Gravel Assessment (BOEM Project)

A highly valuable resource for the assessment of sand and gravel deposits on the NH continental shelf is the WGOM Bathymetry and Backscatter Synthesis (primarily developed by JHC Data Management personnel Paul Johnson and Erin Nagel). The high-resolution bathymetry synthesis provides the base for the surficial sediment mapping and provides a detailed morphology of the seafloor. The completion of the WGOM Bathymetry and Backscatter synthesis allowed the focus of the 2015 efforts to be on the mapping of the seafloor sediments and the characterization of potential sand and gravel resources based on archived seismic surveys.

The most comprehensive subbottom seismic surveys of the NH shelf were conducted by UNH and the USGS in 1981, 1982, and 1985 (see Birch, F.S. 1984, A Geophysical Survey of Sedimentary Deposits on the Inner Continental Shelf of New Hampshire, Northeastern

Geology 6:207-221; hereafter referred to as the Birch surveys). Approximately 1280 km of primarily 3.5 kHz uniboom seismic profiles were acquired in these surveys. In order to fully integrate these analog records with our high resolution databases and enhance the analysis of the seismics, the analog records were converted to digital. Subsequently, the subbottom seismic records were analyzed to determine sand and gravel thicknesses base on seismic facies. This analysis was guided by the original interpretations of Birch (1984).

The conversion of the Birch subbottom seismic survey records from analog to digital records (SEG-Y) was done using Chesapeake Technology ImageToSEGY software. The SEG-Y files were analyzed in SonarWiz 5 to identify and/or verify likely sand and gravel deposits. Location and sand unit thickness were extracted for each seismic line and exported to ArcGIS 10.3 for gridding and development of isopach maps. A raster surface was generated by Kriging applied to sand thickness point values. Subsequently contour lines were created representing equal groupings of sand thickness values from the interpolated surface (isopachs).

Based on the analysis of the subbottom seismics profiles described above, we observe that sandy deposits are largely found landward of the Isles of Shoals and southward of the entrance to Portsmouth Harbor (Figure 5-5). However, it should be noted that the seismic surveys did not extend to Jeffreys Ledge and there are regions that need further review. The thickest sand deposits in the survey area are associated with what appear to be eroded glacial deposits (Figure 5-6). The largest sand body located to date on the NH shelf is found just landward of the Isles of Shoals and is referred to here as the Northern Sand Body (Birch 1984).

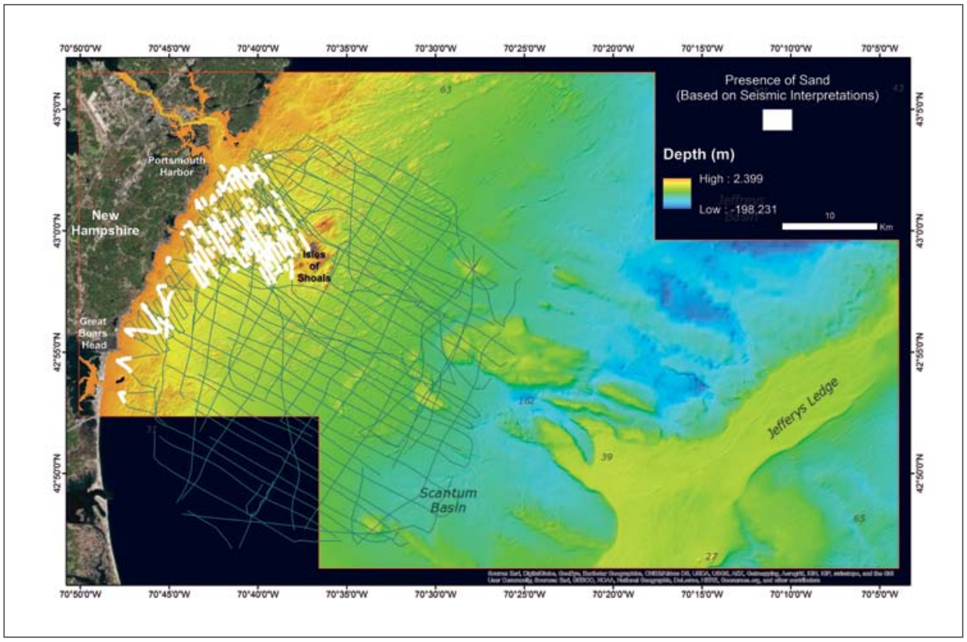


Figure 5-5. Extent of the subbottom seismic surveys conducted in 1981, 1982, and 1985 (solid lines) by Birch (1984). The areas where sand was identified based on the interpretation of the seismics are shown in white.

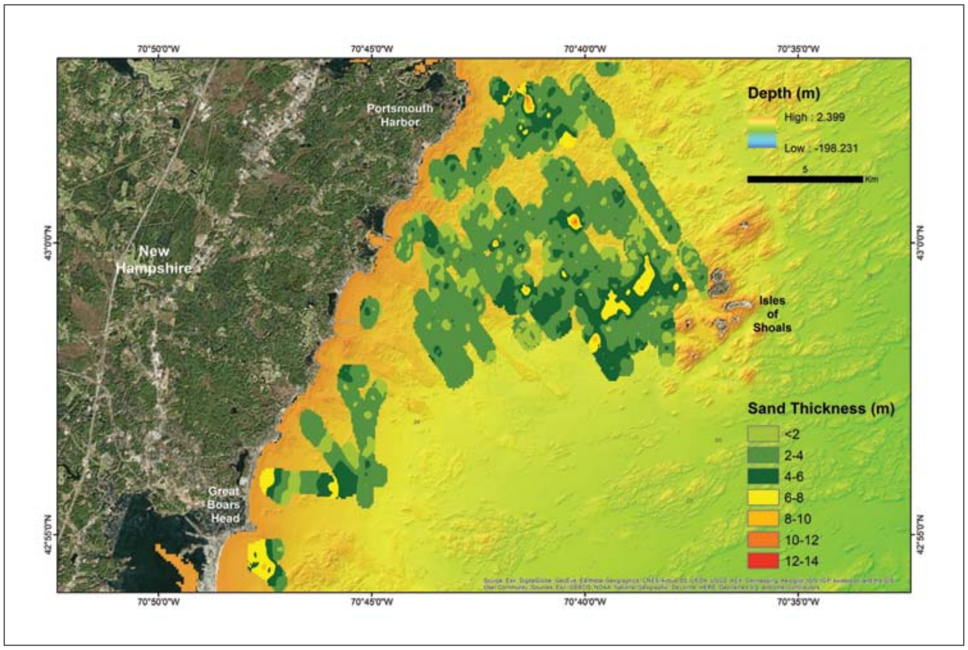


Figure 5-6. Isopach map showing sand thickness based on the interpretation of subbottom seismic profiles.

This feature extends approximately 3.5 km in length, up to 1.5 km wide, with sand thicknesses on the order of 2 to 8 m, but reaching 13 m in some areas. The other sand deposits mapped to date are significantly smaller and are associated with eroded glacial features or the paleochannel of the Piscataqua River.

It is likely that much of the NH inner shelf is covered with a veneer of sandy to gravelly sediments and that there are thicker sand deposits not identified by the earlier Birch surveys. A surficial sediment map is being developed as part of the work on the seafloor characterization (discussed elsewhere in this report). The present archived subbottom seismic records will be reviewed to determine if potential sand resources can be identified further offshore.

Shoreline Characterization and Coastal Resiliency (BOEM Project)

In order to determine the type of sediment (grain size and shell content) needed for beach nourishment along the New Hampshire (NH) coast, it is required that the characteristics of the natural sediment on the beaches be known under equilibrium (summer) and high energy (winter) conditions. In addition, it is important to understand the potential need (volumes) of sediment for beach nourishment in the future in view of projected sea-level rise. Therefore, starting in summer 2015, eight major beaches along the NH coast (Wallis Sands, Jenness Beach, Foss Beach, North Hampton Beach, North Beach, Hampton Beach, and Seabrook Beach) were sampled along three to five transects extending from the dunes or engineering structures to the low water line. At each transect the beach was sampled at three to four locations. In addition, the beach cross-section was profiled and the location of the sediment samples on the profile noted. Profiles were determined primarily using a GPS system on a rover (three-wheeled dolly). However, in some locations the Emery method (using profile rods and the horizon) was used either due to obstructions to the rover or due to availability of the equipment. As a result the sediment and the morphologic setting for beach was determined. Analysis of this database is still underway.

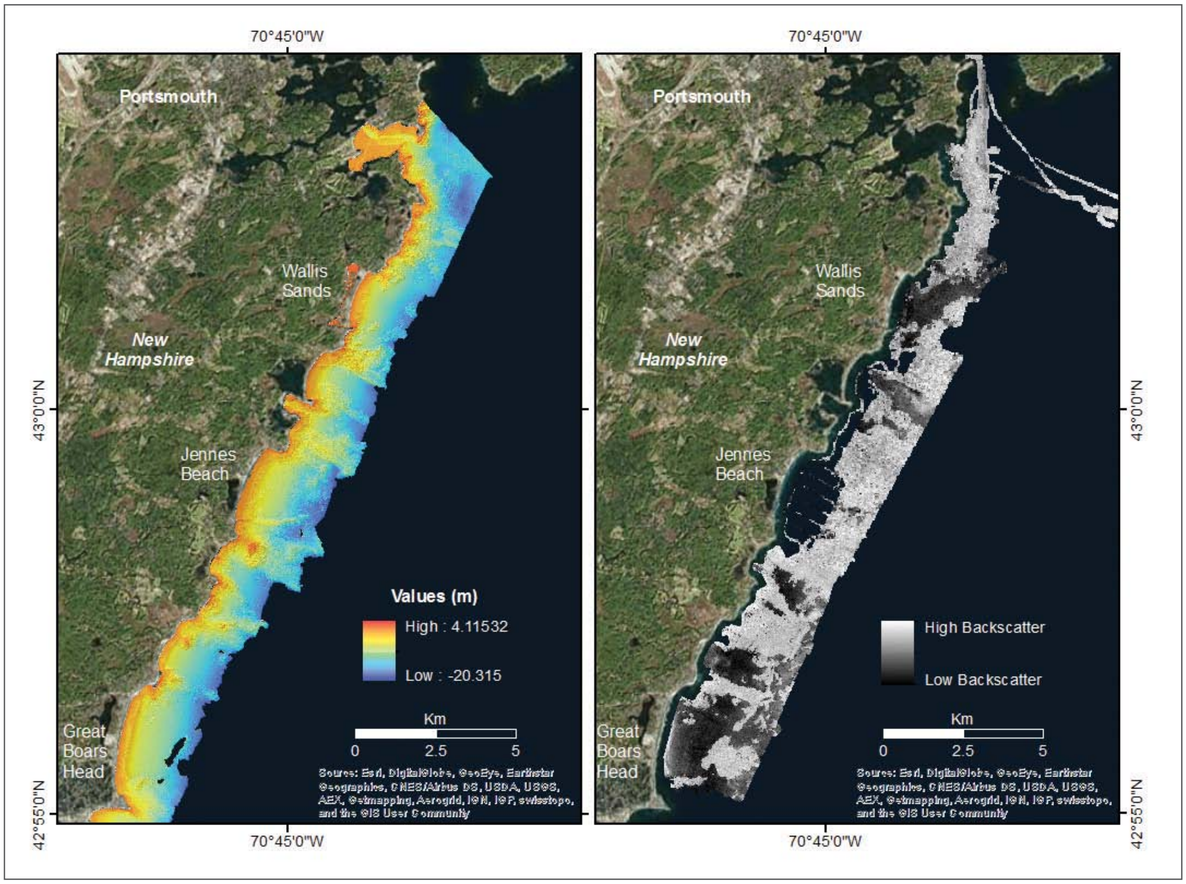


Figure 5-7. Nearshore bathymetry (left panel) based on a 2010 lidar survey by USACE JALBTCX and backscatter based on MBES surveys by JHC (right panel). Mosaics done by JHC Data Management personnel.

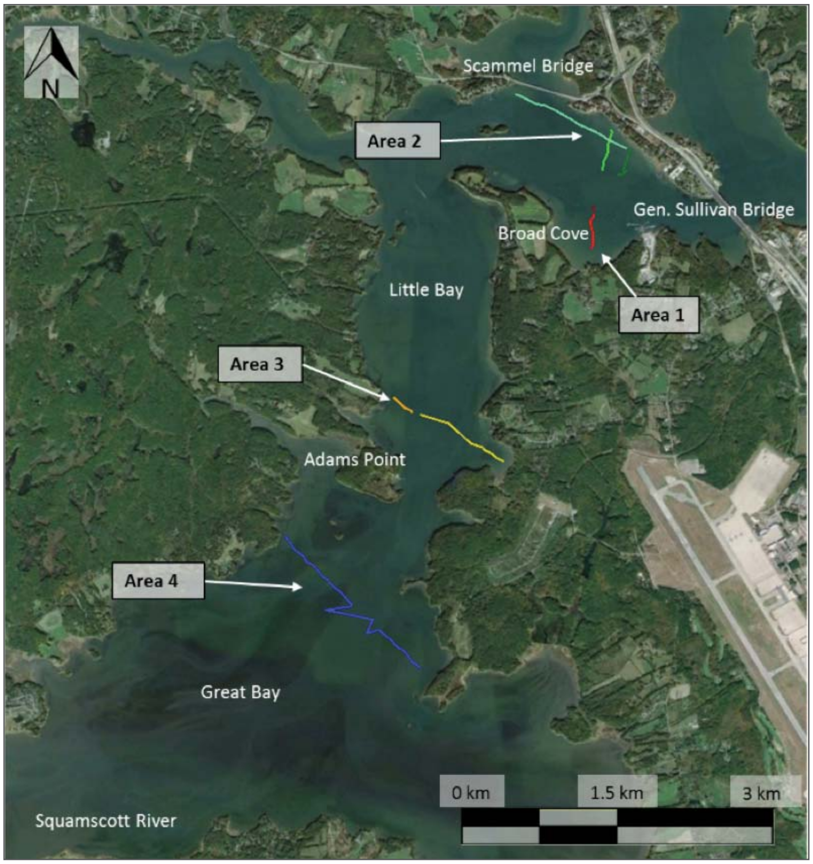


Figure 5-8. Map of Great Bay and Little Bay survey areas.

An unexpected and important finding gained from investigating the seafloor characteristics of the NH inner shelf is the presence of bathymetric highs that extend seaward off headlands between several of the beaches. These bathymetric highs are most prominent north of Great Boars Head and appear to be either bedrock or eroded glacial deposits as indicated by the bathymetry and the backscatter (Figure 5-7). The significance of the bathymetric highs is that longshore transport of sand may be interrupted or even prohibited between the beaches resulting in a predominance of onshore-offshore, rather than longshore, sand transport. For example, the seafloor off Wallis Sands (northern NH) indicates a sandy or softer bottom extending seaward towards the northeast, possibly implying some exchange with the Piscataqua River. The beach north of Rye Harbor (middle NH) appears to extend seaward in some valley type feature. This is confirmed with some of the offshore subbottom seismic work. Although much of the nearshore record is missing off of Jenness Beach, the cross lines indicate a sandy substrate extending seaward. Again, all of these beaches seem to be separated by bathymetric high areas composed potentially of gravel or bedrock and would indicate little interconnectedness between these beaches.

These observations are very preliminary and will be examined much more rigorously. It is hoped that much of the remainder of the nearshore areas along the New Hampshire coast will be surveyed in the coming year (Summer Hydro 2016), allowing this effort to expand into the important Hampton Beach and Seabrook Beach areas.

Great Bay and Little Bay Seafloor Characterization

We have also focused on exploring techniques for the collection of habitat data in the very shallow waters of Little Bay Estuary, NH. In 2014, Tom Lippmann and graduate student Joshua Humberston used a dual frequency (24 and 200 kHz) single beam echo sounder mounted on either the *CBASS* (see **FACILIITIES** section) or a small survey launch to collect acoustic data in an effort to remotely characterize seafloor sediments. This year, Lippman has followed up this work with a ground-truthing program aimed at measuring the geotechnical properties of the seafloor to better understanding the acoustic measurements. Acoustic techniques are standardly used to attempt to characterize the seafloor because large areas can be covered in a relatively short period of time. Difficulties often arise in interpreting the remotely gathered acoustic data because backscatter is affected by geotechnical properties of the seafloor including bulk density and porosity. To better understand the relationship between the acoustic and geotechnical properties as well as the surficial sediment remobilization and deposition processes a series of portable free-fall penetrometer (BlueDrop) measurements were made in Great and Little Bays, NH. The penetrometer has advantages in that it can be rapidly deployed over large spatial areas in a relatively short time, comprehensively sampling the seafloor over scales of interest to habitat characterization studies and seafloor assessment, and it measures the important seafloor properties that affect acoustic impedance. Comparison to acoustic backscatter in concert with knowledge of the seafloor sediment grain size could provide a comprehensive evaluation methodology for seafloor characterization in shallow coastal areas and navigable waterways.

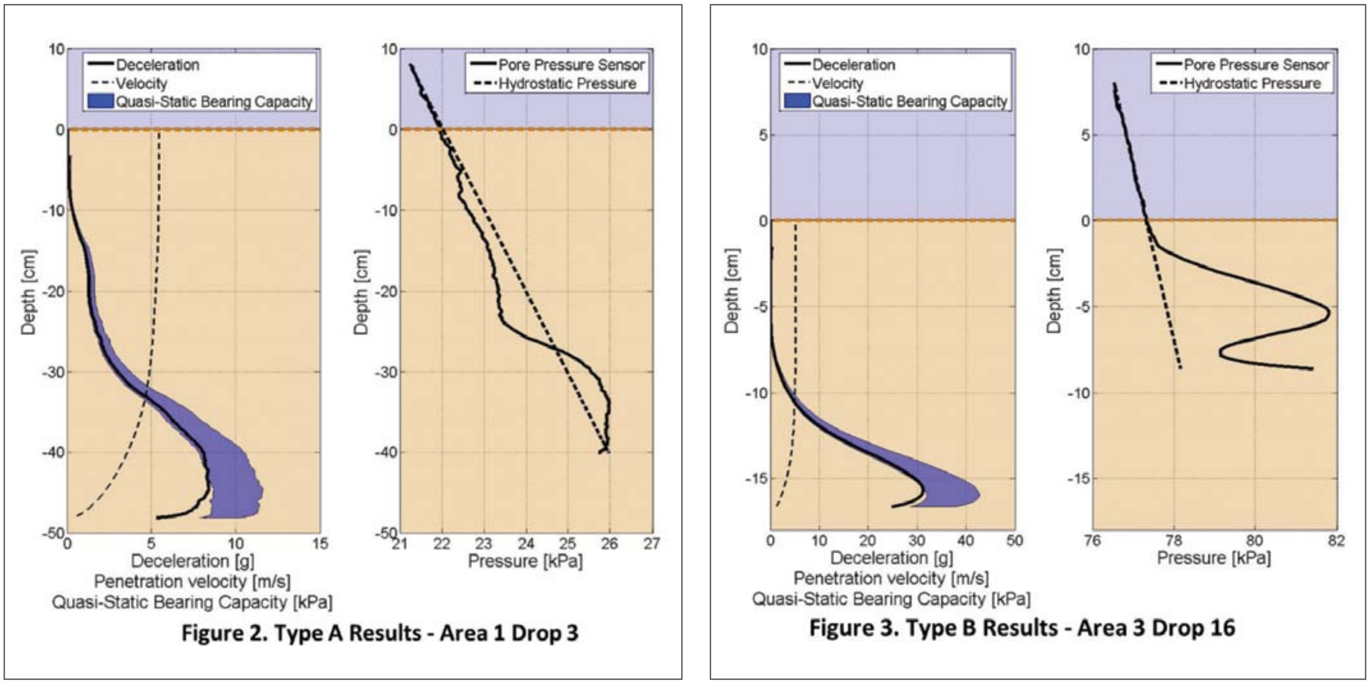


Figure 5-9. Left: Type A results (Area 1 Drop 3). Right: Type B results (Area 3 Drop 16).

BlueDrop measures deceleration using five micro electro-mechanical systems (MEMS) accelerometers, and a pressure transducer is located just behind the tip (u2 position). The data is recorded by an internal data logger at a sampling rate of 2 kHz. The device is designed for the rapid geotechnical assessment of surficial subaqueous sediments, and the investigation of sediment remobilization and deposition processes in marine environments. During this survey, the device was deployed 227 times at 117 locations, which were divided into four areas (Figure 5-8). Thirteen deployments (5.7%) were not included in the analysis due to impact on rock or other disturbances in the data (e.g., tangled rope).

Analysis of the results yielded two distinct profiles of pore pressure response during impact. In the first characteristic profile, subhydrostatic pressures were recorded during penetration into the upper 10–20 cm of the seabed (Figure 5-9, left). In the case shown in Figure 5-9 (left), a top layer of very low sediment strength (sediment depth 0-7 cm; estimated quasi-static bearing capacity qsbc < 0.5 kPa) and slightly subhydrostatic pressure was identified over another soft sediment layer (sediment depth 7-23; qsbc ~ 2 kPa), before penetrating into a stiffer substratum (qsbc$\sim$10 kPa). The stiff stratum was characterized by an increase of pore pressure above hydrostatic pressure until the penetrometer came to a halt. The second characteristic profile displayed pressure increases above hydrostatic levels immediately after penetration into significantly stiffer sediments (e.g., Figure 5-9, right). The deployments were grouped according to the two distinct geotechnical profiles: profiles of type A (Figure 5-9, left) being characterized by significant subhydrostatic pressure in the upper decimeters; and profiles of type B (Figure 5-9, right) being characterized by an immediate suprahydrostatic response to impact. Likely, the behavior observed in profiles of type A was associated to the deposition of a fresh and still poorly consolidated mud layer, while profiles of type B might suggest no sediment deposition, or possibly even sediment erosion.

Comparison to the local bathymetry revealed that profiles of type A were predominantly recorded in areas of shallower water depth (1–3 m). However, a few deployments deviated from the water depth dependent trend. For example, deployments near Scammel Bridge were located in shallow water, but exhibited no evidence of fresh mud deposition (profile type B). Studies on the tidal currents and local knowledge indicated this area has particularly strong currents. Therefore, even though the area is shallow, the strong currents likely prevent the deposition of a mud layer.

The in-situ geotechnical investigation of the Great Bay Estuary, NH, allowed the identification of two characteristic signatures of surficial seafloor sediments expressed in "in-flight" pore pressure and sediment strength profiles. The geotechnical signatures were also related to general characteristics of the local bathymetry and hydrodynamics, contributing to the understanding of on-going sediment remobilization and deposition processes relevant to the maintenance of navigability. Ongoing research will include detailed comparison of the geotechnical properties of the sediments with coincident observation of acoustic backscatter and sediment grain size distribution.

Multi-Spectral Backscatter

Along with the more traditional approaches to seafloor characterization described above, we continue to seek new and innovative approaches to use acoustic data to provide quantitative information on the nature of the seabed. Seabed characterization using multibeam backscatter has become an increasingly routine step for NOAA mapping operations. While problems continue to plague operators concerning proper calibration and data reduction, reasonable results can be obtained in separating major seabed types. One of the frustrations, however, has been that ambiguities in classification can remain where quite different seafloors can produce similar scattering characteristics. This is in part because we are only examining scattering using a single center frequency, analogous to looking at the seabed with a single color rather than full color range.

If, in contrast, the seabed can be imaged using two or more discrete center frequencies (with significantly different wavelengths) the frequency dependence may be used as an additional classifier. Previously, this option had not been feasible due to the strong frequency dependence of attenuation. Recent advances, however, in FM processing have allowed markedly improved range performance and thus (at least for shelf depths) multi-frequency multibeam is now practical.

John Hughes Clarke has been exploring approaches to collecting multispectral backscatter data with multibeam sonars. One approach is to simultaneously operate multiple multibeam systems. This has been implemented twice now using co-located 70–100 kHz and 200-400 kHz multibeams. More recently, a third example has been undertaken by the Marine Institute in Ireland using three systems (EM302, EM1002, EM2040). Using these configurations, examples of improved seabed discrimination have been identified (Figure 5-10). Clear variations in the shape of the angular response curve as well as the relative scattering between frequencies are demonstrated.

Practical limitations that require attention are inter-sonar synchronization, and the complication of the small variations in frequency between sectors within a single system. Specific improvements that could facilitate this method include allowing larger frequency alternations from swath to swath while operating a single system, sharing broader-band transmitters and receivers between multiple systems, and having an option for a common logging stream.

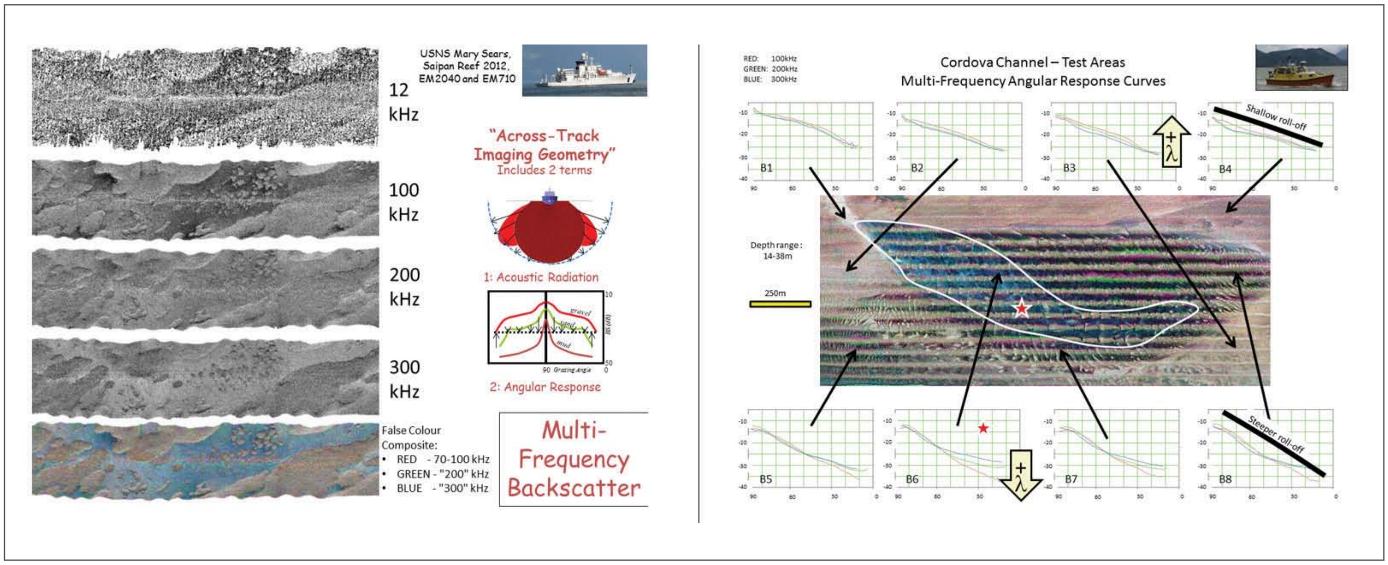


Figure 5-10. Example of changing relative backscatter contrast with sediment type and frequency (left); examples of changing shape of angular response curves with sediment type and frequency (right).

Discussions with Nilsen and Horvei from Kongsberg have confirmed that Kongsberg Maritime would be able to implement alternating center frequencies between dual swath pairs. When developed, this would allow for example: an EM710 (Mk II) to have a 45 kHz swath pair followed by a 95 kHz swath pair. Similarly an EM2040 could have a 210 kHz swath pair followed by a 390 kHz swath pair.

Although inshore small vessels are unlikely to be able to carry the lower frequency hardware (due to weight and size restrictions), this method could become a routine part of shelf surveying operations using NOAA's larger platforms. Typical continental shelf survey vessels need to have ~100 kHz sonars to meet the larger depth/swath width requirements. They operate much of the time though, within ~50m where the higher range resolution of higher frequency systems would be beneficial. Thus if they carry both systems, as they transition through the full range of shelf depths they can always maintain the highest quality bathymetric data collection. And now with the improved range performance of the high frequency systems, both can continue to be operated over the full range of shelf depths (~20-200m) maintaining both optimal bathymetry as well as having the new benefit of multispectral imaging.

With the upgrade of the *Nancy Foster*, *Fairweather* and *Thomas Jefferson*, these ships will have the EM710 MkII, allowing operation between 40 and 100 kHz. Uniquely, the *TJ* will also be getting an EM2040 as part of her upgrade, allowing a major NOAA platform to undertake 40-400 kHz multi-spectral backscatter imaging. The original field program on which this research was based involved the NavO TAGS vessels, UNB's CSL *Heron* and the Irish Marine Institute. In September, the results of that research were presented at a meeting between the Center and the CO and officers of the TJ. Based in part on that, it is now envisioned that, after the sonar upgrades in mid-2016, Hughes Clarke will be directly involved in her field acceptance testing. This will now also include the testing and development of multispectral imaging as part of her standard operational procedures.

Assessment of Gulf of Alaska Untrawlable Habitat in Support of Rockfish Stock Assessment

The NOAA AFSC is exploring new ways to assess rockfish in untrawlable habitats in the Gulf of Alaska. These efforts are based in part on past studies for which the Center has played a role (Jones et al., 2012;

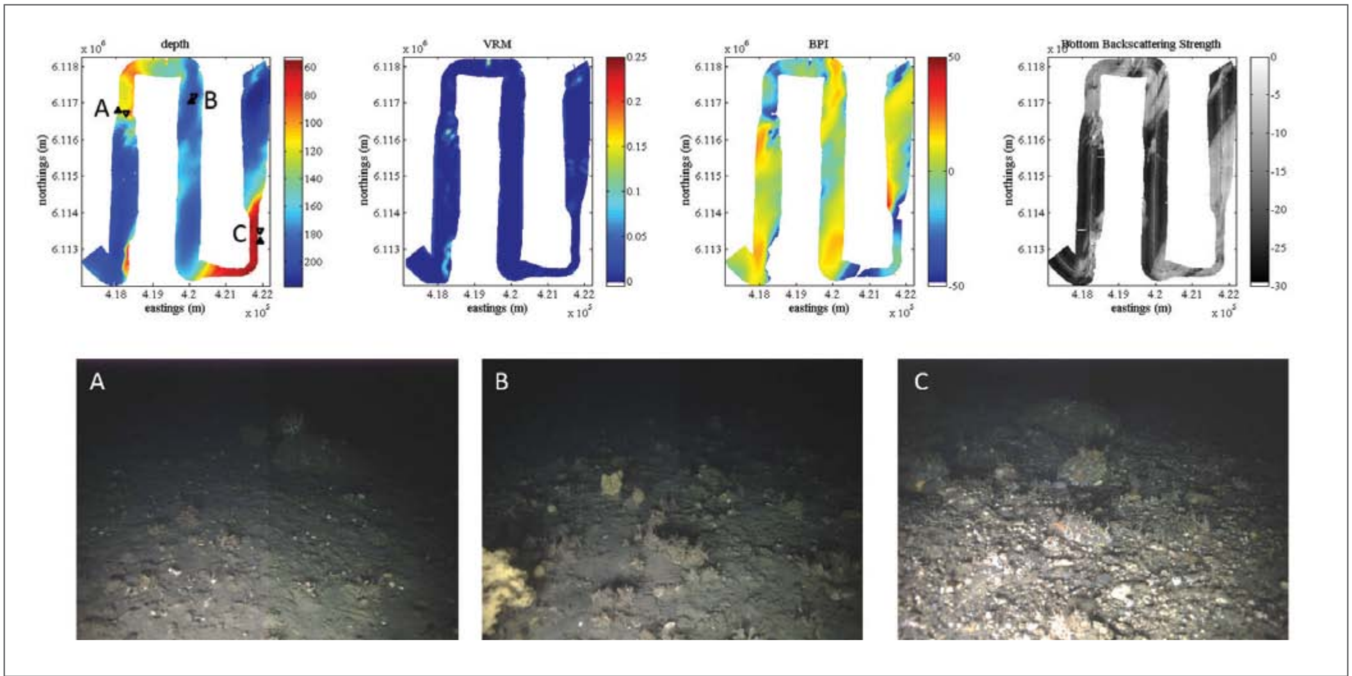


Figure 5-11. Seafloor backscattering metrics from Pirtle et al [2015] extracted from a survey grid during cruise DY1506 on the Oscar Dyson in June 2015. The metrics are derived from Simrad ME70 data and include bathymetry, a vector ruggedness measurement (VRM), bathymetric position index (BPI), and bottom backscattering strength. Camera drops (bottom) are conducted in 2-3 locations in each grid.

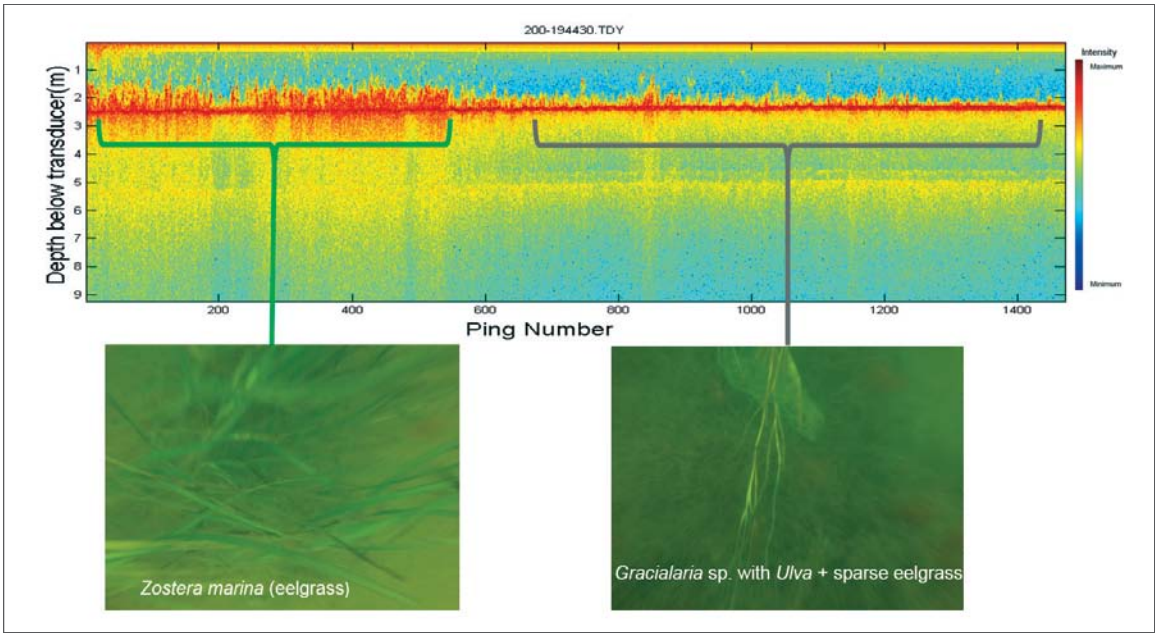


Figure 5-12. Along-track plot of water column backscatter amplitude at nadir from a survey line over a boundary between an eelgrass-dominated area and a nuisance macroalgae dominated area.

Weber et al. 2013; Pirtle et al. 2015). During a summer of 2015 acoustic/trawl survey for walleye pollock in the Gulf of Alaska (nine total weeks of survey), 5 km^2 regions that have been historically classified as either trawlable or untrawlable were randomly revisited. In each 5 km^2 region, an ME70 survey (not full coverage) was run followed by 15-minute drop camera transects in two-three surveyed parts of the grid. The Center is playing a supporting role for the analysis of the ME70 data, using algorithms previously written for generating bathymetry and seafloor backscatter and two new metrics selected by Pirtle et al. [2015] in her general linear model (GLM) that was used to classify the seabed as trawlable or untrawlable based on ME70 data alone. Pirtle et al. [2015] used two topographic metrics: bathymetric position index (BPI) which essentially classifies a location as a bathymetric high or low, and a vector ruggedness measure (VRM) that looks at how the orientations of the cells in gridded bathymetry are distributed. The Center provided MATLAB code and help with interpretation to AFSC who are leading the ME70 data analysis. Examples of the seafloor characterization metrics from a 5 km^2 grid are shown in Figure 5-11. AFSC will also be analyzing the camera drop data to help identify the substrate, enumerate species present, etc. This collaboration is therefore a prime example of Research to Operations (R2O).

Jones, D., C. Wilson, A. De Robertis, C. Rooper, T. Weber, and J. Butler, "Evaluation of Rockfish Abundance in Untrawlable Habitat: Combining Acoustic and Complementary Sampling Tools," *Fish. Bull.,* 110: 332-343. 2012.

Weber, T., C. Rooper, J. Butler, D. Jones, C. Wilson, "Seabed Classification for Trawlability Determined with a Multibeam Echosounder on Snakehead Bank in the Gulf of Alaska," *Fish. Bull.*, 111: 68-77. 2013.

Pirtle, J., T. Weber, C. Wilson, and C. Rooper, "Assessment and Untrawlable Seafloor Using Multibeam-Derived Metrics," *Methods in Oceanography*, May 2015.

Mapping and Characterizing the Eelgrass Canopy

Ashley Norton continues her dissertation research aimed at mapping and characterizing eelgrass canopy through the automated processing of water column data from multibeam echosounders under the supervision of Semme Dijkstra. In July 2015, Teledyne Odom MB1 water column data was collected from the *Galen J* at sites in the Great Bay Estuary in New Hampshire, including sites visited in 2014 and some new sites in the Great Bay that contained a mixture of nuisance macroalgae as well as eelgrass. Drop camera data were also obtained at these sites. Significant differences were seen in the acoustic signatures of areas dominated by nuisance macroalgae (primarily *Gracilaria* and *Ulva* sp.) and areas dominated by eelgrass (Figure 5-12). The Piscataqua Regional Estuaries Partnership, in cooperation

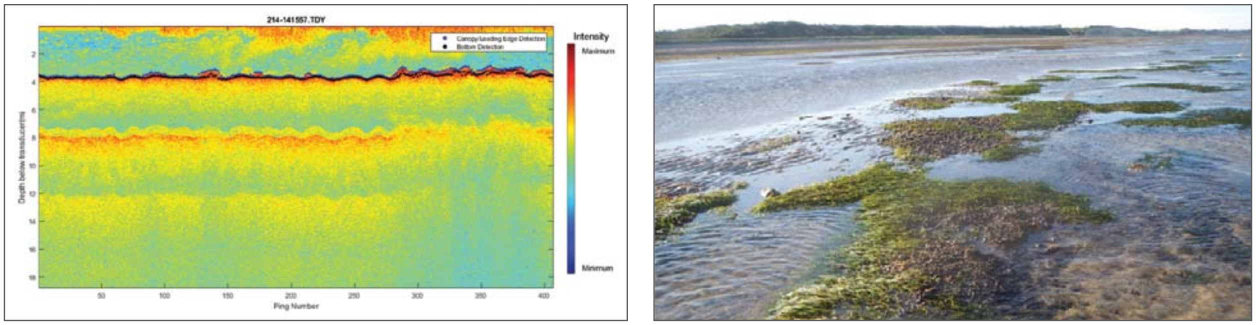


Figure 5-13. Along-track plot of water column backscatter amplitude at nadir from a survey line at Duck Harbor in the vicinity of the photograph (taken at low tide).

with Fred Short from UNH, also obtained aerial imagery and ground-truth (drop camera, diver) data in these areas in August 2015 that can be used to compare with our data.

In August 2015, in cooperation with Mark Borrelli at the Provincetown Center for Coastal Studies (PCCS), Teledyne Odom MB1 water column data was collected at high tide over intertidal eelgrass beds at Duck Harbor, Wellfleet, Massachusetts. This site is the location of an annually-visited Cape Cod National Seashore eelgrass monitoring site where measurements such as canopy height and density are collected, along with photographs, along permanent transects. The eelgrass habitat at this site is also significantly different from that in the Great Bay Estuary; the blades here are shorter, and the environment is more exposed and dynamic (i.e., more wave action, erosion, migrating bedforms). The short blade lengths (10-30 cm) of the eelgrass at this location are probably near the canopy detection limit of the MB1 and the processing methodology (Figure 5-13). Additionally, PCCS later mapped the same site using their phase-measuring bathymetric sidescan system (Edgetech 6205), offering an opportunity to compare the two systems for eelgrass habitat mapping at this location.

The Center was fortunate to have been loaned a Teledyne Oceanscience Z-boat with an integrated MB1 system in October 2015 (Figure 5-14, left). Ashley worked with the Autonomous Vehicle Group. (Val Schmidt, Andy McLeod and others) to collect MB1 water column data over eelgrass beds in Portsmouth Harbor and the Great Bay. These data will be analyzed using the same methods as the water column data collected from the survey boats. Small, remotely-controlled or autonomous survey platforms have great potential for mapping habitats that occur in very shallow water, such as eelgrass, because they can access shallower areas than manned survey boats.

Processing of data from all of the aforementioned field work has been in Hypack (bathymetry) and Matlab. Norton is building on the single-beam work of Semme Dijkstra and Tami Beduhn to extrapolate canopy and bottom detection across the entire multibeam swath. A degree of across-track percent coverage of eelgrass has been obtained with some success by extending the

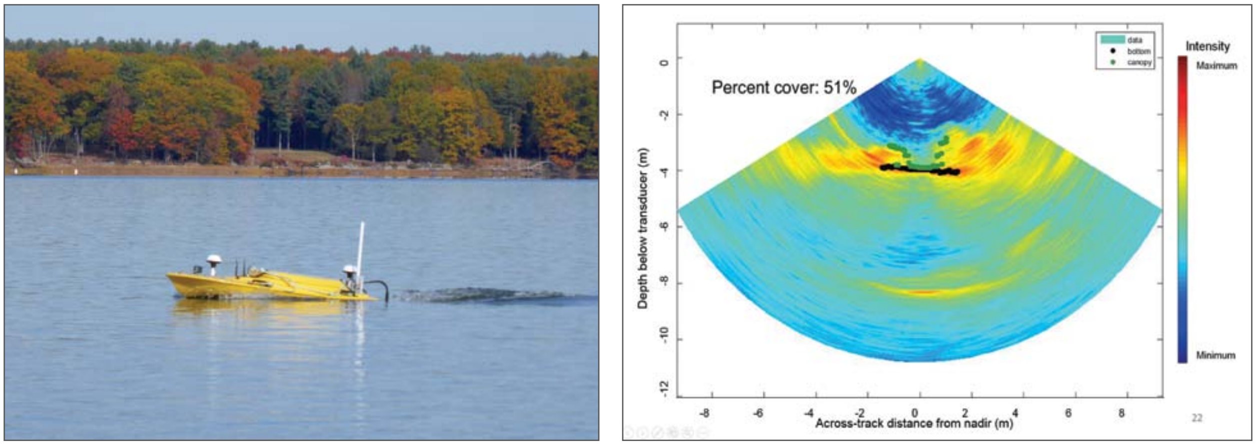


Figure 5-14. Teledyne Oceanscience Z-boat underway in the Great Bay (left) and an across track plot of water column data (5 ping-average), showing bottom and canopy detection in beams +/-20 degrees of nadir (right).

canopy detection methods applied at nadir to beams 20 degrees out on either side of nadir and determining the percentage of those beams that contain a canopy detection a certain height above the bottom detection (Figure 5-14, right).

Norton will perform a second eelgrass backscatter experiment in early summer of 2016 to elucidate the angular dependence of backscatter from an eelgrass canopy and to field test the Luhar and Nepf (2011) model for canopy height deflection under currents. Other next steps in Norton's research include: pushing canopy detection out across the entire swath by removing side-lobe return artifacts, automating the delineation of eelgrass from macroalgae using image processing techniques, and collecting multi-beam water column data with a concurrently running vessel-mounted ADCP to validate hydrodynamic models of canopy height deflection under currents.

Synoptic Optical and Acoustic Imaging Systems for Seafoor Habitat Characterization

Massimo DiStefano's Ph.D. project aims to develop a data-fusion model to integrate various remotely-sensed datasets acquired simultaneously in order to produce a synoptic characterization of the seafloor, using the data described below as a case study.

The complete dataset comprises:

- Six pairs of stereo photos per second collected with the HabCam vehicle,
- A continuous near-bottom CTD record, including conductivity, temperature, depth, dissolved oxygen, chlorophyll fluorescence, and colored dissolved organic matter (CDOM), with periodic vertical excursions through the water column,
- A continuous record of HabCam altitude above the bottom,
- A continuous near-bottom video plankton recorder (VPR) record with periodic vertical excursions through the water column,
- A continuous sidescan sonar record of bottom backscatter (signal strength) along the ship's track,
- A continuous GPS record of ships position,
- A continuous record of the relative positioning between the towed vehicle (HabCam) and the vessel through the adoption of USBL navigation system,
- A continuous record of multibeam sonar bottom topography and backscatter along the ship's track.

Mapping Habitat Preference and Utilization by Crab Species Using a High-Frequency Acoustic Sonar

We are exploring the applicability of very high frequency imaging sonars to map the use of Essential Fish Habitats (EFH; e.g., eelgrasses, oyster reefs) by crustaceans such as lobster and non-native crab species in the Great Bay Estuary. Currently, there is concern that the introduction of non-native crabs to these habitats may be detrimental to these economically important EFHs.

Jenn Dijkstra was loaned a DIDSON 300M (Dual-Frequency Identification Sonar, SoundMetrics Corp.) in May 2015 by NOAA's Chris Taylor. The DIDSON 300M is a high-resolution sonar system that operates at a frequency of 1.1 or 1.8 MHz and produces video-like images. It ensonifies an area ranging from 1 to 30 m from the transducer. The sonar system is particularly useful in turbid environments where traditional video and dive surveys can be problematic. It has been used successfully to examine the behavior, sizes and abundance of various fish species. The novelty in this study is its use to discern hard-shelled crustaceans. If we are successful in developing and demonstrating this approach to survey crustaceans in turbid environments such as the Great Bay Estuary, this approach will likely be a widely useful technology.

