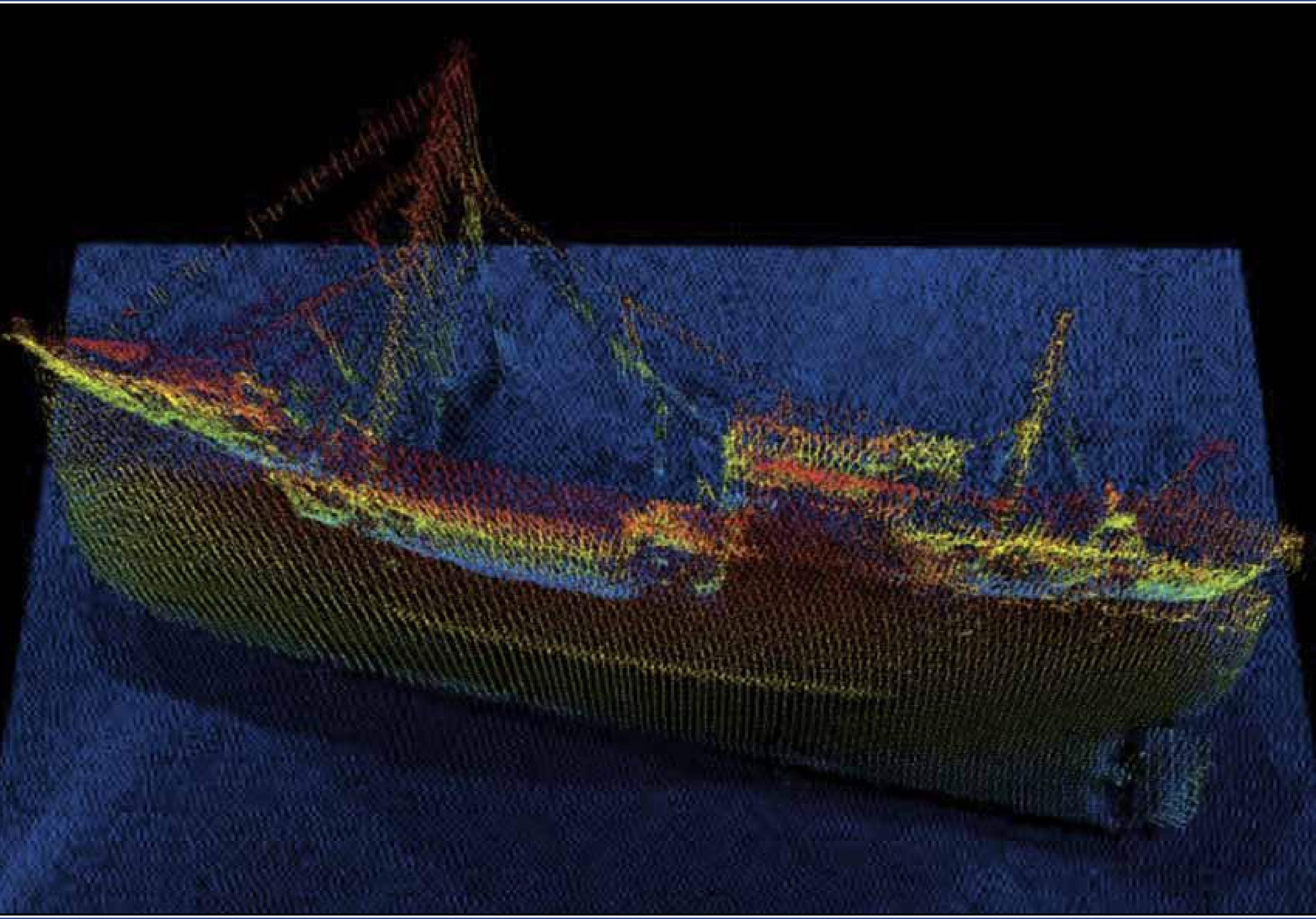
UNH/NOAA Joint Hydrographic Center

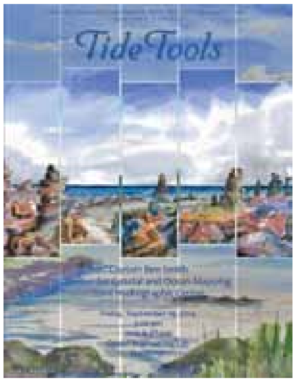
Performance and Progress Report

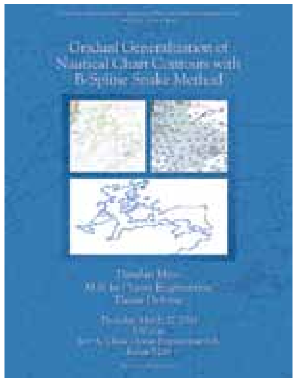


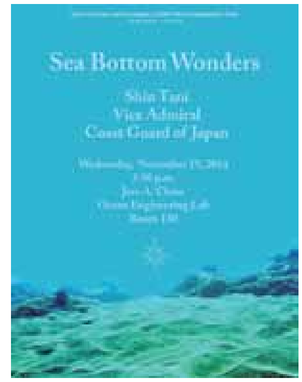
Project Title: Joint Hydrographic Center
Report Period: 01/01/2014 – 12/31/2014