A make-shift cage was built to house the sonar system and the sonar was deployed at the Coastal Marine Laboratory (the system was tested at 1.8 MHz with a 15° incline to the seafloor). Sonar files were viewed using the DIDSON Control and Display software (Figure 5-15).

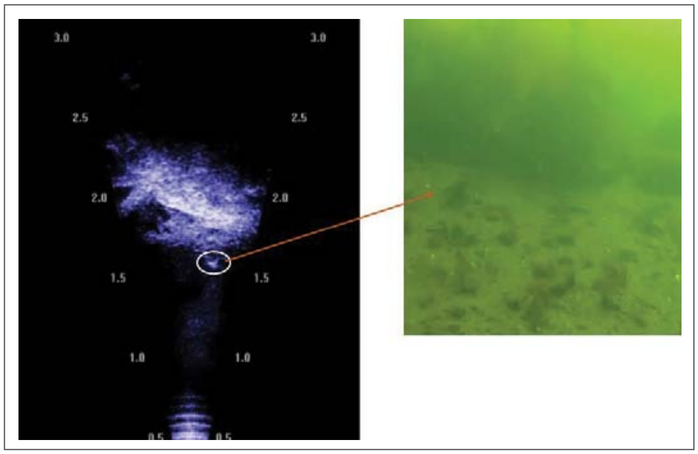


Figure 5-15. DIDSON (left) and GoPro Hero3+ (right) images of a green crab. Interestingly the green crab is difficult to discern in the GoPro video while clearly visible in the DIDSON image.

Preliminary findings suggest that crabs can be observed using this sonar system. Dijkstra also measured the carapace width of the crabs in the image using the measuring tool in the software program. Carapace widths were found to be ~4-5 cm in width.

Lidar, Hyperspectral and Optical Approaches to Habitat and Seafloor Characterization

In addition to using sonar backscatter for the characterization of the seafloor, we are also looking at the potential of using lidar, hyperspectral and optical imagery to derive critical seafloor and habitat information.

Benthic Habitat Mapping from Lidar

Seafloor Characterization Using ALB Waveforms (Bottom Returns)

As part of their efforts to better understand the interaction of lidar waveforms with the water column and the seafloor (see discussion of lidar Simulator under SENSORS Theme). Pe'eri and Post-Doc Firat Eren are also looking at ways of interpreting the returned lidar waveform for seafloor characterization. The hypothesis is that different bottom types manifest themselves as different signatures on the ALB bottom return waveforms. In order to test this hypothesis, ALB data (SHOALS-1000 system) collected in collaboration with USACE over the Merrimack River Embayment, Gulf of Maine in 2007 was compared with ground-truth data collected at over 250 locations in the same area. The study site is characterized with different bottom features: sand, rocky outcrops, and vegetation. The sandy sediment offshore from the Merrimack River Delta consists of two main different grain-size sand types that also differ in mineral characteristics. The waveform features were used to discriminate between the seafloor types based on their apparent signature on the waveform.

The ALB bottom return was found to be dependent on both hardware and environmental factors. Assuming all hardware conditions are kept the same during the survey, then changes in the bottom return are dependent on slope, roughness and composition of the seafloor. In this work, the bottom return characteristics of each individual laser measurement can be used for classification. The current steps in the classification procedure are as follows:

- Identification of the bottom return—The location of the bottom return area in the waveform is identified.
- Extraction—The bottom return area is extracted from the full waveform and a radiometric correction is applied to the bottom return.
- Generating a bottom return signature—Two tangent trends generate a confining triangle based on the slopes of the bottom return. The residual area between the bottom return and the top of the triangle generate a bottom-return signature. In an ideal strong return from a sandy bottom, an asymmetric triangular signal should appear (Figure 5-16).
- Classification—Either a supervised or an unsupervised classification can be used to classify the ALB survey areas into bottom types.

Current work is focused on algorithm development to discriminate between large-scale bottom features (sand and rock). Later work will focus on grain-size. Different classifiers are now being evaluated and the results are planned to be compared against the bottom sample and available backscatter collected by the USGS.

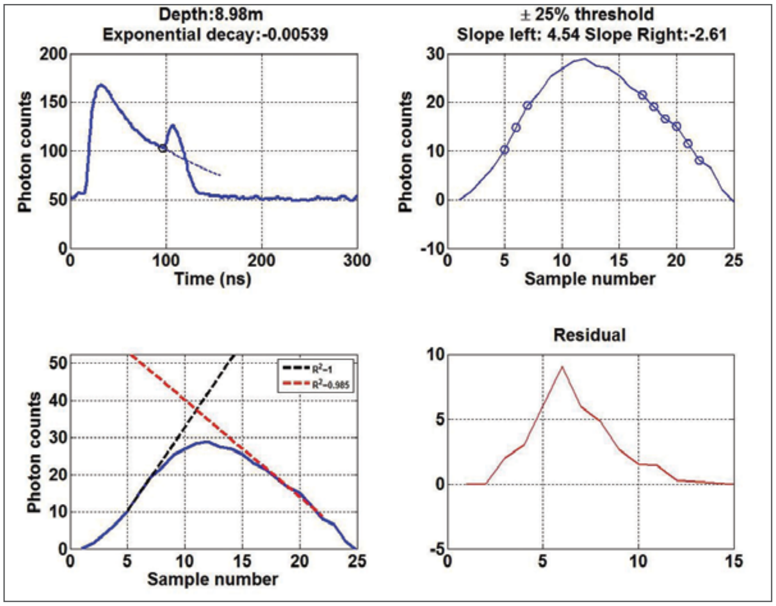


Figure 5-16. (top left) identification of the bottom return, (top right) extracted bottom, (bottom left) tangent trends of the slopes of the bottom return generating a confining triangle based, and (bottom right) residual bottom return Assymetric triangular signature.

Habitat Mapping and Change Analysis in Sandy-Impacted Areas

For information – funding through another NOAA grant

Ongoing research at the Center has enabled imagery and topo-bathy lidar data collected by NOAA and partner agencies in the region impacted by Super Storm Sandy to serve the needs of many users, including coastal zone managers (an IOCM objective). A Center research team that includes Chris Parrish, Jenn Dijkstra, Victoria Price, Erin Nagel and Shachak Pe'eri is investigating the use of imagery and NOAA topo-bathy lidar data to document morphological and submerged aquatic vegetation (SAV) habitat changes that resulted from Super Storm Sandy. In the initial phase of this work, the team is investigating the ability to map benthic habitats in Barnegat Bay, a shallow estuary located along the New Jersey coast that was heavily impacted by the storm where two meters of storm surge occurred, as well as barrier island breach and overwash. For each case (SAV and morphological change) several approaches have been taken. This work, completed at the end of 2015, has demonstrated the applicability of our work to national disasters and will set the stage for future habitat-oriented research at the Center.

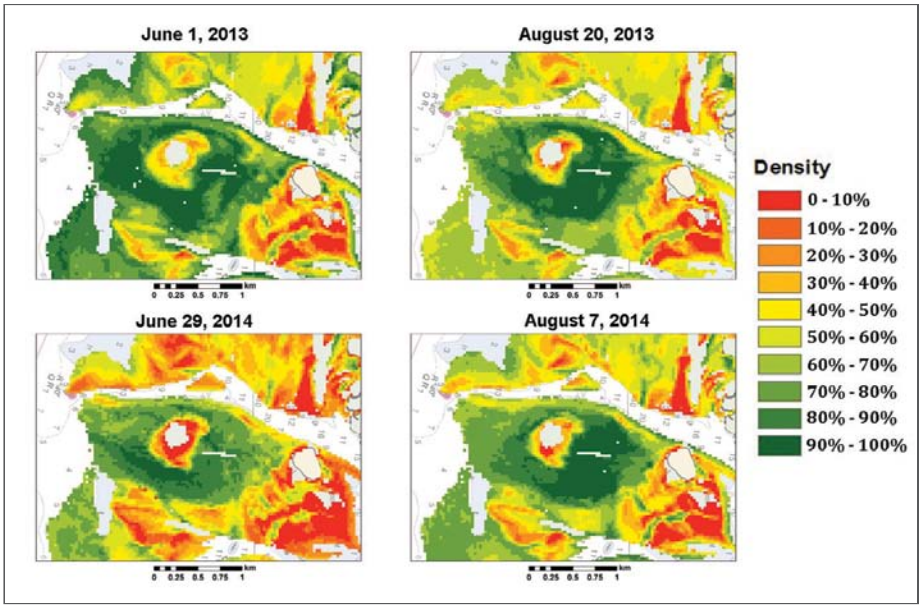


Figure 5-17. SAV density using Landsat 8 imagery from four different time periods. Barnegat Bay Inlet, NJ.

Mapping Submerged Aquatic Vegetation from Multispectral Imagery (MSI) – Pixel-based Approach

The goal of this effort was to establish procedures to map the distribution of Submerged Aquatic Vegetation (seagrass and macroalgae) from multispectral imagery (MSI) with the overall objective of quantifying the impact of Super Storm Sandy on SAV coverage. Using satellite imagery from Landsat 8 and WV-2, preliminary SAV maps were created over the Barnegat Bay region. The layers were created using the following steps:

- A Band-ratio index algorithm was applied to the imagery: blue/green for satellite derived bathymetry (SDB) and a green/red band ratio to determine the location of optically deep waters, including deep channels of the inlet.
- Dry land and optically-deep waters were removed from the imagery.
- The green band in the satellite imagery was used as a condition to separate areas of vegetation from those of sandy/non-vegetated regions depending on the return strength of the green band.
- The resulting vegetated areas were classified based on vegetation density.

Wide availability of imagery means that the procedure provides good temporal resolution for monitoring overall changes in the area.

To further classify SAV and provide a habitat monitoring tool, a procedure was created to distinguish the vegetation density (Figure 5-17). Changes in the SAV patterns were observed from September 2010 to September 2014. Coverage and density of the SAV mapping results from satellite imagery were compared to Rutgers University 2009 survey result. The overall accuracy of the classification was conducted using a confusion matrix approach. It is important to note that the resolution of the satellite imagery (spatially and spectrally) makes it difficult to determine the type and properties of the SAV using only the green band.

Figure 5-18. The initial data layers input into eCognition—the aerial imagery collected simultaneously with the lidar data (left), the lidarreflectance (center), and the elevation (right).

Submerged Aquatic Vegetation from Lidar and Imagery – Object-based Approach

While the approach to identifying SAV described above is "pixel-based" (i.e., the analyses tools were applied to each pixel of the image), we have also taken an "object-based" approach to identifying SAV. Traditional methods of mapping submerged aquatic vegetation (SAV) habitats involve manual classification of habitat from imagery, a process that is extremely time consuming and subjective. Object-based image analysis (OBIA) is being explored as an efficient alternative to this methodology that allows for multiple users to apply a single rule set across multiple data sets in an effort to semi-autonomously classify SAV habitats.

Seagrass beds were mapped using aerial imagery, lidar bathymetry, and lidar waveform features (specifically from the NOAA Riegl VQ-820-G system and the AHAB Chiroptera system) using the eCognition software package (Trimble, Sunnyvale, CA) in collaboration with Jarlath O'Neil-Dunne at the University of Vermont. eCognition uses a method of image classification that segments data layers at an object level rather than a pixel level, and can include holistic information from the analyst in the classification process. The ability to integrate multiple data types, such as imagery and lidar point clouds, and to input user knowledge on an algorithmic level are extremely useful for defining objects that may otherwise have similar properties on a pixel level. For this project, imagery, lidar bathymetry, and reflectance were used as data layers and a map for the Barnegat Bay Inlet was created delineating areas of dense eelgrass, sparse eelgrass, mixed SAV and sand (Figures 5-18 and 5-19).

Habitat maps generated using lidar and eCognition were compared against those created using traditional manual classification methods (Figure 5-20), with no statistically significant differences being found between the methods for the metrics assessed. This illustrates that semi-automated classification can produce similar results to the current methodology of manually classifying SAV habitat from imagery, but in a fraction of the time. SAV maps of overlapping coverage areas collected by the Riegl and Chiroptera systems were also compared (Figure 5-21), with the only significant difference between the systems being patch perimeter to area ratio. These results indicate that one rule set can be used with minimal modifications to compare lidar data collected by multiple agencies in the same geographic areas. Wave form features from the pre- and post-Sandy EAARL-B lidar collection efforts are currently being extracted so

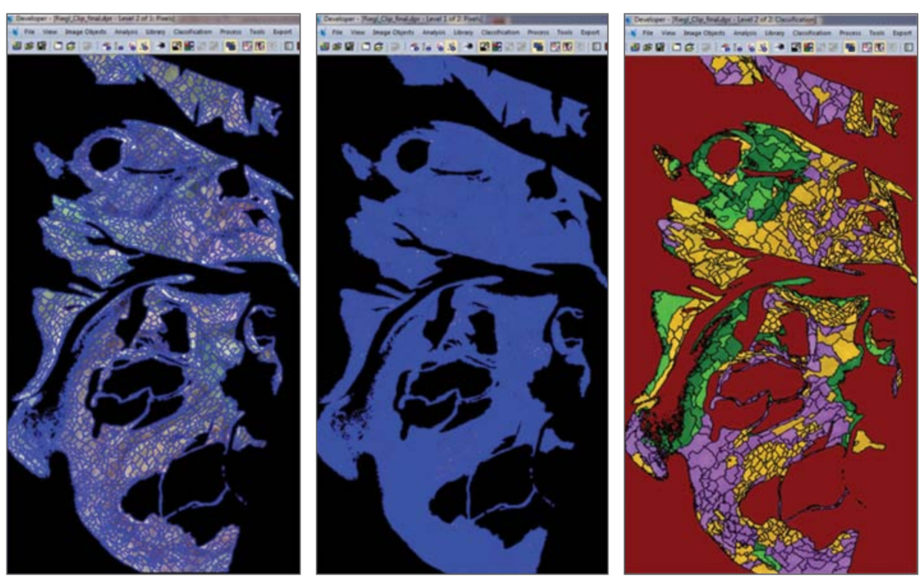


Figure 5-19. Multilevel segmentation (left and center) and segment classification (right) in eCognition.

Figure 5-20. Habitat map from Barnegat Inlet generated using manual classification using imagery alone (left) and eCognition classification using lidar and imagery (right).

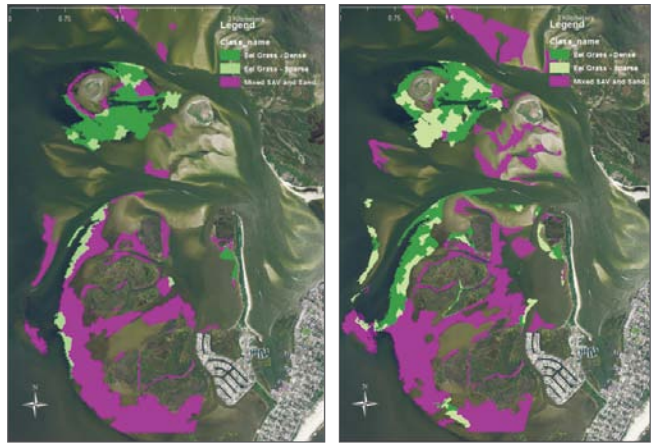


Figure 5-21. Habitat map from Barnegat Inlet generated using eCognition from Chiroptera data (left) and Riegl data (right).

that the effects of Hurricane Sandy on SAV habitat in Barnegat Bay can be assessed using the current eCognition rule set.

Aerial imagery from 2002, 2006, 2007, 2010, 2012-2014 are currently being manually analyzed for seagrass, mixed SAV, and sand-only habitats so that pre- and post-storm habitat maps can be compared to historical data and seagrass habitat coverage across the entire Barnegat Bay region may be compared over time (Figure 5-22).

Long-term Effects of Storm on Submerged Aquatic Vegetation from Imagery

Super Storm Sandy unquestionably caused substantial damage to the Northeastern U.S. New Jersey and New York coast lines. Immediate impacts of the storm included extensive coastal erosion in New Jersey, New York, and other mid-Atlantic states. As discussed above, the effects of the storm on Submerged Aquatic Vegetation (SAV) such as seagrass are still being assessed, but are expected to be severe. In order to understand the magnitude of this impact within the context of long-term variability, we have also looked at long-term time series of seagrass coverage in the Barnegat Bay area. Manual classification of dense and sparse seagrass as well as mixed SAV and sand were classified between 2006 and 2013 using orthophotos collected by the state of New Jersey and the National Agricultural Imagery Program (NAIP; Figure 5-23). The remotely-sensed and manually classified 2006-2013 trend map suggests a decline in seagrass cover, particularly at the southern portions of Barnegat Bay. Our June 2012 and 2013 field campaigns corroborated our remotely-sensed

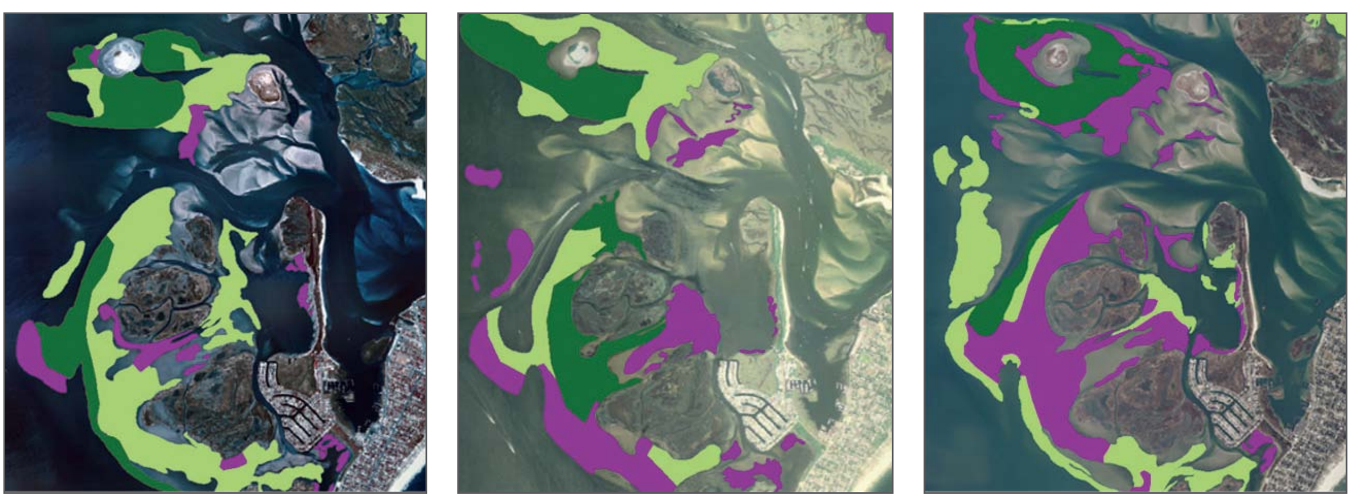


Figure 5-22. A sample of manually generated habitat maps from 2002 (left), 2006 (center), and 2012 (right). The variation in imagery quality across years makes consistent classification difficult.

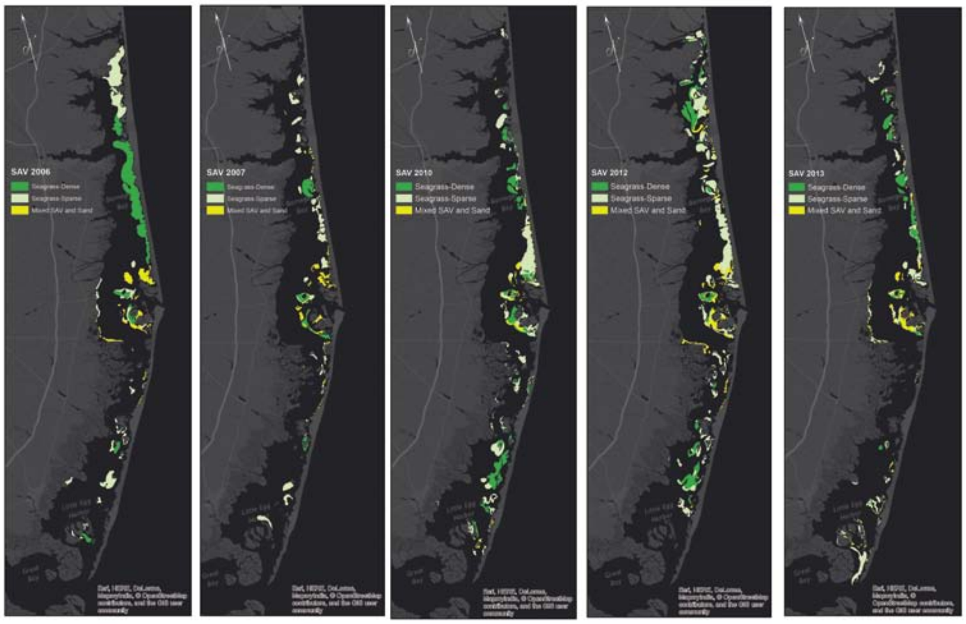


Figure 5-23. Time-series of manual classification of seagrass and mixed SAV and sand cover between 2006 and 2013.

results of the presence of seagrass along the northern portion of Barnegat Bay and Barnegat Inlet. Further, the remotely-sensed monitoring trend indicates a decline in the area of dense seagrass in 2013 vs. 2006. Differences in image quality and the seasonal period of image acquisition may account for some differences in the mapped area and in the apparent thinning of seagrass density as imagery for the 2006, 2010, and 2013 were acquired in the growing season (July and August), while the 2007 and 2012 surveys were acquired early in the growing season (March and April).

These maps were then compared to earlier dataset of GIS layers of SAV that were identified by the Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University. Preliminary results indicate that SAV cover is temporally variable with a noticeable decadal decline in SAV from 1968 to 2013, specifically with seagrass (Figure 5-24). It appears that the decline in seagrass is not confined to one particular region, but has occurred throughout the entire bay. These results are consistent with previous studies demonstrating decadal loss of seagrass habitat and will help set the context for the Super Storm Sandy studies.

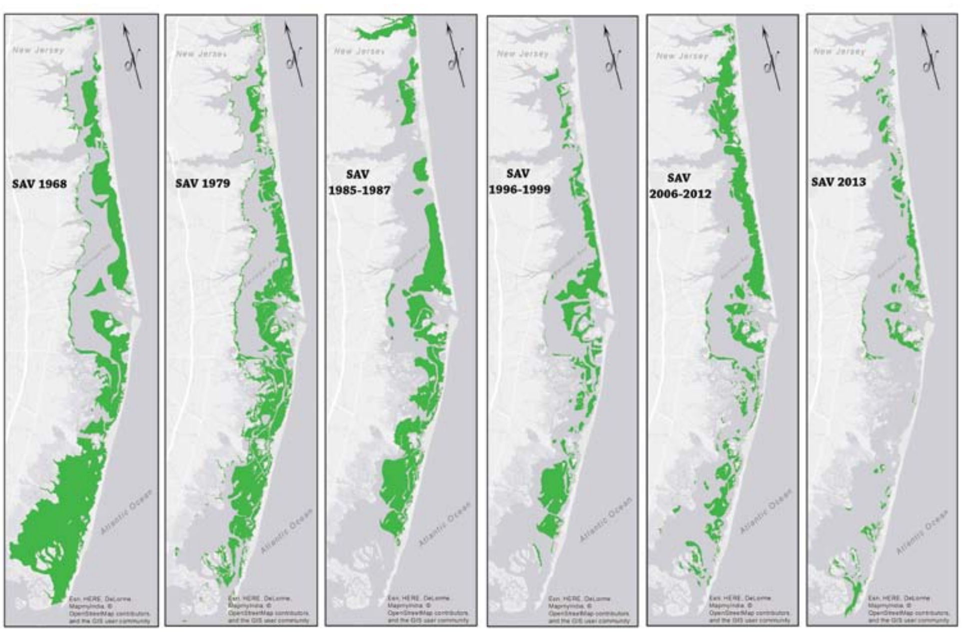


Figure 5-24. Remotely-sensed maps showing SAV coverage from 1968 to 2013. Orthophotos were collected by the state of New Jersey and SAV from 1968 to 1999 were identified and analyzed by the Center for Remote Sensing and Spatial Analysis.

Morphological Change After Super Storm Sandy from Imagery

Bathymetric variations due to a storm can be determined by a number of methods, but the use of satellite imagery has the potential advantage that it is easier to collect after the storm than more local remote-sensing methods, and that is has a significantly greater potential to have a data record immediately prior to the storm event. We have therefore been examining the potential for bathymetric variation analysis based only on imagery products.

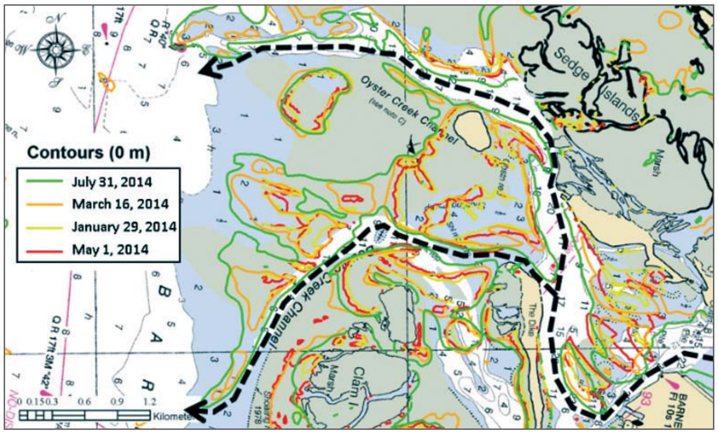


Figure 5-25. Seasonal changes in bottom morphology of Barnegat Bay during 2014.

One potential approach is to use satellite-derived bathymetry (SDB) methods for the analysis. However, unsupported SDB methods can have difficulties in establishing absolute depths. Relative maps, for example, for slopes, do not suffer from the same problem. To examine this possibility, once approaches for identifying SAV were established, all vegetated areas, dry land, and optically-deep areas were removed from the imagery. Bathymetry for the remaining sandy/muddy areas was then calculated using satellite-derived bathymetry (SDB) at 30-m resolution. A slope map was derived from the bathymetry and spatial differences between the slopes were used to identify the dynamic and stable areas in the inlet. From the analysis, seasonal and annual morphological changes (dynamic shoals) were identified within the Bay. The eastern side of these shoals (exposed to current) changed with season. The channels within the bay were stable, but their location was different from where they were charted.

In addition to the slope maps that were produced in 2014, direct stacking of the images was used to define stable channels that can be used for navigation (Figure 5-25). Turbidity maps utilizing the green/red channels were also used to monitor changes of shoals along the channel path. This work is now being expanded as part of Ricardo Freire's work over the Yukon River, Alaska and the Amazonas, Brazil.

Instruments and Approaches to Ground Truth Sonar, ALB, Hyper-spectral and Other Remotely Sensed Data

As we strive to better understand the ability of our sonar or lidar systems to provide quantitative information about the seafloor and water column, we inevitably must "ground-truth" the remote measurements we make. To ensure that we can accurately determine the properties of the seafloor and water column within which we are making our measurements, we have developed a suite of tools and approaches.

Underwater Spectrometer

An underwater spectrometer system was designed and built by Lanzoni under the direction of Rzhanov to calibrate underwater imagery for use in applications like seafloor characterization. The purpose of the device is twofold. First, it can be used for easy collection of spectral signatures (profiles) of various species and substrates underwater for addition to, and enrichment of, existing spectral libraries, such as the one maintained

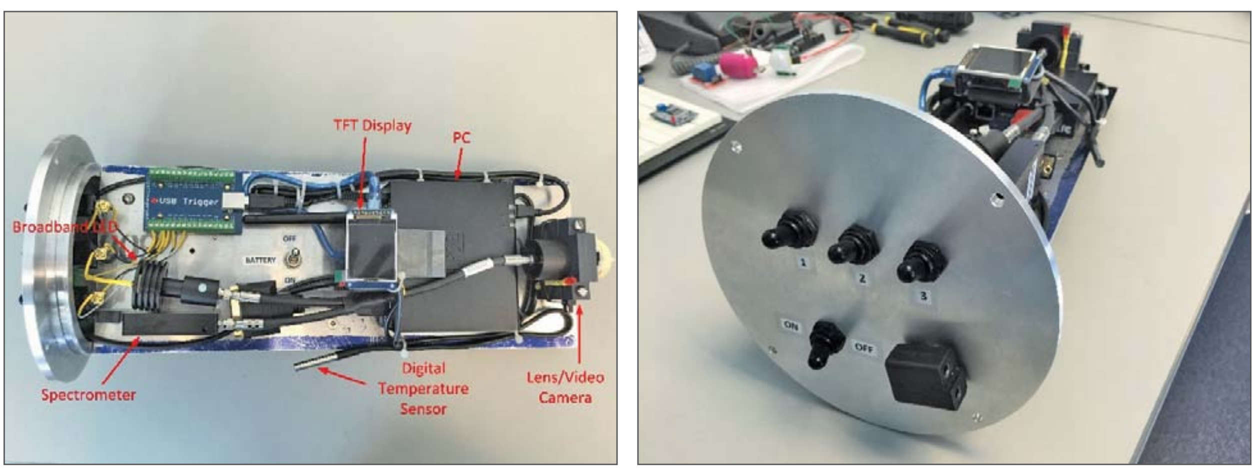


Figure 5-26. Underwater Spectrometer System.

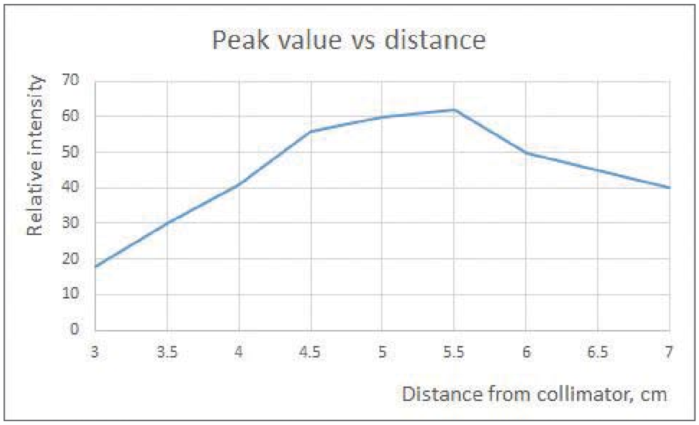


Figure 5-27. Intensity of illumination vs distance from the collimator carrying light from LED.

by USGS. Second, and most importantly, the collected signatures can be used for classification of underwater scenes using routinely collected RGB imagery. A trichromatic response recorded by a conventional camera is usually insufficient for reliable classification due to wavelength-dependent absorption of light by water. However, knowledge of water properties, camera sensor sensitivity functions, and range allows for estimation of the probability that a pixel of certain color, images a flora species with known spectral signature.

The device was designed to be operated underwater by a diver, providing a minimum of two hours of operation time. It incorporates a personal computer (PC), a broadband LED light source, a temperature sensor, a video camera, and a TFT screen for monitoring the system operation. The device is under final test. Figure 5-26 shows the underwater spectrometer system.

Initial field trials of the system have shown that the recorded spectral intensities are much lower than expected and are sometimes at the noise level. Laboratory measurements showed that the volume where the light cone from the LED intersects with the cone that is being registered by the spectrometer is almost entirely outside the expected range. The optimal distance from the collimators' edge was measured to be 5.5 cm (Figure 5-27).

Discussion of application of the spectrometer can be found in the HABITAT theme.

Grab Camera

During conventional hydrographic operations, survey units are required to take sediment samples in order to determine, among other things, suitability of an area for anchoring. Most commonly in current practice this is done with a small grab sampler of some kind, often a Petit PONAR system. One common problem with this, however, is that if the grab sampler does not return any sediment, it is unclear to the operators whether this is because the sediment is sufficiently hard to preclude sampling, or if the sampler simply did not correctly trigger on contact with the sea floor. After some experimentation with a simple GoPro camera attached to their grab sampler, personnel from the NOAA Ship *Hassler* approached the Center to see whether we might use some of the expertise gained through other camera systems developed previously in order to improve on the system. Consequently, Calder, McLeod, Pe'eri, Rzhanov, and Lavoie have been working on a project to engineer a reliable and robust camera system that can be deployed readily by field personnel, and which matches the operational tempo of NOAA field units.

After discussion with NOAA personnel on the requirements for the camera, and operational constraints, the project team developed a set of core requirements, and then designed and fabricated an experimental camera system to meet those constraints. The camera system, Figure 5-28, is compact and relatively light, is powered by standard Lithium rechargeable batteries, and can be controlled from the outside of the pressure casings via

Figure 5-28. The Grab Camera system being tested from the *Galen J* on 2015-06-19 in Portsmouth Harbor, NH.

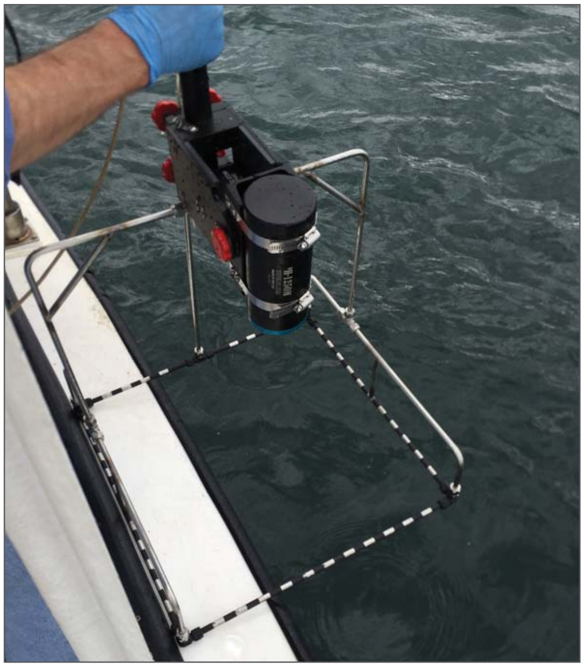


Figure 5-29. Deployment of the Grab Camera system with lightweight imaging frame. The lightweight frame is used for purely optical sampling. Portsmouth Harbor, NH, 2015-10-14.

WiFi (camera) and a modified reed-switch mechanism (lights) to allow them to be manipulated on deck without having to open or otherwise adjust the water-tight seals. The camera and light are designed to be field positionable with respect to the grab sampler through a specially machined clamp that rides on the support pole, and to operate for a full survey day without having to either recharge batteries, or off-load data.

Capturing still image data at 2Hz limits the amount of data required to be reviewed by the operator, while WiFi playback when on deck allows for rapid review of imagery after deployment to determine the cause for any difficulty with the grab sample. In addition, imagery from the camera can be archived with the sample to provide supporting information for the survey report. The primary role of this camera is likely to be for use where real-time feedback from the camera during the deployment is not required, but where rapid assessment of the imagery from the camera on deck is. The camera system can, of course, be used on any other deployable sensor. One example might be to attach the system to the haul of a CTD sensor, allowing for opportunistic optical bottom sampling on each cast. When a separate instrument is not required, the camera can also be deployed with a lightweight frame, Figure 5-29, which maintains the camera a fixed distance off-ground to avoid impact damage.

The initial revision of the camera system has been tested by the project team in Portsmouth Harbor, NH, was further tested by the the Center's Summer Hydrographic Field Course students on 30 June. An upgraded version of the system, which added a floatation device to provide some extra buoyancy and help the sampler "bite" properly, along with the lightweight support frame, was tested on 14 October during which a number of ground-truth and optical-only samples were successfully taken for comparison. Grab samples were passed to Larry Ward for processing and archival.

A slightly refined version of the camera has subsequently been developed, which avoids issues of lens distortion when submerged, and adds extra light to avoid motion blur during image capture; this version is currently being tested. Refinements of the design, for example to include a simple accelerometer that can detect bottom contact (triggering image capture only when required), or to improve recharge/maintenance robustness, may be considered in future reporting periods.

Video Mosaic for the Dual Purpose of Ground-Truthing Sonar Data and Assisting in Habitat Characterization

Yuri Rzhanov has developed a suite of automated mosaicking algorithms and software to generate mosaics of benthic communities dominated by different algal species. These mosaics have been used as ground-truth for acoustic data and to spatially characterize benthic habitats. Videos were collected at nine sites dominated by different algal species using a GoPro Hero 2 and 3+ with video dimensions of 1920x1080 at 30 frames per second. While SCUBA diving, a 100 m2 rope grid was laid out over a seaweed bed with attached parallel ropes every 1.2m (Figure 5-30). The diver remained one to two meters above the algal bed, or as high as

Figure 5-30. 100m^2 rope grid that was placed on the seafloor and used by divers to follow in a lawnmower pattern.

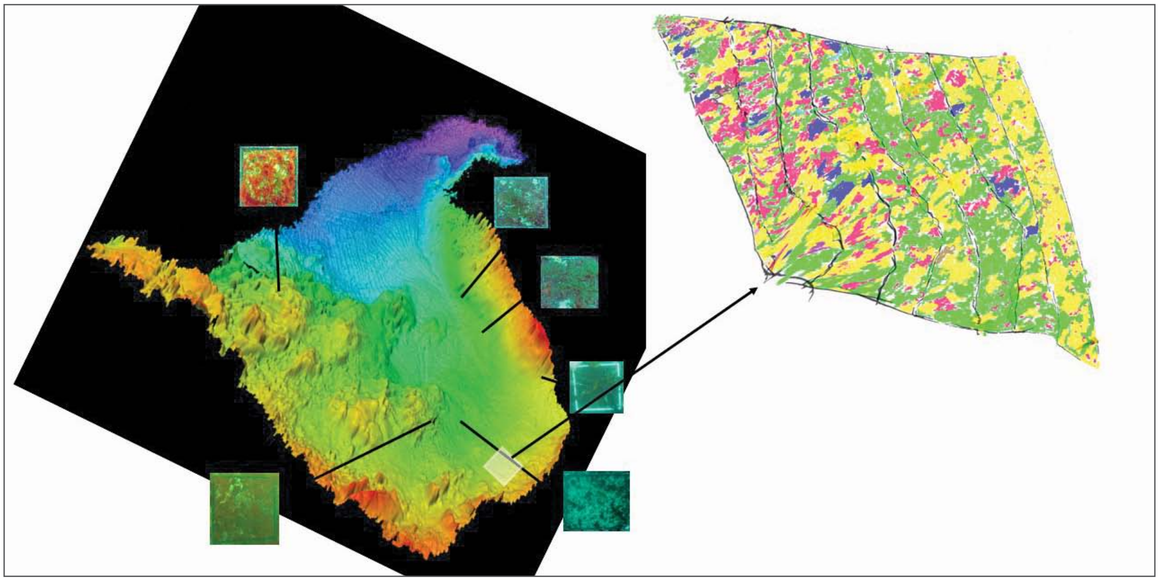


Figure 5-31. Mosaic of a mixed seaweed assemblage at Nubble Light House in York, ME. Each color denotes a different seaweed species or free space.

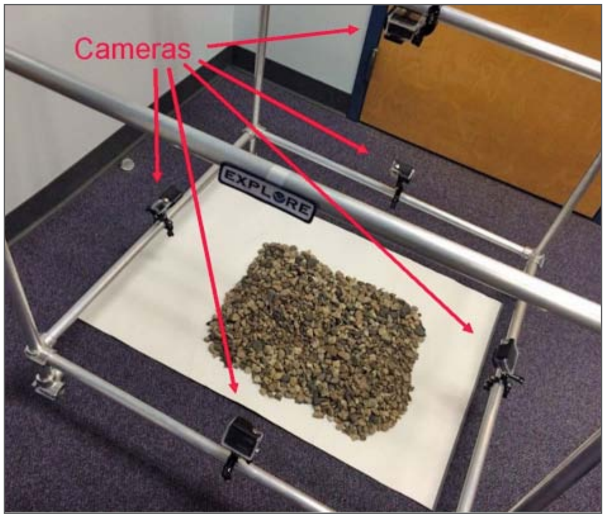
visibility allowed and swam in a lawnmower pattern to record the video. A number of steps were completed to create the mosaic using a combination of COTS software packages and Center-created software and finally pieced together in Adobe Photoshop to recreate the full 100 m2 mosaic.

All nine videos have been mosaicked and manual delineation and identification of flora (seaweeds) to the lowest possible classification is complete on half of the mosaics (Figure 5-31). In connection with this project, Dijkstra, Litterer and Mello collected one hour of fish behavior video at eight of our sites with the goal of connecting fish abundance and behavior patterns with native and non-native algal assemblages (Figure 5-32). The fish videos, in combination with our other data (e.g., video mosaics) will provide the opportunity to determine how non-native species affect ecosystem processes.

Reconstruction of the Fine Bathymetric Structure of the Seafloor—Determination of Spatial Frequencies of the Seafloor from Multi-View Imagery

The purpose of the system is to acquire detailed information from a relatively small (~1 sq.m.) patch of a seafloor and reconstruct its 3D structure with submillimeter accuracy. The system will be used for non-invasive and inexpensive ground-truthing of video and acoustic information about the seafloor. The initial

Figure 5-32. Two fish, juvenile Pollock (lower fish) and Cunner, that utilize seaweed habitats as refuge from predators and to forage for food.



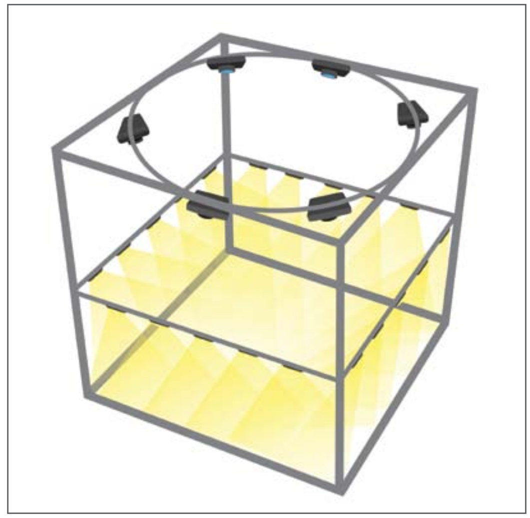


Figure 5-33. The experimental design of the multicamera rig (left). The master camera looks at the scene from above, while the other cameras are observing the same scene from all four sides. Proposed optimal design (right).

stage of research is concentrating on understanding the optimal design of the rig, given the specifications of the cameras and the content of the underwater scene (spatial frequency spectrum, coloring, etc.). The goal of the first stage is to formulate a set of recommendations about acquisition conditions depending on the targeted scenery and available instrumentation. Once these are formulated, the rig will be constructed and field tested. A test device for acquisition of spectral signatures underwater (UROSS—Underwater Recorder of Spectral Signatures) has been completed and tested (Figure 5-33).

Test imaging indicated that modeling and simulation of image acquisition was necessary to develop optimal processing approaches. Rzhanov and graduate student Igor Kozlov have developed a software suite allowing for the specification of the internal and external parameters of several cameras, surfaces with user defined elevation model and texture, and the modeling of the image formation process. A set of images and information about the cameras are used to reconstruct the original surface, which can then be compared with the known ground truth data (Figure 5-34). Errors in reconstruction are due to many factors: contrast of elevation model and texture (variations in depth and color), spatial frequencies of depth and texture (as compared to camera-limited spatial resolution), rig geometry, camera resolution, resolution of voxel array used for reconstruction, errors in camera calibration (intrinsic and extrinsic), etc. The next step is to develop a metric for the reconstruction of errors and determination of the relative importance of each factor by means of numerical modeling. The outcome should be a set of recommendations for optimal data collection strategy for specific objects and conditions.

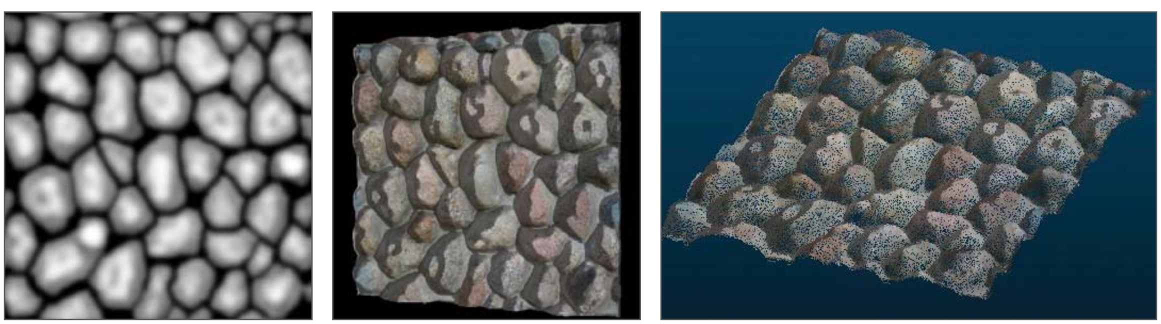


Figure 5-34. (left) The digital elevation map of the structure. Brighter areas denote larger heights; (middle) One of the simulated images acquired by a side camera. (right) Perspective view of the point cloud reconstructed from five images.

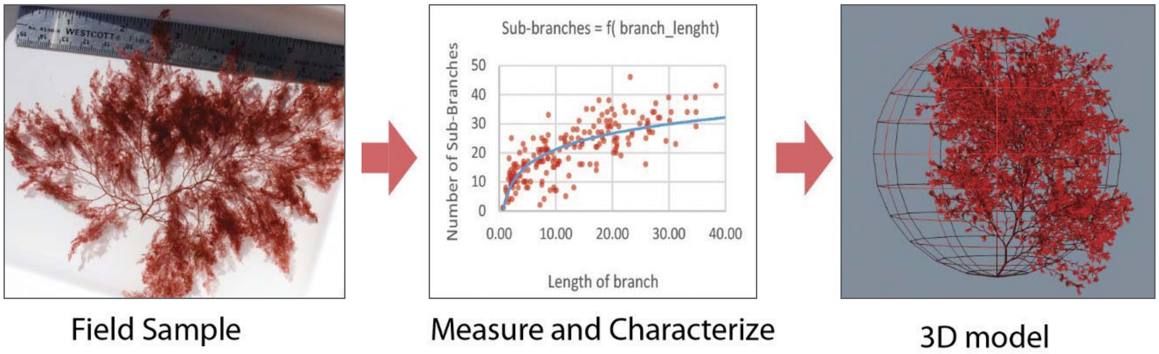


Figure 5-35. To develop 3D models of macroalgae, samples were obtained from the field, these are photographed both in situ and in the laboratory. Sample measurements are made from the images and the results characterized in terms of the limb sizes, limb branching structures, and their variability. 3D generative computer graphics models based on these statistics can be used to generate any number of examples.

Modelling Macroalgae and Habitat Mapping

Marine benthic habitats are made up of species that form complex 3D structures providing habitat and refuge for a wide variety of commercially important invertebrate (e.g., crab) and vertebrate (e.g., fish) species. Along with seafloor mapping technologies such as high frequency sonar, lidar, and photographic methods that are used to characterize and segment benthic habitats into 2D space, Colin Ware and Jenn Dijkstra are developing new techniques for defining the 3D structure of seaweed species. These methods promise to provide a bridge between mapped areas of macroalgae and the habitat they afford for associated species.

Dasysophonia japonica was collected from York, ME and detailed measurements of the structure of this invasive seaweed were made (Figure 5-35). These measurements were used to create a 3D model of the seaweed species. Associated invertebrate species from the algae were removed, measured and identified to the lowest taxonomic denominator. These data will support 3D theoretical models relating total volume of the algae to species richness, numbers of individuals, and volume of interstitial spaces. Since these environments provide incubators for commercially important species such as crustaceans, gastropods and mollusks, our methods will ultimately provide links between habitat and these species.

Associated with this effort, the group is developing a new method called spherical space analysis to estimate the volume of free habitat for organisms of different sizes within the interstitial spaces of difference species of seaweed. Figure 5-36 illustrates the method applied to *Codium fragile* spp. *fragile*, another invasive species that is now common in the Gulf of Maine. The method can be used to estimate the whether or not the seaweed can provide habitat for the invertebrates using computer generated models. A similar metric: inaccessible surface area is calculated in parallel.

Sedimentology Lab

The interaction of both sound and light with the seafloor is often dependent on the nature of the seafloor and, in particular, the distribution of grain size in the sediment. In 2013, the Center contributed to an upgrade of the Sedimentology Lab at the UNH Jackson Lab so that we would have assured access to sediment-analysis facilities. The laboratory utilizes standard sieve and pipette techniques to determine grain size. We also have access, through a collaborative agreement with

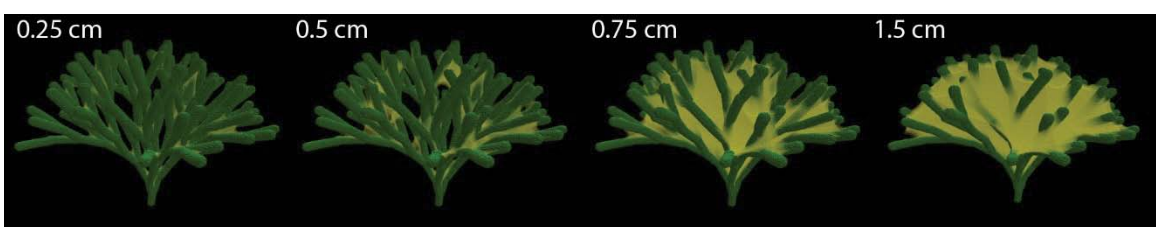


Figure 5-36. A computer generated model of Codium, an invasive species of macroalgae found in the Gulf of Maine. Yellow regions represent the volume that is inaccessible by organisms of different sizes and larger

the Dept. of Earth Sciences, to a Malvern Mastersizer Hydro 2000-G Laser Particle Size Analyzer. Routine sediment analyses for grain size were conducted during the second half of 2013 and the first half of 2014 for the NEWBEX study (~170 samples analyzed). In addition, Dr. Thomas Lippmann utilized the Sedimentology Lab for grain-size analyses. A procedure to determine the $CaCO_3$ content of sediment samples using an HCl digestion and weight-loss technique was developed and tested to add to our capabilities to analyze sediments. This work will continue until the procedure is established and the uncertainty in the analysis assessed. The laboratory is now fully functional and available for use for all Center projects. In 2015, the Sedimentology Lab was heavily used particularly in support of the projects directed at understanding the distribution of sediment offshore New Hampshire.

Water Column Mapping

Although fisheries sonars have imaged the water column for some time, this capability is relatively new to multibeam sonars. The ability to simultaneously image the water column and the seafloor over wide swaths with high-resolutions offers great opportunities for new applications and increased survey efficiencies. The Center has been very active in developing tools to capture, analyze and visualize water-column data and these tools proved extremely valuable in our efforts to map the deep oil plume and monitor the integrity of the Macondo well-head during 2010's Deepwater Horizon crisis (see the 2010 annual report for a full description of our activities related to Deepwater Horizon). Our demonstration of the viability of using sonar systems for mapping natural gas seeps and leaking well-heads in the Gulf of Mexico during the Deepwater Horizon spill have led to several follow-up studies aimed at moving these techniques from qualitative descriptions to quantitative assessments.

Seep Mapping on the *Okeanos Explorer* in the Gulf of Mexico

Immediately following the Deepwater Horizon explosion and leak of the Macondo well head, we proposed the use of a 30-kHz multibeam sonar with water-column mapping capability (Kongsberg Maritime EM302) as a tool for mapping deep oil and gas spills and monitoring the well head for leaks. Such a system was not available at the time of the spill (the *Okeanos Explorer* equipped with an EM302 was deployed in Indonesia) and thus we used 18- and 38-kHz fisheries sonars. These sonars proved very effective for the identification of gas seeps and leaks but have limited areal coverage and limited spatial resolution as compared with the multibeam sonar. We finally had the opportunity in August/September 2011 to bring NOAA Ship *Okeanos Explorer* to the Gulf of Mexico in order to test the EM302 water-column mapping capability to detect and characterize methane gas seeps. We also carried out comparisons with data collected with a Simrad 18-kHz EK60 split-beam echosounder, a system known for finding seeps in the Gulf of Mexico that was purchased and installed on the *Okeanos Explorer*, for this cruise. During this relatively short cruise (less than two weeks of active mapping), a Center team led by Tom Weber and including Jonathan Beaudoin, Glen Rice, Kevin Jerram and Maddie Schroth-Miller, mapped 17,477 km^2 of the northern Gulf of Mexico and made observations of 573 seeps (some of which were repeat observations of the same seep) with an EM302. Weber developed seep-detection algorithms for water depths of 1200 to 2500 m, whereas Beaudoin developed software that allowed the precise geo-location of the targets for presentation in a 3D context. We found that we were able to most reliably detect seeps over a swath that was approximately twice the water depth; farther ranges encountered reverberations from the seafloor that tended to dominate the return from the seep and significantly reduced the likelihood of detection. The results from this cruise demonstrated a new mid-water mapping technology for the *Okeanos Explorer*, and also suggested that wide-scale mapping of seeps in the deep Gulf of Mexico is viable, an objective that is important for both scientific and industry management perspectives.

We followed up these studies in 2012 with another program on the *Okeanos Explorer.* Tom Weber, Larry Mayer and Kevin Jerram, guided (from shore) the science behind ROV dives aboard the *Okeanos Explorer* that were aimed at ground-truthing the mid-water acoustic-mapping efforts. Center involvement led to the development of a direct methane flux-measurement device that was successfully deployed during the cruise from Little Herc (thanks to some outstanding engineering efforts by the NOAA Office of Ocean Exploration ROV team), as well as a calibrated bubble grid for the measurement of bubble sizes and general methane gas-seep exploration from EM302 and EK60 data that were used as acoustic "guides" for the ROV expeditions. Data collected during this cruise greatly increased our ability to properly interpret and analyze acoustic data collected during mid-water mapping expeditions in the same area.

In 2013, we continued to analyze acoustic and ROV data collected with the *Okeanos Explorer* in our attempts to further our capabilities to detect, localize, and quantify gas seeps with both split-beam and multibeam echosounders. These systems provide complementary data: we exploit the multibeam for its wide field of view and accurate positioning capability in order to examine the locations, morphologies and rise heights of the plumes and we exploit the split-beam echosounder to provide calibrated measurements of seep target strength that can be related to gas flux if we know the distribution of bubble sizes. A comparison of estimates of gas fluxes made from acoustic and ROV direct-capture methods has shown a remarkably close agreement (within 20%) from a seep on the Pascagoula Dome in the Gulf of Mexico, which is an encouraging result.

Analyses of acoustic and ROV data collected with the *Okeanos Explorer* aimed at the detection, localization and quantification of gas seeps were completed with the acceptance of a manuscript in G3, and the M.S. defense of Jerram early in the 2014 spring semester. In January 2015, Jerram published a peer-reviewed article with Tom Weber and Jonathan Beaudoin describing methods for detecting, georeferencing, and characterizing plumes of gas bubbles rising from natural methane seeps. This article provides a basis for acoustical comparison of gas plumes observed with different survey configurations, such as EK60 data from other studies and other NOAA vessels.

At present, EK60 echosounders with frequencies of 18-200 kHz are widely installed among NOAA vessels, enabling detection of bubbles in diverse size distributions and water column conditions. Many of the data processing concepts developed for the EK60 are now being applied to the broadband EK80 echosounders; these broadband systems expand the useful frequency bands for existing transducers, improve the range resolution of midwater measurements. Work by graduate student Liz Wiedner, analyzing data from East Siberian Margin has demonstrated that the EK-80 can also provide quantitative estimates of bubble size distribution within a seep, a key component to the eventual estimation of gas flux.

To maximize the utility of EK60 data collected aboard the NOAA Ship *Okeanos Explorer* during the 2015 season, Jerram joined Weber and NOAA personnel in Rhode Island in February to conduct a series of beam pattern measurements with a calibration sphere of a known acoustic target strength. The results of these measurements yielded an in situ calibration to improve target strength measurements of water column features, such as methane bubbles, observed with the EK60.

The tools developed for mapping oil and gas, originally in response to the Deepwater Horizon spill, have attracted much interest from the community and have fostered a number of follow-on studies. Epitomizing the role of the Ocean Exploration Program, this initial work on seep mapping and analysis has led to follow-up funding from several other agencies including NSF, DOE, and the Sloan Foundation. These follow-up projects each seek to look deeper into our ability to be quantitative about the flux and fate of the oil and gas that have been the target of our seep mapping.

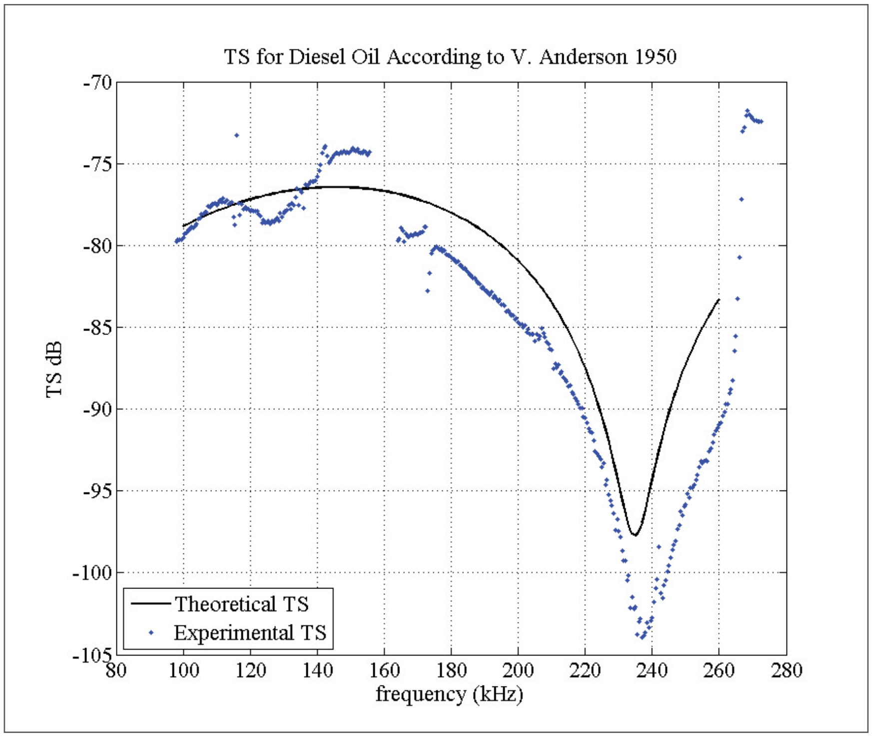


Figure 5-36. An example of broadband acoustic backscatter from an oil droplet (blue dots) compared with a theoretical model by Anderson [1950] (black line).

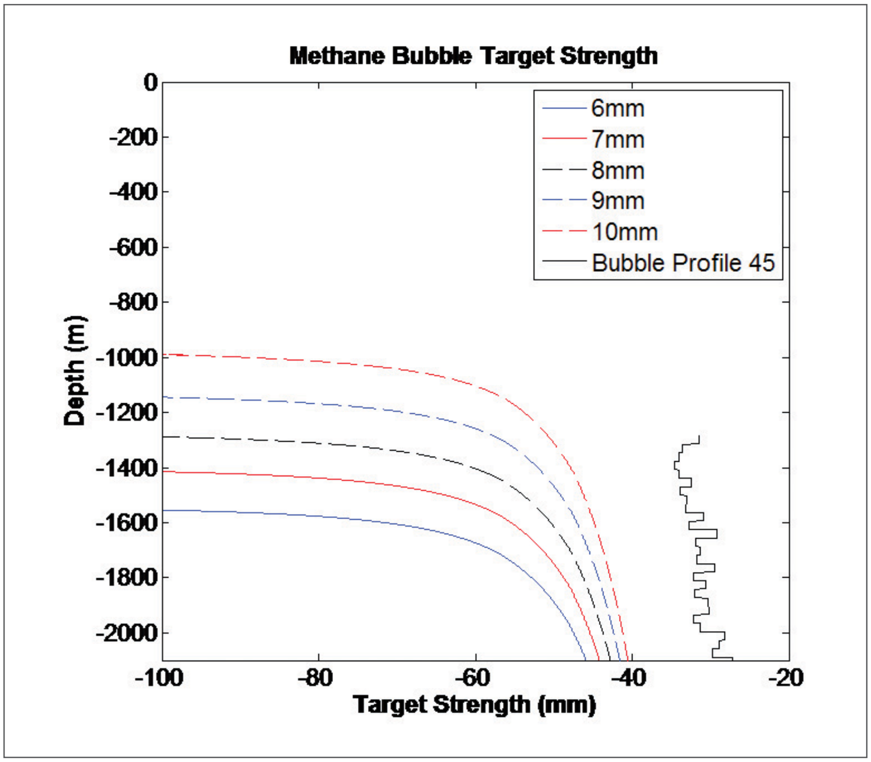


Figure 5-37 Modeled single-bubble TS profiles and comparison with a deep water observation in the western Atlantic.

Target Strength of Oil Droplets

The seeps we map may consist of oil droplets, gas bubbles, or both. In order to discriminate between oil and gas and to better understand how we can use acoustics to map and monitor subsurface dispersed oil droplets, a better understanding is required of the acoustic response of oil droplets. Under the supervision of Tom Weber, graduate student Scott Loranger has built an apparatus to create oil droplets of varying size and density. The apparatus has been completed and tests are underway. This work has been focused on foundational acoustic work in order to make sure we understand and can correctly predict the acoustic scattering response of oil droplets. One of the main goals of this project is to be able to provide better quantitative response tools for monitoring the dispersion of subsea releases of oil, whether the dispersant be anthropogenic or natural. To do so requires a detailed understanding of the frequency response for individual bubbles, such as that shown in Figure 5-37, which is from a series of tank tests using broadband acoustic echosounders that have been conducted by Loranger. An important aspect of these tests is understanding the acoustic impedance (density and sound speed) of the droplets. Accordingly, undergraduate mechanical engineering student Ryan Tingley is working on a laboratory device intended to measure the sound speed of the droplet fluids of interest (e.g., diesel, crude oil). Of particular interest in these tests are the levels of dispersion in these fluids, which we hope to test by making measurements of sound speed over a wide range of frequencies. These tests (both acoustic scattering from droplets and sound speed measurements) are expected to continue over the next year as we refine our understanding of both broadband echosounder technology and acoustic scattering from droplets.

Fate of Methane Emitted from Dissociating Marine Hydrates

For information – funded by non-NOAA sources

One of our long-term objectives has been to refine the use of acoustic echosounder measurements of methane gas seeps in order to more accurately assess the flux of methane gas exiting the seabed and rising through the water column. This has been the subject of several recent externally funded proposals, not least of which is a DOE funded project which funded Liam Pillsbury's work (graduated December 2015). Pillsbury refined the work of Kevin Jerram to more accurately estimate target strength (TS) profiles of gas bubbles as they rise through the water column—particularly those that have a low signal-to-noise ratio. He is then using these adjusted TS profiles as a constraint on models (based on the work of McGinniss et al. [2006]) of gas bubbles rising through the water column. An early result of this work suggests that at least some of the bubbles exiting the seafloor must be > 6 mm if they are to survive to the observed depths.

McGinnis, D. F., Greinert, J., Artemov, Y., Beaubien, S. E., & Wüest, A. N. D. A. (2006). Fate of rising methane bubbles in stratified waters: How Much Methane Reaches the Atmosphere?, *Journal of Geophysical Research: Oceans (1978–2012)*, 111(C9).

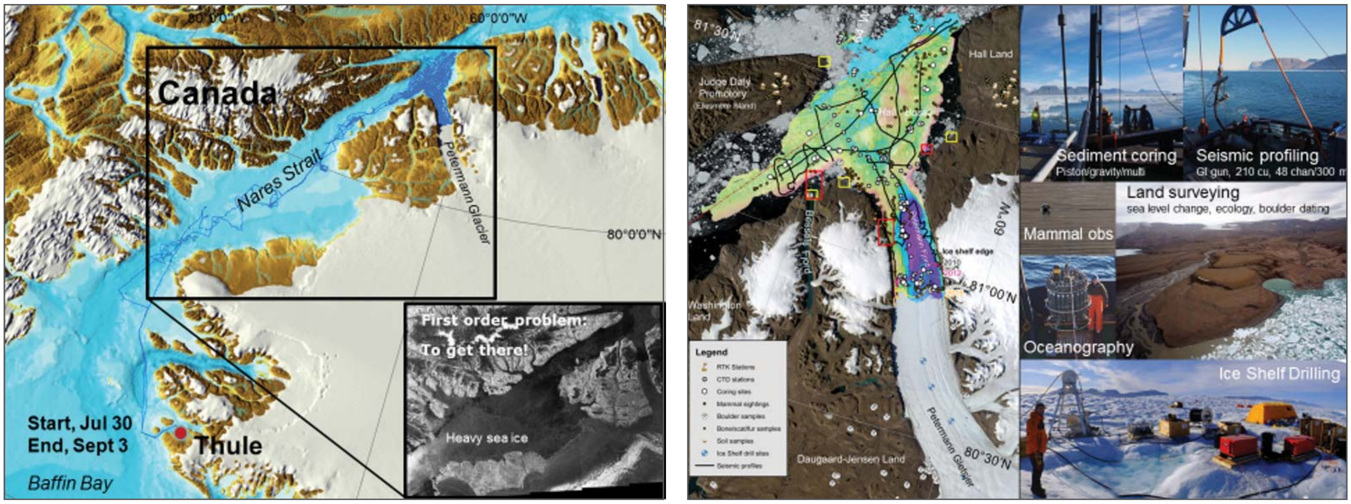


Figure 5-38. Location of Petermann Fjord and Glacier in northwestern Greenland (left); overview of mapping and other programs during the Petermann 2015 expedition (right).

Mid-Water Mapping in Petermann Fjord Greenland Using a Wide-Band Transceiver

(For information – funded by non-NOAA sources)

In the summer of 2015 Larry Mayer, and Kevin Jerram participated in an NSF-sponsored cruise aboard the Icebreaker *Oden* to Petermann Fjord, northwest Greenland (Figure 5-38. The cruise was designed to understand the history of the Petermann Glacier (through seafloor and land mapping and coring) and the processes responsible for its rapid degradation.

Our component of the program focused on the Kongsberg EM122 multibeam echosounder, the Simrad EK80 wideband split-beam echosounder, and the SBP120 sub-bottom profiler, providing the first high-resolution maps of the seafloor and water column in this remote region. Preliminary water column results suggest the presence of several scattered gas plumes and highly stratified layers of glacial meltwater; these are being more closely examined to identify possible correlations with CTD records and water samples collected in the region (Figure 5-39). The field experiences aboard *Oden* directly inform Jerram's support for midwater mapping programs with EK60, EK80, and EM302 sonar systems aboard NOAA vessels.

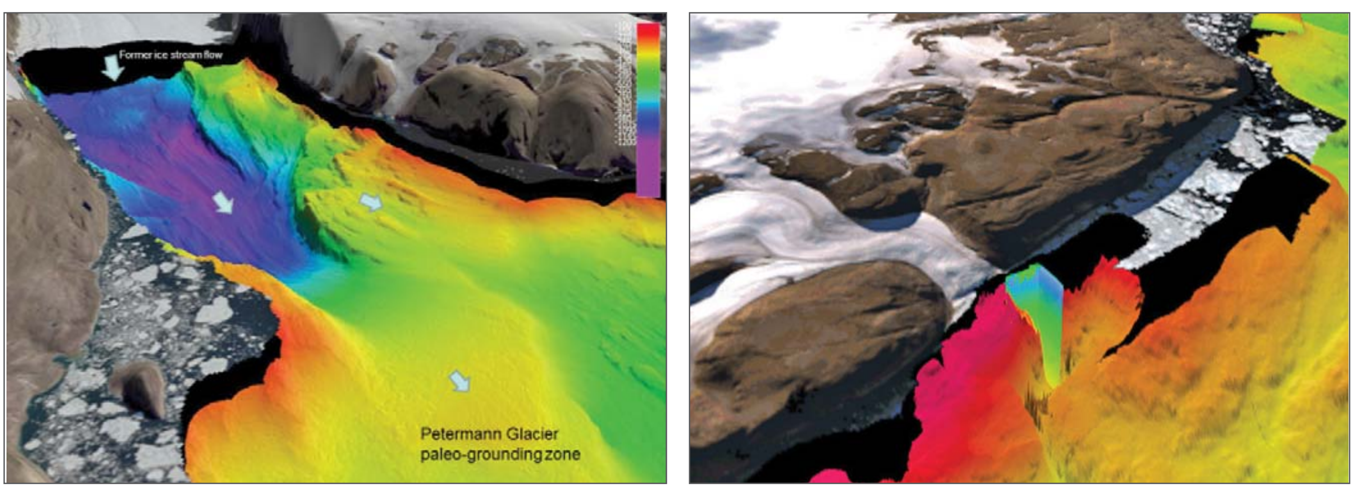


Figure 5-39. Multibeam sonar map of seafloor in front of Petermann Glacier showing past grounding lines (left); water column data at outlet of tide-water glacier in fjord showing sediment laden freshwater plume (right).

Theme 4 – IOCM

Developing Tools, Protocols, Non-Standard Products, and Approaches that Support the Concept of "Map Once – Use Many Times," i.e., Integrated Coastal and Ocean Mapping

A critical component of the Center's effort has been to maintain an Integrated Ocean and Coastal Mapping Processing Center that would support NOAA's new focused efforts on Integrated Ocean and Coastal Mapping as outlined in the Coastal and Ocean Mapping Integration Act of PL-111-11. The IOCM Center brings to fruition years of effort to demonstrate to the hydrographic community that the data collected in support of safe navigation may have tremendous value for other purposes. It is the tangible expression of a mantra we have long espoused: "map once–use many times." The fundamental purpose of the Center is to develop protocols that turn data collected for safety of navigation into products useful for fisheries habitat, environmental studies, archeological investigations and many other purposes, and conversely, to establish ways to ensure that data collected for non-hydrographic purposes (e.g., fisheries, ocean exploration, etc.) will be useful for charting. Our goal is to have NOAA employees from several different NOAA lines and divisions (NOS Coast Survey, Sanctuaries, Fisheries, Ocean Exploration, etc.) at the Center and have them work hand-in-hand with Center researchers to ensure that the products we develop at the Center meet NOAA needs. The NOAA employees will develop skills in the use of these products so that they can return to their respective divisions or the field as knowledgeable and experienced users.

Representing the Office of Coast Survey at the Center, Glen Rice and Sara Wolfskehl have partnered with a number of Center staff members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. In addition, Glen provides a direct link when specific operational difficulties arise in the field, allowing Center personnel to take part in designing an appropriate solution. The addition, in 2014, of the Super Storm Sandy Grant and Contract teams brings much greater depth to our IOCM efforts as almost all of the work these teams do fits well within the context of the IOCM theme. This pairing really epitomizes the concept of IOCM and of bringing research to operations. The Super Storm Sandy Grant team built on research already being done in the Center to develop algorithms and protocols specifically designed for the Super Storm Sandy effort (and described throughout this report). The Super Storm Sandy Contract Team applied these tools to produce a series of products of direct relevance to NOAA charting.

In 2015, our IOCM efforts focused on collaborations with the Office of Coast Survey, Office of Ocean Exploration and Research, National Marine Fisheries Service and with NOS's Marine Modeling and Development Office. Many of the efforts previously described (particularly those described under HABITAT, MIDWATER MAPPING, LIDAR AND DATA PROCESSING themes) could just as easily be listed under the IOCM theme; below we focus on those projects that, for the most part, have been specifically incorporated into NOAA's IOCM projects and in particular outline some of the IOCM-relevant results of the Super Storm Sandy Contract team. We only describe them briefly here; more detailed descriptions of these projects can be found in the Super Storm Sandy final reports (**http://sandy.ccom.unh.edu**).

Backscatter from Hydrographic Vessels

NOAA continues to require seafloor acoustic backscatter as a deliverable for all hydrographic surveys yet there are still questions about the current approach to collecting and processing backscatter. Under the leadership of Glen Rice and with input from many members of the Center, information is being gathered and synthesized to develop a "business case" for how Coast Survey deals with backscatter. These efforts are aided by the Center's (and Rice's) involvement in the Backscatter Working Group where an international team is looking at both the use of and needs for backscatter data as well as developing optimal protocols for the collection of high-quality backscatter data. In 2015, Glen represented the GEOHAB Backscatter Working Group at the Kongsberg Maritime Subsea Forum for Exchange of Mutual Multibeam Experience (FEMME). Summary comments made by Kongsberg noted a reaffirmed appreciation for quality backscatter as an important part of the data produced. Additional presentations about the Backscatter Working Group results were made by Xavier Lurton at Seabed and Sediment Acoustics (UK), and Shallow Survey (UK), and Erin Heffron at AGU.

Figure 6-1. Hypack screen capture during acquisition of ME70 data on the *Oscar Dyson* in June 2015.

The development and maintenance of the NOAA seafloor acoustic backscatter workflow has transferred from NOAA HSTB and is now managed by the Hydrographic Surveys Division (HSD) branches. HSTB continues to maintain expertise in backscatter so that they may advise HSD in backscatter collection and processing. Backscatter processing may move from HSD into the hydrographic field units during the next year.

Bathymetry from the NOAA FSVs

The collection of multipurpose data from NOAA hydro-graphic vessels (e.g., backscatter data that can be useful for habitat mapping) is only one aspect of the IOCM effort. Just as importantly there is the design of protocols to ensure that as the fisheries vessels use their multibeam sonars they produce bathymetry and other outputs that can serve hydrographic and other purposes. This effort was epitomized in 2011 when Tom Weber, Jodi Pirtle and Glen Rice demonstrated that the fisheries sonar on the NOAA Ship *Oscar Dyson*, designed for mid-water fisheries studies, could also be used to provide hydrographic quality bathymetry, map the seafloor for trawlable/untrawlable habitat (see HABITAT Theme), and identify gas seeps. In one example, during a pollock survey, a Danger to Navigation (DTON) was identified from the data collected by the fisheries sonar (see 2011 Progress Report).

The approaches developed at the Center are now being put into practice. Simrad ME70 fisheries multibeam echosounders (MBES) are now installed on each of five NOAA Fisheries Survey Vessels (FSVs). Weber's ME70 software for producing bathymetry and seafloor backscatter is being integrated with the Hypack acquisition software that is standardly used on these vessels. This integration enables the ME70 sonar to simultaneously collect water column and bathymetric data, improving survey operations aboard the FSVs by increasing data collection, enabling visualization of ME70 bathymetry in real-time, and providing mapping and data processing tools. In June 2015, we had the opportunity to test Hypack's development on the *Oscar Dyson*. The Hypack development has progressed nicely (Figure 6-1), and it appears there are only a few items left to incorporate (e.g., the ability to turn roll and pitch compensation—which the ME70 already does—off; the ability to log backscatter data). This effort has been a prime example of Research to Operations (R2O).

Super Storm Sandy ICOM Examples

As discussed earlier, Super Storm Sandy supplemental funding provided an accelerated opportunity to turn many of the on-going research projects in the lab into products needed to help understand and mitigate the impact of one of the worst storms recorded in U.S. history. This was achieved through the funding of a research team (the Sandy Grant team under the supervision of Brian Calder) who developed a number of algorithms and processes specific to the Sandy need based on on-going research in the lab, and a production team (the Sandy Contract team under the leadership of Juliet Kinney and supervision of Andy Armstrong) that applied these algorithms to generate products that were designed to help NOAA and others measure the impact of the storm and design mitigation processes. Common to many of these procedures was the concept of using the data sets available for as many applications as possible, i.e., the concept of IOCM. Here we summarize some of the most relevant IOCM products than came out of this effort. More detailed discussion of these topics can be found in the documents provided at: **http://sandy.ccom.unh.edu/**.

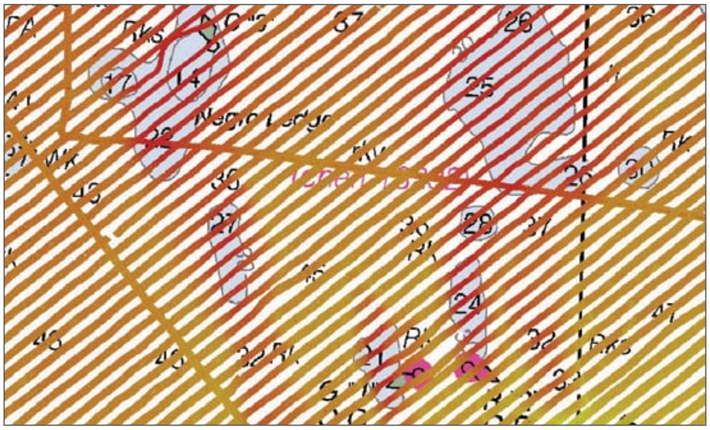


Figure 6-2. Small subset of the Buzzard's Bay filtered USGS dataset.

Assessment of Existing Post Sandy Mapping Data Sets

To start their efforts, the Sandy contract group did an extensive search for relevant existing data in the Sandy-impacted region including lidar both topographic and topobathymetric (topobathy), acoustic bathymetry, sidescan sonar, aerial imagery, and other data such as marine debris removal information, location of grab samples, and Secchi depths. These data were then accumulated in a GIS database.

The GIS database is proving very useful for the Composite Coastal Bathymetry Project (with Shachak Pe'eri). The database has been shared with NOAA's MCD branch with additional attention to metadata, converting to a common datum and full-resolution data to give MCD quick coverage maps.

Use of Non-Traditional Data Sources for Mapping Outputs

Acoustic Data to the Chart

USGS Interferometric Sonar Data to the Chart

Many surveys collected by the USGS in recent years have been in NOAA high-priority survey areas. The use of existing USGS PMBS data in this area would save NOAA valuable ship time and resources as well as significantly reduce the number of NOAA survey areas where safety (due to proximity to shore) is a concern. The overall goal of this project is to assess the utility of the USGS PMBS data for charting, including the assessment of data quality and comprehensive ability to meet NOAA specifications and deliverables as well as IHO requirements. A data set collected by the USGS in Buzzard's Bay, MA (where NOAA data would be available) was used as a test case.

USGS data were filtered and processed as a normal multibeam survey (using only 120 degrees of the swath) within HIPS. The purpose for filtering these data was to remove as much noise on the outer edges of the swath as possible. These data are currently being treated as single beam data with 100% side scan coverage due to the resulting gaps (averaging 40-50m) between survey lines (Figure 6-2). However, if future analysis prove the full-coverage data to meet NOAA standards the full data set could be submitted for charting (see discussion of PMBS under DATA PROCESSING theme).

In preparation for a NOAA hydrographic survey in the region, features measuring 1m or larger were identified as contacts. Over 11,000 contacts were initially

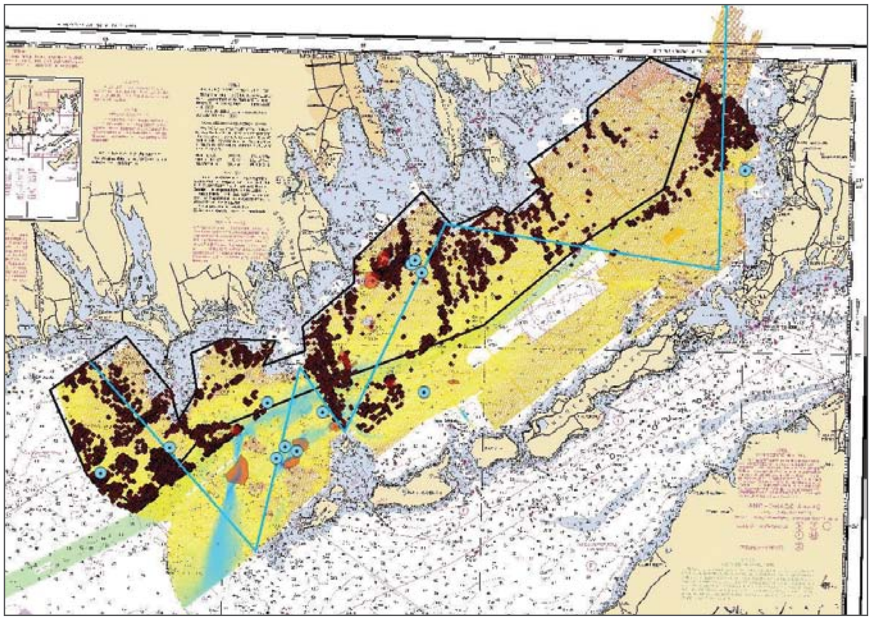


Figure 6-3. Above is an image of the results of the USGS collected Buzzard's Bay initial analysis. A 1m CUBE surface with side scan contacts overlain in red with the OCS focus area outlined in black. The blue lines represent the IOCM center's suggested NOAA ship crosslines and the red areas represent areas of significant change from current chart soundings. The blue circles represent both charted and uncharted wrecks within the survey bounds. The blank area in the middle of the survey above is where the NOAA ship RUDE surveyed Buzzard's Bay with multibeam data in 2004.

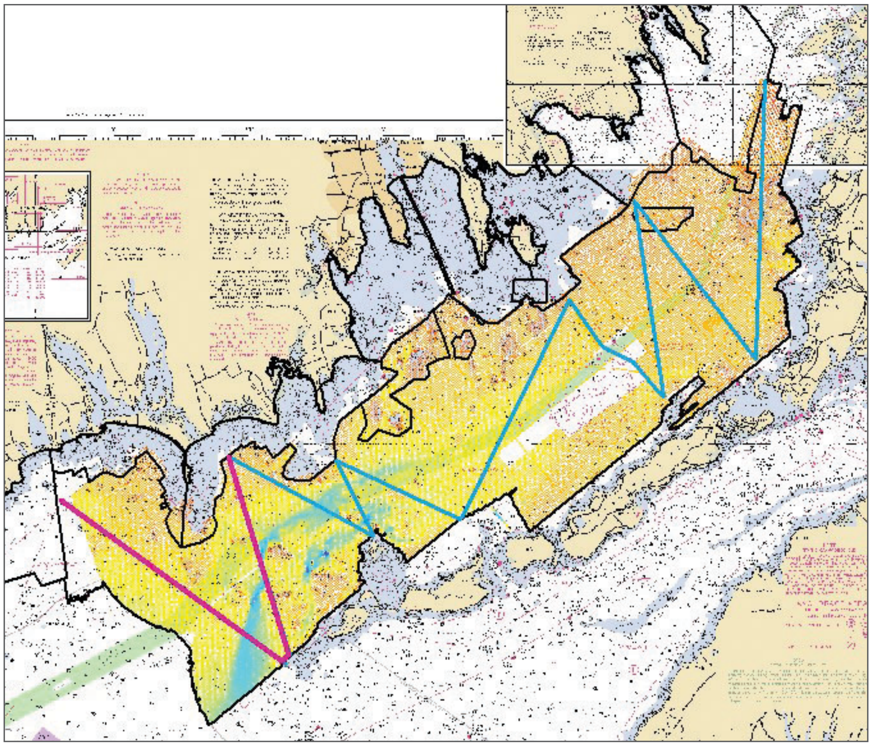


Figure 6-4. The above image depicts the final validation crossline plan through the USGS PMBS survey area. Due to unforeseen technical difficulties, crossline acquisition was split into two days. The blue line segments represent data collected on the first day of acquisition. The pink line segments represent data collected on the second day of acquisition.

identified within the focus area (see Figure 6-3). One meter CUBE surfaces were created from filtered USGS Buzzard's Bay data and compared to the current chart soundings. Areas of shoaling and/or drastic change were identified. Based on the initial analysis, Cassie Bongiovanni (with suggestions from Sarah Wolfskehl) created priority-based suggestions for NOAA ship crosslines and feature investigations. These suggestions were presented to the NOAA OPS project manager for the cruise and reviewed for implementation in the final feature requirements sent to the ship.

Cassie Bongiovanni was aboard the first leg of the NOAA Ship *Thomas Jefferson's* Buzzard's Bay summer 2015 acquisition cruise to aid both her analysis of the USGS data for charting and the *Thomas Jefferson*'s crew with the validation efforts as designated in the NOAA project instructions for the cruise. The *TJ's* efforts resulted in data that covered over half a dozen uncharted wrecks, 15 potential rock DTONs, and 9km worth of strategically designed crosslines through the USGS dataset (Figure 6-4).

After resolving a tidal correction problem between the two data sets, comparison of the crossline data collected by the *Thomas Jefferson* to the USGS-derived data revealed that average agreement between the two datasets where within IHO requirements. Comparison of contacts is ongoing. An important aspect of this effort was the enhanced communication between NOAA and the USGS that led to an increased understanding of the objectives of each organization for data collection and a renewed commitment to increase collaboration and reduce redundancy in survey efforts. During these discussions the USGS was encouraged to begin to use SeaSketch for submitting survey needs, priorities, and plans.

Third Party (USGS/ USACE) Multibeam Data to the Chart

The use of third party multibeam sonar data (data not collected by NOAA OCS) for charting was examined using USGS data from a coastal process study around Fire Island, and U.S. Army Corps of Engineering data from an ongoing coastal storm damage risk management study in Sandy-impacted areas. In the IOCM spirit of "map once-use many times," Sarah Wolfskehl repurposed these data a third time by post processing the data for application to the nautical chart through submission to the OCS Hydrographic Surveys Division. In the course of these efforts, techniques and workflows were established to optimize the process and documented.

FEMA and State/Local Funded Sidescan and Single Beam to Chart

After Super Storm Sandy a tremendous amount of single beam and sidescan sonar data were collected for FEMA by state and local agencies for the purpose of determining if channels needing dredging, and for debris detection. These efforts are leading to better coordination with NOAA, particularly with the NJ Departments of Transport and Environmental Protection. Data sets currently being investigated for incorporation into NOAA charts include are those provided by the NJ DOT and data from the Town of Hempstead Bay, NY. The Sandy Contract Team is assessing the quality of the data, and documenting what types of information, formats, and other ancillary data may make it easier to qualify the data.

Marine Debris Accounting for Charting

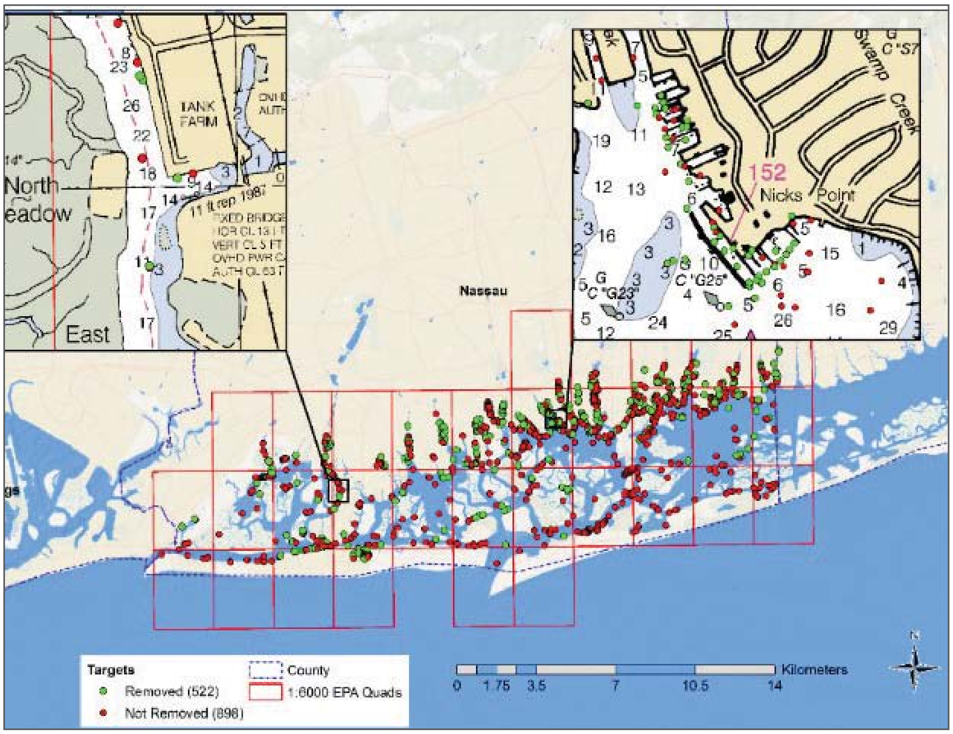


Figure 6-5. Nassau County, NY debris removed and features not removed. Some features not removed include things such as cables or other non-debris items, noise in the sonar rather than objects. Some features were no longer present, while others were deemed too deep. The two zoomed-in inset maps show the location of reported debris relative to the chart.

Super Storm Sandy created a great deal of marine debris, some in navigable waters. Different agencies and groups within the Sandy affected region received FEMA funds to map debris, and to remove the debris that was considered a navigational hazard. While the Coast Guard was responsible for removing storm debris that caused major dangers to navigation from federal channels, there are large areas of navigational use that are the domain of state and local agencies. The Sandy IOCM contract team conducted assessments of FEMA and state funded marine debris identified versus removed for updating navigational charts; additional efforts by the Sandy Grant team with respect to modelling and identifying marine debris are discussed in the DATA PROCESSING section of this report. Data were compiled and an interactive GIS created to track identified marine debris (Figure 6-5). Comparison with OCS Contract surveys and removed debris found in that survey, and associated documentation of debris removal, allowed AHB to flag DTONS as removed before application to the chart.

Lidar Data to the Chart

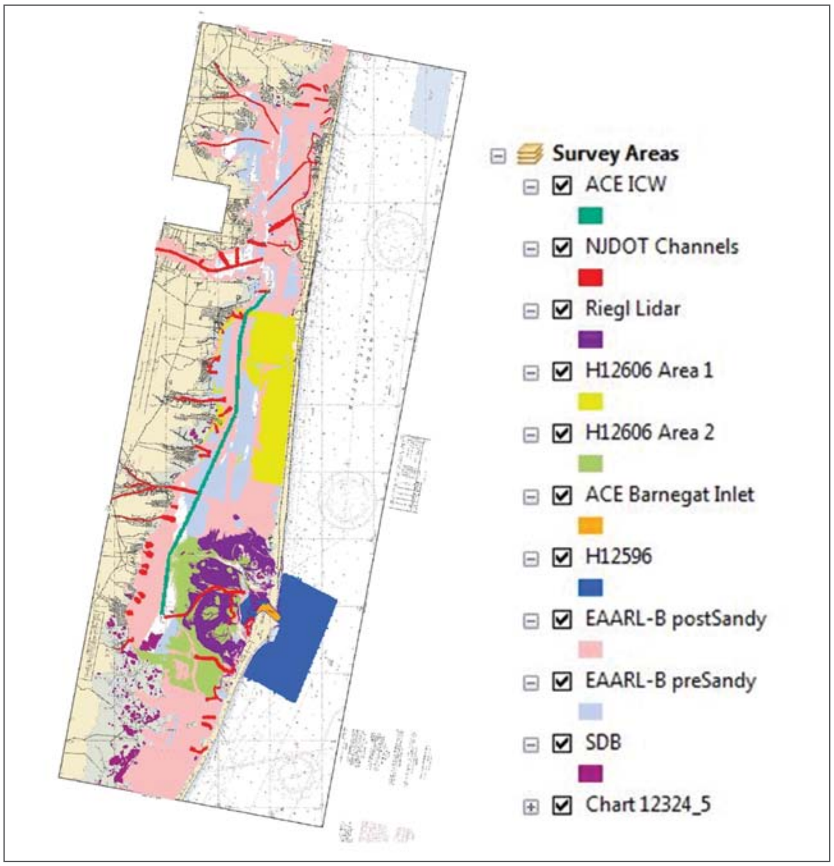
Composite Coastal Bathymetry Project (Improving Chart Adequacy Using Merged Source and Outside Source Data)

In response to Super Storm Sandy, the NOAA Remote Sensing Division (RSD) collected bathymetric lidar data using a Riegl VQ820G sensor to update the National Shoreline from South Carolina to New York. Shachak Pe'eri identified the widespread collection of this data as an opportunity to utilize this and other publicly accessible data to update chart morphology in shallow areas. Under his guidance the IOCM Center is processing data from a variety of sources in an effort to integrate multiple levels of data quality to inform chart update activities. These data will be shared directly with the NOAA Marine Chart Division (MCD) for their evaluation and use in improving the adequacy of the 1:40,000 scale charts of New Jersey and New York.