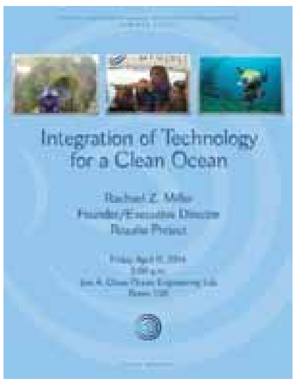
Principal Investigator: Larry A. Mayer

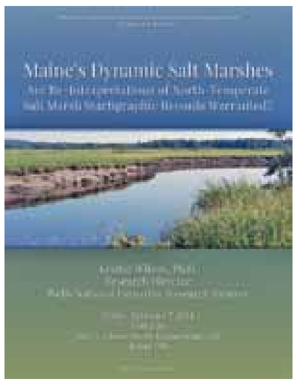
NOAA Ref No: NA10NOS4000073

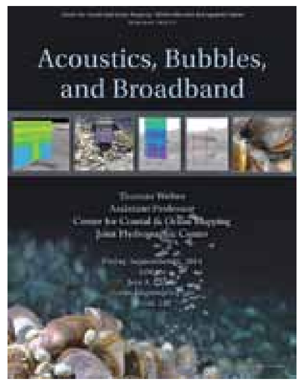


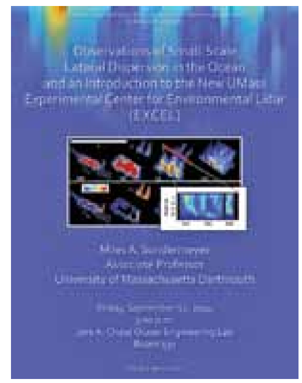


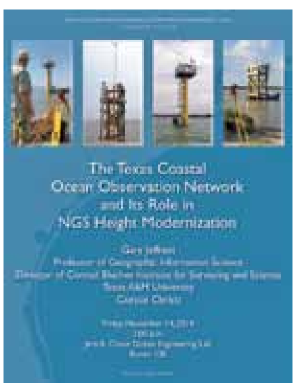


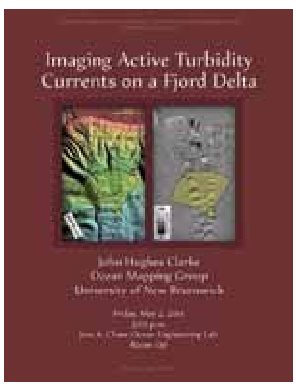


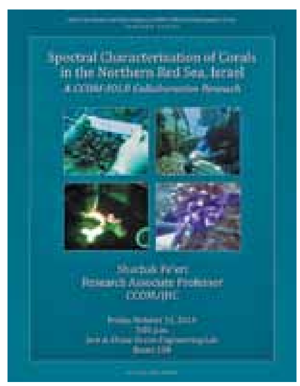


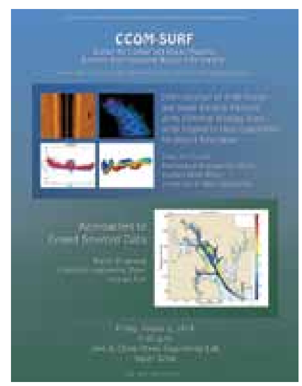


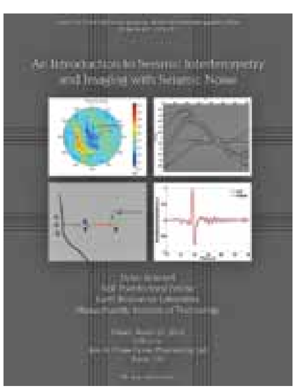


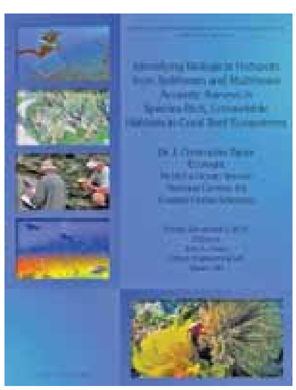


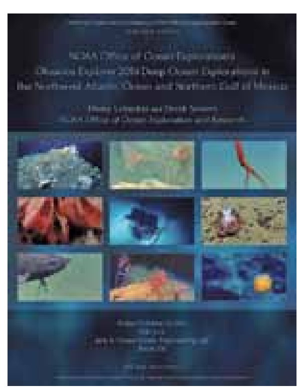


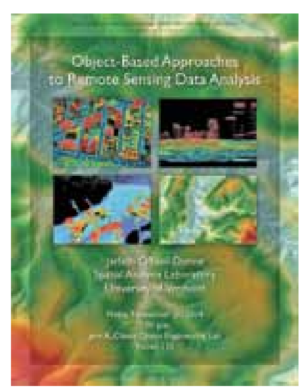












Flyers from the 2014 JHC/CCOM Seminar Series.

Cover image courtesy of the NOAA Office of Coast Survey.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded fifteen 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, funds 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 are 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 an 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, 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 