Bathymetric digital elevation models (DEM) from lidar and acoustic data sources have been constructed within chart boundaries, accompanied by shapefiles of DEM coverage areas with associated attribute tables containing information related to the quality of the data. These attribute tables, under development, will include the information needed for MCD to create source diagrams including critical data adequacy information such as category of zone of confidence (CATZOC). The final DEM will be systematically merged so the most accurate data is reflected in the surface where instances of overlap occur. Where no lidar or acoustic data is available the IOCM Center will generate satellite derived bathymetry (SDB) grids using LANDSAT 8 imagery. SDB grids will be provided as individual products and will be the last supporting tier of data in the final merged DEM.

Chart 12324_5 (Bay Head, NJ to Surf City, NJ), covering the Intracoastal Waterway of the Barnegat Bay, NJ region (Figure 6-6), was chosen as the pilot project area. This area was chosen because the IOCM Center had access to several post-Sandy datasets collected within the chart boundaries, including a small portion of RSD Riegl data that RSD had finished processing and made available. Other data the IOCM Center had on hand include NOAA OCS's Chirpteralidar survey H12606, OCS acoustic survey H12596, pre- and post-Sandy EAARL-B lidar surveys, and NJ Department of Transportation (NJ DOT) singlebeam channel surveys. Paul Turner, NOAA NOS physical scientist, had previously connected the IOCM Center to the NJ DOT in order to help facilitate the exchange of the channel survey data. Juliet Kinney worked with the U.S. Army Corps of Engineers (USACE) to identify and request additional data in order to include high quality USACE data collected in deeper areas throughout the chart and thus allow for a more accurate final DEM. USACE then shared two recent singlebeam surveys with the IOCM Center, including a survey of Barnegat Inlet and a survey along the length of the ICW channel marker.

Samantha Bruce gridded and merged all of the data, created coverage area shapefiles (Figure 6-6 top) and used supporting documents to qualify the data into attribute tables (Figure 6-6 bottom). Andy Armstrong reviewed the M_QUAL information to assess for accuracy and particularly to provide insight on the correct category of zone of confidence for each dataset. Using standard operating procedures developed by Shachak Pe'eri as a guide, Bruce generated SDB for the bay area. The SDB was calibrated using the Chiroptera lidar and clipped at the limit of imagery accuracy beyond which values are not representative of true depth. The IOCM Center has been collaborating with Pe'eri in order to test, refine and incorporate his SDB methodologies into production. The project pilot area, RNC 12324_5, has been completed and all products except for the final workflow have been shared with MCD.



barnbay_riegl

FID	Shape *	CATZOC	DRVAL1	DRVAL2	POSACC	SOUACC	SUREND	SURSTA	TECSOU	VERDAT	INFORM
0	Polygon ZM	3	0.01	3.11	1	0.15	20130924	20130923	7	12	W00279, OSD-AHB-14, NOAA RSD, Riegl VQ820G LIDAR

TXTDSC	SORDAT	SORIND
NOAA Coastal Mapping Program Project Completion Report Project NJ1301 Barnegat Inlet, New Jersey	20130924	US, US, graph, W00279

Figure 6-6. (Top) Shapefile polygons of each dataset used in the pilot project area over RNC 12324_5. (Bottom) Riegl survey M_QUAL attribute table of qualifying information.

USGS EAARL-B DEM for Charting

Quality control analysis and production workflow procedures were also established to create DEM products for charting from USGS EAARL-B lidar data. Part of this process is learning about USGS processing of raw data (ALPS) and DEM products, and looking at full data sets for possible S-57 type features.

The USGS EAARL-B team published a pre- and post-Sandy set of .las files and DEMs for bathymetry of Barnegat Bay, NJ. The IOCM data center received the raw data, and has been able to process a portion of the files in the USGS's in-house software, ALPS.

Samantha Bruce gridded data, making source diagrams by generating coverage polygons, MQUAL, and contouring gridded data for MCD as part of the charting adequacy project.

One of the key goals is to determine if there are debris items or shoalest values, or other chart pertinent information not incorporated in the published bathymetry files from the open file report for Barnegat Bay. Further analysis may reveal adjusted best practices for processing different lidar systems and best uses for charting based on ability to detect objects, point density, penetration of system in the water, etc. In the future, the team may investigate processing additional post Sandy EAARL-B data sets to the chart.

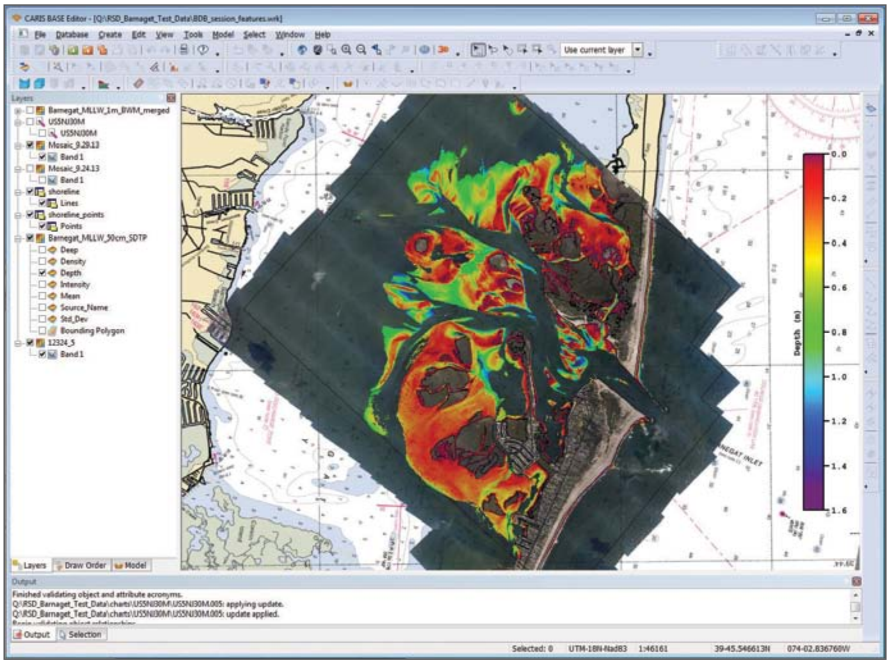


Figure 6-7. RSD bathymetric lidar test data set in Barnegat Bay used to demonstrate tools for understanding, organizing, and gridding lidar point clouds and aerial imagery using ArcGIS, LASTools and Caris BathyDatabase.

Remote Sensing Division Lidar to OCS for Charting

In response to Super Storm Sandy, NOAA's Remote Sensing Division (RSD) collected topobathymetric lidar data with a Riegl VQ820G along the eastern seaboard, from South Carolina to New York to update the National Shoreline. At the same time, RSD has been working on submitting bathymetric lidar to OCS for application to the chart, but OCS has limited experience with lidar point cloud data formats. The Sandy contract team is working with other Center researchers, RSD, and Atlantic Hydrographic Branch (AHB) to process the additional Sandy lidar data that could be applied to the chart and make recommendations for tools and procedures to help AHB process future lidar data. The IOCM center received two test data sets from RSD (Figure 6-7). Using these data, Wolfskel tested software and worked through procedures already established by the Sandy Grant team and AHB to tailor them to AHB's needs. A draft SOP with recommendations on understanding, organizing, and gridding lidar point cloud data using tools the Branch has on hand or are available for free, such as ArcGIS and LasTools, was submitted to AHB for initial review. Feedback was quick and positive and applied to the SOP.

USACE CZMIL Topobathy Lidar for Charting

The Sandy contract team is also evaluating the use of USACE CZMIL topobathy lidar data to help create DEMs and update charts. USACE JABTLCX have recommended that the team use PFM – ABE to examine topobathymetric lidar data, and particularly use it for the CZMIL data. PFM ABE is a free software package created by the US NavO (Naval Oceanographic Office) that is used by JABLTCX for all CZMIL work. PFM-ABE has been downloaded and is being installed. USACE JABLTCX has now sent a CZMIL dataset from NJ, and other areas within the Sandy region that will be the basis for our generation of workflows for CZMIL data.

Development of Habitat and Seafloor Character Maps Using Backscatter and Reflectivity

EAARL-B Lidar Reflectivity Maps

The Sandy contract team is using OCS collected bathymetric data and USGS EAARL-B bathymetric lidar data to create acoustic backscatter and reflectivity maps that can be used as a more accurate overall representation of the seafloor and eventually lead to the creation of sediment and habitat maps for specific areas of

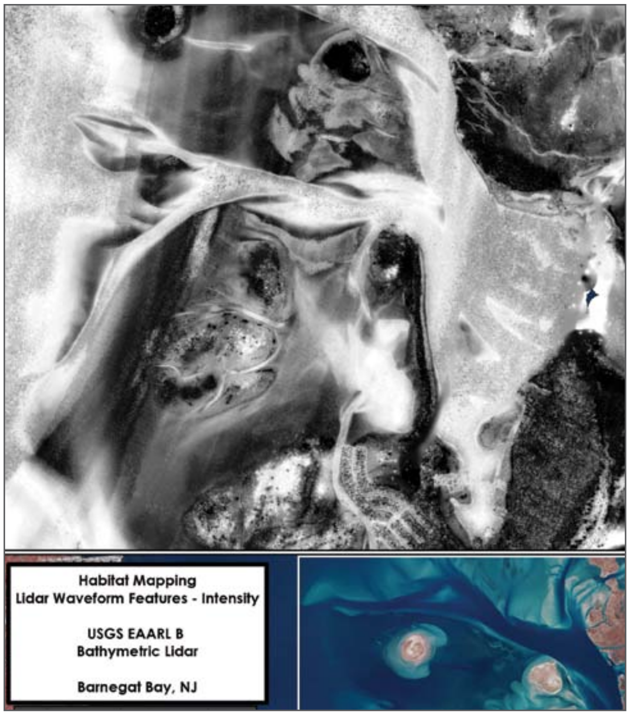


Figure 6-8. Example of USGS EAARLB Channel 1 waveform outputs with correct processing settings, converted to reflectivity, generated by Juliet Kinney and Erin Nagel.

interest. In parallel with the efforts to use EAARL-B data for charting, the team is developing approaches for processing waveform statistics and extracting information from the USGS EAARL-B lidar that is useful for habitat mapping and seafloor characterization. Once waveform statistics have been extracted and appropriate workflow procedures established, processing of the Barnegat Bay pre- and post-Sandy data can be applied to the entire Bay (Figure 6-8).

Generation of Habitat/ Sediment Maps from Acoustic Data

Cassie Bongiovanni is processing OCS backscatter and sidescan mosaics through the implementation of workflows developed in previous years at the JHC through IOCM projects (Figure 6-9; see Backscatter section of the DATA PROCESSING theme). The ability to interact with Glen Rice (NOAA/CCOM) and other Center members has been invaluable in quickly troubleshooting bugs in software and other issues. A lower priority is seeking out BOEM data to create a workflow for BOEM data (multibeam, sidescan & single beam) to pass on to NOAA offices to help identify reef structures, or other habitat information.

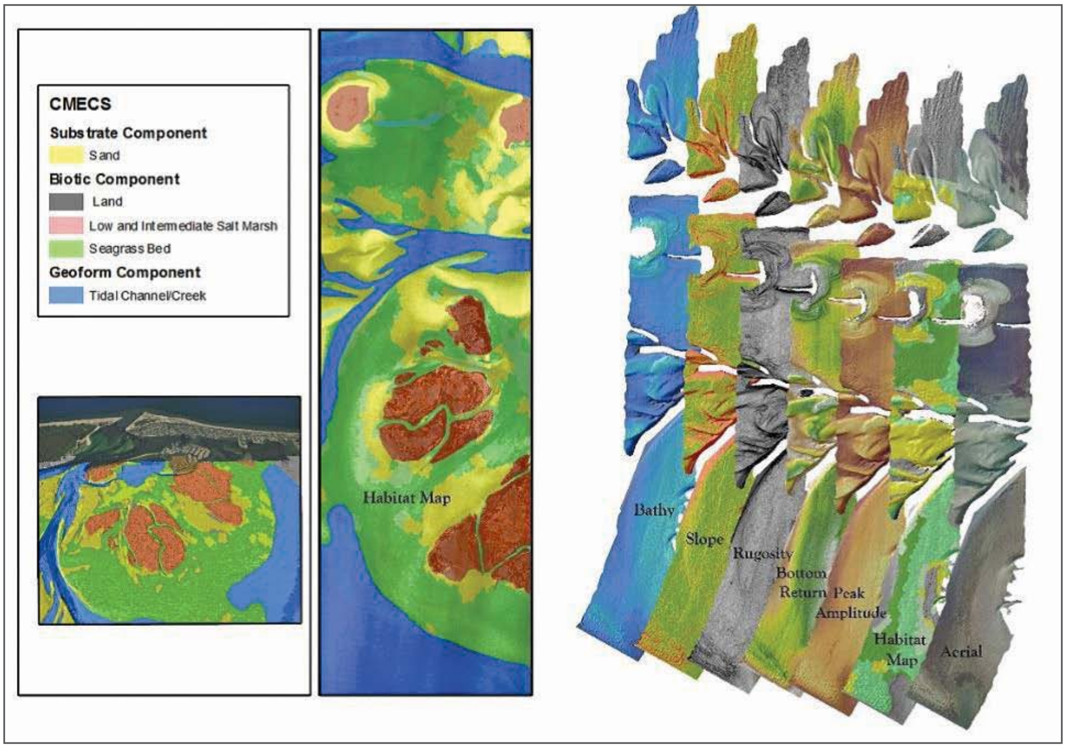


Figure 6-9. Example of characterization of habitat and input/ associated input layers for the general approach developed by Jenn Djikstra, Erin Nagel, and Victoria Price during the Super Storm Sandy grant activities that will be adjusted and used by the Sandy contract team as needed.

Theme 5 – Visualization

New and Innovative Approaches for the 3D and 4D Visualization of Hydrographic and Ocean Mapping Data Sets, Including Better Representation of Uncertainty, and Complex Time- and Space-Varying Oceanographic, Biological and Geological Phenomena

The Center continues to have a very strong focus on the development of innovative approaches to data visualization and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team (Arsenault, Butkiewicz, and Sullivan), under the leadership and direction of Lab Director Colin Ware, have produced a number of novel and innovative 3D and 4D visualization tools designed to address a range of ocean-mapping applications (as reported in earlier progress reports). Efforts this year have focused on the research designed to enhance the display and understanding of bathymetric, and environmental (currents, waves, etc.) data including uncertainty, innovative approaches for interacting with complex ocean mapping data sets, tools to help oceanographers, hydrographers, ocean engineers, biologists and others interpret complex data from a variety of sensors, models and data sets, and several tools created specifically to support our Super Storm Sandy efforts including those designed to help identify marine debris, and several outreach tools.

Space Filling (Dynamic) Contour Lines

A prior human factors study conducted by Butkiewicz reinforced existing research findings that contour lines as a surface texturing technique are extremely effective at providing the critical perceptual cues that help viewers correctly perceive the shape of 3D terrain/bathymetry models. His research continues to investigate potential modifications to this classic technique which can be applied to improve 3D bathymetric visualizations.

An important behavior of contour lines is the increased texel (texture element) density and concentration in regions of higher slope. However, this also means decreased texel density in relatively flat, low-slope areas, which translates to a lack of shape cues in these regions. The traditional approach to dealing with this issue is to reduce the contour line spacing. However, decreasing contour intervals to add detail to low-slope areas necessarily means overcrowding high-slope areas with so many lines that they obscure the terrain model and blend together, losing their effectiveness.

Butkiewicz is experimenting with a novel dynamic contour line algorithm which intelligently subdivides contour lines to add more detail where needed, while attempting to preserve slope-dependent texel density. Prominent major contour lines maintain strict mappings with depth measurements (e.g., 1m or 100m spacing), while much subtler minor contour lines dynamically subdivide into variable depth mappings based on the local region's characteristics (Figure 7-1). Bathymetry/terrain models are analyzed using image processing algorithms to quantify the shape cue coverage of the major contour lines, and identify sparse regions to fill in with additional minor contour lines. This pre-processing stage can be somewhat computationally intensive, but needs only be done once, while the actual rendering of the contour lines is quickly accomplished using custom GLSL shaders.

While this makes great sense it leads to an important research question: Is it possible to mix countable, fixed-interval contour lines with dynamically spaced contour lines in the same presentation, or do the two techniques conflict with each other and degrade performance, particularly with experience mariners or interpreter? Butkiewicz is currently designing a human factors study to investigate these issues.

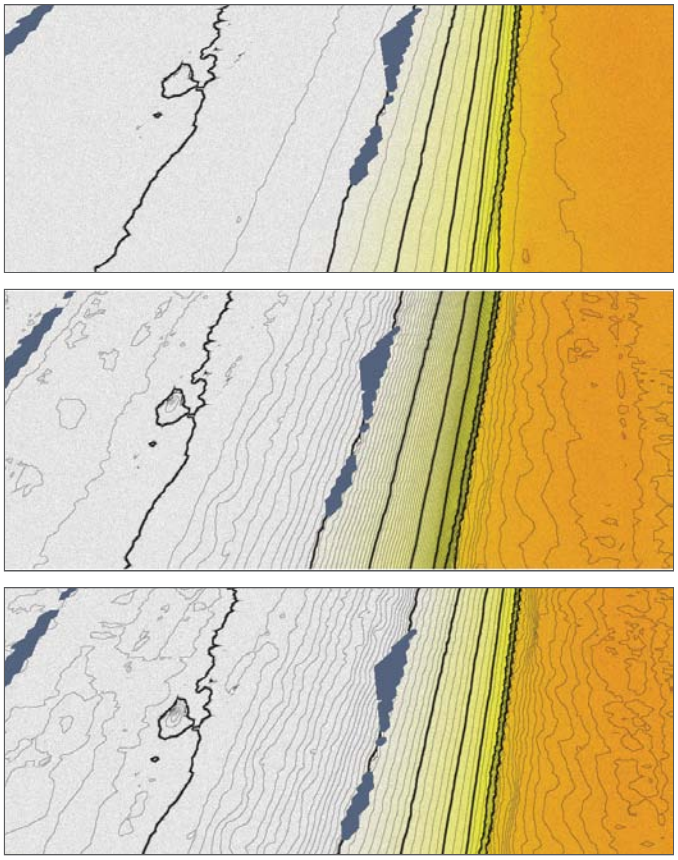


Figure 7-1. (Top) Widely spaced contours, notice no contour lines to provide detail in flat areas. (Middle) Narrowly spaced contours, notice too many contour lines in steep areas, blending together and obscuring terrain. (Bottom) Dynamically spaced contour lines, provide even coverage with detail, while major contour lines remain locked to 1m spacing.

Visualization of Dynamic Bathymetry

As our ability to produce precisely navigated, high-resolution, renderings of seafloor bathymetry improves, we are beginning to be able to address the question of small (or large-scale such as in response to storm events) changes in the seafloor. Butkiewicz and Ware have conducted a human factors study to determine the optimal methods to illustrate dynamically changing bathymetry surfaces within 4D visualizations. Previous perceptual research has shown that viewers perceive the shape/orientation of a terrain surface better when a grid pattern is projected onto it, versus shading alone or with the use of contour lines and other similar visual cues. However, this research only examined the effectiveness of these techniques on static surfaces, not the dynamically changing surfaces now being generated from multi-survey time-varying bathymetry datasets, sediment transport simulation model output, etc. This distinction is important because previous research has indicated a difference in shape-cue perception between static and dynamic environments. The results of this study are directly applicable to enhancing hydrographic visualization efforts at the Center and elsewhere.

The study had two main tasks for subjects to complete. First, in comparison tasks, subjects viewed two side-by-side animations of a randomly generated dynamic terrain and judged which side experienced a larger change (Figure 7-2). This task helped determine what technique is more effective at differentiating the relative sizes of changes. And second, in detection tasks, subjects monitored a rotating (to ensure continuous movement) randomized terrain model, which occasionally exhibited small changes. Subjects indicated whenever they detected a change. This task measured how attention-getting each technique's visual cues are in noisy surroundings or during navigation.

The results of the study did not indicate any particular technique was most effective across the board, but instead it identified more nuanced trends and interactions, which can be applied to improve a number of aspects of dynamic 4D visualizations. On the one hand, to make correct comparisons, grids, which were the strongest performer in static scenes, did not statistically fare any better than shading alone. On the other hand, contours increased the chance of making a correct comparison by 24% over shading alone.

The number of times subjects watched the animations before making correct decisions revealed that although they re-watched contoured surfaces the longest, that additional decision-making time did correspond to increased accuracy. This could be due to the inherent countability of contour lines, which have a varying

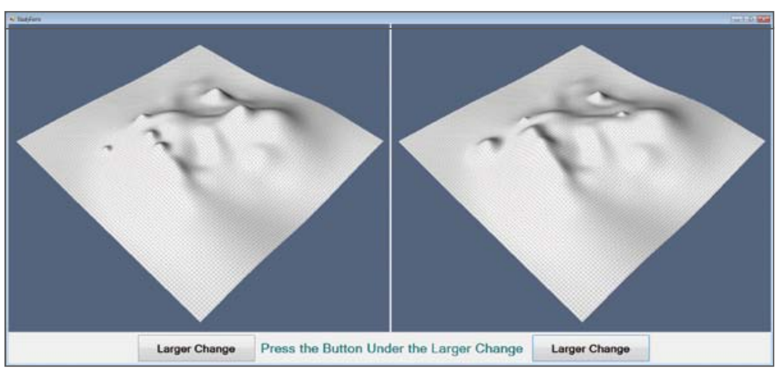


Figure 7-2. An example comparison task, in which subjects watch side-by-side animations and choose which side exhibited a larger change.

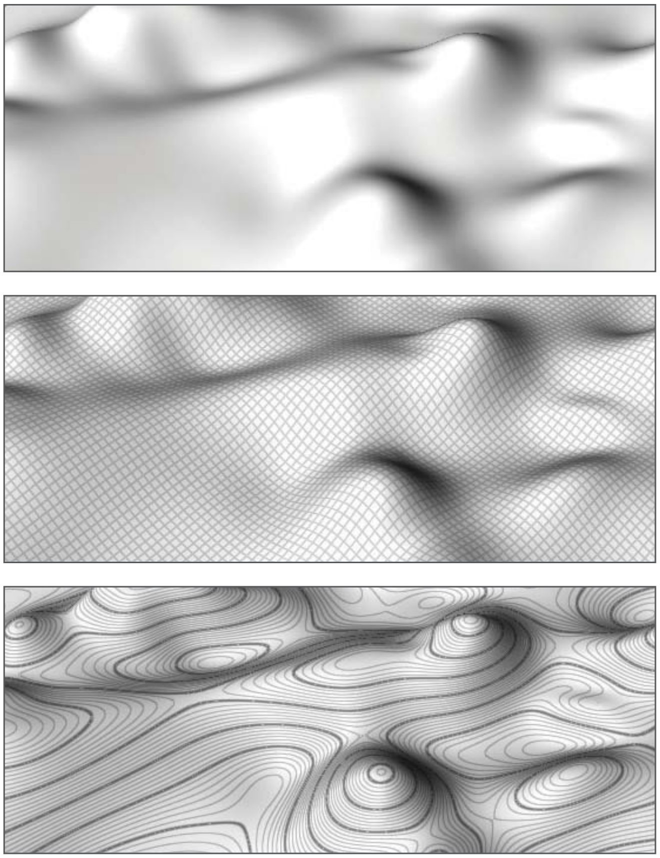


Figure 7-3. The basic texturing techniques: (top) plain shading, (middle) grids, (bottom) contours.

number and density of texture elements (texels), compared to techniques such as grids, which have a static number of texels that only deform.

Interestingly, for detection of very small changes, plain shading performed better than both grids and contours. It is likely this was because by adding textures to the surface, the amount of visual noise is increased, which can make it harder to notice very small changes. For larger changes, contours performed strongly, showing a clear advantage over plain shading and grids in all scenarios (Figure 7-3). To determine if the benefits of contour lines could be incorporated within existing texturing techniques, these tasks were performed again, pitting a standard smoothly interpolated rainbow color map against a banded rainbow color map that had hard discontinuities between a discrete set of colors (Figure 7-4). The experimental results show that these sharp boundaries between colors did indeed have the same perceptual benefits as the explicit contour lines. This suggests that for 4D visualizations, if one must use a rainbow color map (which, while commonplace, suffers from many well-known perceptual issues), its effectiveness can be increased by switching from smooth interpolation to sharply defined bands of discrete colors. Presumably other color scales would also benefit from this modification.

The details of this research were presented in a paper entitled "Effectiveness of Structured Textures on Dynamically Changing Terrain-like Surfaces," which was presented at, and published in the proceedings of, IEEE Vis 2016, the premier visualization conference, and also in the January 2016 special issue of IEEE *Transactions on Visualization and Computer Graphics*.

A follow up study is being designed to further explore these texturing techniques. One aspect is the way in which these textures assist in the encoding process of our short term working memory, which is tested using recognition tasks. We intend to determine if it is possible that contour lines, as they follow the perimeter of features, reinforce encoding of the features shapes, while grid lines may be better for helping to encode 2D area/size of features. Another aspect we are interested in examining further is the relationship between contour line intervals and feature sizes. Obviously as intervals widen, changes and features that fall between them will not be reflected in their shape cues. However, it would be helpful to determine the optimal intervals needed to reveal features of interest. This knowledge could help drive better texturing algorithms, for example, the dynamic contour line project described in a following section.

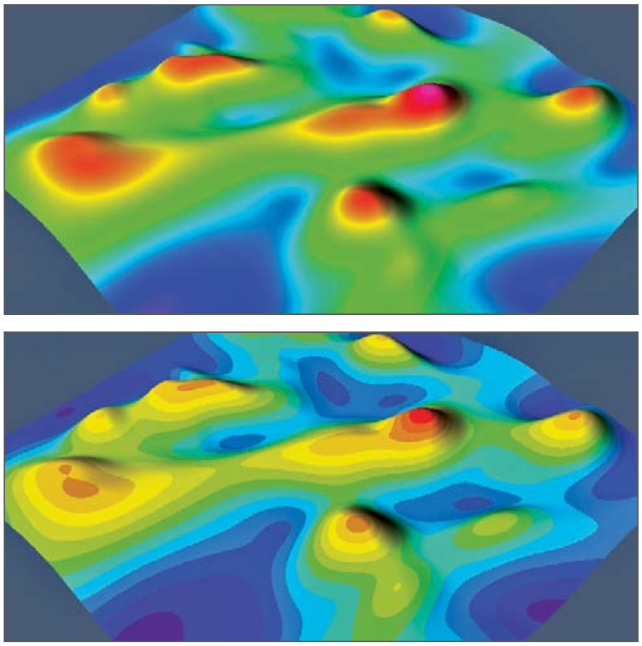


Figure 7-4. (top) Standard smooth rainbow color map, (bottom) banded rainbow color map.

Visualizing Currents and Sea State

The Center is continuing to work on portrayal of meteorological data for the navigator, including currents from operational flow models, sea state from the Wavewatch III model and weather from NOAA Mesoscale operational forecast models. This work has been bolstered by a substantial grant from ONR to supply these sorts of data to the submarine community in compact form.

Based on earlier work of the Center in collaboration with the NowCoast project, the capability to display animated harbor and near-shore flows patterns from operational forecast models is now available even with low end laptop and desktop computers, tablets and even some smart phones. The same technologies can be used to portray wind and wave forecasts. However, the best way to use an animation to portray this information has received little attention by the community.

Animation has two major advantages. First, it can be used to portray dynamic changes in flow patterns over time, and second, animated transparent flow patterns generate less interference with the visibility of other chart information. Work on the theory of flow portrayal (Ware and Plumlee 2013; Ware et al., 2014) suggests that visual channel theory can be applied to the problem. Different regions of the brain's visual cortex are devoted to static and moving patterns. This allows a person, when looking at a display that has both static and moving elements, to focus attention on either the moving elements or the static elements.

Flow Pattern Identification Study: Animated vs Static Portrayal

The visualization of 2D vector fields has applications including surface ocean currents, surface wind pattern as well as slices through electromagnetic fields. Significant effort has gone into determining the most effective method for statically representing these patterns but the use of animation to show flows and other vector fields has not been previously evaluated despite the fact that this is a common practice. There would seem to be no obvious reason to use animation to represent 2D data based on phenomena that do not change over time; animation is generally more costly to generate in terms of computation and more difficult to deliver to the viewer. Nevertheless the fact that flow patterns inherently involve movement suggests that animation should be an intuitive model of representation. Also, it is possible that an animated version of a pattern may be easier to perceive than a statically represented version of the same pattern.

We have carried out an experiment comparing static and animated representations of simulated flow patterns. Figure 7-5 shows an example of four renderings of one of the target patterns used in the experiment. Participants were required to search for a clockwise eddy in a set of counter clockwise eddies. The results show that animation can greatly improve our ability to see steady 2D flow patterns.

We have previously shown that animation interferes less with background chart information. These new results add to the weight of evidence supporting the use on animated portrayals of winds and currents.

Vector Field Data Reduction for Web Dissemination

We currently have two lines of research aimed at making data from ocean current and weather forecasts more readily available for web dissemination. The first (with Arsenault), is concerned with compact storage and transmission of equally spaced streamlines

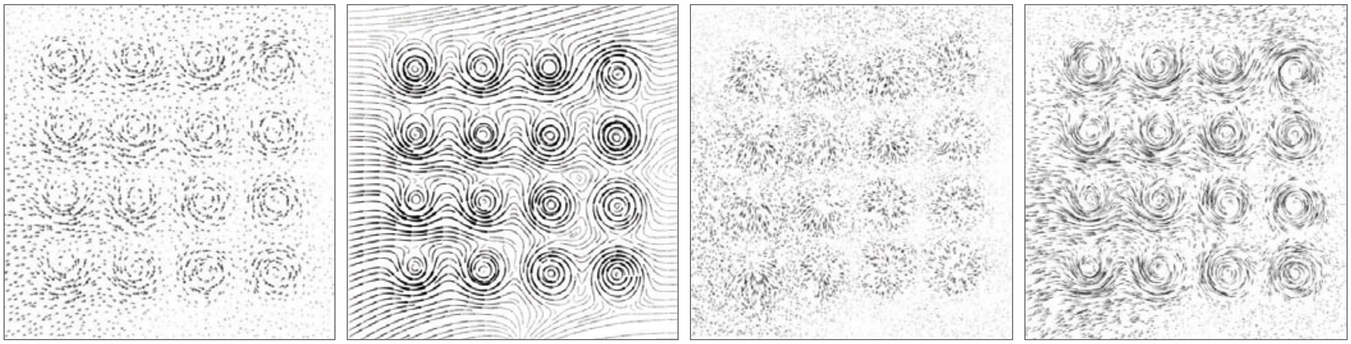


Figure 7-5. Four renderings of rotating patterns. The two on the right were animated. Results show that pattern detection was faster and more accurate with the animated renderings.

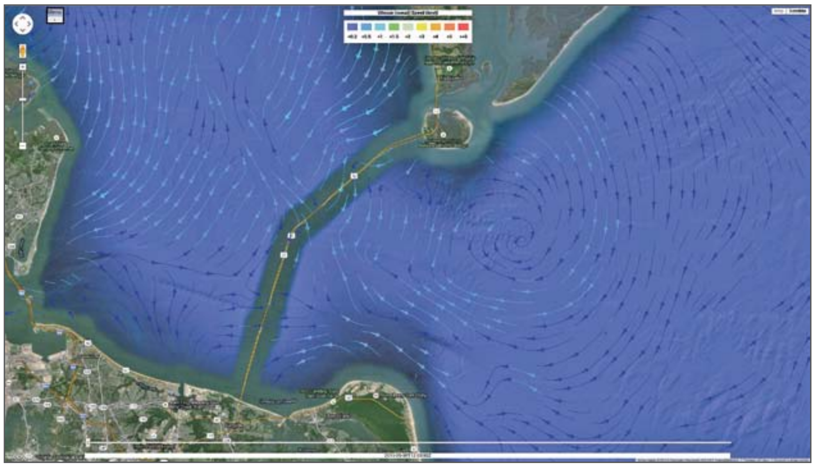


Figure 7-6. Currents from the CBOFS forecast model being displayed as streamlines over Google Maps.

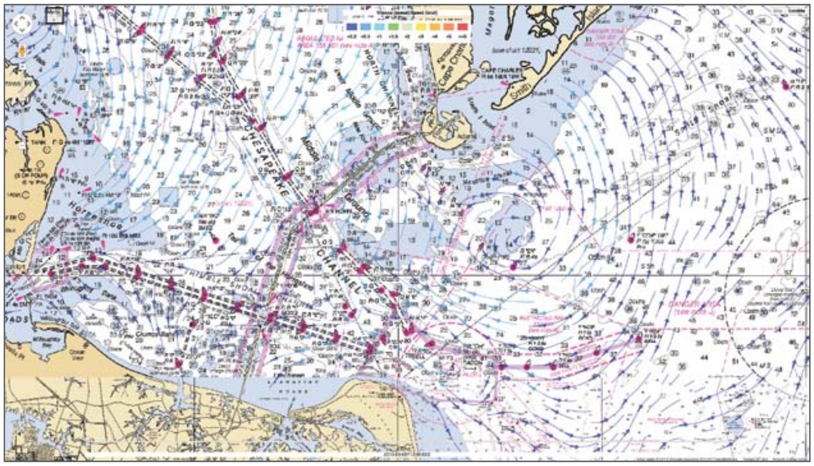


Figure 7-7. Currents from the CBOFS forecast model being displayed as streamlines over a WMS layer of nautical charts from OCS' ENC Direct service.

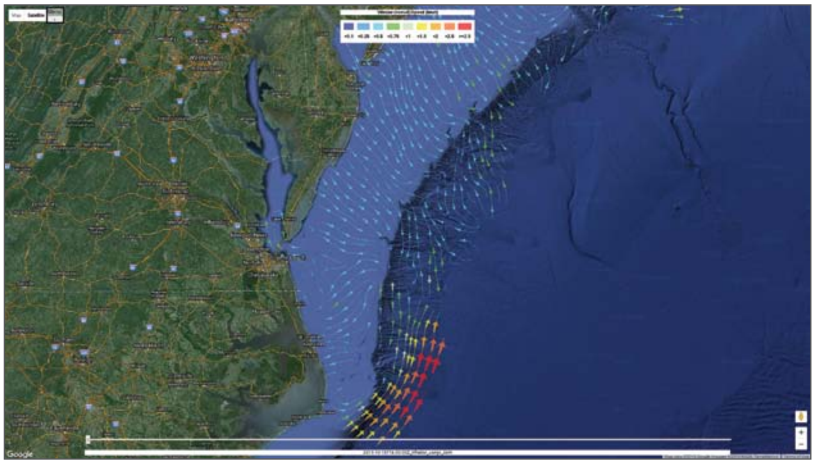


Figure 7-8. Streamlines generated from High Frequency Radar measurements of currents.

A web-based JavaScript implementation of streamlined current visualization has been adapted for use with NOAA's Operational Forecast System (OFS) products. The first target is the model for Chesapeake Bay (CBOFS). The streamlines are displayed as a layer over Google Maps (Figure 7-6). They may also be displayed over a chart layer (Figure 7-7) provided by OCS' ENC Direct service via Web Mapping Service (WMS). The system is being developed to be automatically updated when new forecast models are made available.

As a data source, High Frequency Radar (HFRadar) provides near real time current measurements and the data is available online via OpenDAP. Python scripts are being developed to produce streamlines from HFRadar OpenDAP data. Figure 7-8 shows preliminary results of showing streamlines generated from HFRadar data. HFRadar data is made available in various resolutions with the higher resolutions areas being smaller while the lower resolutions cover a bigger area. This is being used to develop an enhancement to the streamline generating system to support underlying datasets with varying resolutions.

The second line of research is concerned with the need to show wind and current patterns as an animated sequence. Equally spaced streamlines cannot be used for animations, and we use animated particle traces instead. Weather and ocean models are generally saved at every kth time step, where k may represent an interval of one to six hours. For the purposes of data visualization this may be sub-optimal; saving every kth time step may not preserve critical patterns and features. Moreover, if it is important to disseminate weather and current information over wireless channels to portable devices such as cell phones, minimizing the amount of data to be transferred is critical. In a demonstration project with Department of Energy support, 200 days of the UCAR Parallel Ocean Program ocean model flow data have been acquired and used in a surface

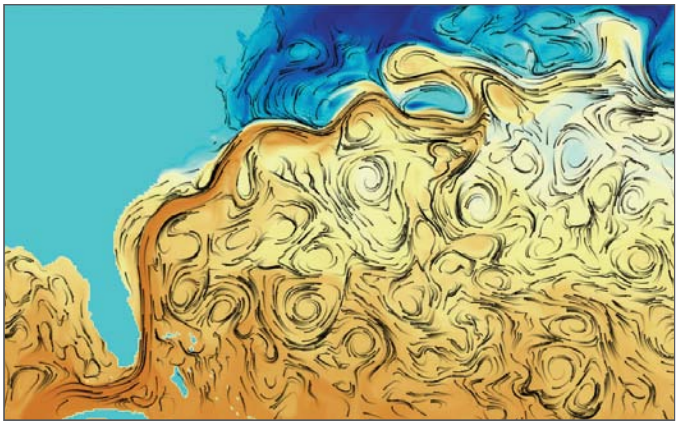


Figure 7-9. Animated Gulf Stream. A frame from an animated sequence from the POP model. It can be replayed with different subsampling schemes.

current visualization using animated streamlines. Figure 7-9 shows a single frame. Different sampling schemes have been implemented; a 27:1 reduction in data using the conventional kth frame method fails to convey the structure of eddy genesis, whereas other sampling schemes can convey it without perceptible loss.

Portrayal of Bathymetric Uncertainty

Ware, in collaboration with Calder, has begun a new initiative to investigate methods for the portrayal of bathymetric uncertainty or risk. Ideally mariners should be able to view both best estimates of bathymetry and any uncertainties and risks associated with it. However, portrayals of uncertainty should not overly interfere with the representation of other chart information. For this reason we have been exploring the use of transparent textures to convey uncertainty. Textures have the advantage that they are not currently used in charting to any significant extent. Textures can be constructed that are see-through and can be overlaid on underlying bathymetry as well as other chart information.

Three possibilities have been identified.

1. Represent uncertainty of chart contours. Uncertainty ranges surrounding contours are represented using bands of texture (Figure 7-10a&c).
2. Represent unsafe areas. Unsafe areas are presented by regions of texture (Figure 7-10b).
3. Represent uncertainty over chart. A sequence of textures is used to represent uncertainty ranges over the entire chart (Figure 7-10d).

In addition to the question of which of the three methods are most useful to the mariner, there is also the design of the texture to be used. Texture has been chosen, instead of color, because it is not currently used to a significant extent either with electronic or paper charts. In addition, textures can be designed which interfere only minimally with other chart information.

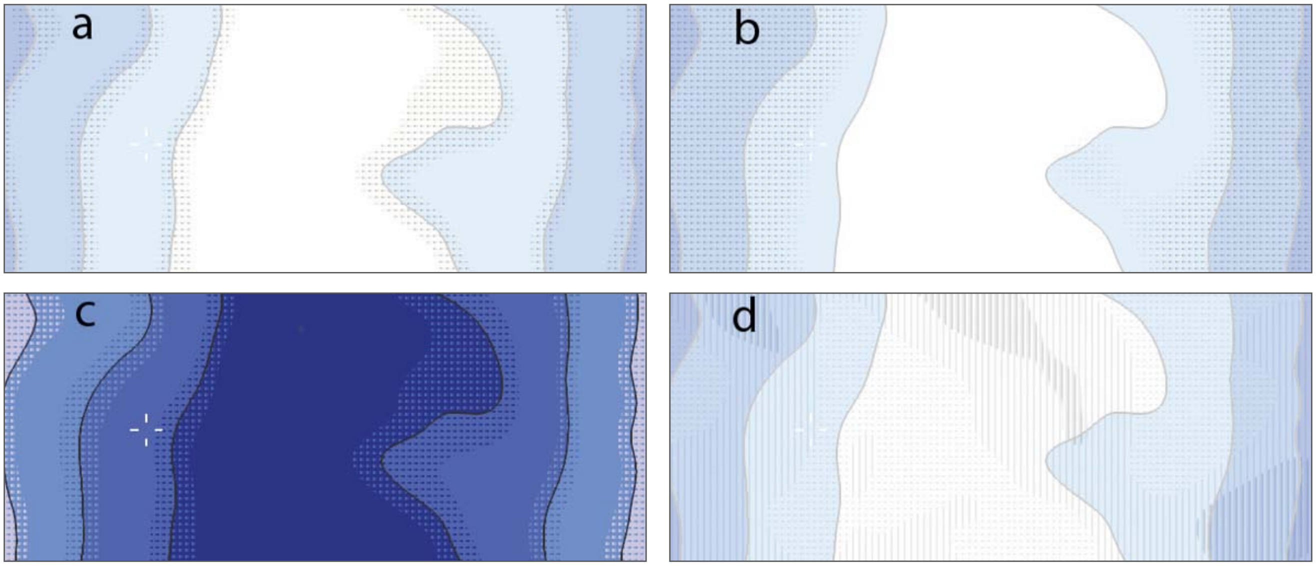


Figure 7-10. Four methods for representing bathymetric uncertainty. (a and c) texture shows uncertainty ranges around contours. (b) texture is used to designate no-go areas. (d) a sequence of textures is used to represent the degree of depth uncertainty over the entire chart.

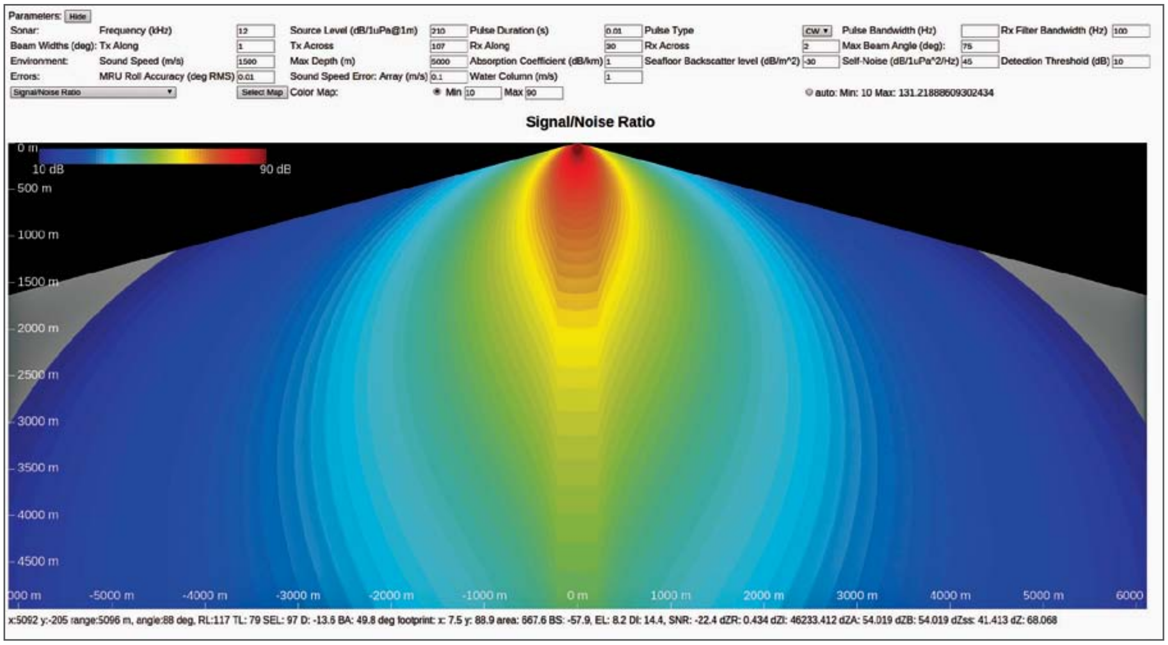


Figure 7-11. New WebGL implementation of Lurton's sonar-equation based multibeam sonar performance tool.

Future work on this project will include the evaluation of alternative schemes by a survey of mariners, as well as the design and evaluation of alternative texture designs.

Multibeam Sonar Performance Visualization

Working in collaboration with Xavier Lurton of IFREMER, Roland Arsenault has developed a HTML5/JavaScript-based portable web-based application that implements Lurton's sonar-equation based model for multibeam sonar performance. The web-based tool allows input of a range of sonar specifications including frequency, source level, pulse duration, pulse type, bandwidth, transmit and receive beam widths, seafloor backscatter level, noise levels, detection threshold, motion sensor accuracy, and sound speed parameters, and produces an interactive graphic output of predicted sonar performance vs. depth and swath width. This tool is similar to that being distributed by the MAC (see MAC discussion under DATA PROCESSING theme), but is web-based and interactive and thus available to a much broader audience, making it an excellent teaching and training tool.

In 2015, an updated version (Figure 11) of the tool has been developed using WebGL to enhance the user experience. In the previous version, the calculations were made in a single CPU thread. This resulted in the browser pausing for many seconds in response to changes in parameters in order to calculate new results. To improve the workflow, the calculations have been move to the GPU, where multiple cores work in parallel to calculate new results. With this new improvement, results appear almost instantaneously when values are modified, encouraging the user to explore the various input parameters.

New tools and Approaches for Interacting with Complex Datasets

Pantograph Multitouch Study

Butkiewicz and Ware previously developed the Pantograph multitouch technique for positioning and selection in stereoscopic 3D environments. It has been used mainly for ocean flow visualization, and is now being added to other 3D interfaces, where it will again be the center of human factors studies. In this application, instead of just positioning and selection, it will be used in a dense 3D dataset to control a 3D opacity lens which highlights its contents while simultaneously fading out surrounding data that would usually obscure the region of interest.

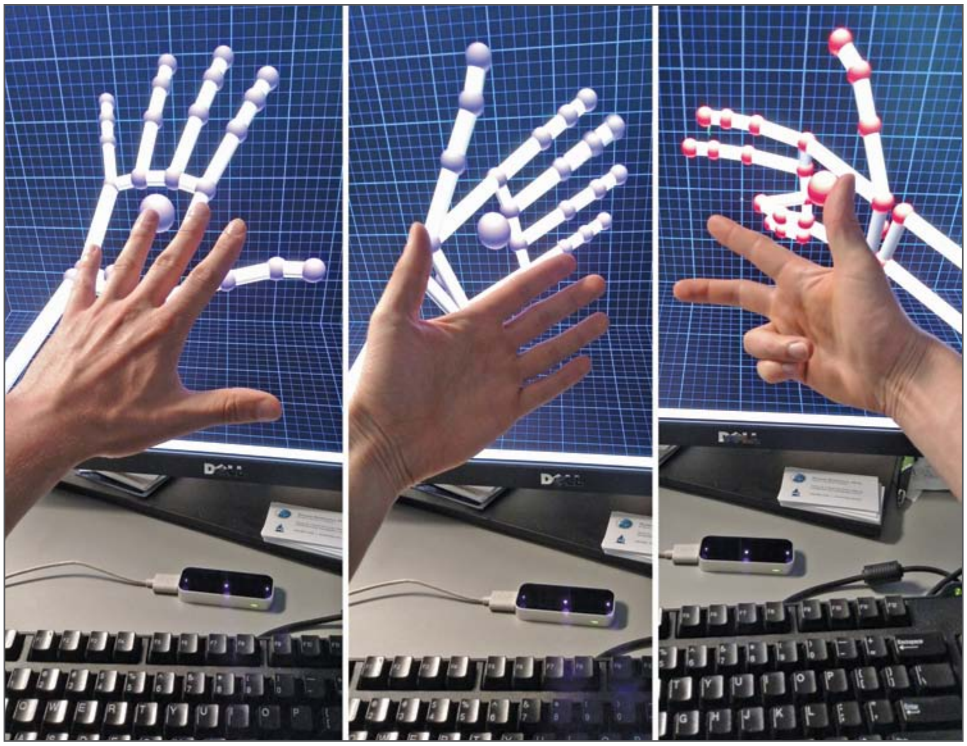


Figure 7-12. Butkiewicz testing the Leap Motion device for hand tracking accuracy.

Natural Hand-Based Interaction for Virtual Test Tank 4D

Butkiewicz has continued to experiment with new human interface technologies for hydrographic visualization, integrating the Leap Motion device into our research visualization environment, VTT4D (see earlier progress reports for discussion of VTT4D). The Leap Motion is an inexpensive ($80) and small (the size of a pack of gum) sensor that uses infrared LEDs and grayscale stereo cameras to image the user's hands. The sensor sits on the table under a user's monitor and tracks their hands in roughly a cubic meter of space. However, since it can only see from below, it can have issues maintaining finger tracking whenever hands obscure them. Butkiewicz addressed this loss of finger-tracking by creating a smaller set of more simplified gestures that are more robustly detected, even when most of the fingers are being obscured.

VTT4D now supports using the Leap Motion device to freely position dye particle emitters within 3D/4D flow models and simulations. The 1m³ tracked space above the device is automatically mapped to the onscreen workspace, allowing the users hands to "reach into" the screen (Figure 7-12), leading to a very intuitive method for positioning dye emitters (Figure 7-13). Another features permits using one's hand as an interactive cutting plane through volumetric 4D datasets (Figure 7-14). Cutting planes have a long history of being an effective method for visualization of 2D slices through 3D contents, however positioning them interactively has always been tricky, as the task requires six degrees-of-freedom. The best solutions often require expensive devices such as Polhemus electromagnetic trackers. Butkiewicz's software ties the cutting plane's position and orientation to the user's right hand, which they can reposition and reorient freely and naturally. The left hand can then be used as a modifying tool to re-size the cutting plane or change display parameters. Future expansion may support more complex parameter adjustment as well, for example adjusting the advection length of 3D tubes that flow outward from the cutting plane along with the flow direction (as in Steven's work).

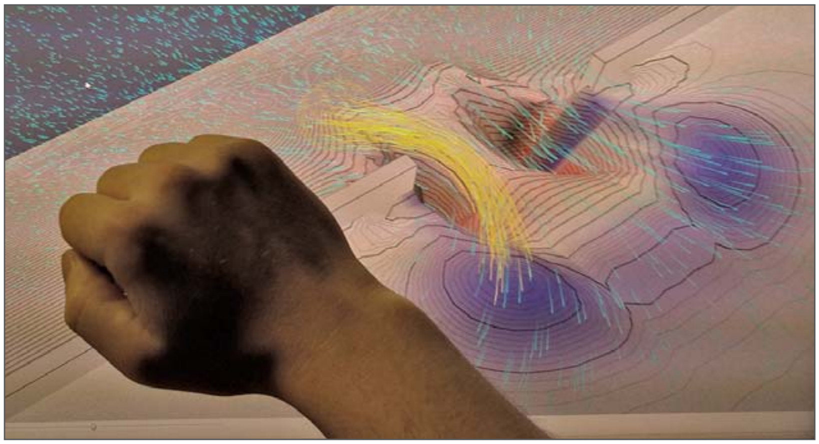


Figure 7-13. Hand based positioning of a spherical dye emitter inside a 4D flow model

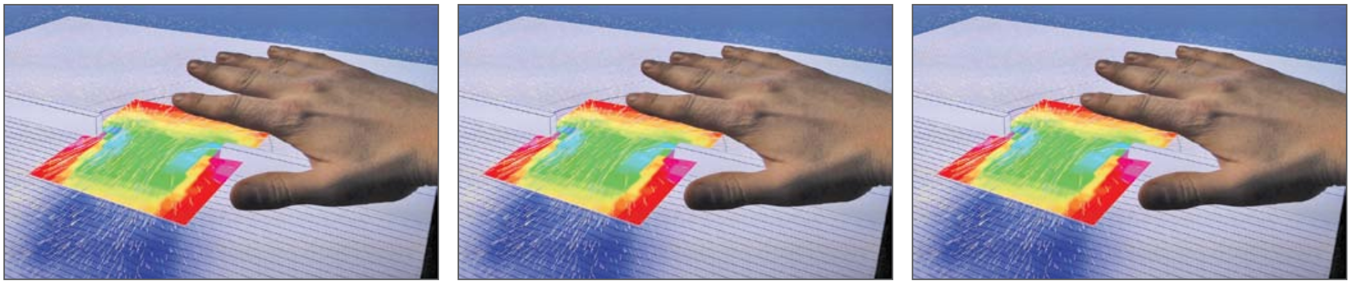


Figure 7-14. Hand based positioning and orientation of a cutting plane within a 4D flow model, with colors indicating flow velocity.

Visualization Tools to Support Super Storm Sandy Research

In support of the work of the Super Storm Sandy Grant team, the visualization lab developed tools to aid in the location and identification of marine debris and to help visualize the impact of Super Storm Sandy.

Marine Debris Visualization

Finding and identifying marine debris is a tedious and time consuming task. Automatic target recognition algorithms greatly speed up the task by searching vast survey datasets for anomalies that could be debris. However, they generate thousands of potential marine debris targets that need to be individually examined. Butkiewicz has developed a pair of tools that speed up and distribute this analytical process: a rapid decision tool and a crowdsourcing website. Together, they can increase analysts' efficiency and decrease disaster response times. The Marine Debris Rapid Decision Tool (MDRDT) automates many of the common and repetitive steps in the marine debris target evaluation workflow. The tool automatically calculates multiple optimal views for each debris target. These optimal views are likely to reveal enough shape information for analysts to make decisions without the need for manually repositioning the camera themselves. These optimal views were also utilized in an experimental crowdsourcing website that invited the public to participate in marine debris target evaluation. We found that, even though participants were untrained and inexperienced in the task, most were able to understand and complete the task with reasonable accuracy. Their collective decisions could be used to greatly reduce the number of marine debris targets that must be evaluated by the limited pool of trained analysts. This could increase analytical capacity in time-critical disaster response situations.

Complete details on our analysis tool, its optimal view algorithms, and the crowdsourcing website design and results can be found in the paper entitled "Streamlining the Evaluation of Potential Marine Debris Targets for Disaster Response," which was published in MTS/IEEE OCEANS'15, Oct 2015 and is available online.

Marine Debris Rapid Decision Tool (MDRDT)

The use of multiple optimal views can save an enormous amount of analyst time. Traditional, single-perspective interfaces require users to repeatedly move

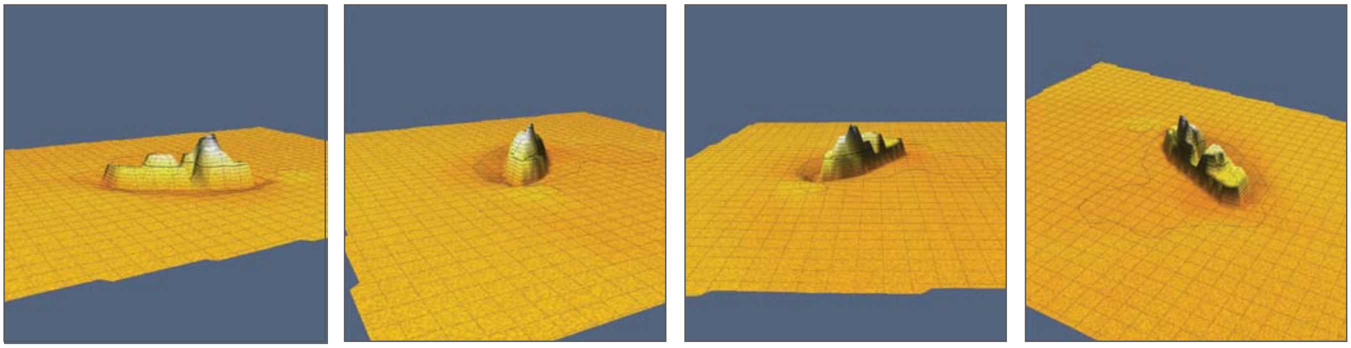


Figure 7-15. The top four views chosen for a debris object mesh of a shipwreck using our optimal view algorithm.

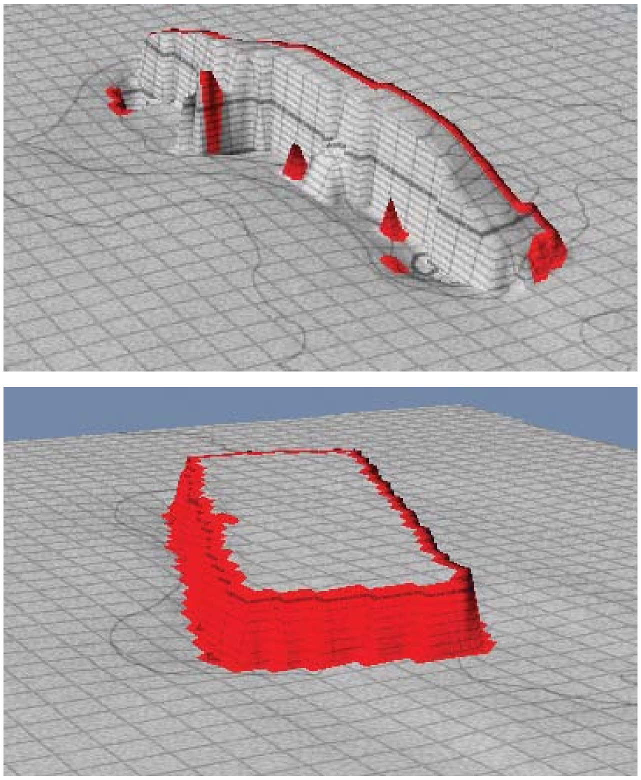


Figure 7-16. In these views of a debris target mesh, the faces highlighted in red have silhouette edges for the current camera viewpoint.

and rotate the camera to view targets from multiple angles. The MDRDT's multiple viewing windows each show different, optimized views of the debris object. If these views are not sufficient, each can be manipulated as necessary, as they are fully-interactive instances of our Virtual Test Tank 4D software.

The multiple optimal views are chosen by calculating how the target will appear as viewed from a wide range of possible camera locations and viewing angles (Figure 7-15). Each view is scored based on how many features it reveals, primarily based on the concept of silhouette edges. In 3D computer graphics, silhouette edges are often used to illustratively emphasize shape features. In bathymetry/terrain models, these silhouette edge often fall along edges of prominent features or objects, where they generally form the boundary between the foreground and the background. This can be seen in in Figure 7-16 (left), which shows faces with silhouette edges along a shipwreck from a single camera viewpoint.

Views producing prominent silhouette edges are likely to reveal the shape of target objects, and the multiple diverse viewpoints ensure all shape information is being revealed. This can be seen in Figure 7-16 (right), which shows the faces with silhouette edges revealed by picking the top four optimal views. Notice that the entire perimeter of the target object has been marked as revealed by the four views, indicating comprehensive depiction of the target's shape.

Analysts can use MDRDT to mark targets as natural features or marine debris, along with confidence levels, including a no-confidence 'unknown' option. By having analysts include uncertainty measures in their decisions, ambiguous targets can be re-displayed for other analysts. The tool records these decisions, confidence levels, and target information into simplified report files. The tool can also render and export the optimal views of entire datasets for use outside the tool, e.g., for web-based analysis.

Crowdsourcing Marine Debris Evaluation or Marine Debris Citizen Science

After a disaster, minimizing response times is critical. While it is best to have trained analysts perform debris identification, their numbers and time are limited. Butkiewicz and Drew Stevens experimented with and evaluated the concept of using crowdsourcing to conduct marine debris identification as method of increasing capacity during times of high demand.

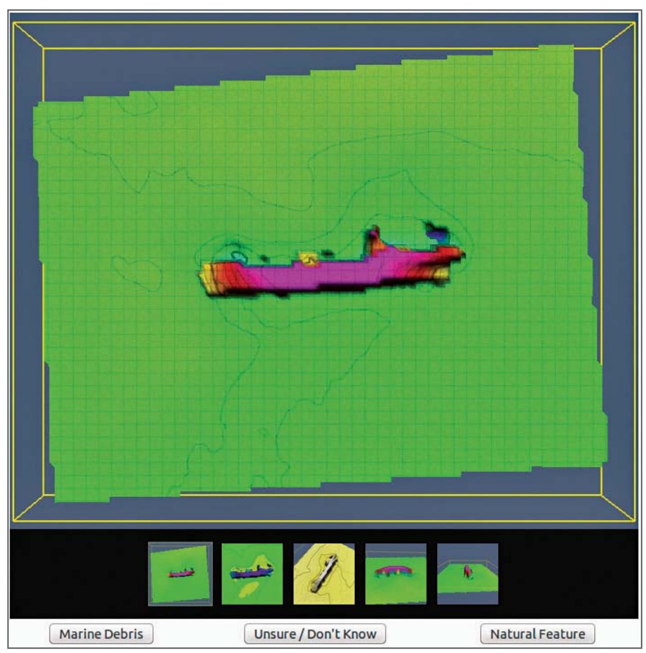


Figure 7-17. A screenshot of the web-based crowdsourcing interface. Users see a single zoomed-in image, and can scroll through or click on the thumbnail images at the bottom to view each of them as many times as needed.

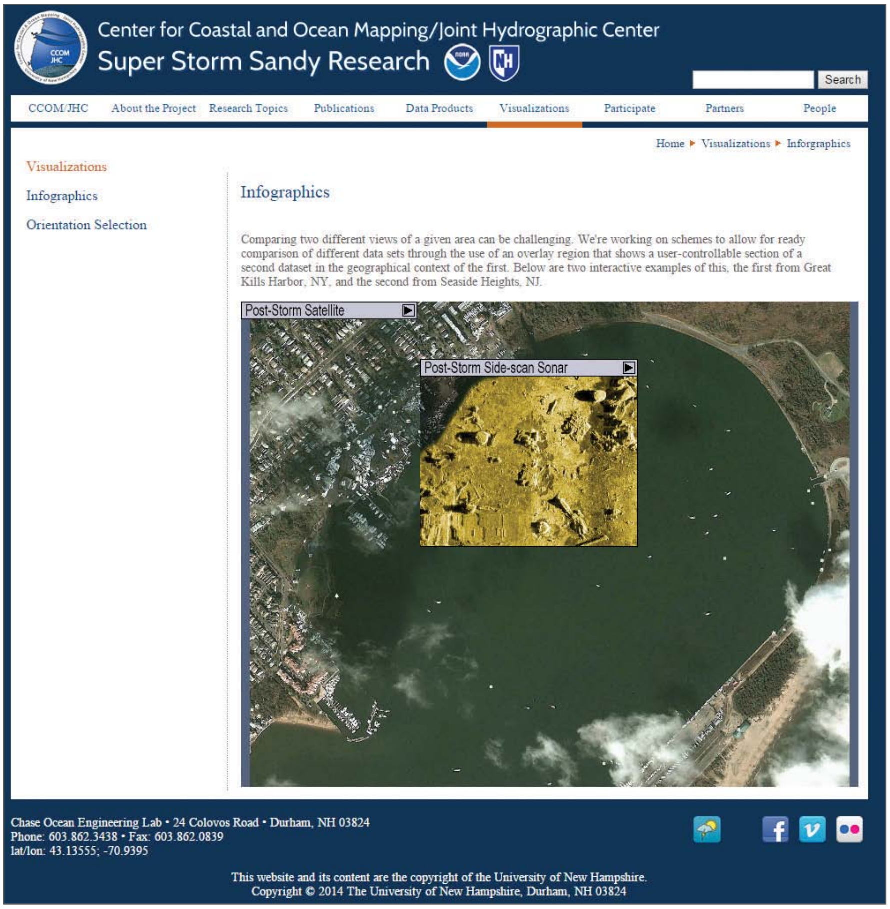


Figure 7-18. The WebLens tool on The Center's Super Storm Sandy website, showing data from Great Kills Harbor, NY.

The general public was invited to conduct debris analyses via an interface on our website, which displays the optimal views generated by the MDRDT (Figure 7-17). While these users have no formal training, if large majorities make the same decision, they are likely to be correct. Even if their decisions are not 100% reliable, they can still be used to filter massive collections of targets into more manageable numbers for re-examination by trained analysts.

The project was advertised through the Center's social media accounts and the University's main webpage. Users were given a brief overview of the project's goals and motivations. They were provided with only the bare minimum of basic directions and examples, enough to ensure they understood the task, but not detailed or in-depth enough to be considered training. A total of 82 targets were available for evaluation via the online interface. To assist in data quality assessment, we included 12 targets whose categorizations were already known, and visually were obviously debris or featureless seafloor.

Over the course of a week, approximately 800 members of the public visited the crowdsourcing site and 34 registered and participated in the project. Additionally, an expert familiar with interpreting hydrographic data evaluated the targets using the same interface, to provide a baseline by which to compare the participants' evaluations. To assess the quality of the data collected from participants, raw percentage agreements between users was calculated as a rough metric of user quality. 73% of targets were agreed upon by a majority of the users who rated them. The inter-rater percentage agreements had a weighted average agreement of 77.4%. Comparing the crowd to the expert's evaluations yielded a weighted average agreement of 78.9%. Furthermore, after using the quality assessment targets to filter out the lower-quality evaluators, agreement with the expert reached 84%, indicating that crowdsourcing marine debris identification is a promising approach for increasing analytical capacity during time-critical disaster response, particularly for filtering and drastically reducing the number of targets that must be evaluated by trained analysts.

WebLens Tool

Further supporting our Super Storm Sandy efforts, Butkiewicz developed a HTML5/WebGL based version of the visualization technique known as the "Magic Lens" (Magic Lens is a Xerox trademark). This tool takes multiple overlapping images and presents them to the user with interactive "lens" tools that allow them to peer between layers simultaneously. Unlike other methods of viewing multiple layers, for example switching back-and-forth or viewing side-by-side, the lens maintains the context between the layers and ensures that changes are noticed because they appear right around the area on which the eye is focused. This tool was utilized with our Super Storm Sandy work, with before and after images of Great Kills Harbor, NY (Figure 7-18) and a series of before, after, demolition, and rebuilding images of the iconic pier in Seaside Heights, NJ (Figure 7-19). Like many of the other tools developed in support of our Super Storm Sandy efforts, there are clear applications in support of hydrography in general. Figure 7-20 shows the ability of the tool to quickly compare backscatter to bathymetry, another important approach to understanding the nature of targets on the seafloor.

Figure 7-19. The WebLens tool showing a series of satellite imagery of the iconic Seaside Heights, NJ pier.

This tool itself was written to be extremely easy for others to utilize on any website to display their own data layers. All that is necessary is to include the single JavaScript file and edit the few lines of provided code to let it know which images you want to use for layers. The code is freely available for use by the Center, NOAA, and the public. A human factors study may be conducted, possibly in collaboration with similar research by Ware, to investigate its ability to maintain context and prevent change-blindness over other more common multi-layer techniques.

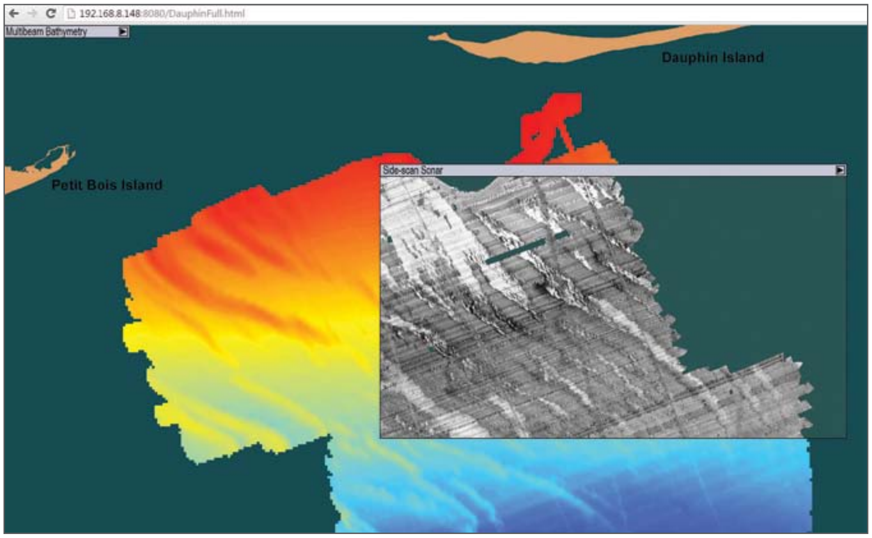


Figure 7-20. The WebLens tool showing multibeam and side-scan sonar data for Dauphin Island (data from USGS).

Theme 6 – Chart of the Future

Developing Innovative Approaches and Concepts for the Electronic Chart of the Future and E-Navigation

The Chart of the Future project is an effort to define the components of the electronic chart of the future by taking advantage of our expertise in visualization, data processing, and navigation. We are taking a two-pronged approach to trying to define the electronic chart of the future. One track of this project is an evolutionary approach to see how additional, non-standard layers (e.g., the navigation surface bathymetric grid, real-time tide information, etc.) can be added to existing electronic charts. This approach requires careful attention to present-day standards and the restrictive constraints of today's electronic charts. This work is being done in conjunction with the standards committees (represented by Center researcher Briana Sullivan) and the electronic chart manufacturers and is intended to provide short-term solutions for the need to see updated electronic charts. In concert with this evolutionary development, we also have a revolutionary development with researchers in our Visualization Lab exploring new paradigms in electronic chart design, unconstrained by existing standards or concepts. This exercise takes full advantage of the psychology-based human-computer interaction expertise of our visualization researchers to explore optimal designs for displays, the role of 3D or 4D flow visualization, stereo, multiple windows, etc. From this research, we hope to establish a new approach to electronic charts that will set the standards for the future. Throughout this project (both the evolutionary and revolutionary efforts), experienced NOAA mariners are playing a key role, ensuring that everything that is developed will be useful and functional.

Evolutionary

An Electronic Chart Display Information System (ECDIS) is no longer a static display of primarily chart-related information. Instead, it has evolved into a decision-support system capable of providing predicted, forecast, and real-time information. To do so, Electronic Nautical Chart (ENC) data is being expanded to include both vertical and time dimensions. Using ENC data produced from high-density hydrographic surveys (e.g., multibeam sonar), a tidal value can be applied to ENC depth areas or contours at arbitrarily fine intervals. The ENC data is not changed, only the display of safe or unsafe water depending on under-keel clearance of the vessel (a parameter set by the ECDIS user) or changes in water levels (e.g., predicted or real-time values). Briana Sullivan and Brian Calder are working with various standards bodies to better understand current constraints and to offer evolutionary suggestions to align the ENC with modern capabilities.

Open Navigation Surface

Efforts continue to standardize formats for the distribution of full-density bathymetric data to be included in ENCs through the Open Navigation Surface Working Group. Brian Calder serves as the Chair of the Open Navigation Surface (ONS) Working Group and as a member of its Architecture Review Board. His role is primarily as facilitator, but he also serves as release manager for the library and keeps the website updated as appropriate. The ONS Working Group has continued to develop the Bathymetric Attributed Grid (BAG) format since its adoption as S-102 in 2012. BAG version 1.5.3 was released 2014-06-07 that provides a more stable release with bug-fixes and the repository has been transitioned (mainly through the efforts of CARIS) from the Center's SubVersion server to a Center-owned, Git-based, BitBucket-hosted, distributed repository. This change in the repository allows for more flexible development and also adds an issue-tracker for bug reporting, and a wiki that can capture information on how to build the code, etc.

In 2014, Calder, in conjunction with Wade Ladner at NAVOCEANO, made a proposal to the Open Navigation Surface Working Group for a variable-resolution extension to the Bathymetric Attributed Grid (BAG) file format. These extensions were modelled after the data structures used in CHRT, and were intended to provide a mechanism to allow for interchange of variable-resolution structured grids between vendors, as well as archival of data.

Following review by the ONSWG Architecture Review Board, the proposal (with minor modifications) was approved for inclusion in BAG, starting with version 1.6 of the library. Calder therefore contributed a concrete implementation of the extensions in a new branch of the source-code library that serves as the reference implementation of the BAG file format. The source-code is undergoing review, and will be merged and released early in 2016.

One difficulty with variable-resolution BAG files is that there is currently a dearth of tools for their manipulation and visualization. Changing to a non-uniform grid entails wholesale replacement of most grid-manipulation toolchains. To assist with this, Calder has been working with Arsenault on the development of a simple, cross-platform 3D visualization environment for variable-resolution BAG files, to be included with the BAG reference library. The tool is still at an early stage of development, but will provide the means for those charged with development and testing of variable-resolution surfaces, and BAG-VR implementations to verify operation (see IMPROVED DATA PROCESSING FLOW under DATA PROCESSING Theme). In addition, Masetti has developed a plug-in for HDF Compass that allows it to open BAG files with some understanding of the internal structure (i.e., rather than as plain HDF-5 data object), which allows the user to verify the structure of BAG files, inspect the metadata, etc. (see discussion of HYDROFFICE under DATA PROCESSING Theme).

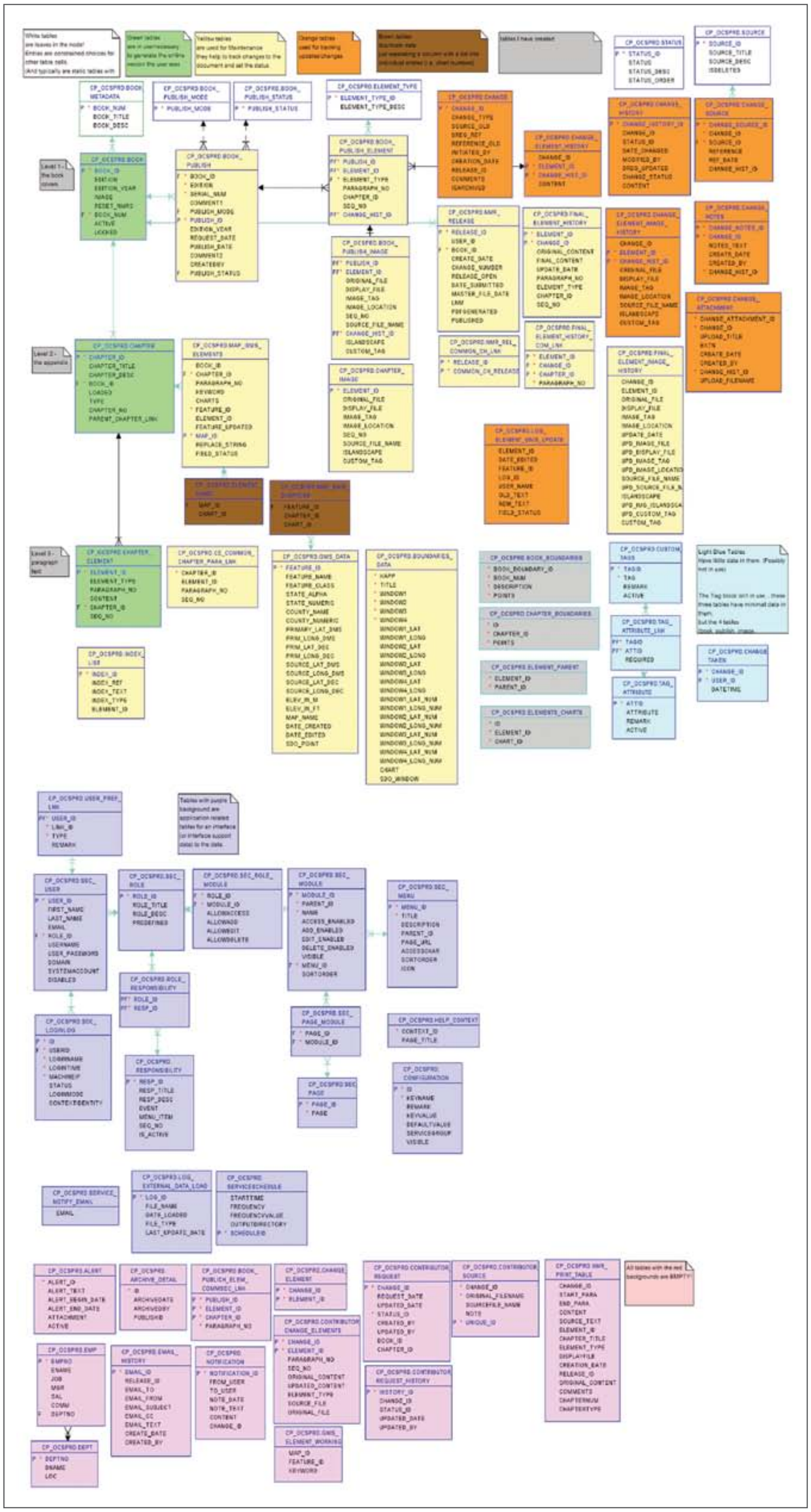


Figure 8-1. Coast Pilot® database color-coded and organized to show structure.

Figure 8-2. Coast Pilot® chapter boundaries.

Coast Pilot Database

In previous years, we have reported on the development of a proof-of-concept of a digital version of the Coast Pilot that provides georeferenced, digital images of coastal features that could be interactively selected to bring one directly to the text description of that target or vice versa—selecting the text describing a feature could bring you directly to an image of that feature. At the end of 2014, Sullivan received a copy of the Oracle database that contains information used to generate the Coast Pilot® publications. Sullivan spent time organizing and analyzing the setup/layout of the database (Figure 8-1) to help illustrate that the database has followed the format of the nautical publication, when it needs to be *data-centric* if it is to be, "higher quality than the sum of its parts," (former NASA engineer Michael Weiss-Malik, talking about Google Maps data). The study of the database inspired a meeting with Tom Loeper (Chief of the Coast Pilot® Branch at the Office of Coast Survey, NOAA) to talk about the next few years of effort with geo-tagging the database. Loeper invited Sullivan to share her insights of the data structure to the Nautical Information Provision Working Group (NIPWG) in June 2015. The goal of her communications at the meeting was not just demonstrating a new data structure, but showing with a proof-of-concept just how Loeper and his team can go from where they are now to the new data structure using all the tools they currently utilize.

Sullivan's work on the prototype started with adding a few new tables to the database and populating them with scripts or by hand, the goal being to give everything a geographic reference. Figure 8-2 shows the chapter boundaries that were added to the database. This is something that the Coast Pilot® branch can use right away and tweak, if necessary. It will also help to serve content that is related to chapters instead of just related to entire books. Tables were also added that assign chart numbers to most paragraphs in the Coast Pilot®. This means that, using the chart boundaries table, data can be served at a more granular level.

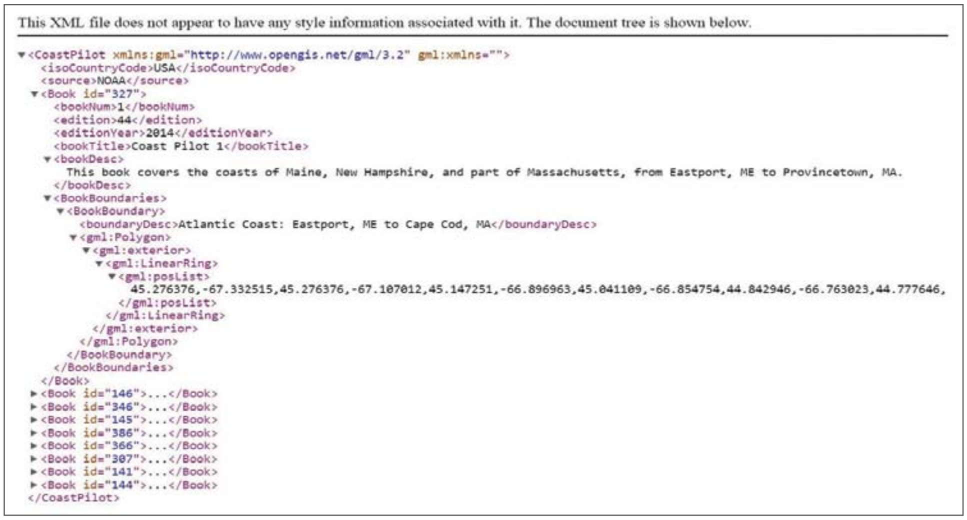

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Figure 8-3. Example XML web service for the Coast Pilot® general info.

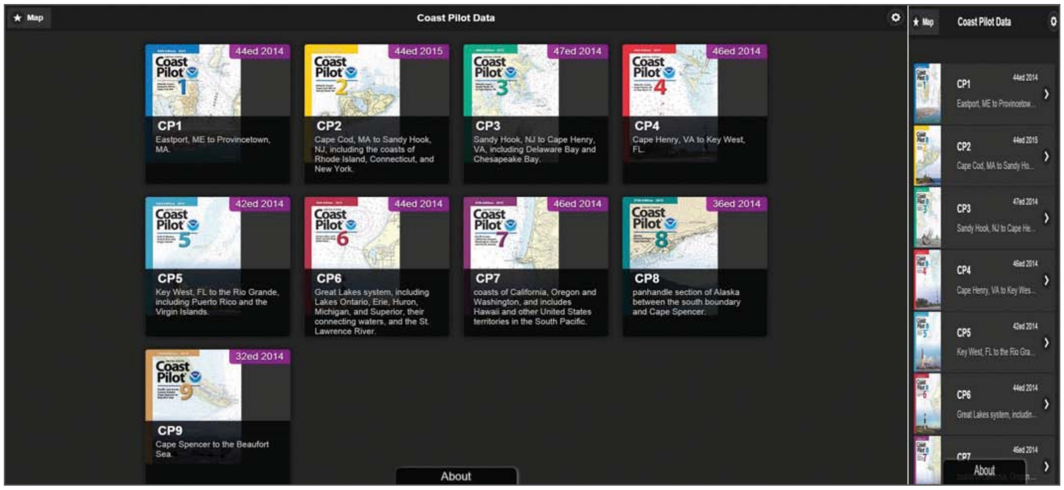

Figure 8-4. Demonstrating jQuery Mobile fluid layout on computer screen (left) and mobile device (right).

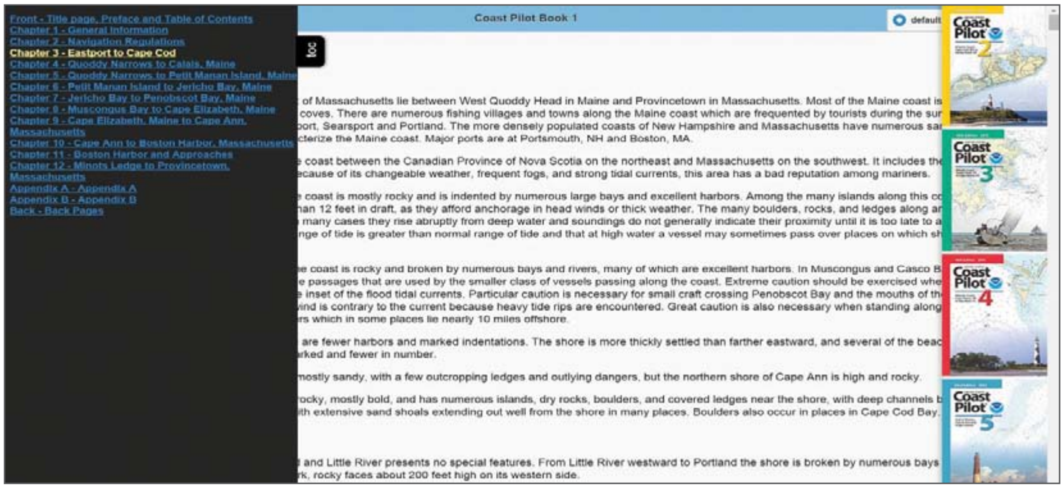

Figure 8-5. Demonstrating jQuery Mobile tabs (hidden when not in use) within text view of chapters for easier navigation.

Sullivan has also worked on creating a prototype web-service that will serve XML data in a new format for Coast Pilot® information at the Book level. This is to illustrate how things could be tagged in a very useful manner for programmers as well as the way to reduce reliance on attributes within tags and incorporate the use of Geographic Markup Language-GML (Figure 8-3). More services will be created that will demonstrate how to search for data within a geographic location.

Sullivan has an initial web-based prototype in place that sets up the Coast Pilot® data from the database using jQuery mobile's fluid layout (Figure 8-4) to demonstrate how things can be ready for any device/any platform using the same code. Another part of the prototype involves a more efficient way to navigate within the text-based layout (Figure 8-5) as well as accessing the Coast Pilot® data in a geo-referenced environment with user location geo-enabled (blue dot in Figure 8-6). Figure 8-6 demonstrates how the data, when tagged with chart numbers, will only be available when the associated chart boundary is within the viewport of the screen. Ideally, the future objective is to have each item geo-referenced so as to filter out even more data.

Sullivan has also been experimenting with Natural Language Processing techniques to see how much data she can extract from, and mark-up in, the Coast Pilot data in an automated way. The goal is to pick out features from the text, associate them with ENC (electronic nautical chart) features as well as data about the same features from various locations on the internet. Having spent a significant amount of time researching the Resource Description Framework (RDF) and the semantic

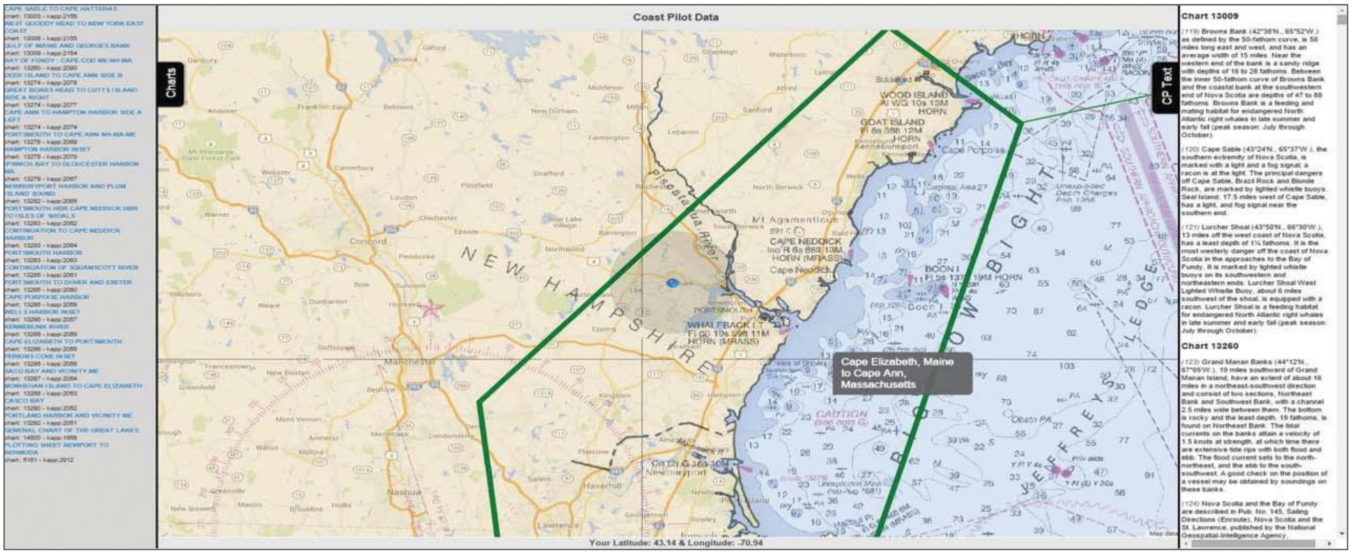

Figure 8-6. Coast Pilot® data in a geo-referenced environment.

web during this reporting period, she feels this could be the "intelligent" direction for nautical publications in the future. RDF is a way to represent data as a connected graph. Using triples made up of an object, a predicate and a subject allows statements to be made about resources. These connected graphs will maintain relationships that exist between features (or resources). The ultimate goal is to use this technology to merge multiple datasets and follow the theme of the IOCM "mark-up once, use many times…in many domains."

S-111 Product Specification

Sullivan has also spent a significant portion of her time from January through April working closely with Carl Kammerer on a revised version of the S-111 (Surface Currents) Product Specification that was put into the latest S-100 template. Together they managed to clean up and present to the Surface Currents Working Group the updated version, which was well received by all at their last meeting in Tokyo. Sullivan also spent time on

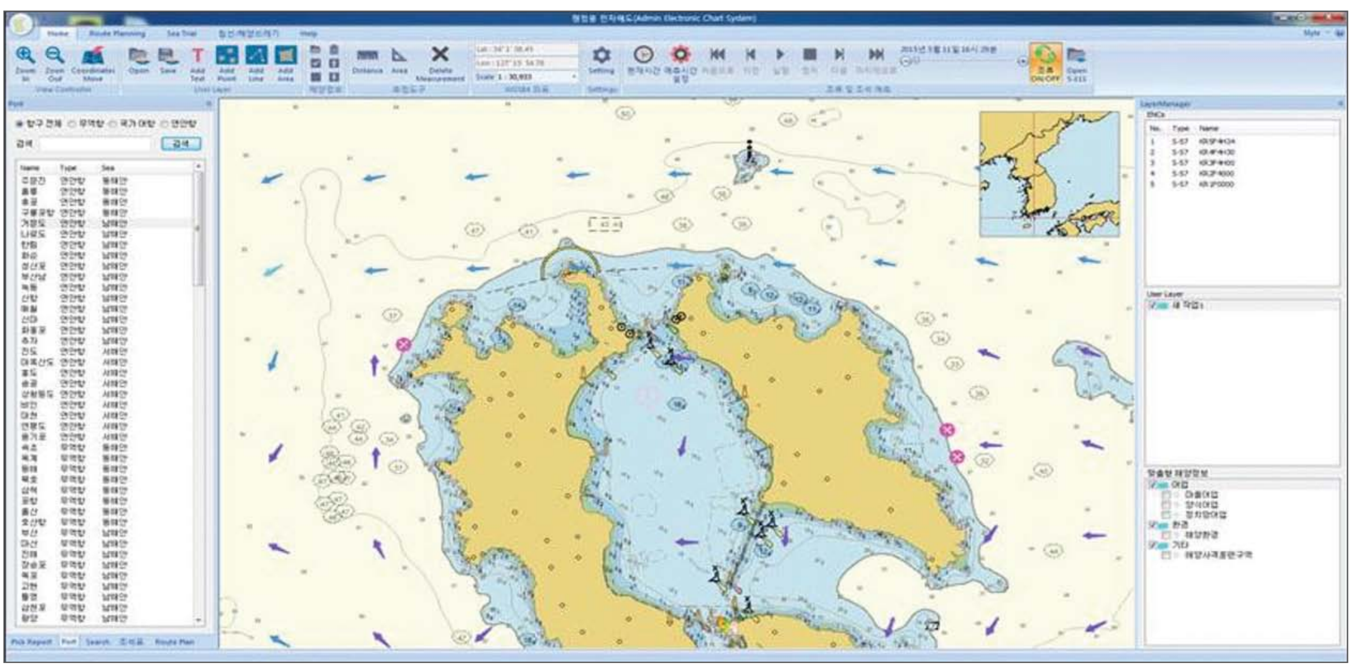

Figure 8-7. Korean implementation of UNH suggested arrow design.

the Portrayal Section of the document and saw working prototypes from both Korea (Figure 8-7) and SPAWAR developed as a result of her write up.

In collaboration with the VisLab and an NGA contractor, Sullivan has been working on the task items
assigned by the SCWG (Surface Currents Working Group) to determine the proper thinning algorithm for arrow density at various zoom levels as well as investigating maximum vector size and scaling information. Recommendations have been submitted to the SCWG chair for addition to the agenda for the Tides, Water level and Currents Working Group (TWCWG) meeting next year when the SCWG will merge with the TWLWG (Tides and Water Levels Working Group).

Sullivan was also able to demonstrate a proof-of-concept use of the S-100 required Scalable Vector Graphic (SVG) element as a dynamic arrow (Figure 8-8) that the S-111 product specification could use and gave it to SPAWAR for use in their prototype of the Electric Nautical Charting system.

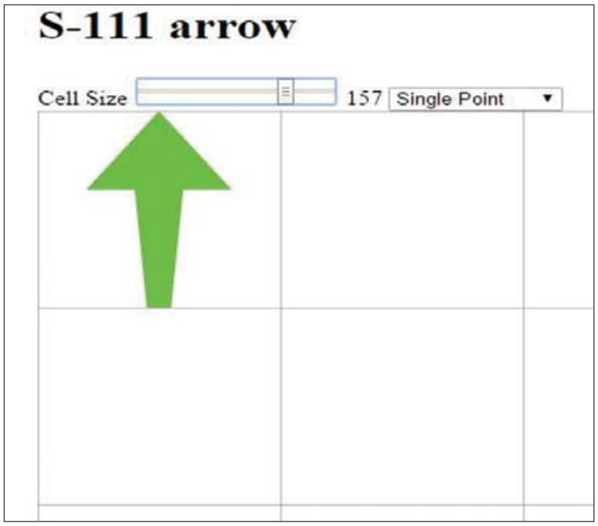

Figure 8-8. Demonstration of dynamic SVG arrow. Cell size slider changes the arrow size and arrow color changes depending on size.

The use of SVG in the S-100 standard has opened the doors to possible animation of the surface currents sooner than expected.

Research to Operation Weather/Currents Display

Following up on the work done in the Visualization Lab to develop optimal displays of weather and current information (see **VISUALIZATION** theme) Capt. Shep Smith and Rick Brennan are continuing their effort to connect with their contact at Rose Point (makers of the Coastal Explorer software) who will be willing to work with the Vislab to use their platform for our weather displays. Sullivan has begun the process of looking at Open CPN as an alternative. Colin Ware also has contacts at KitWare that we are hoping to utilize for this project. Another avenue we are pursuing is the
HFRadar group, with Greg Dusek, and porting our code to create images for the surface current streamlines as a first step. Ideally, we would prefer the streamlines generated and rendered locally, but displaying them will at least be a step in the right direction.

Revolutionary

Within the context of the “revolutionary” effort, Colin Ware, Tom Butkiewicz, Matt Plumlee, Briana Sullivan and Roland Arsenault have been developing specific visualization applications for the Chart of the Future. This year’s efforts are still more within the research realm and can be found described under the **VISUALIZATION** theme.

Theme 7 – Law of the Sea

Being National Leaders in the Planning, Acquisition, Processing, Analysis and Interpretation of Bathymetric Data Collected in Support of a Potential Submission by the U.S. for an Extended Continental Shelf Under Article 76 of the United Nations Convention on the Law of the Sea

Growing recognition that the implementation of United Nations Convention on the Law of the Sea (UNCLOS) Article 76 could confer sovereign rights to resources over large areas of the seabed beyond our current 200 nautical mile (nm) Exclusive Economic Zone has renewed interest in the potential for U.S. accession to the Law of the Sea Treaty. In this context, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding the nation's EEZ with emphasis on determining their usefulness for substantiating the extension of resource or other national jurisdictions beyond the present 200 nm limit. This report was submitted to Congress on 31 May 2002.

Following up on the recommendations made in the UNH study, the Center has been funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than 2.45 million square kilometers of new high-resolution multibeam sonar data on 28 cruises including eight in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, two in the Gulf of Alaska, two on the Necker Ridge area off Hawaii, three off Kingman Reef and Palmyra Atoll, four in the Marianas region, and two on Mendocino Fracture Zone (Figure 9-1). Summaries of each of these cruises can be found in previous progress reports and detailed descriptions and access to the data and derivative products can be found at **http://www.ccom.unh.edu/law_of_the_sea.html**. The raw data and derived grids are also provided to the National Geophysical Data Center and other public repositories within months of data collection and will provide a wealth of information for scientific studies for years to come.

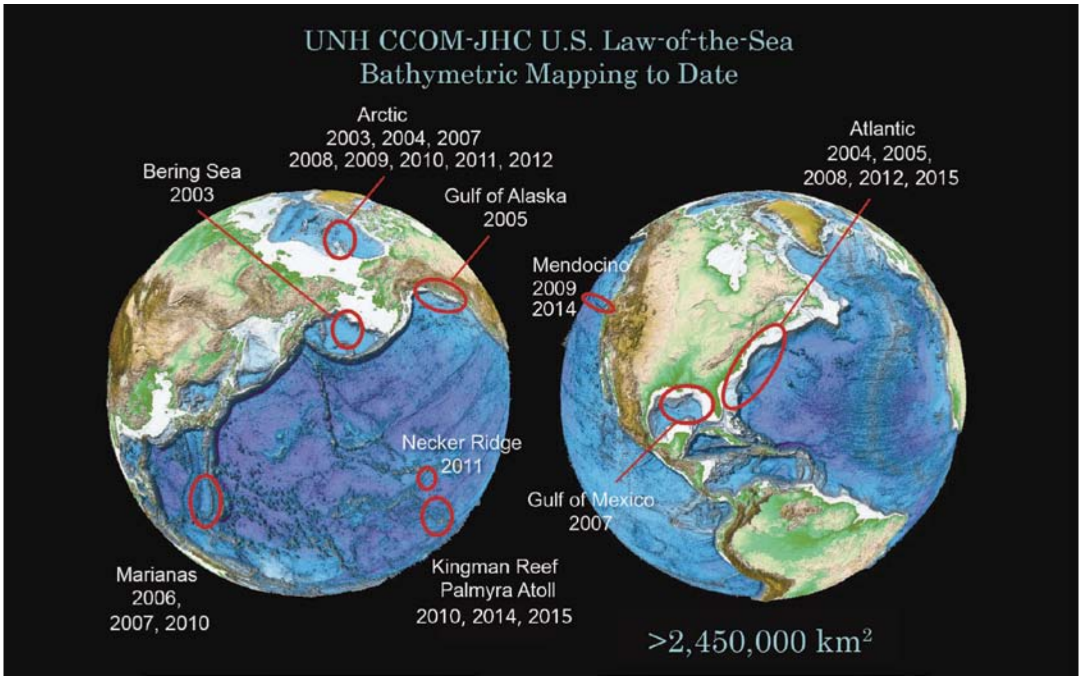

Figure 9-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center. To date, more than 2.45 million square km of data have been collected.

2015 Law of the Sea Activities

Two ECS cruises were competed in 2015; one completing our mapping of the Atlantic aboard the R/V *Langseth* and the second a return to the Kingman/Palmyra region on board the R/V *Kilo Moana*.

U.S. Atlantic Margin

In 2015, a 30-day cruise designed to complete all ECS bathymetry needs for the U.S. Atlantic margin was planned and organized by Jim Gardner, with Brian Calder serving as the chief scientist during the cruise. The objective of the cruise was to map the lower margin out to 350 nm from the coastline in an area that stretches southeast of Delaware to the U.S.-Canadian boundary. The cruise used the R/V *Marcus G. Langseth* of the Lamont-Doherty Earth Observatory at Columbia University, departing New York City on 30 July 2014 and returning to Woods Hole, MA on 29 August 2015. The *Langseth* was equipped with a Kongsberg Maritime EM122 multibeam echosounder, a Knudsen 3260 Chirp subbottom profiler and a Bell BGM-3 gravity meter. All systems performed to expectations during the cruise with 157,166 sq. km of high-resolution multibeam bathymetry and backscatter collected over the 30-day cruise (Figure 9-2). Post-cruise, Jim Gardner and Paul Johnson archived data (both at the Center and NCEI/Boulder), generated metadata and created derivative products from the data.

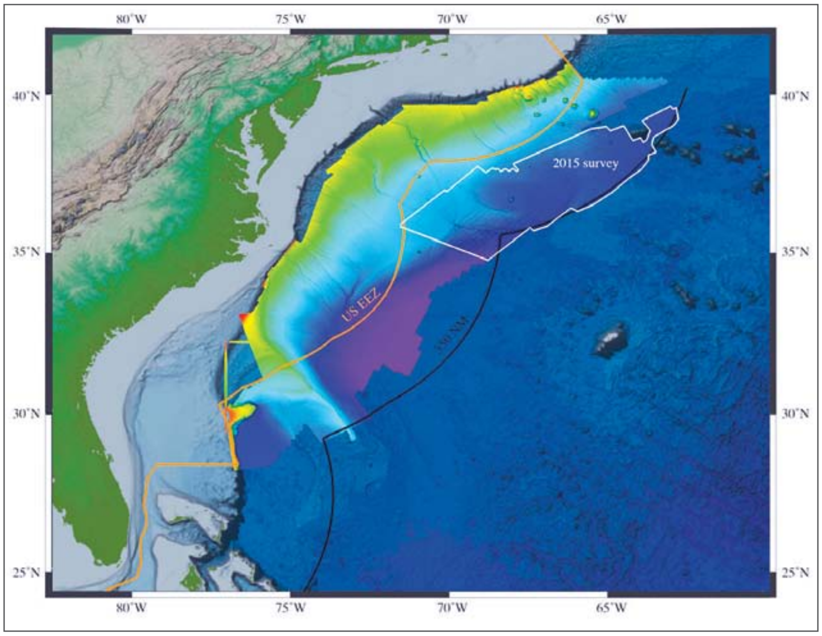

Figure 9-2. 2015 *Langseth* survey added on to previous ECS data.

The processed data from the cruise reveal an astonishing amount of subtle down-slope movement that has occurred, or is occurring, on the distal reaches of the U.S. Atlantic margin. Figure 9-3a is an example that shows a large area of flat, almost featureless bathymetry in ~5500m of water. Figure 9-3b shows the acoustic backscatter of the same area. The backscatter documents the intricate pattern of anastomosing pathways of downslope transport of material to the Sohm Abyssal Plain to the immediate southeast. The high-backscatter material in Figure 9-3b shows how sediment is deflected to the southeast by a ridge (white arrows in Figure 9-3a) that rises 20 m on the northeast side and drops 40 m on the southwest side. The height of the ridge decreases to the southeast but a second ridge (red arrows on Figure 9-3a) rises ~100 m and together the two ridges have created a funnel that has redirected the high-backscatter sediment (in the middle of the map) to the south towards the Sohm Abyssal Plain.

Kingman Reef-Palmyra Atoll, Central Equatorial Pacific

The second 2015 ECS cruise, also organized and planned by Jim Gardner, was a 30-day ECS bathymetric mapping cruise to the Kingman Reef-Palmyra Atoll area of the central Equatorial Pacific (Figure 9-4). The cruise used the University of Hawaii's R/V *Kilo Moana* equipped with the same suite of equipment as the *Langseth*—a Kongsberg Maritime EM122 multibeam echosounder, Knudsen 3260 Chirp subbottom profiler and Bell BGM-3 gravity meter. Brian Calder again served as chief scientist, with the *Kilo Moana* departing Honolulu on 20 November and returning to the same port on 20 December. The cruise objectives were to map the northern extent of the Line Islands platform, a broad feature that rises as much as 1000 m above the adjacent deep-sea floor (white area shallower than 5150 m in Figures 9-3 and 9-4). Over the 30-day cruise, 164,200 sq. km of high-resolution multibeam sonar and backscatter data were collected (Figure 9-4). Inasmuch as the cruise only just returned at the time of writing this report, results will be presented in the next progress report.

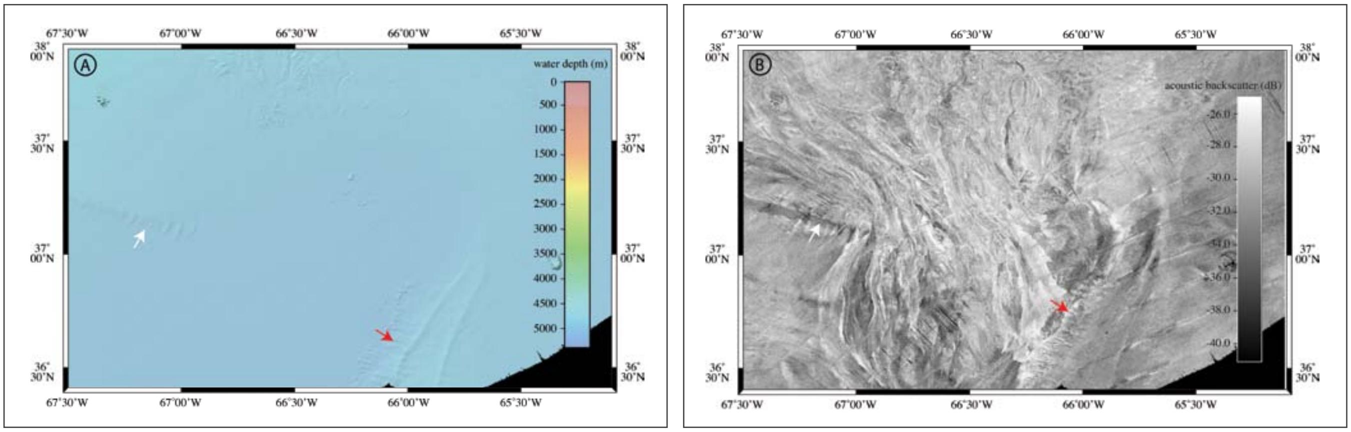

Figure 9-3. (A) Multibeam bathymetry of area on the distal reaches of the U.S. Atlantic margin. (B) Multibeam acoustic backscatter of same area. White arrow shows location of ridge. Location shown in Figure 9-2.

Other ECS Activities

In 2015, a new faculty member, David Mosher, joined the Center faculty and has become an important member of our ECS team (starting to fill in for Jim Gardner as he moves towards retirement). Since arriving, David has successfully acquired two software donations for seismic data processing and seismic data interpretation from Schlumberger Geophysical (Vista) and IHS (Kingdom Suite), respectively. The estimated value of these donations exceeds $100K. Seismic data are a fundamental component for defining the outer limits of the continental margin in an Extended Continental Shelf submission under article 76 of the Law of the Sea. They are necessary for establishing sediment thickness and sediment continuity in establishing the Gardiner formula and they are necessary as supporting evidence in establishment of the base of the continental slope and the foot of the continental slope.

Mosher is also continuing his basic research aimed at understanding geologic processes in the Arctic and along the Atlantic continental margins. Knowledge of the geology in these regions supports Extended Continental Shelf mapping efforts by providing the tectonic and geologic framework that underpins a coastal State's arguments and for defining the specific elements mentioned above. As the Arctic in particular is extremely poorly known, new data sets in this region are only now being interpreted in this context.

The Center ECS Team (Armstrong, Gardner, Mayer, and Mosher) have spent much time analyzing ECS data and participating in ECS meetings and reviews including meetings of Integrated Regional Teams (IRTs)—Armstrong chairs the Arctic IRT, Mayer chairs the Atlantic IRT, and Gardner is the bathymetry expert on five of the six IRTs. Numerous Extended Continental Shelf (ECS) conference calls, video conferences and specific IRT calls occurred throughout the year. Monthly ECS Working Group conference calls were scheduled to review

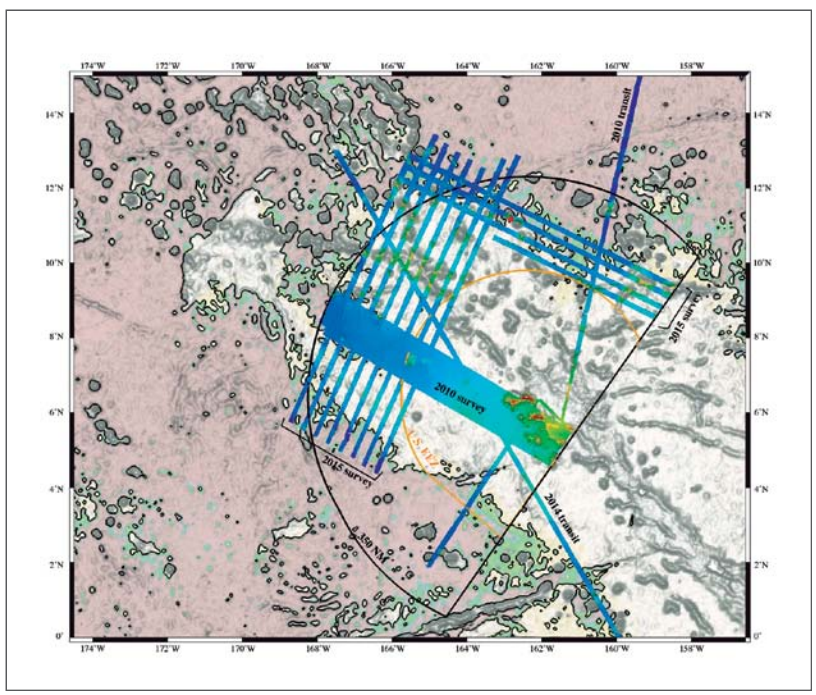

Figure 9-4. Base map of bathymetry of Kingman Reef-Palmyra Atoll area (GMRT, 2015) with overlay of legacy multibeam bathymetry (blue NNE-SSW lines) and JHC/CCOM 2010 and 2015 multibeam data (large blue NW-SE area and blue NE-SW lines). Black contour is 5150 m isobath.

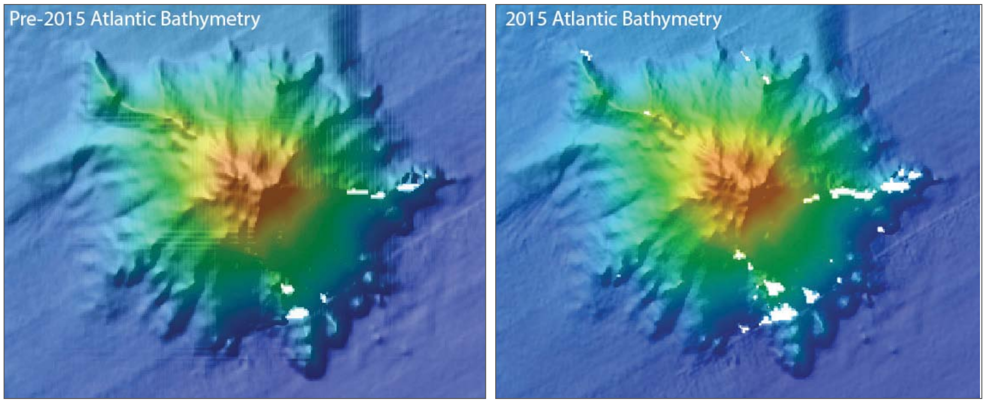

Figure 9-5. Examples of the original Atlantic bathymetry (left) and post 2015 reprocessed version (right). Notice the apparent gridding artifacts on the steep slopes of the seamounts.

overall ECS progress as well as unscheduled phone calls and video conferences to discuss specific IRT details. There was also a week-long review session for all IRTs in Boulder, and two meetings with external experts, one in Breckenridge and one in San Francisco.

As discussed in the Data Management section of the DATA PROCESSING theme, Paul Johnson has done much to upgrade our database capabilities and, working with Jim Gardner, has added data and capabilities to our Law of the Sea database and website. Along with the ongoing process of entering all new data into the database and assuring metadata standards are met, during the spring and fall of 2015, Gardner and Johnson began the process of regenerating the bathymetry and backscatter grids for each of the Center's Law of the Sea survey sites. This large undertaking was driven by the desire to improve and validate each site's grids. Small gridding artifacts had been recognized in earlier versions of some grids (see Figure 9-5); to eliminate these, as well as to validate each grid from every site, all grids were regenerated.

An audit was conducted to confirm that all files that had been acquired and processed for each site were in fact contributing to their respective grids. Following this, each site's bathymetry and backscatter grid were regenerated and then rigorously inspected for any potential gridding issues (see Figure 9-6). As part of the grid validation, track-line navigation from each contributing file was extracted and processed to generate a GIS shapefile which, in turn, was used to verify that the full inventory of files had indeed been used to generate the grid. Each newly generated grid was then compared to the already existing grid to verify the new grid for both completeness and quality. Metadata for each grid was then updated to reflect any changes made since the creation of the original metadata record.

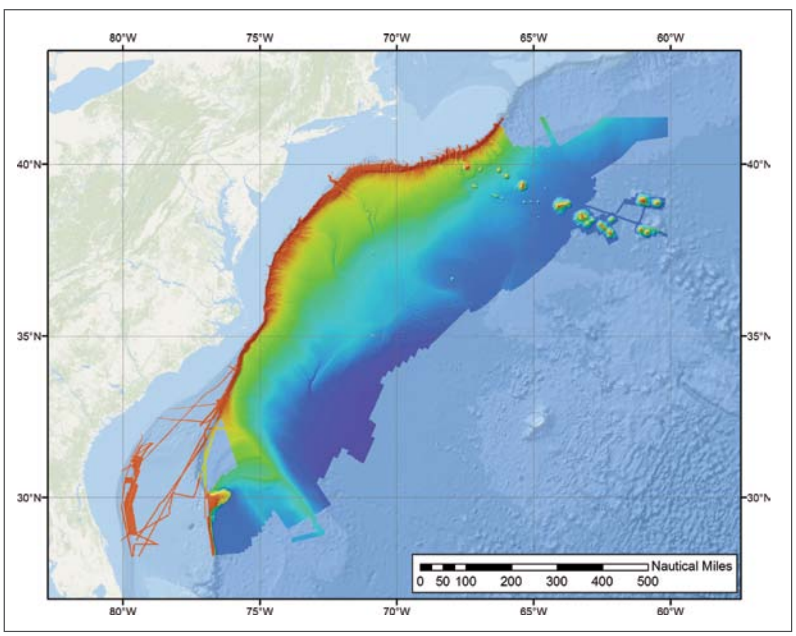

Figure 9-6. Atlantic Extended Continental Shelf bathymetry grid. This grid is a synthesis of the Center's LOTs surveys fused with bathymetry collected by the NOAA Ship *Okeanos Explorer.*

Three separate downloadable products were then generated for each new grid, a Fledermaus SD grid file, an ESRI ArcGIS grid file, and an ASCII file. These files were bundled with the metadata file for the grid and then zipped into a single file for distribution. Final ESRI grid files are currently being loaded on to the Center's GIS server for use by users within the lab or by those interacting with the Center's dynamic map webpages (see DATA MANAGEMENT discussion).

Extended Use of ECS Data

Demonstrating the value of the ECS multibeam sonar data beyond the establishment of an extended continental shelf, Jim Gardner and the rest of the Center's Law of the Sea team have been involved in writing peer-reviewed journal articles and we have begun a new research effort aimed specifically at looking at the potential of ECS data to be used for regional habitat studies.

In 2015, Jim published a manuscript, Gardner, Armstrong and Calder, 2015, Hatteras Transverse Canyon, Hatteras Outer Ridge and environs of the U.S. Atlantic margin: A View from Multibeam Bathymetry and Backscatter, *Marine Geology*, v. 371, p. 18-32, that documents the geomorphology of a unique feature of the U.S. Atlantic margin and the area that surrounds it (Figure 9-7). Hatteras Transverse Canyon strikes parallel, not perpendicular, to the regional isobaths because of a large sediment-drift barrier, Hatteras Outer Ridge. The canyon is presently blocked by landslide deposits that rise at more than 20 m above the channel floor. Landslide headwall scarps are found along walls that are the remnants of the walls that collapsed.

The multibeam backscatter data shows a ~6500 km^2 area to the immediate west of HTC with anomalously high values (Figure 9-8b). The high-backscatter area is roughly confined between the 4600 and 5150 m isobaths (Figure 9-8a). Typical backscatter values outside this anomalous region range from -36 to -30 dB whereas within the anomalous area backscatter values are -28 to -25 dB. Long (~50 km), low (<15 m) linear ridges that strike N20˚E, 60˚ to the regional slope occur only within the high backscatter area (white arrowheads in Figure 9-8). This region has been previously referred to as hummocky terrain that resulted from a slump, blocky slide debris, mud waves, or an old landslide draped by hemipelagic sediment. Water depths of the high-backscatter area coincide with the lower depth range of the effects from the Western Boundary Undercurrent which suggests that the area is a region of outcrops with only a very thin sediment cover most likely because of relatively recent erosion by the West Boundary Undercurrent.

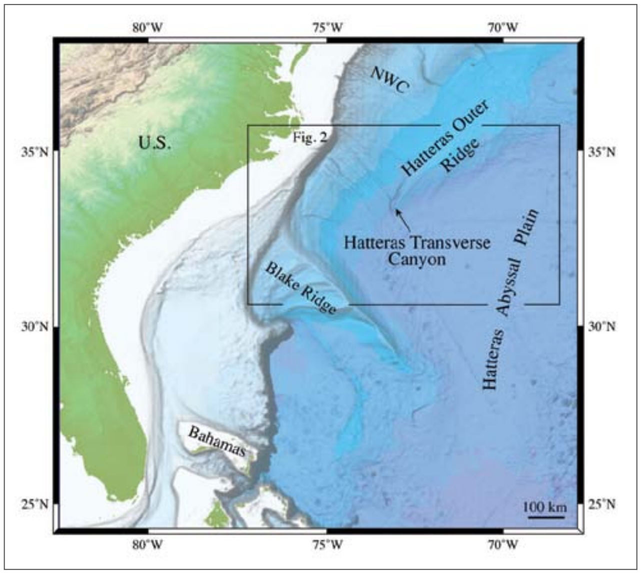

Figure 9-7. Location map of Hatteras Transverse Canyon and environs.

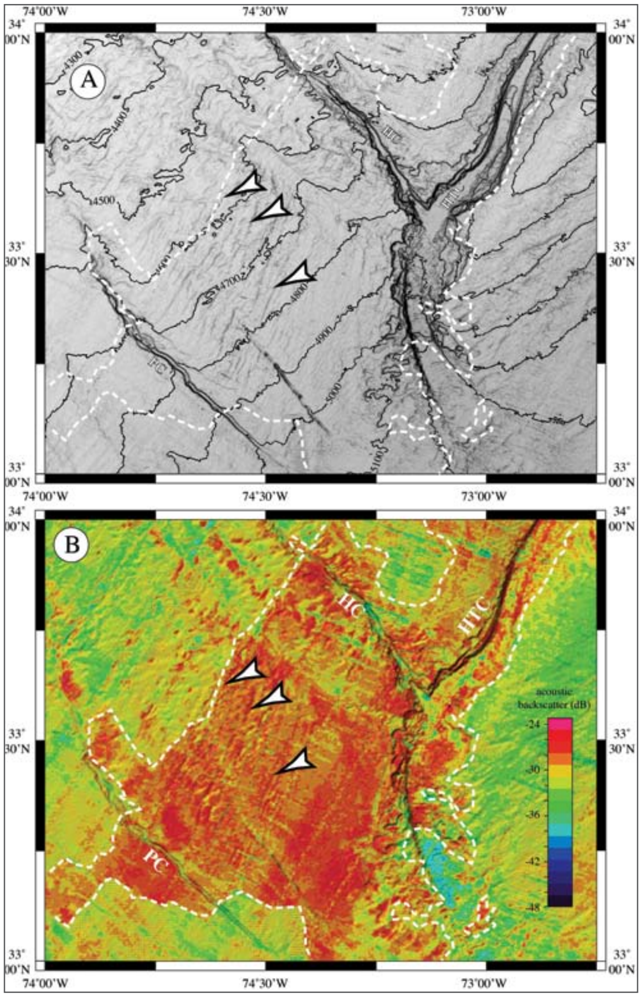

Figure 9-8. Area within and immediately west of Hatteras Transverse Canyon (HTC) with anomalously high backscatter.

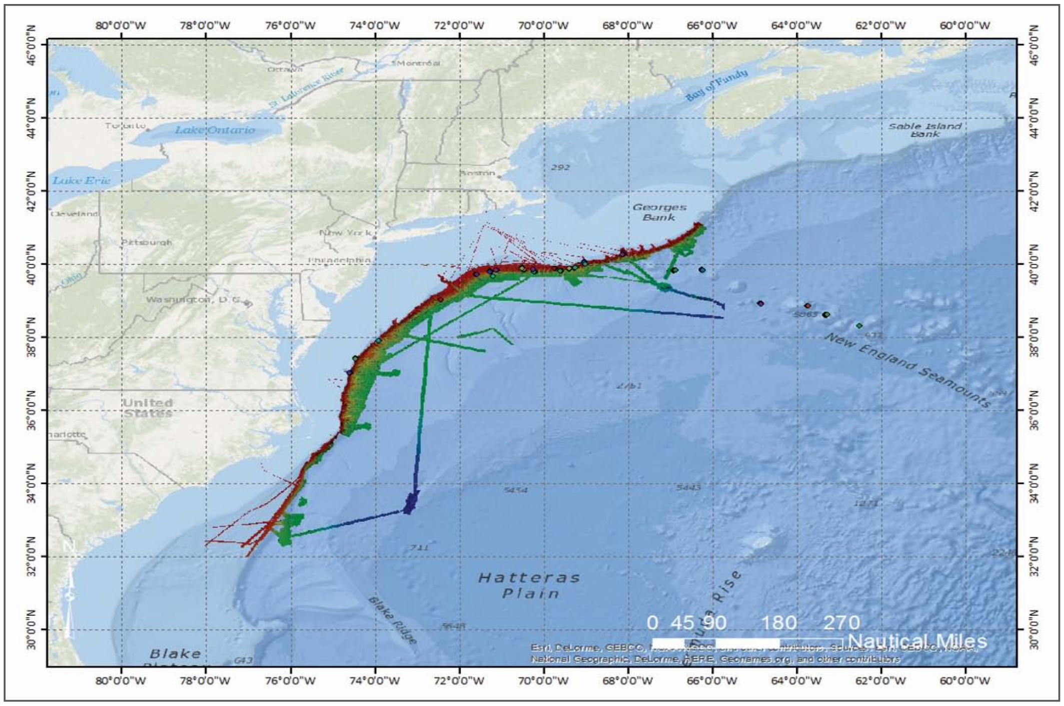

Figure 9-9. Map of deep sea sites used for analysis. White box indicates site of Washington Canyon.

A second paper published in 2015, Armstrong, Mayer and Gardner, 2015, Seamounts, Submarine Channels, and New Discoveries: Benefits of Continental Shelf Surveys Extend Beyond Defining the Limits of the Shelf, Journal of Ocean Technology, v. 10, p. 114, provides a brief review of all the areas the Center Law of the Sea team has mapped in the 12 years of the project. The paper highlights features mapped in the Bering Sea, Arctic Ocean, Northwest Atlantic Ocean, Gulf of Alaska, western Pacific around the U.S. Territory of Guam and the Commonwealth of the Northern Mariana Islands, eastern and central Pacific. The paper emphasizes the importance the team has placed on using multibeam systems that are correctly integrated with supporting sensors such as high-quality global navigation satellite systems, top-quality inertial motion units, and continuous surface sound speed monitors. The importance of careful system calibrations prior to each cruise and quality-control checks during each cruise to ensure the highest-quality data was also emphasized. And finally, the paper points out that perhaps the most significant aspect of the program is that all the data are archived at the NOAA National Centers for Environmental Information (formerly the National Geophysical Data Center) and are made publicly available within six months of data acquisition. This open-access to the data has prompted several additional mapping projects and scientific investigations and represents a gold mine for the next generation of marine scientists to study the deep ocean floor.

Finally, Mosher published a paper and was an invited keynote speaker at a conference on submarine landslides. His specific topic on the paper and the lecture concerned the role of submarine landslides in extended continental shelf mapping. He addressed the issue via five case-studies of coastal States for which recommendations from the Commission on the Limits of the Continental Shelf have been rendered and for which submarine landslides were successfully utilized to establish foot of the continental slope positions. It was the first time that this information was presented in a public forum as a refereed publication. Public recognition of these precedent-setting decisions is critical for future ECS deliberations.

Use of ECS Data for Broad-Scale Habitat Mapping

Graduate student Derek Sowers, under the supervision of Larry Mayer, has been investigating the potential of using the data collected in support of ECS studies for broad-scale habitat mapping. His initial focus has been the ECS data collected along the Atlantic Margin, where large amounts of ancillary data (images, core samples, ecological studies) already exist. These datasets include multibeam sonar from eight Center cruises conducted for the U.S. Atlantic ECS work and six exploration cruises of the Northeast Atlantic canyons by the NOAA vessel *Okeanos Explorer*. Other datasets evaluated include biological samples, video, and photos previously collected for the region and archived in data repositories such as the usSEABED database, GeoMapApp, and the National Geodatabase of Deep Sea Coral Observations.

In 2015, Sowers coordinated closely with Jenn Dijkstra and Kristen Mello to stay informed on their work interpreting and annotating high resolution video data collected by *Okeanos Explorer* ROVs during dives on features in the Atlantic Canyons and New England Seamounts regions This video interpretation work is providing important ground truth information to be compared with multibeam sonar bathymetry and backscatter data (see below). Sowers also helped to ensure that Dijkstra and Mello had access to utilize a newly-developed research tool that NOAA OER's Mashkoor Malik created to support improved analysis and annotation of ROV video. After reviewing data available throughout the U.S. Atlantic continental margin study region, Sowers selected Veatch Canyon as a pilot study area and coordinated with Dijkstra and Mello to ensure that they were analyzing *Okeanos* ROV dive videos located within the pilot area. Sowers refined workflow methodologies for using existing datasets to classify geoform and substrate components of his study region using the Coastal and Marine Ecological Classification Standard (CMECS). Applying these workflows to the pilot study area is the current focus of the research effort.

Sowers has also been designated to represent NOAA OER on the federal inter-agency Coastal and Marine Classification System (CMECS) Implementation Group. Sowers is working with this group to promote the adoption and application of a standardized "common language" of marine habitats across government agencies and management jurisdictions. Sowers developed a vision statement defining how CMECS implementation can be carried out through the work of OER and is leading efforts to specifically integrate CMECS classification units into exploration missions conducted by the *Okeanos Explorer* during the 2016 field season.

Analyzing ECS Video Data for Habitat Identification

As a first step towards mapping and characterizing deep-sea benthic habitats, Mello and Dijkstra have focused on the Atlantic Continental Margin. The ultimate goal of the project is two-fold. First, these data will provide valuable information on the densities of species assemblages, including essential fish habitats such as corals, along a latitudinal gradient and among different seafloor features (canyons, seamounts, and seeps). Second, these data will be correlated to substrate type and integrated with multibeam backscatter products that will support Sowers' work on the use of backscatter for seafloor and habitat characterization.

Mello and Dijkstra have identified sites of video analysis and have in hand the ROV video data of each site. This includes three seeps, six seamounts and nine canyons; a total of 18 sites. These sites span a range of substrate

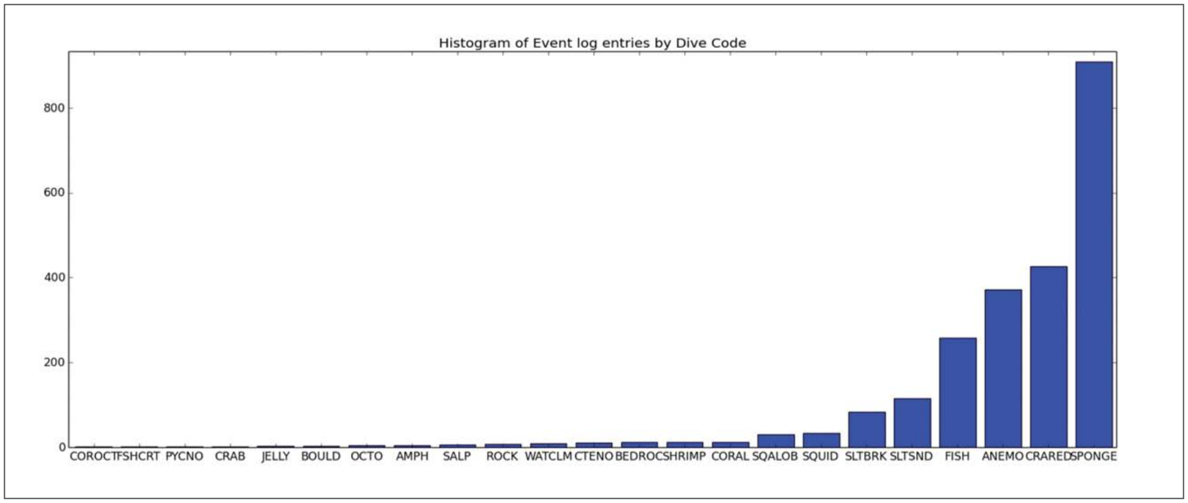

Figure 9-10. Frequency of occurrence of species or groups of species that were observed along the ROV track in Washington Canyon.

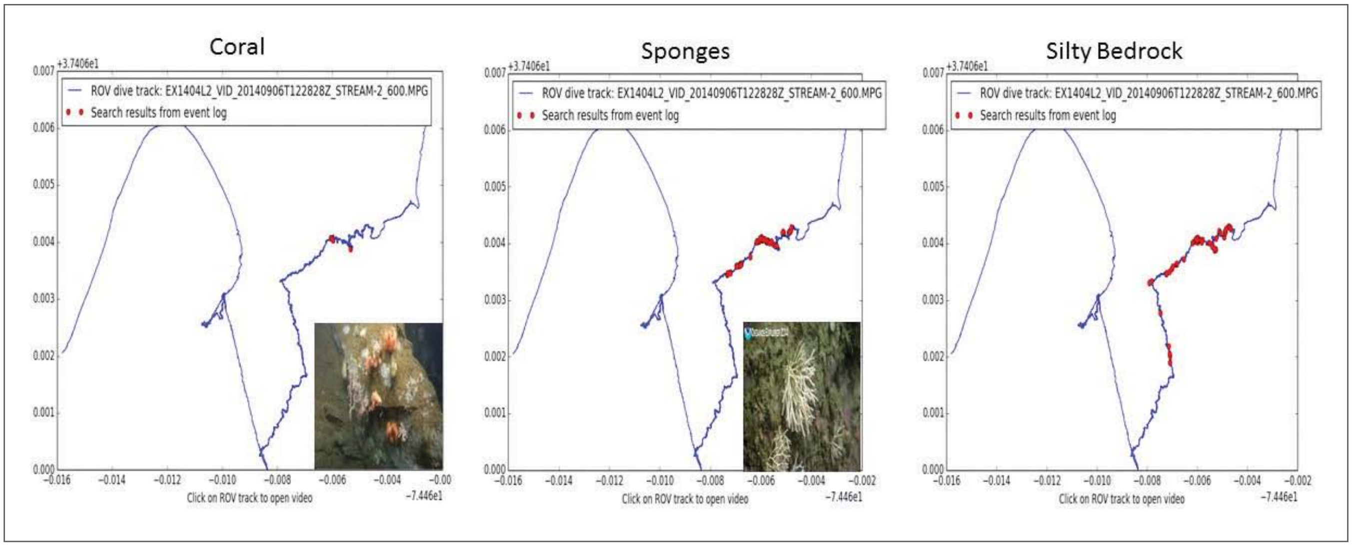

Figure 9-11. Distribution of sponges (left image) and sediments (right image) along the Washington Canyon ROV track.

types and coral cover. Dijkstra and Mello have created an ArcGIS project using 100m resolution bathymetry as the backdrop and have imported the ROV transects from four cruises (EX1304L1, EX1304L2, EX1404L2, EX1404L3; Figure 9-9). Mello has created a catalog of coral and other species for ease of species identification. This catalog will be continually improved upon with new species added as they are identified on the ROV video.

In the current reporting period, Mello and Dijkstra collaborated with NOAA's Ocean Exploration (OER) group (Mashkoor Malik, Lindsey McKenna, Derek Sowers and Meme Loebecker) to coordinate our efforts for ROV video analysis. The OER team has developed an ROV data analyzer tool that we are modifying for our own purposes. This tool can perform a number of functions. The first function allows the user to plot species distribution patterns along a ROV transect using the event log that was created during the original cruise. The event log is a file that contains the date, time (HH:MM:SS.SSS), time in seconds since the Unix epoch (1970-01-01/0000), latitude and longitude (decimal degrees), depth, altitude, and any sighted species. The second function allows the user to plot the frequency of species occurrence along an entire ROV transect (Figure 9-10). The third function allows the user to create their own event log. Using this event log, we can then plot species distribution along a ROV transect (Figure 9-11).

Mello has modified the existing OER tool in order to increase the number of species or groups of species that can be added to the event log and we have added substrate types. Mello is currently using this modified tool to create event logs for each ROV transect and has completed an event log for Washington Canyon. The classification scheme, as much as possible, is following the Coastal and Marine Classification System (CMECS) developed by NOAA.

As an initial step towards video analysis, Mello analyzed species assemblages and substrate type for the Washington Canyon data using two methods. The first method involved analysis of the entire area observed by the ROV. Using this method provides a good overview of species distribution, but does not allow for quantifying densities of individuals or species. The second method involves analysis of the ROV transect in which the lasers mounted on the ROV are visible on the computer screen. This type of analysis will allow Dijkstra and Mello to determine densities of organisms on the seafloor for comparisons of species assemblages among substrate types and along a transect. The lasers are mounted 10 cm apart and Mello analyzed three times the width of the mounted lasers (30 cm). This was done as 10 cm is too small a width to get an accurate assessment of species assemblages. Dijkstra and Mello intend to compare these two methods to determine if the analysis of 30 cm is sufficient for the examination of species assemblages along the ROV transect (i.e., do we need to analyze a wider area (e.g., 60 cm) in order for the resultant data to be representative of the area).

Outreach

In addition to our research efforts, we also recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those that ultimately fund our work. We also recognize the importance of engaging young people in our activities so as to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have upgraded our web presence and expanded our outreach activities and staff (Tara Hicks Johnson, an experienced outreach specialist joined our staff in 2011). Tara now coordinates Center activities with UNH Media Relations to collaborate on Center-related news releases and media events and has begun working with NOAA media personnel to prepare releases that feature Center faculty. The Center continues to attract significant media attention. A partial list of media reports on Center activities is provided below:

2015-02-12	QINSy and Fledermaus Training Provided as Part of Industrial Partnership	*QPS News*
2015-03-06	NOAA Hydro Officers Honored	*NOAA's Coast Survey Blog*
2015-03-17	Hill Library SeaPerch Teams Visit UNH	*Foster's Daily Democrat*
2015-04-22	7 Things We've Learned About Earth Since the Last Earth Day	*Vox*
2015-05-10	The Unknown America	*60 Minutes*
2015-06-01	NOAA Represents U.S. in Atlantic Ocean Research Alliance Mapping Survey	NOAA
2015-06-03	Atlantic Ocean Research Alliance Launches Trans-Atlantic Mapping Survey	*Scientists@Sea*
2015-06-05	High-Tech Mapping Sheds New Light on the Atlantic Seafloor	*National Geographic*
2015-07-23	Avoiding Rock Bottom: How Landsat Aids Nautical Charting	NASA Landsat Science
2015-07-28	All American Marine Wins Research Vessel Contract	*MarineLog*
2015-07-28	New Research Vessel for University of New Hampshire	*MarineLink*
2015-07-28	New Research Vessel for University of New Hampshire	*Marine Technology News*
2015-08-04	All American Marine to Build New UNH Research Vessel	*Subsea World News*
2015-08-15	Keeping False Pass True	NASA's Earth Observatory
2015-08-24	Press Release: Shaheen Applauds Ocean Research Grant to University of New Hampshire	Senator Jeanne Shaheen's Office
2015-08-24	UNH Receives $6M Grant for Ocean Mapping	*Foster's Daily Democrat*
2015-08-26	On Top of the World	*UNH Today*
2015-09-02	Deep-Sea Exploration off Hawaii Reveals Strange Creatures	*CBS News*
2015-09-03	NOAA Exploration Offers Front-Row Seats to Hawaii's Bizarre Deep-Sea Ecosystems	*Huffington Post*
2015-09-03	Deep Sea Creature Stuns Explorers	CNN
2015-10-02	UNH Hosts Free Ocean Discovery Day Oct. 17	*Foster's Daily Democrat*
2015-10-17	Discovering an Ocean of Knowledge	*Foster's Daily Democrat*
2015-10-29	Ocean Day Makes a Splash at UNH	*The New Hampshire*
2015-11-05	Change of Command for NOAA Ship *Ferdinand Hassler*	*NOAA's Coast Survey Blog*

Outreach Events

The facilities at the Center provide a wonderful opportunity to engage students and the public in the types of research that we do. In 2015, the Center provided individual tours for almost 800 students and individuals from a number schools and organizations (see list below):

150 students	Oyster River Middle School 8th Grade
150 students	Hillside Middle School
22 students	Sacred Heart School
110 students	Barrington Middle School
30 students	Immaculate Conception Catholic School
30 students	Hampstead Academy
13 students	Brooks High School
30 students	Paul School
30 students	Kearsarge Regional High School
55 students	Greenland Central School
10 students	Dover Housing Authority
12 students	Hill Library
10 students	Souhegan Science Club
60 Undergraduates	UNH Computer Science Majors
20 Kindergarten	UNH Child Study and Development Center
12 Undergraduates	UNH Teachers of Tomorrow Group
25 students	4H Tech Wizards
~20 members	UNH Emeriti and Retired Faculty Association

In addition to these small groups coming to the lab, we also have hosted several large and specialized events including SeaPerch ROV events, the annual UNH "Ocean Discovery Days" event, and several workshops for educators.

SeaPerch ROV

Throughout the year, the Center worked with the Portsmouth Naval Shipyard (PNS) and UNH Cooperative Extension to build relationships with and host participating schools, after-school programs and community groups that have built SeaPerch ROVs and wish to test them out in our facilities. Local schools have brought their students to test drive ROVs in our deep tank, and tour both our Center and the Engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012.

The fourth annual UNH Seacoast SeaPerch Competition was held Saturday, April 11, 2015 on the UNH campus. Forty-eight teams from New Hampshire, Maine and Massachusetts schools, afterschool programs and community groups competed in this ROV challenge, using ROVs that they built themselves (Figures 10-1 and 10-2). A SeaPerch is an underwater Remotely Operated Vehicle (ROV) made from simple materials like PVC pipe, electric motors and simple switches. While there is a basic SeaPerch ROV design, participants have the freedom to innovate and create new designs that might be better suited for that year's specific challenge. This year's competition included challenges such as an obstacle course where pilots have to navigate their ROV through five submerged hoops, a finesse course where they had to manipulate three challenges including pressing target buttons to raise a flag, lifting submerged rods and placing them in vertical tubes, and sliding movable collars on a submerged ladder, like an abacus, and a poster session where they presented posters and explained their building process to a panel of judges. "These teams face the same types of challenges as ROV operators the world over; visibility, tether management, vehicle power and maneuverability," said Rick Cecchetti, the PNS SeaPerch coordinator. "While building and testing the SeaPerch ROV, students learn and apply basic engineering principles and science concepts with a marine engineering theme. Our mission is to inspire the next generation of scientists, engineers and technologists."

Winning teams this year then went on to represent the Seacoast in the Final SeaPerch competition in Massachusetts, which was a wonderful opportunity for our local students to experience competition on a higher level. The coach from one of our top teams, Derek Davis from Weare Middle School, commented that he, "would love to see this program grow and all kids who want to participate get the opportunity to do so. It was the SeaPerch program that doubled the size of my Science Club from last year to this year."

Within our Seacoast SeaPerch program, we also hold builds with school groups, after school programs and community groups. One very rewarding example this year was a build we did with Wildcat Friends, a group of developmentally delayed adults from the group Friends in Action Portsmouth. With the help of some students from Oyster River Middle school with whom we had just finished a build, we were able to build ROVs for these adults to test out in our tanks here in Chase. The ORMS students used their time in technology class to solder and drill together gear boxes (the most difficult part of the SeaPerch build) for this group of adults so that they could complete and then decorate their ROVs. It was a wonderful partnership, and the adults that were able to participate really loved

Figure 10-1. April 2015 SeaPerch competition before a full-house at the UNH pool.

Figure 10-2. Kindergarten class working with SeaPerch ROVs.

being able to drive their own ROVs in our tanks. Many of the groups that we work with come to test out their newly built ROVs in the Chase engineering tanks. We have courses to set up in the tanks to test agility, and can have the students modify their SeaPerch ROVs to address an engineering challenge, such as a ping pong ball oil spill using just materials provided.

Our youngest student group this year was the kindergarten class of the UNH Child Student Development Center. They assisted in the measuring, and construction of the elements to form the frame of the ROV, and then came to Chase so that each could operate it. Back in their classroom, they watched some highlight videos from the *Okeanos Explorer* website, and talked about all of the ways to explore the ocean (Figure 10-2).

SeaPerch Educator Workshop

We have many SeaPerch-related events throughout the year. Twice in 2015, the Seacoast SeaPerch program held educator ROV workshops at the Center, first in August and then again in November (Figure 10-3). These training programs are open to formal and informal educators, 4-H leaders, afterschool providers, community partners and homeschool parents. The trainings included building a SeaPerch ROV, a discussion about starting SeaPerch ROV teams, and ways to incorporate ROVs into learning experiences. Each educator was able to take a SeaPerch kit back to their institution. This year, we offered a second day for seasoned SeaPerch educators, where we discussed sensors and other technology that can be added to the ROVs, as well as challenges and ideas to expand on the basic build experience.

In attendance were informal and formal educators from all over the state. Groups represented included afterschool 4-H leaders from several counties, UNH Cooperative Extension, homeschool educators, and teachers from 23 different schools from New Hampshire, Maine and Massachusetts. The principal from Nute School in Milton, NH is now registering more teachers for our January educator workshop after rave reviews from the teachers that attended our November workshop. To spread the word about the SeaPerch program and the other outreach opportunities at the Center we

Figure 10-3. Educators' workshops at the Center.

Figure 10-4a. The Chase Ocean Engineering Lab's highbay on Ocean Discovery Day.

utilize state science teacher conferences. Hicks-Johnson hosted a booth at the New Hampshire Science Teachers Association meeting, and held a workshop at the Maine Science Teachers Association meeting. This workshop was proposed by a Maine science teacher who had taken our educator workshop, conducted a school build, and then brought a team to our regional competition. His excitement for the program helped to introduce more teachers to our program, and many teachers that attended the workshop at the Maine meeting attended our educator workshop in Chase in November.

The Seacoast SeaPerch program also hosts two strands of UNH Tech Camp. Tech Camp is a two-week camp for boys and girls that offers two concurrent programs for campers entering grades 7 & 8 and 9 &10. In the SeaPerch advanced strand, ~20 campers work to solve an engineering challenge that requires a ROV. This past year, the campers needed to design SeaPerch ROVs to collect biological samples "under the ice" in the Chase Ocean Engineering Laboratory's wave tank. There was also a simulated oil well head that was leaking and needed repair. Students came up with the action plan and design, then used tools to modify their SeaPerch ROVs.

Ocean Discovery Day

Ocean Discovery Day is an annual two-day event held at the Chase Ocean Engineering Lab. On Friday, October 16, more than 1,300 students from school groups and homeschool associations all over New Hampshire, Maine, and Massachusetts came to visit our facilities and learn about the exciting research happening here at the Center. Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, ASVs, ROVs, ocean engineering, coastal ecology, lidar, and ocean visualization. The event was open to the public on Saturday, October the 17, when close to 700 more kids and adults came to learn about marine science.

Students and the public were able to tour our engineering tanks in our highbay, watch video taken on the seafloor in our Telepresence Room, and try their hand at mapping the ocean floor. They could check out the jet ski (CBASS—see SENSORS Theme) that we use to map shallow coastal areas, learn how we will use ASVs for ocean research, see how scientists explore the ocean using sound waves, and test drive SeaPerch ROVs. Our visualization team showed off their interactive weather map and ocean visualization tools.

Figure 10-4b. Scenes from Ocean Discovery Day.

Ocean Discovery Day is a joint outreach event run through the Center, the New Hampshire Sea Grant office, and the School of Marine Science and Ocean Engineering and relies on faculty, staff, and student volunteers from UNH, and volunteers from the UNH Marine Docent program.

Website and Other Outreach Activities

Website

The JHC/CCOM website, **www.ccom.unh.edu**, is the public face of the Center (Figure 10-5). It has now been more than two years since the redesign and, while content is constantly updated, the structure needs some tweaking and there are interactive features and new modules that we would like to add. We have hired web developer Jennifer Crosby to work on this as well as on our in-house sites, such as the progress reporting system. She is also working closely with UNH librarians Eleta Exline and Dale Osborne to migrate our extensive publication catalog to a research data management company, Scholars' Repository. Hopefully, going forward, she will be able to make some of the updates and implement some of the Drupal modules that will make the website more user-friendly and richer in content.

The website is dynamic with new content continually being added. In particular, the publications, seminars and events, and news articles are updated frequently. Nineteen front page slides were featured in 2015 highlighting cruise reports, television interviews, news articles, and outreach events.

In 2015, the website received 43,232 visits from 26,628 unique visitors. 40% of those were first time visitors. The average visit lasted 2 minutes and 46 seconds with an average of 2.98 pages visited. Of these visits, 1,183 were referred by social media with Facebook leading at 86% of referrals.

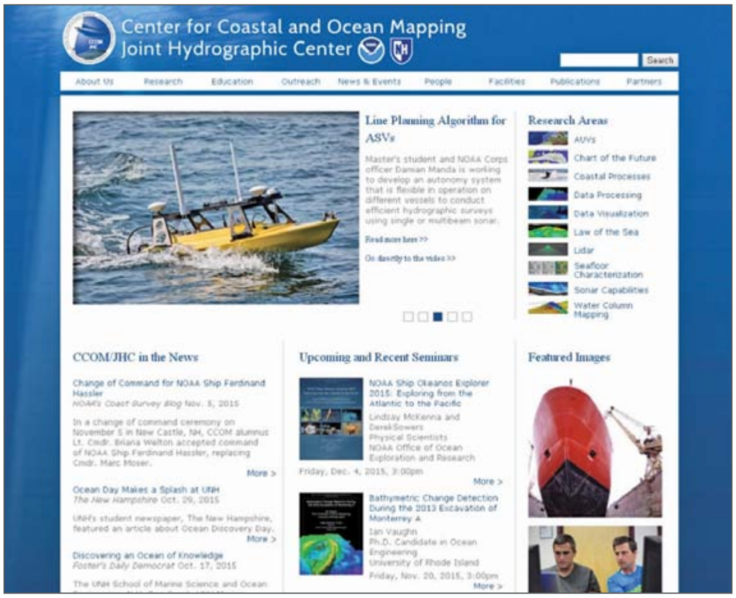

Figure 10-5. The homepage of the Center's website.

The most popular landing page is the home page with 17K visits, followed by Publications with 2.8K, and Law of the Sea with 1.8K. From the distinctive jagged graphing of visits (Figure 10-6) we can surmise that most of these visits are made during the work week.

A spike in sessions on August 4 was in response to a request for participation in the Super Storm Sandy Marine Debris Citizen Science Project. The project was featured on the UNH homepage which dramatically increased traffic to our website.

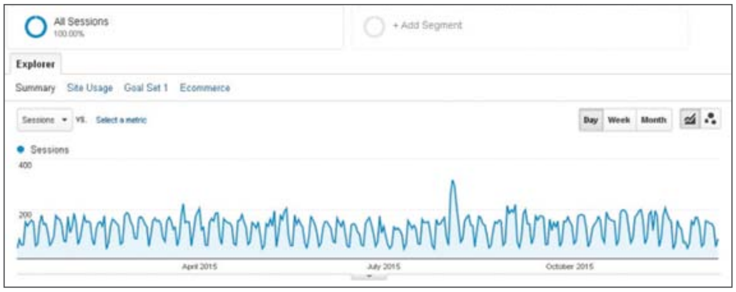

Figure 10-6. Google Analytics graph showing the clear trend of work week visits.

Sixty-one percent of visitors are under the age of 35, after which the numbers taper off quickly. Perhaps this is good news for the future of hydrography? The gender distribution, however, is nearly even with 45.85% female and 54.15% male. Sixty-seven percent of visits originated in the U.S. while the other 33% is spread all over the world. In fact, we have had visits from 170 countries outside the U.S., including such exotic locales as Vanuatu, Nepal, and Antarctica.

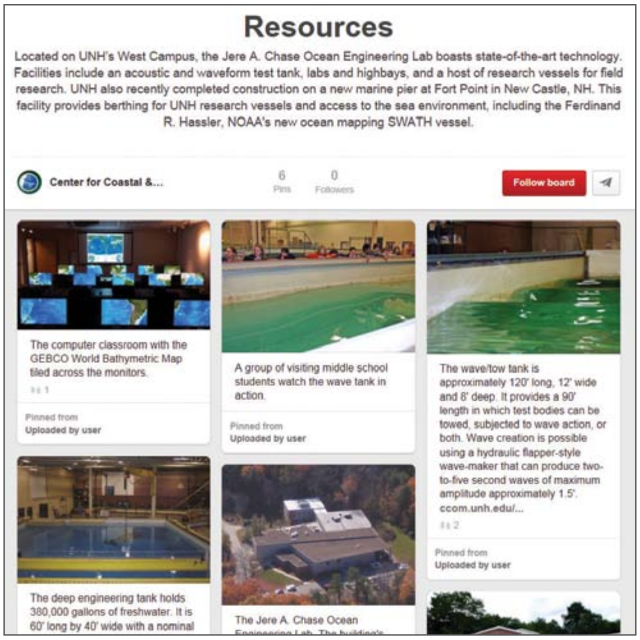

Figure 10-7. The Resources board on the Center's Pinterest page.

Pinterest

The Center's Pinterest page (**www.pinterest.com/ccomjhc**) has a board for faculty members, which serves as a kind of look book for prospective students (Figure 10-7). A board dedicated to the Center's facilities and a board for research vessels have also been created. Pinterest serves as another social media outlet to enhance the Center's digital presence, particularly in reference to attracting graduate students.

Figure 10-8. The Center's Flickr photostream.

Flickr

There are currently 2,033 images in the Center's Flickr photostream (**www.flickr.com/photos/ ccom_jhc**). Since the account was created in August 2009, these images have received a total of 232,084 views (Figure 10-8).

Vimeo

The Center's videos are hosted by Vimeo (vimeo.com/ccomjhc). There are currently 80 videos in the Center's catalog (Figure 10-9). Some of these videos are short clips, such as "Arctic Flyover" or "Creating an AUV Plot with Interactive Visualization Tools." Other videos are full-length recordings of our seminar series. In addition to broadcasting the seminars as webinars, talks are recorded—as long as the speaker is amenable. Will Fessenden and Colleen Mitchell then edit the videos and upload them to the Vimeo site.

In 2015, the Center's videos were played 7,457 times. It should be noted that Vimeo's statistics differentiate between "loads" and "plays." Our videos were loaded 60,000 times this year but we have no way of knowing if they were watched all the way through to the end. Therefore, the "plays" number is more reliable. While the U.S. is the origin of most plays (4,440), Center videos have been viewed in 146 countries, including Turkey, Cameroon, and St. Kitts and Nevis. The most popular video continues to be, "Mariana Trench Fly Through," with nearly 22.3k plays. It was created by Research Professor Jim Gardner and has been a featured video on the website.

Figure 10-9. A sampling of the videos available in the Center's Vimeo catalog.

Figure 10-10. Some of the 26 flyers produced for the 2015 Seminar Series.

Seminar Series

Twenty-six seminars comprised the 2015 seminar series. Five of these seminars were master's thesis defenses and the rest were presented by Center researchers or experts from industry and academia.

Graduate students Kelly Nifong and Scott Loranger served as seminar coordinators for the 2014/2015 academic year and did an exemplary job of populating the schedule and interfacing with the speakers. They were excellent communicators, sharing information and updates with the rest of the seminar team in a timely manner. In September, Onni Irish and John Kidd took over as student coordinators. System Administrator Will Fessenden continues to help the speakers set up their presentations, making sure that the webinars run smoothly and recording the presentations' video and audio. Colleen Mitchell advertises the seminars with customized flyers (Figure 10-10) that are posted on the Center's website and Facebook page and appear in the Center's kiosk slideshow in the lobby of Chase.

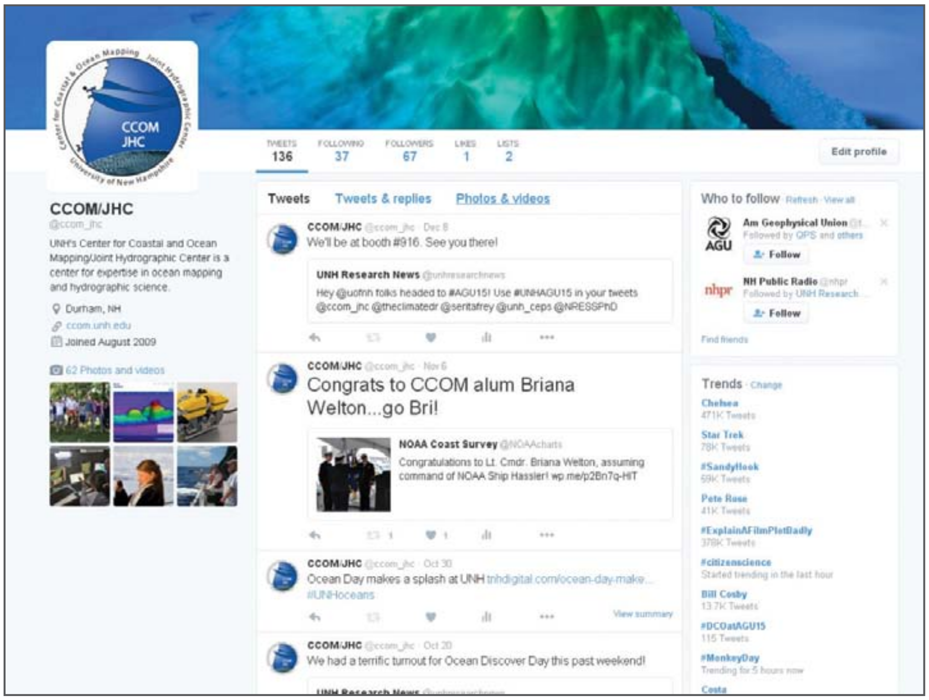

Figure 10-11. The Center's Twitter page.

Twitter

A Center Twitter account was set up years ago but was not used except for automatic posts from Vimeo every time a video was posted. Recently, Colleen Mitchell, who maintains all of the Center's social media, began using the account and is learning the best practices of using Twitter. While the Center's Facebook page is a more relaxed and casual reflection of the website, it is important to maintain a strong identity with the Center's work which means there are no posts where the relationship to JHC/CCOM is

Figure 10-12. Two of the **#girlswithtoys** tweets from our Twitter account.

too tenuous. Because re-tweeting is such an integral part of Twitter, it is easier to pass on news from other entities. For instance, we only share news from the E/V *Nautilus* on Facebook if someone from the Center is on board but, on Twitter, we can easily re-tweet one of *Nautilus*'s tweets about a dive or an exciting find. This is an excellent way to develop a supportive community. Conversely, it allows others to share our news. UNH Media follows our account and is quick to pick up on our news, sometimes giving our stories "legs." To date, we have tweeted 136 times, although most of those are the -Vimeo alerts. We are following 37 groups or individuals in the ocean community and 67 people or groups are following us (Figure 10-11).

When the #girlswithtoys hashtag was trending (and NOAA had participated), we posted a few pictures of Center women in the field with their "toys" (Figure 10-12).

Facebook

The Center's Facebook page (**www.facebook.com/CCOM-JHC**) mirrors the website and provides a less formal venue for posting Center news, announcements, videos, and photos (Figure 10-13). The page currently has 653 followers. Colleen Mitchell, who administers the page, creates posts that are interesting and informative, carefully monitoring the frequency of posts so they do not become tiresome. It is very rare that anyone resigns from the page. Posts are frequently "liked" or shared so that they appear in individuals' news feeds, increasing exposure significantly. Like the website, the Center's Facebook page is vibrant and content-rich and the two sites work in tandem to increase the Center's on-line presence. It also provides an easy way for alumni to stay involved with the Center.

Figure 10-13. The Center's Facebook page.

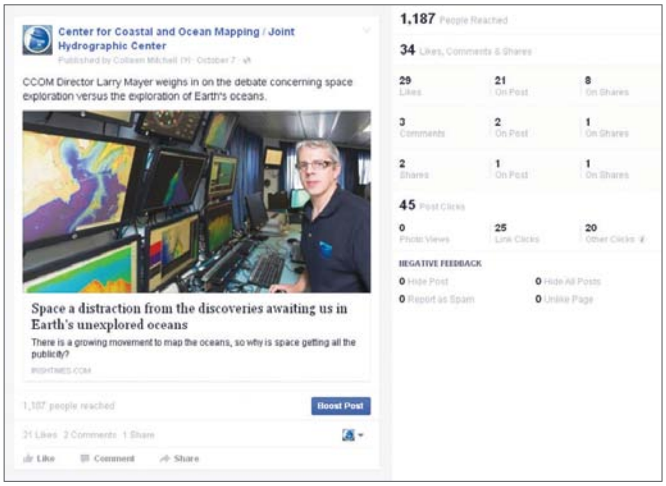

Figure 10-14. The post with the most exposure in 2015.

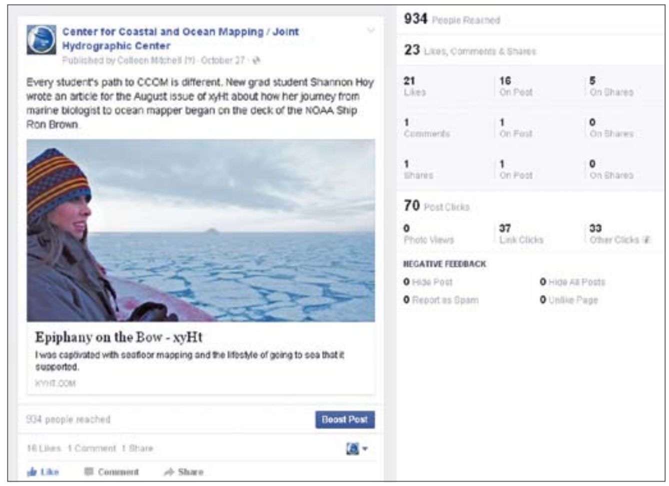

Figure 10-15. Posts featuring people always get a lot of play.

The most popular post this year was on October 7 when we linked to an article from the Irish Times featuring quotes from Center Director Larry Mayer (Figure 10-14). This post reached 1,187 people and was liked and shared numerous times.

The second most popular post this year, reaching 934 people, was an article written by new graduate student Shannon Hoy for xyHt.com about the path that led her to the Center (Figure 10-15). Posts that followers can relate to on a personal level are usually very popular.

Seacoast Science Center Hurricane Marine Debris Exhibit/Game

As part of the outreach component of the Super Storm Sandy project, the Center partnered with the Seacoast Science Center in Rye, NH to develop an interactive museum exhibit that engages the public with a touchscreen based game revolving around the detection and identification of marine debris. "A Hurricane Hits Home" is a multi-station touchscreen exhibit geared towards children, and integrates a portion of a historical wooden shipwreck into its physical design (Figures 10-16–10-18).

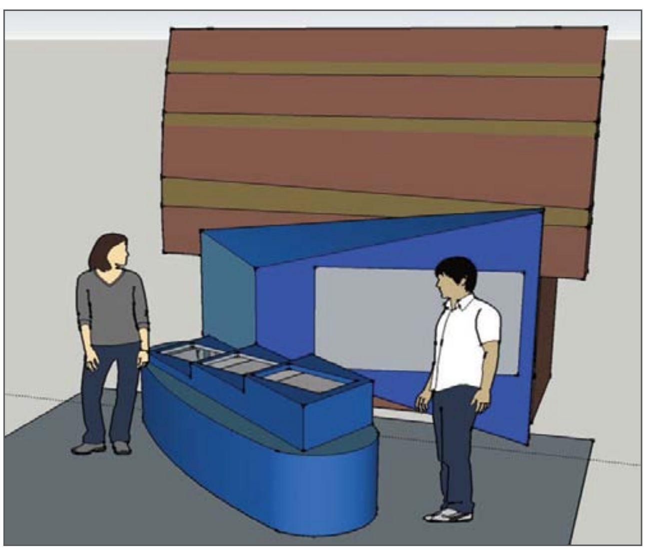

Figure 10-16.Mockup of the final exhibit design, with three touchscreen stations in front of the museums existing piece of a historical shipwreck.

Figure 10-17. Exhibit currently under construction at The Seacoast Science Center.

The game invites people to examine a number of coastal regions and harbors in Sandy-affected areas. It teaches visitors about modern mapping technology by having them control boats with multibeam sonars and airplanes with lidar sensors. They drag these vehicles around maps to reveal the underlying bathymetry below the satellite photos. They learn the applications and limitations of sonar and lidar from where the vehicles can and cannot collect survey data (e.g., lidar does not work in deep water, and the boat cannot go into shallow areas).

As users collect bathymetry data, they occasionally reveal marine debris objects on the seafloor. Once all the debris objects in a level have been located, the game challenges them to identify them based on their appearance in the bathymetry data. They must compare the simulated bathymetry images of the debris targets to photos of possible objects, and choose the correct matches to achieve a high score.

This exhibit is set to open at the Seacoast Science Center in late 2015 or early 2016.

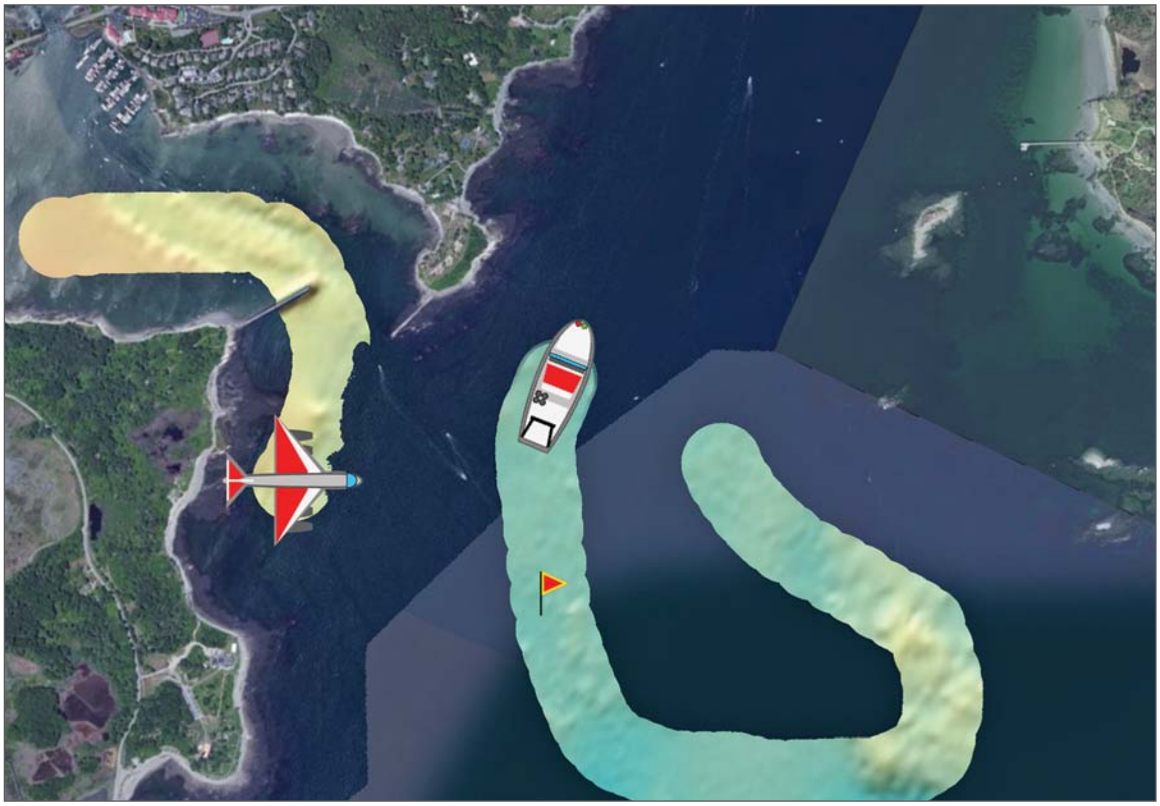

Figure 10-18. A screenshot of the gameplay in the science museum exhibit, showing the user dragging boats and planes around to reveal bathymetry and find debris targets.

Partnerships and Ancillary Programs

One of the goals of the Joint Hydrographic Center is, through its partner organization the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a $5 million endowment; $1 million of this endowment has been earmarked for support of post-doctoral fellows at the Center for Coastal and Ocean Mapping. Our interaction with the private sector has been formalized into an industrial partner program that is continually growing, and at present includes:

- Acoustic Imaging Pty LTD
- Airborne Hydrography AB
- Alidade Hydrographic
- AML Oceanographic
- ASV Global LTD
- Bluefin Robotics
- C&C Technologies Inc.
- CARIS, Inc.
- Chesapeake Technologies
- Clearwater Seafoods
- EarthNC, Inc.
- EdgeTech
- Environmental Systems Research Institute, Inc. (ESRI)
- Exxon Mobil
- Fugro Inc. (Pelagos)
- Hydroid – subsidiary of Kongsberg
- HYPACK, Inc.
- IFREMER
- IIC Technologies
- Instituto Hidrografico (IH) – Marinha Portuguesa (IH)
- Kongsberg Underwater Technology, Inc. (KUTI)
- L-3 Communications Klein Associates
- Leidos
- Norbit Subsea
- Novatel
- Ocean High Technology Institute
- Ocean Imaging Consultants, Inc.
- Ocean Science
- Phoenix International
- QPS - Quality Positioning Services B.V.
- Rolls Royce Canada Ltd.
- SevenCs
- SMT Kingdom
- Substructure
- Survice Engineering Company
- Teledyne Benthos, Inc.
- Teledyne Odom Hydrographic
- Teledyne Optech
- Teledyne-Reson
- Triton Imaging Inc.
- Tycom LTD
- YSI, Inc.

In addition, grants are in place with:

- Bureau of Ocean Energy and Management
- Columbia University/Sloan Foundation
- Earth Resources Technology, Inc.
- Exxon-Mobil
- Massachusetts Institute of Technology
- National Science Foundation
- Nippon Foundation/GEBCO
- NOAA National Marine Fisheries Services
- Ocean Exploration Trust
- Office of Naval Research
- Schmidt Ocean Institute
- Systems & Technology Research, LLC
- University Corporation for Atmospheric Research
- UK Hydrographic Office
- U.S. Department of Energy
- U.S. Geological Survey

The Center has also received support from other sources of approximately $2,325,528 M for 2015 (see Appendix C).

Appendix A: Graduate Degrees in Ocean Mapping

The University of New Hampshire offers Ocean Mapping options leading to Master of Science and Doctor of Philosophy degrees in Ocean Engineering and in Earth Sciences. These interdisciplinary degree programs are provided through the Center and the respective academic departments of the College of Engineering and Physical Sciences. The University has been awarded recognition as a Category "A" hydrographic education program by the International Federation of Surveyors (FIG)/International Hydrographic Organization (IHO)/International Cartographic Association (ICA). Requirements for the Ph.D. in Earth Sciences and Engineering are described in the respective sections of the UNH Graduate School catalog. MS degree requirements are described below.

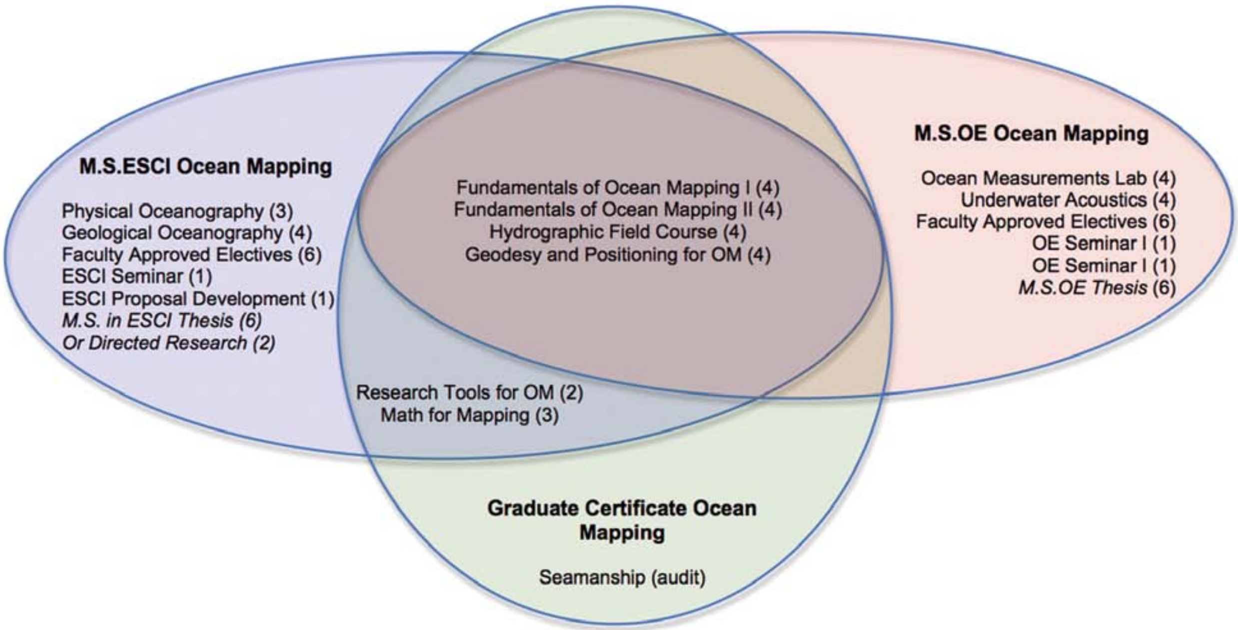

Figure 10-19. Curricula for master's degrees and certificates in Ocean Mapping at UNH JHC/CCOM.

Figure 10-17. 2015 incoming students.

Master of Science in Ocean Engineering–Ocean Mapping Option

Core Requirements		Credit Hours
OE 810	Ocean Measurements Lab	4
OE/ESCI 874	Fundamentals of Ocean Mapping I	4
OE/ESCI 875	Fundamentals of Ocean Mapping II	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	3
OE/ESCI 895	Underwater Acoustics	3
OE/ESCI 972	Hydrographic Field Course	4
OE 990	Ocean Engineering Seminar I	1
OE 991	Ocean Engineering Seminar II	1
OE 899	Thesis	6

At Least Six Additional Credits from the Electives Below

ESCI 858	Introduction to Physical Oceanography	3
OE 854	Ocean Waves and Tides	4
ESCI 859	Geological Oceanography	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4
	Other related courses with approval	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences–Ocean Mapping Option

Core Requirements		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	3
ESCI/OE 875	Fundamentals of Ocean Mapping II	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4
ESCI 997	Seminar in Earth Sciences	1
ESCI 998	Proposal Development	1
ESCI 899	Thesis	6

Approved Electives

OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences (Non-Thesis Option)–Ocean Mapping Option

Core Requirements		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	3
ESCI/OE 875	Fundamentals of Ocean Mapping II	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4
ESCI 997	Seminar in Earth Sciences	1
ESCI 998	Proposal Development	1
ESCI 898	Directed Research	6

At Least Four Additional Credits from the Electives Below

OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Graduate Certificate in Ocean Mapping

Core Requirements

Core Requirements		Credit Hours
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	4
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4

Approved Electives

ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Appendix B: Field Programs

Fairweather EM710 Acceptance Cruise, February 1-June 14, NOAA Ship *Fairweather*. Acceptance of a new Kongsberg EM710 MK1 (Glen Rice)

EX-15-01 Patch Test & Ship Shakedown, February 8-11, NOAA Ship *Okeanos Explorer.* Annual ship patch test and shakedown just prior to commencing field season. (Derek Sowers, Meme Lobecker)

Nancy Foster EM710 Acceptance Cruise, March 6-March 14, NOAA Ship *Nancy Foster.* Acceptance of a new Kongsberg EM710 MKII multibeam echosounder. (Glen Rice)

EX-15-02 Leg 2 Exploration, Caribbean (Mapping), March 15-April 4, NOAA Ship *Okeanos Explorer*. Mapping exploration activities in region of Puerto Rico Trench. (Meme Lobecker; Kristen Mello was one of three interns.)

NA055 E/V *Nautilus* EM302 Quality Assurance Test, March 31-May 5, E/V *Nautilus*. Shipboard quality assurance testing of the EM302 multibeam echosounder system. Activities included site selection and mission planning, a review of system installation offsets and angles, swath performance testing, ship self-noise determination, and system accuracy assessment. (Kevin Jerram, Paul Johnson)

EX-15-02 Leg 3 *Okeanos Explorer*, Oceano Profundo: Exploring Puerto Rico's Trenches, Seamounts, and Troughs, April 9-30, *Okeanos Explorer*. ROV and mapping expedition exploring deep water habitats and geology within Puerto Rico's EEZ. (Derek Sowers)

KM1505 R/V *Kilo Moana* EM122 & EM710 Quality Assurance Visit, April 28-29, R/V *Kilo Moana*. Multibeam Advisory Committee (MAC) shipboard quality assurance testing of the EM122 and EM710 multibeam echosounder systems. Activities included site selection and mission planning, a review of system installation offsets and angles, swath performance testing, ship self-noise determination, and system accuracy assessment. (Kevin Jerram, Paul Johnson)

R/V *Daiber*-Edgetech 6205 Shakedown, May 4-8, R/V *Daiber*, Integration of an Edgetech 6205 sonar and Coda F190 navigation system aboard the University of Delaware's R/V *Daiber* in collaboration with Art Trembanis. (Val E. Schmidt)

PNSY Current Surveys, May 11-31, CBASS. Measure currents in the Piscataqua River for Tidal Energy Assessment. (Jon Hunt, Tom Lippmann)

Nifong-Ward Harbor Mapping, May 12-26, R/V *Coastal Surveyor.* Survey of Portsmouth Harbor using the EdgeTech 4600 sonar. Survey area overlapped with the 2012 and 2013 Summer Hydro surveys. (Larry Ward, Val E. Schmidt, Cassandra Bon Giovanni, Samantha Bruce, Michael Bogonko, Juliet Kinney, Kelly Nifong)

Summer Hydro 2015, May 25-July 10, R/V *Coastal Surveyor,* R/V *Cocheco*, and R/V *Galen J*. The Summer Hydro course, which involves the planning, execution and processing of a multi beam and sidescan sonar survey in the New Hampshire and Massachusetts coastal waters. For this course, the students create a "Descriptive Report" that will be submitted to NOAA OCS along with the processed data, so that they may be used for future updates. (Ben Smith, Emily Terry, Andy McLeod, John Kidd, Anderson Barbosa Da Cruz Pecanha, Onni Irish, Damian Manda, Massimo Di Stefano, Semme J. Dijkstra)

Harbor Mapping, May 27-29, R/V *Cocheco*. Collection of bottom videos and bottom samples using the Wilcox grab sampler at 23 stations throughout the harbor and nearshore area. (Larry Ward, Michael Bogonko, Cassandra Bon Giovanni, Samantha Bruce, Juliet Kinney, Kelly Nifong)

CE-15-01 *Celtic Explorer,* North Atlantic Transect, June 1-8, *Celtic Explorer.* This mapping expedition gathered EM302 multibeam, EK60 split-beam, and sub-bottom data along a transect across the North Atlantic Ocean from St. John's, Newfoundland to Galway, Ireland. The expedition was a pilot cruise serving as a tangible achievement resulting from the efforts of the Atlantic Seabed Mapping International Working Group as part of the implementation of the Galway Statement on Trans-Atlantic Cooperation endorsed by Ireland, Canada, the U.S., and the European Commission. The partners are striving to map the majority of the Atlantic Ocean by 2020. Derek served as the American representative on behalf of NOAA OER, and helped to operate mapping sonars, process data, and exchange ideas with international colleagues. (Larry Mayer, Derek Sowers)

NBP1505 RVIB *Palmer* EM122 Shipboard Acceptance Testing, June 10-15, RVIB *Nathaniel B. Palmer.* Multibeam Advisory Committee (MAC) shipboard acceptance testing of the newly installed EM122 receive and transmit arrays. Activities included site selection and mission planning, a review of system installation offsets and angles, swath performance testing, ship self-noise determination, and system accuracy assessment. (Kevin Jerram, Paul Johnson)

2015 NEFSc Scallop Survey Leg 3, June 10-22, R/V *Hugh Sharp*. The survey was conduct by the U.S. Department of Commerce NOAA, NMFS NEFSC to map the Sea Scallops habitat. Leg 3 focused on the Georges Bank area. During the survey acoustic (MBES and SSS), images (still stereo pair photos) and physical sampling (8 feet dredge) data were collected. (Massimo Di Stefano)

Whale Shark Tagging, June 25-July 3, Local boats rented in Cancun, Mexico. The goal of this project is to better understand how whale sharks respond to tourism boats. We put tags on the animals for between 24 and 94 hours. Colin's role was to tag data processing and help with the extraction of behavior patterns. (Colin Ware)

Scallop Incident Mortality Cruise Mobilization, July 6-7, F/V *Christian and Alexa*. Although unable to participate on the cruise itself, Schmidt aided in mobilization and installation of the equipment and team aboard the vessel in Point Pleasant, NJ, prior to departure. (Val E. Schmidt)

Seaweed Mapping Using Video, July 6-August 26, R/V *Galen J* and shore dives. During this time, we made ~12-15 dives at nine sites to collect video of a benthic habitat for the creation of a video mosaic for the purpose of investigating the spatial structure of different seaweed assemblages. These data can also (and will) be used as ground truth for sonar data. (Jenn Dijkstra, Kristen Mello and Amber Litterer (summer and current undergraduate student)

EX1504 Leg 1 *Okeanos Explorer*, Hohonu Moana, July 10-24, NOAA Ship *Okeanos Explorer*. Mapped approximately 10,300 square nautical miles of seafloor in the Johnston Atoll region of the Pacific Remote Islands Marine National Monument. This was the first exploration cruise of the 2015 Hohonu Moana expedition series near Hawaii. Managed seven interns and trained them on ocean mapping watchstanding duties. (Derek Sowers)

Eelgrass Mapping with MB1 for Ashley Norton, July 18-22, R/V *Galen J.* A number of surveys were conducted in support of Ashley Norton's eelgrass mapping graduate work. For this purpose, we used a pole mounted Odom MB 1 and conducted surveys in the Great Bay as well as near Fort Foster in Kittery, ME and Little Harbor in New Castle, NH. These sites were revisits from MB 1 surveys carried out in the summer 2014 and additional data for them is available in the form of areal imagery and coverage maps created by others. (Ashley Norton, Semme J. Dijkstra)

Isles of Shoals Ecosystem Mapping, July 27-September 2, R/V *Galen J* and shore dives. We made ~11 dives at eight sites. The purpose of the dives was to deploy Go-Pro cameras to investigate the association of fish with various seaweed habitat types. (Jenn Dijkstra, Kristen Mello and Amber Litterer (summer and current undergraduate student))

U.S. Law of the Sea Cruise to Map the Foot of the Slope of the Northeast U.S. Atlantic Continental Margin: Leg 7 MGL15-12, July 30-August 29, R/V *Marcus G. Langseth*. MGL15-12 is a leg of the continuing long-term bathymetric mapping of the continental margin on the eastern seaboard of the U.S. (Brian Calder, Scott Loranger, Giuseppe Masetti)

Cape Cod Eelgrass Mapping with the MB1, July 31-August 3, R/V *Marindin*. In cooperation with Mark Borrelli at the Provincetown Center for Coastal Studies (PCCS), an MB1 was temporarily installed on the PCCS mapping vessel the R/V *Marindin*. Survey lines were run over National Park Service and SeagrassNet eelgrass monitoring transects in Wellfleet with both the MB1 and an Edgetech 6205 bathymetric sidescan sonar, providing a point of comparison for the capabilities of these systems for eelgrass mapping and canopy detection. The monitoring dataset also offers detailed manual measurements of eelgrass characteristics such as canopy height and stem density, to be used as ground validation of the acoustic data. (Semme J. Dijkstra, Ashley Norton)

Seaweed mapping Using the MB1, August 7, R/V *Galen J.* We used the MB1 to collect water-column data of different benthic habitats at Nubble Light House in York, ME. (Semme J. Dijkstra, Ashley Norton, Jenn Dijkstra)

Mendums Pond Survey, August 8, *CBASS*. Multibeam survey of the shallow region near the community sailing center. (Tom Lippmann)

KM1514 R/V *Kilo Moana* EM122 Multibeam Echosounder Review, August 9-13, R/V *Kilo Moana*. This was an engineering shakedown leg (KM1514) to assess acoustic noise issues documented during the KM1505 Quality Assessment Visit (QAT) conducted by the Multibeam Advisory Committee (MAC) in April, 2015. Undertaking this assessment were Vicki Ferrini and Paul Johnson as the MAC Quality Assessment Team, Tim Gates and Marisa Yearta as the Noise Assessment Team, Scott Ferguson representing the University of Hawaii’s Ocean Technology Group (OTG), and Chuck Hohing and Travis Eliasen representing Kongsberg Maritime. (Paul Johnson)

UDEL Robotics Discovery Lab AUV Field Testing, August 10-14, R/V *Daiber*. This week-long event involved many tasks, including post system upgrade field testing and evaluation of the University of Delaware's Gavia AUV, general operational field testing of the U.S. Naval Academy's Gavia AUV, swath mapping of the Redbird Reef site by both AUV and Edgetech systems, data processing and general house-keeping of the Robotics Discovery Lab. NOAA Corps Officer Lt. Sam Greenaway participated in the Edgetech seafloor mapping endeavors. (Val E. Schmidt)

Mapping Large-Scale Disturbances, August 10-14, shore dives. The purpose of the dives was to set up an experiment, one that is being replicated around the world, to determine large-scale spatial effects of disturbance on seaweed habitats. We also surveyed flora and fauna in the area. (Jenn Dijkstra)

Great Bay Current Deployments, August 25-September 22. Deployed five ADCPs in the Great Bay and one Environmental Buoy for verification of numerical modeling efforts. (Jon Hunt, Tom Lippmann)

EX1504 Leg 3 *Okeanos Explorer*, Hohonu Moana, August 28-September 3, NOAA Ship *Okeanos Explorer.* Led successful mapping operations on EX1504 Leg 3 expedition in the vicinity of the main Hawaiian Islands and Geologists Seamount Group. This work involved training new mapping watch-standers, preparing data and high resolution seafloor map products for the ship’s ROV Team and Science Leads, updating the ship’s Standard Operating Procedures documents, and providing the ship with detailed navigation plans for daily transits between ROV dive locations. Mapped over 6,400 square kilometers of seafloor terrain during the cruise. (Derek Sowers)

Groundtruth for MB1, September 3-30, shore dives. During this period, we made 10 dives (September 3, 15, 17, and 30). The purpose of the dives were to collect 1m2 quadrat photographs, GPS coordinates of these photographs and heights of algal assemblages for ground-truth of the MB1. (Jenn Dijkstra)

Piscataqua River Surveying, September 21-29, *CBASS*. Conducted surveys for current structure and fine scale bathymetry (multibeam) near the Portsmouth Naval Shipyard. (Jon Hunt, Tom Lippmann)

Naval Undersea Warfare Center Harbor Security Testing, September 21- 25. This project involved a series of harbor security tests involving AUVs and swimmers for the Naval Undersea Warfare Center. Schmidt was chief engineer and the project lead for the five-day event. (Andy McLeod, Val E. Schmidt)

FK20150925 R/V *Falkor* Multibeam Echosounder System Review, September 25-30, R/V *Falkor*. Yearly system review of the EM302 and EM710 multibeam echosounder systems. System tests were run off of Oahu, Hawaii. (Kevin Jerram, Paul Johnson)

Piscataqua River Currents, October 9-December 18. Deployed and retrieved ADCP's in the Piscataqua River near the Portsmouth Naval Shipyard. (Tom Lippmann)

Leg 1 Teledyne Z-Boat Testing and Eel Grass Mapping, October 21, R/V *Galen J*. Field testing of the Teledyne Z-Boat, along with eel-grass mapping in Portsmouth Harbor. (Andy McLeod, Damian Manda, Ashley Norton, Val E. Schmidt)

Leg 2 Teledyne Z-Boat Testing and Eel Grass Mapping, October 26, various small boats. Field testing of the Teledyne Z-Boat, along with eel-grass mapping in Portsmouth Harbor. (Andy McLeod, Damian Manda, Ashley Norton, Val E. Schmidt)

Leg 3 Teledyne Z-Boat Testing and Eel Grass Mapping, October 27, various small boats. Field testing of the Teledyne Z-Boat, along with eel-grass mapping in Portsmouth Harbor. (Andy McLeod, Damian Manda, Ashley Norton, Val E. Schmidt)

U.S. Law of the Sea Cruise to Map the Western Flank of the Kingman Reef-Palmyra Atoll Section of the Line Islands Equatorial Pacific Ocean - Leg 2 KM15-20, November 20-December 20, R/V *Kilo Moana*. KM15-20 is a leg of the continuing long-term bathymetric mapping of the area around Kingman Reef and Palmyra Atoll, in the equatorial Pacific. (Brian Calder, Giuseppe Masetti)

Great Bay Surveying, November 23-December 31, R/V *Galen J.* Began a resurvey of the Great Bay Estuary. (Jon Hunt, Tom Lippmann)

Humpback Tagging SBNMS, December 11, R/V *Auk*. Project to understand the behavior of humpback whales in the Gulf of Maine with the goal of conservation. Through better understanding, we hope to influence policy and regulations relating to shipping and fishing gear We used a variety of short term tags attached with suction cups.. (Colin Ware)

UDEL Robotics Discovery Lab AUV Repair Preparations, December 14–18. Preparations for repair of the University of Delaware's Gavia AUV in Iceland, as well as AUV system data processing, Edgetech sonar system troubleshooting and laboratory upkeep and maintenance. (Val E. Schmidt)

Appendix C: Other Funding

Name of Project	PI	Grantor	FY Award	Total Award	Length
Development of Theoretical and Computational Methods for Single-source Bathymetric Data	Calder, B.	Office of Naval Research	94,761	84,761	1 year, 1 month
IT Support for NOAA Employees	Calder, B.	NOAA	53,444	105,019	2 years
NOAA Link OCS Sandy Task Order	Calder, B.	Earth Resources Technology	57,002	57,002	3 years
IOCM Research in Support of Super Storm Sandy Disaster Relief	Calder, B. Mayer, L.	NOAA	-	999,984	2 years
Faculty Research Incentive Award	Dijkstra, J.	Shoals Marine Laboratory Faculty Research Incentive-Undergarduate Internship Program for Summer 2015	12,000	12000	4 months
Optimizing Multibeam Data Acquisition, Operations, and Quality for U.S. Academic Research Fleet	Johnson, P.	National Science Foundation	-	420,527	3 years
Supporting Multibeam Sonar	Johnson, P.	National Science Foundation	486,026	666,841	3 years
Large Scale Observations	Lippmann, T.	Office of Naval Research	75,000	174,174	2 years
Tyco Endowment Interest from Perpetuity	Mayer, L.	TYCO	46,958	-	in perpetuity
GEBCO 11th Year & Travel Support for Monaco	Mayer, L.	General Bathymetric Chart of the Oceans	-	630,000	1 year
GEBCO Yr. 12	Mayer, L.	General Bathymetric Chart of the Oceans	604,301	604,301	1 year
GEBCO Yrs. 1-10	Mayer, L.	General Bathymetric Chart of the Oceans	-	5,383,922	10 years
Indian Ocean Project	Mayer, L.	General Bathymetric Chart of the Oceans	-	245,269	2 years
NF GEBCO Ambassador	Mayer, L.	General Bathymetric Chart of the Oceans	40,500	40,500	2 years
NF GEBCO Ocean Floor Forum	Mayer, L.	General Bathymetric Chart of the Oceans	322,788	322,788	1.5 years
Petermann Gletscher, Greenland	Mayer, L.	National Science Foundation	-	249,278	3 years
Seafloor Methane Deposits	Mayer, L.	Columbia University/Sloan Foundation	-	46,250	1 year
Support for R/V *Falkor* Mapping Support	Mayer, L.	Ocean Exploration Trust	-	19,260	2 year
Seafloor Video Mosaic Research	Rzhanov, Y.	U.S. Geological Survey	10,000	74,644	5 years
Developing Analytical Techniques from Integrated Aerial and Acoustic Surveys in Support of Fisheries Independent Surveys of Juvenile Atlantic Bluefin Tuna	Rzhanov, Y.	U. Mass Amherst/NOAA National Marine Fisheries Services	-	15,858	1 year
Assessment for Offshore Sources of Sand and Gravel for Beach Nourishment in New Hampshire	Ward, L.	Bureau of Ocean Energy Management		199,997	2 years
TrackPlot	Ware, C.	Office of Naval Research	34,518	78,179	1.5 years
Visualization of Human Systemns	Ware, C.	Systems & Technology Reserach LCC	-	205,000	2 years
Optimizing the Energy Usage and Cognitive Value of Extreme Scale Data Analysis Approaches	Ware, C.	U.S. Department of Energy	115,000	245,000	3 years
Enhancements to a Mission Planning Application through Visualization of Currents, Sea State and Weather Variables, and Improvements in Bathymetric Modeling	Ware, C. Calder, R.	Office of Naval Research	-	167,641	1 year
Fate of Methane	Weber, T.	Massachusetts Institute of Technology	84,843	690,785	5 years
Increased Efficiency for Detection of Gas Seeps	Weber, T.	Exxon-Mobil	150,000	150,000	10 months
Development of a Broadband Acoustic System for Quantifying the Flux of Free Gas in Methane Seeps	Weber, T.	National Science Foundation	84,841	690,785	5 years
Modeling Statistics of Fish Patchiness and Predicting Associated Influence on Statistics of Acoustic Echoes	Weber, T.	Office of Naval Research	-	180,720	3 years
Chart Adequacy Workshop	Wigley, R.	UK Hydrographic Office	39,960	39,960	1 year
TOTAL			2,325,528	12,365,448	

Appendix D: Publications

Journal Articles

Armstrong, A.A., Mayer, L.A., and Gardner, J.V., Seamounts, Submarine Channels, and New Discoveries, *Journal of Ocean Technology*, Vol. 10, No. 3. Fisheries and Marine Institute of Memorial University of Newfoundland, St. John's, Newfoundland, Canada, pp. 1-14, 2015.

Brumley, K., Miller, E.L., Konstantinou, A., Grove, M., Meisling, K.E., and Mayer, L.A., First Bedrock Samples Dredged from Submarine Outcrops in the Chukchi Borderland, Arctic Ocean, *Geosphere*, Vol. 11, No. 1. The Geological Society of America, pp. 76-92.

Byrne, S., Schmidt, V., Hegrenaes, O., and Brodet, S., AUV-Acquired Bathymetry, Methods: Scrutinizing AUV Mission Planning, Operations and Data Processing, *Sea Technology*, Vol. 11, pp. 17-22.

Calder, B.R., On Risk-Based Expression of Hydrographic Uncertainty, *Marine Geodesy*, Vol. 38(2), Taylor & Francis, pp. 99-127.

MacKenzie, R.A., Chen, C.Y., and Dijkstra, J.A., Dedication to Dr. Michele Dionne (1954-2012), *Estuaries and Coasts*, Vol. 38, Springer, pp. 1213-1214.

Eakins, B., Armstrong, A.A., Westington, M., Jencks, J., Lim, E., McLean, S.J., Warnken, R.R., and Bohan, M.L., NOAA's Role in Defining the U.S., *Marine Technology Society Journal*, Vol. 49, No. 2, Marine Technology Society, Washington, DC, pp. 204-210(7).

Freire, F.F., Gyllencreutz, R., Greenwood, S., Mayer, L.A., Egilsson, A., Thorsteinsson, T., and Jakobsson, M., High Resolution Mapping of Offshore and Onshore Glaciogenic Features in Metamorphic Bedrock Terrain, Melville Bay, Northwestern Greenland, *Geomorphology*, Vol. 250, Elsevier, pp. 29-40.

Gardner, J.V., Armstrong, A.A., and Calder, B.R., Hatteras Transverse Canyon, Hatteras Outer Ridge and Environs of the U.S. Atlantic Margin: A View from Multibeam Bathymetry and Backscatter, *Marine Geology*, Vol. 371, Elsevier, pp. 18-32.

Hansen, R.E., Lyons, A.P., Sæbø, T.O., Callow, H.J., and Cook, D.A., The Effect of Internal Wave-Related Features on Synthetic Aperture Sonar, I*EEE Journal of Oceanic Engineering*, Vol. 40, No. 3, IEEE, pp. 621-631.

Jakobsson, M., Mayer, L.A., and Monahan, D., Arctic Ocean Bathymetry: A Necessary Geospatial Framework, *ARCTIC*, Vol. 68, No. 5, Arctic Institute of North America, Calgary, Canada, pp. 41-47.

Jerram, K., Weber, T.C., and Beaudoin, J., Split-beam Echosounder Observations of Natural Methane Seep Variability in the Northern Gulf of Mexico, *Geochemistry, Geophysics, Geosystems*, 2015.

Lin, Y-T., Duda, T.F., Emerson, C., Gawarkiewicz, G.G., Newhall, A.E., Calder, B.R., Lynch, J.F., Abbot, P., Yang, Y-J., and Jan, S., Experimental and Numerical Studies of Sound Propagation over a Submarine Canyon Northeast of Taiwan, *IEEE Journal of Oceanic Engineering*, Vol. 40(1), IEEE, pp. 237-249.

Masetti, G. and Calder, B.R., Huddl: the Hydrographic Universal Data Description Language, *International Hydrographic Review*, Vol. 13, International Hydrographic Bureau, Monaco, Monaco Cedex, Monaco, pp. 17-32.

MacKenzie, R.A., Chen, C.Y., and Dijkstra, J.A., Dedication to Dr. Michele Dionne (1954-2012), *Estuaries and Coasts*, Vol. 38, Springer, pp. 1213-1214.

Pe’eri, S., Keown, P., and Gonsalves, M., Reconnaissance Surveying Using Satellite-Derived Bathymetry, *Hydro International*, Vol. 19 (7), pp. 21-23.

Pirtle, J.L., Weber, T.C., Wilson, C.D., and Rooper, C.N., Assessment of Trawlable and Untrawlable Seafloor Using Multibeam-Derived Metrics, *Methods in Oceanography*, Vol. 12, Elsevier, pp. 18–35.

Rogers, J.N., Parrish, C.E., Ward, L.G., and Burdick, D.M., Evaluation of Field-Measured Vertical Obscuration and Full Waveform Lidar to Assess Salt Marsh Vegetation Biophysical Parameters, *Remote Sensing of Environment*, Vol. 156, pp. 264-275.

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Weber, T.C. and Ward, L.G., Observations of Backscatter from Sand and Gravel Seafloors Between 170 and 250 kHz, *The Journal of the Acoustical Society of America*, Vol. 138, Acoustical Society of America, pp. 2169–2180.

Yao, F., Parrish, C.E., Pe'eri, S., Calder, B.R., and Rzhanov, Y., Modeling Uncertainty in Photogrammetry-Derived National Shoreline, *Marine Geodesy*, Vol. 38(2), pp. 128-145.

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Byrne, J.S. and Schmidt, V.E., Uncertainty Modeling for AUV Acquired Bathymetry, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, National Harbor, MD, March 16–19.

Chase, A.L., Dijkstra, J.A., and Harris, L.G., Does Settlement Plate Material Matter? The Influence of Substrate Type on Fouling Community Development, Benthic Ecology Meetings, Quebec City, Quebec, Canada, March 4–8.

Dijkstra, J.A., Mello, K., Litterer, A., Wells, C., Harris, L.G., and Ware, C., Introduced Species Increase Complexity and Biodiversity of Rocky Subtidal Seascapes, Benthic Ecology Meetings, Quebec City, Quebec, Canada, March 4–8.

Hiley, A., Dijkstra, J.A., Seavey, J., and Chen, C.Y., Mercury Concentrations in Rocky Shore Island and Mainland Populations, Regional Association for Research in the Gulf of Maine, Portsmouth, NH, October 15.

Hu, H., Rzhanov, Y., Hatcher, P.J., and Bergeron, R.D., Binary Adaptive Semi-Global Matching Based on Image Edges, 7th International Conference on Digital Image Processing, Singapore, April 9–10.

Jakobsson, M., O'Regan, M.A., Kirchner, N., Ananiev, R., Bachman, J., Barrientos, N., Chernykh, D., Coxall, H., Cronin, T., Koshurnikov, A., Lobkovsky, L., Mayer, L.A., Noormets, R., Muschitiello, F., Nilsson, J., Pearce, C., Semiltov, I., and Stranne, C., On the Existence of an East-Siberian-Chukchi Ice Sheet: New Insights from the SWERUS-C3 Expedition 2014, 2015 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 14–18.

Klemm, A., Pe'eri, S., and Nyberg, J., Initiatives in Using Crowdsourcing, Satellite Derived Bathymetry, and Other Non-Traditional Hydrographic/Bathymetric Measurements, 10th GEBCO Science Day 2015, Kuala Lampur, Malaysia, October 5.

Manda, D., D'Amore, A., Thein, M-W., and Armstrong, A.A., A Flexible, Low-Cost MOOS-IvP Based Platform for Marine Autonomy Research, MOOS-DAWG, MIT, Boston, MA, July 22–23.

Masetti, G., Calder, B.R., and Wilson, M., A Marine Object Manager for Detected and Database-stored Features, Shallow Survey 2015, Plymouth, UK, September 13-18.

Masetti, G. and Calder, B.R., Marine Object Manager as Information Fusion Tool for Detected and Database-Stored Shipwrecks, WRECKS OF THE WORLD III: Shipwreck Risk Assessment, Gothenburg, Sweden, October 12–13.

Mayer, L.A., Weidner, E., Jerram, K., Weber, T.C., Jakobsson, M., Chernykh, D., Ananiev, R., Mohammad, R., and Semiltov, I., A Multi-Frequency Look at Gas Seeps on the East Siberian Margin, 2015 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 14–18.

Nifong, K., Development of Late Quaternary Depositional History of Portsmouth Harbor, NH, Geological Society of America (GSA) Annual Meeting, Baltimore, MD, November 1–4.

Norton, A.R. and Dijkstra, S.J., Detecting and Characterizing the Deep Edge and Canopy Height of Eelgrass Beds Using a Multi-beam Echosounder, Coastal and Estuarine Research Federation Biennial Conference, Portland, OR, November 8–13.

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Pe'eri, S., Kidd, J., Pradith, V., Jablonski, H., and Davidson, M., Integrating Industrial Multichannel Laser Scanners for Small Vessel Operation, 16th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, Corvallis, OR, June 16–18.

Price, V.E., Dijkstra, J.A., O'Neil-Dunne, J.P.M., Parrish, C.E., Nagle, E., and Pe'eri, S., Developing Methodology for Efficient Eelgrass Habitat Mapping Across Lidar Systems, Marine Geological and Biological Habitat Mapping (GEOHAB), Salvador, Brazil, May 3–8.

Ward, L.G., McAvoy, Z.S., Johnson, P., and Greenaway, S.F., Use of High Resolution Bathymetry and Backscatter for Mapping Depositional Environments on the New Hampshire Continental Shelf, Geological Society of America (GSA) Annual Meeting, Northeastern Section, Bretton Woods, NH, March 23–25.

Ward, L.G., McAvoy, Z., Vallee-Anziani, M., Nagel, E., and Nifong, K., Depositional Systems on the Northern Massachusetts and New Hampshire Inner Continental Shelf: Use of High Resolution Seafloor Mapping to Understand Impacts of Glaciation, Marine Processes and Sea-Level Fluctuations, Geological Society of America (GSA) Annual Meeting, Baltimore, MD, November 1–4.

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Alexander, L. and McLeay, C., S-100 Overlays: A Brave New World.? U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Armstrong, A.A., Gardner, J.V., Calder, B.R., and Masetti, G., Multibeam Mapping of Feature Rich Seafloor in the U.S. Pacific Remote Islands Marine National Monument and on Mendocino Ridge off the California Coast, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Butkiewicz, T. and Stevens, A.H., Effectiveness on Dynamically Changing Terrain-like Surfaces, IEEE Visualization (VIS), IEEE, Chicago, IL, October 25–30.

Butkiewicz, T. and Stevens, A.H., Streamlining the Evaluation of Potential Marine Debris Targets for Disaster Response, OCEANS 2015, IEEE, Washington, DC, October 19–22.

Calder, B.R. and Masetti, G., Huddler: A Multi-Language Compiler for Automatically Generated Format-Specific Data Drivers, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Calvo, D.C., Nicholas, M., Fialkowski, J.M., Gauss, R.C., Olson, D.R., and Lyons, A.P., Scale-Model Scattering Experiments Using 3D-Printed Representations of Ocean Bottom Features, OCEANS 2015, IEEE, Washington, DC, October 19–22.

Freire, R., Pe'eri, S., Madore, B., Rzhanov, Y., Alexander, L., Parrish, C.E., and Lippmann, T.C., Monitoring Near-Shore Bathymetry Using a Multi-Image Satellite-Derived Bathymetry Approach, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Gauss, R.C., Fialkowski, J.M., Calvo, D.C., Olson, D.R., and Lyons, A.P., Moment-Based Method to Statistically Categorize Geological Features, OCEANS 2015, IEEE, Washington, DC, October 19–22.

Klemm, A., Pe'eri, S., Freire, R., Nyberg, J., and Smith, S.M., Nautical Chart Adequacy Evaluation Using Publicly-Available Data, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Lyons, A.P., Olson, D.R., Hansen, R.E., and Sæbø, T.O., Estimation of Seafloor Height Fields with Side-Looking Sonar Systems, Conference on Seabed and Sediment Acoustics: Measurements and Modeling, Bath, UK, September 7–9.

Manda, D., Thein, M-W., and Armstrong, A.A., Depth Adaptive Hydrographic Survey Behavior for Autonomous Surface Vessels, IEEE/MTS Oceans '15, IEEE, National Harbor, MD, October 19–22.

Manda, D., Thein, M-W., D'Amore, A., and Armstrong, A.A., A Low Cost System for Autonomous Surface Vehicle based Hydrographic Survey, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Masetti, G. and Calder, B.R., A Bayesian Marine Debris Detector Using Existing Hydrographic Data Products, IEEE Oceans, IEEE, Genoa, Italy, May 18–21.

Mosher, D.C., Courtney, R.C., Jakobsson, M., Gebhardt, C., and Mayer, L.A., Mapping the Surficial Geology of the Arctic Ocean: A Layer for the IBCAO, Offshore Technology Conference (OTC), Society of Petroleum Engineers, Copenhagen, Denmark, March 23–25.

Mukasa, S.B., Mayer, L.A., Aviado, K., Bryce, J., Andronikov, A., Brumley, K., Blichert-Toft, J., Petrov, O., and Shokalsky, S., Alpha / Mendeleev Ridge and Chukchi Borderland 40Ar/39Ar Geochronology and Geochemistry: Character of the First Submarine Intraplate Lavas Recovered from the Arctic Ocean, EGU General Assembly 2015, Vol. 17. Vienna, Austria, April 12–17.

Pe’eri, S., Keown, P., Snyder, L.P., Gonsalves, M., and Nyberg, J., Reconnaissance Surveying of Bechevin Bay, AK Using Satellite-Derived Bathymetry, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Pradith, V., Pe'eri, S., Maddock, D., Oroshnik, D., Riley, J., and Murray, B., Integrating Industrial Laser Scanners for Small Vessel Operations, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Rzhanov, Y., Pe'eri, S., and Shashkov, A., Ambiguity of Underwater Color Measurement and Color-based Habitat Classification, 4th Topical Meeting on Blue Photonics, Barcelona, Spain, May 11–13.

Rzhanov, Y., Pe'eri, S., and Shashkov, A., Probabilistic Reconstruction of Color for Species’ Classification Underwater, IEEE/MTS Oceans '15, Genova, Italy, May 18–21.

Conference Posters

Arie, L.G., Kamaruddin, Y., Kimeli, A., Klemm, A., Kurita, H., Pe'eri, S., Prasetyawan, I.B., Roh, J-Y., Roperez, J., Samarakoon, N., Sydenham, J., Vallee, M., and Wigley, R., Chart Adequacy: Workshop and GEBCO Training, GEBCO Science Day, Kuala Lampur, Malaysia, October 5.

Johnson, P., Beaudoin, J., and Ferrini, V.L., The Multibeam Advisory Committee—Working Towards the Consistent Acquisition of High Quality Multibeam Echosounder Data Across the U.S. Academic Fleet, U.S. Hydrographic Conference (US HYDRO), National Harbor, MD, March 16–19.

Klemm, A., Pe'eri, S., and Nyberg, J., Chart Adequacy Procedure Using Publically-Available Information, GEBCO Science Day, Kuala Lampur, Malaysia, October 5.

McKenna, L., Cantwell, K., Kennedy, B., Elliott, K., Lobecker, E., and Sowers, D., Exploring Deep Sea Habitats for Baseline Characterization Using NOAA Ship *Okeanos Explorer,* 2015 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 14–18.

Norton, A.R. and Dijkstra, S.J., Mapping and Measuring Eelgrass with a Multi-beam Sonar in the Great Bay Estuary, New Hampshire, Annual Eelgrass Meeting, EPA Zone 1, Boston, MA, March 25.

Stevens, A.H. and Ware, C., Visualizing 3D Flow Through Cutting Planes, IEEE Visualization (VIS), IEEE, Chicago, IL, USA, October 25–30.

Ware, C., Alternating Asymmetric Swimming Strokes in California Sea Lions, 21st Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, San Francisco, CA, December 13–18.

Reports

Calder, B.R., U.S. Law of the Sea Cruise to Map the Foot of the Slope of the Northeast U.S. Atlantic Continental Margin: Leg 8.

Johnson, P. and Jerram, K., R/V *Falkor* Multibeam Echosounder System Review September 25–30, 2015.

Johnson, P. and Jerram, K., RVIB *Nathaniel B. Palmer*: EM122 Multibeam Echosounder Sea Acceptance Trial for TX/RX Arrays, NBP1505, June 10–15, 2015.

Johnson, P., Jerram, K., and Ferrini, V. L., R/V *Kilo Moana*: EM122 Multibeam Echosounder Review, KM1514, August 9–13, 2015.

Theses

Bajor, E.J., *High-Frequency Broadband Seafloor Backscatter in a Sandy Estuarine Environment*, Master of Science in Mechanical Engineering, University of New Hampshire, Durham, NH.

Borba, C., *Integration of Tide/Water Level Information into ECDIS for Guanabara Bay*, Master of Science in Ocean Mapping, University of New Hampshire, Durham, NH.

Hu, H., *Euclidean Reconstruction of Natural Underwater Scenes Using Optic Imagery Sequence*, Master of Science in Ocean Engineering, University of New Hampshire, Durham, NH.

Humberston, J., E*stimating Surficial Seafloor Sediment Properties Using an Empirical Orthogonal Decomposition on Acoustic Backscatter Waveform Properties*, Master of Science in Oceanography, University of New Hampshire, Durham, NH.

Pillsbury, L., *Characterizing and Quantifying Marine Methane Gas Seeps Using Acoustic Observations and Bubble Dissolution Models*, Master of Science in Ocean Engineering, University of New Hampshire, Durham, NH.

Wolfson-Schwehr, M., *The Relationship Between Oceanic Transform Fault Segmentation, Seismicity, and Thermal Structure*, Doctor of Philosophy in Oceanography, University of New Hampshire, Durham, NH.

Appendix E: Technical Presentations and Seminars

Brian Calder, Invited, January 14-16, "Storm Response Lidar Data Processing," UJNR/JHOD, UJNR Meeting 2015, Tokyo, Japan. Description of lidar processing being conducted for the Super Storm Sandy grant, including habitat classification, shoreline change, and deposition/erosion prediction.

Brian Calder, Invited, January 14-16, "Object Detection for Storm Response," UJNR/JHOD, UJNR Meeting 2015, Tokyo, Japan. Description of object detection research being conducted for the Super Storm Sandy grant.

Brian Calder, Invited, January 27-29, "Slopes, Bits, Objects and Risks: A Series of Projects at CCOM/JHC," NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Norfolk, VA. Description of current projects at CCOM/JHC for NOAA Field Procedures Workshop.

Glen Rice, Invited, January 29, "Status of Coast Survey Backscatter," NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Norfolk, VA. An overview of how Coast Survey is doing with multibeam seafloor backscatter collection and processing and its value.

Larry Mayer, Invited, February 12, "Acoustic Mapping of Gas Seeps: From Deep Water Horizon to the East Siberian Arctic, Bigelow Laboratory for Ocean Sciences," Boothbay, ME.

Larry Mayer, Invited, February 18, "Understanding Article 76 and Its Application in the Arctic," Yale School of Law, New Haven, CT.

Sam Greenaway and Larry Ward, Invited, February 27, "Data Deliverables, Archival, and End Use," NOAA Office of the Coast Survey, Advanced Hydrographic Training Course, Durham, NH. NOS Web-Conference presentation on use of backscatter in BOEM sand and gravel study.

Brian Calder, Invited, March 12, "Bathymetric Uncertainty," NOAA, Arctic IRT Meeting, Durham, NH. Description of bathymetric uncertainty handling for ECS purposes, and in particular the effects of slope uncertainty on location of the 2500m isobath.

Shachak Peeri, Contributed, March 16-19, "Reconnaissance Surveying of Bechevin Bay, AK Using Satellite-Derived bathymetry," THSOA, U.S. Hydro 2015, National Harbor, MD. Presented the use of single-image satellite-derived bathymetry (SDB) as an economic alternative approach.

Shachak Peeri, Invited, March 16, "Satellite activities in NOAA: Satellite-Derived Bathymetry (SDB)," International Hydrographic Organization, US-Canada Hydrographic Commission, National Harbor, MD. General overview of SDB research in NOAA that included single image, multi-temporal and turbidity products generated from SDB. In addition to NOAA, there were participants from US Navy, NGA, IHB, CHS, UKHO and the Mexican Navy.

Mashkoor A. Malik, Contributed, March 18, "Limited Resources and Increasing Demand: Augmenting Hydrographic Training Through Self-paced Online Learning." U.S. Hydro 2015, Washington, DC.

Brian Calder and Giuseppe Masetti, Keynote, March 18, "Huddler: A Multi-language Compiler for Automatically Generated Format-specific Data Drivers," U.S. Hydro 2015, National Harbor, MD.

Paul Johnson, Contributed, March 18, "The Multibeam Advisory Committee—Working Towards the Consistent Acquisition of High Quality Multibeam Echosounder Data Across the U.S. Academic Fleet," U.S. Hydro 2015, National Harbor, MD. Lightning talk about the Multibeam Advisory Committee activities over the last three years.

Damian Manda, Contributed, March 18, "A Low Cost System for Autonomous Surface Vehicle-based Hydrographic Survey," U.S. Hydro 2015, National Harbor, MD.

Larry Mayer and Mashkoor A. Malik, Contributed, March 19, "Evaluation of Uncertainty in Multibeam Echo Sounder Derived Seafloor Backscatter Data,: U.S. Hydro 2015, National Harbor, MD.

Paul Johnson, Sam Greenaway, and Larry Ward, Contributed, March 24, "Use of High Resolution Bathymetry and Backscatter for Mapping Depositional Environments on the New Hampshire Continental Shelf," Geological Society of America, Northeastern Section, Annual Convention, Bretton Woods, NH. Presentation describing the research being conducted on the New Hampshire continental shelf.

Semme J. Dijkstra and Ashley Norton, Contributed, March 25, "Mapping and Measuring Eelgrass with a Multibeam Sonar in the Great Bay Estuary, New Hampshire," EPA Region 1 (New England), 24th Annual Zosterapalooza, Boston, MA.

Jenn Dijkstra, Chris Parrish, Erin Nagel, Shachak Peeri, and Victoria Price, Contributed, March 25, "Mapping Eelgrass Beds after Hurricane Sandy in Barnegat Bay, New Jersey Using Lidar and RGB Imagery," U.S. EPA, 24th Annual Zoosterapalooza, Boston, MA. General trends in submerged aquatic vegetation (SAV) coverage in Barnegat Bay, NJ were discussed, as well as comparing methodologies between manual classification and semi-automated object-based image analysis (OBIA) classification of SAV habitat.

Damian Manda, Contributed, April 7, "Development of Control for Multiple Autonomous Surface Vehicles (ASV)," Naval Engineering Education Consortium, NEEC Annual Meeting, West Bethesda, MD. Joint poster presentation to NEEC Meeting with UNH ASV senior project team and ME Ph.D. student Andrew D'Amore. Discussed implementation of electronics and software on NOAA EMILY vehicle and preliminary path planning simulation.

Damian Manda, Contributed, April 13, "Development of Control for Multiple Autonomous Surface Vehicles (ASV)," UNH Graduate Research Conference, Durham, NH Presented poster from NEEC Meeting (as described in that item) in the School of Marine Science and Ocean Engineering session during the lead up to the UNH Graduate Research Conference. Presented alone on autonomy hardware and software implementation for NOAA EMILY vessel. Specifically focused on adaptability of the hardware and hydrographic survey line planning algorithm.

Jenn Dijkstra, Chris Parrish, Erin Nagel, Shachak Peeri, and Victoria Price, Contributed, May 7, "Developing Methodology for Efficient Eelgrass Habitat Mapping Across Lidar Systems," GEOHAB Annual Meeting, Salvador, Bahia, Brazil.

Briana Sullivan, Invited, May 14, "S-111 Portrayal Issues," IHO Surface Current Working Group (SCWG)," SCWG Annual Meeting 2, Tokyo, Japan. Issues in portraying the S-111 version of gridded surface currents.

Brian Calder and Giuseppe Masetti, Keynote, May 20, "A Bayesian Marine Debris Detector Using Existing Hydrographic Data Products," IEEE MTS, IEEE Oceans, Genoa, Italy. A detection methodology for marine debris presence after a natural disaster was described.

Meme Lobecker, Keynote, June 4, "Overview of the NOAA Office of Ocean Exploration and Research and Recent *Okeanos Explorer* Expeditions," Society for Underwater Technology, Monthly Luncheon, Houston, TX. Presented an Overview of the NOAA Office of Ocean Exploration and Research and Recent *Okeanos Explorer* Expeditions, in the Atlantic and Gulf of Mexico. SUT is a trade group of oil and gas science professionals.

Meme Lobecker, Invited, June 5, "Overview of the NOAA Office of Ocean Exploration and Research and Recent *Okeanos Explorer* Expeditions," Operators Geohazards Forum, Bi-Annual Conference, Houston, TX. The purpose of the presentation was to familiarize the oil and gas industry in Houston with the NOAA OER program and *Okeanos Explorer* expeditions. In attendance were more than 70 geoscientists from at least 27 companies in the oil and gas industry. The focus was on seeps technology and data processing, and the Okeanos role in leading use of this tech which was developed in partnership with the Center.

John Kidd and Shachak Peeri, Contributed, June 16-18, "Complementing ALB: Marine Surveying Using an Industrial Laser Scanner," Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), JALBTCX workshop, Corvallis, OR. The NOAA Navigation Response Teams (NRTs) perform hydrographic surveys to support nautical charting updates for 175 ports of the United States Marine Transportation System.

Shachak Peeri, Invited, June 24, "Satellite-Derived Bathymetry: A Reconnaissance Tool for Hydrography," NOAA/MCD, MCD Brown Bag series, Silver Spring, MD.

Briana Sullivan, Contributed, June 29-July 3, "The Coast Pilot Data Structure," The Nautical Information Provision Working Group 1, Monaco.

Damian Manda, Contributed, July 22, "A Flexible, Low-Cost MOOS-IvP Based Platform for Marine Autonomy Research," MOOS-DAWG 2015, Cambridge, MA. This presentation concerned the hardware and software development that occurred to operate the NOAA EMILY small autonomous vehicle using minimal cost, open-source components. The development methodology, specifics of the final system and testing performed were discussed.

Sarah Wolfskehl, Samantha Bruce, Michael Bogonko, Cassandra Bon Giovanni, Erin Nagel, Shachak Peeri, Chris Parrish, and Juliet Kinney, Contributed, July 22, "Examples of Topobathymetric Lidar for Habitat Mapping and Charting by NOAA's IOCM Sandy Project," University of Massachusetts Experimental Center for Environmental Lidar (ExCEL), ExCEL 2015 LIDAR Workshop, Lowell, MA.

Damian Manda and Val E. Schmidt, Contributed, July 22, "Requirements for an Operational ASV for Hydrographic Survey: A Rookie's View of MOOS," MOOS Development and Applications Working Group, MOOS-DAWG, Cambridge, MA. This presentation provided background on the art of hydrographic surveying as applicable to design and operation of an autonomous surface vehicle to conduct the same.

Anthony Lyons, Contributed, September 8, "Estimation of Seafloor Height Fields with Side-looking Sonar Systems," Seabed and Sediment Acoustics: Measurements and Modeling Conference, Bath, United Kingdom.

Briana Sullivan, Invited, September 29, "State of the Art Data Visualization," NMEA (National Marine Electronics Association) 2015 Conference and Expo, NOAA Navigation Industry Day 2015, Baltimore, MD. NOAA partners with the University of New Hampshire to develop the "next generation" tools for collecting, processing, and visualizing ocean data, including advanced techniques in 3-D data visualization.

Larry Mayer, Invited, October 1, Law of the Sea and Mapping in the Arctic (and elsewhere), U.S. Naval War College, Arctic Studies Group, Newport, RI, Talk on Law of the Sea and Mapping in the Arctic (and elsewhere)

Jim Gardner, Brian Calder, and Larry Mayer, Invited, October 1, "U.S. Extended Continental Shelf Mapping 2002–2015," Ocean Exploration Advisory Board, Narragansett, RI.

Larry Mayer, Invited, October 1, "Law of the Sea and Mapping the Extended Continental Shelf," Invited Lecture, School of Marine Policy, University of Rhode Island, Kingston, RI. Talk on Law of the Sea and Mapping the Extended Continental Shelf, Invited Lecture

Larry Mayer, Invited, October 1, "Law of the Sea and Mapping the Extended Continental Shelf in the Arctic," Roger Williams School of Law, Bristol, RI. Talk on Law of the Sea and Mapping the Extended Continental Shelf in the Arctic

Ashley Norton, Invited, October 6, "Mapping and Measuring Eelgrass Beds with an MB1 Sonar," Teledyne Marine Technology Workshop, San Diego, CA. Using the Odom MB1 to detect and measure eelgrass beds, focusing on our field work and preliminary data products. The audience consisted of other users of Teledyne Marine products, and employees of Teledyne Marine companies.

Thomas Butkiewicz, Contributed, October 20, "Streamlining the Evaluation of Potential Marine Debris Targets for Disaster Response," IEEE MTS, IEEE MTS OCEANS '15, Washington, DC.

Damian Manda, Contributed, October 21, "Depth Adaptive Hydrographic Survey Behavior for Autonomous Surface Vessels," IEEE, MTS, IEEE MTS OCEANS '15, National Harbor, MD. This presentation discussed the details of the autonomous swatch matching multibeam sonar survey algorithm developed by Damian Manda. The specifics of the generation of survey paths as well as how the behaviors fit into the overall autonomous survey framework. Testing results with a single beam sonar extrapolated to simulate a multibeam were included.

Thomas Butkiewicz, Contributed, October 28, "Effectiveness of Structured Textures on Dynamically Changing Terrain-like Surfaces," IEEE Vis 2016, Chicago, IL. Presented texturing/contour research detailed the premier visualization conference.

Andrew Stevens, Contributed, October 28, "Visualizing 3D Flow Through Cutting Planes," IEEE, IEEE Vis 2015, Chicago, IL. Presented a poster describing ongoing research into the design of cutting planes for visualizing and exploring three-dimensional vector field data.

Larry Mayer, Invited, October 29, "Gazing into the Crystal Ball: The Future of Ocean Mapping," Ocean Innovations, St. John's, Newfoundland, Canada. Invited Plenary Talk.

Larry Mayer, Invited, November 2, "The Arctic and the Gulf Oil Spill: What if Deepwater Horizon Happened in the Arctic?," River Woods, Exeter, NH. .

Kelly Nifong and Larry Ward, Contributed, November 2, "Depositional systems on the northern Massachusetts and New Hampshire Inner Continental Shelf: Use of High Resolution Seafloor Mapping to Understand Impacts of Glaciation, Marine Processes and Sea-level Fluctuations," Geological Society of America Annual Meeting, Baltimore, MD. Oral presentation on seafloor mapping in New Hampshire.

Kevin Jerram and Paul Johnson, Contributed, November 4, "Multibeam Advisory Committee (MAC) Breakout Session, Research Vessel Technical Enhancement Committee," 2015 RVTEC, Miami, FL. Breakout session on Multibeam Advisory Activities for the U.S. academic fleet's technicians and mangers. Session consisted of presenting accomplishments of the MAC over the last year, followed up by an open forum with questions and discussion of issues seen with multibeam systems across the fleet.

Ashley Norton, Contributed, November 9, "Detecting and Characterizing the Deep Edge and Canopy Height of Eelgrass Beds Using a Multi-beam Echosounder," Coastal and Estuarine Research Federation, 23rd Biennial CERF Conference, Portland, OR. Presentation as part of the session titled "Seagrass ecosystems: challenges in evaluating function, health, abundance and restoration (Mapping)." The audience consisted of seagrass ecologists, remote sensing experts, and resource managers.

Larry Mayer, Invited, November 12, "Acoustic Mapping of Gas Seeps: From Deep Water Horizon to the East Siberian Arctic," Syracuse University, K. Douglas Nelson Colloquium, Syracuse, NY.

Damian Manda and Val E. Schmidt, Invited, November 18, "How to Build An Operational Robot," NOAA Office of Coast Survey (OCS), NOAA-ACT ASV Workshop, Solomons Island, MD. An introduction to the features and capabilities of robotic systems that make them successful in a field environment.

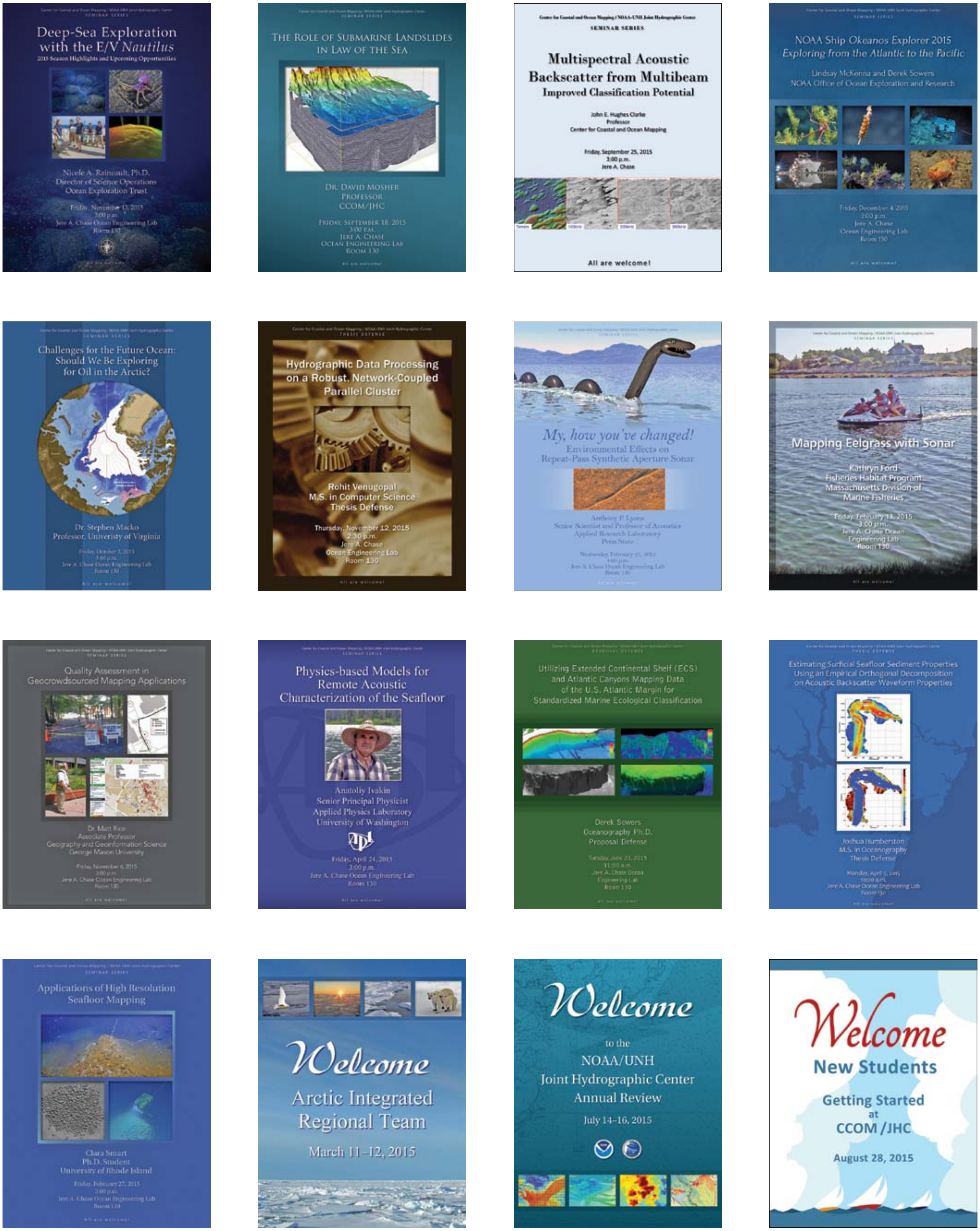
Paul Johnson and Kevin Jerram, Contributed, November 19, "Better Offshore Surveys Through Better Shipyard Survey Reports," Kongsberg User Group, FEMME 2015, Singapore, Singapore.

Kevin Jerram and Paul Johnson, Contributed, December 10, "Multibeam Advisory Committee (MAC)—Pursuing Consistent High Quality Multibeam Echosounder Data Across the U.S. Acdemic Fleet," Forum for Exchange of Mutual Multibeam Experiences, FEMME 2015, Singapore, Singapore. Presentation on the results of the Multibeam Advisory Committee working with the U.S. academic fleet over the last four years.

Larry Mayer, Contributed, December 14-18, "On the Existence of an East-Siberian-Chukchi Ice Sheet: New Insights from the SWERUS-C3 Expedition 2014," Abs. #C43A-0775, American Geophysical Union, 2015 AGU Meeting, San Francisco, CA..

Elizabeth Weidner, Kevin Jerram, Tom Weber, and Larry Mayer, Contributed, December 14-18, "A Multi-Frequency Look at Gas Seeps on the East Siberian Margin," Abs. #C43A-0779, American Geophysical Union, 2015 Fall Meeting, San Francisco, CA.

Erin Heffron, Contributed, December 14, "Multibeam Sonar Backscatter Data Acquisition and Processing: Guidelines and Recommendations from the GEOHAB Backscatter Working Group," American Geophysical Union, AGU Fall Meeting, San Francisco, CA. Presented a poster on the recently completed (May 2015) Geohab Backscatter Working Group document, "Backscatter Measurements by Seafloor-Mapping Sonars: Guidelines and Recommendations."



Welcome signs and flyers from the 2015 JHC/CCOM Seminar Series.

The NOAA-UNH Joint Hydrographic Center
The Center for Coastal and Ocean Mapping

Jere A. Chase Ocean Engineering Lab
24 Colovos Road
Durham, NH 03824

603.862.3438 *tel*
603.862.0839 *fax*

www.ccom.unh.edu