incorporated 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 aboard the 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 2014 one of our industrial partners is now 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).

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.

Figure ES-1. JHC/CCOM and UNH receiving credit on ABC National News for imagery of the seafloor in the vicinity of the Malaysia airline MH370 search area.

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 WhaleAlert 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 2014 Program

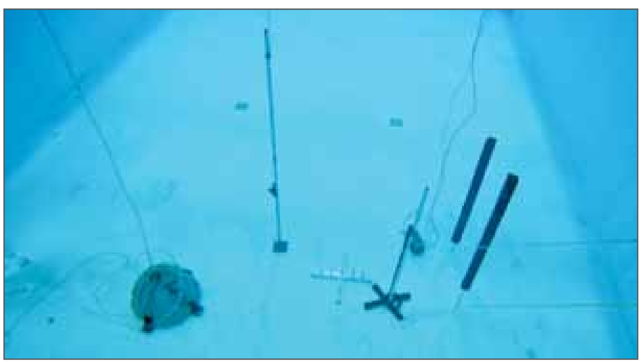
Our efforts in 2014 represent the continued growth and refinement of successful ongoing research programs combined with the evolution of new programs developed within the seven research themes prescribed by the Cooperative Agreement with NOAA (Sensors, Processing, Habitat and Water Column Mapping, IOCM, Visualization, Chart of the Future, and Law of the Sea). In 2014, as in 2013, some of our efforts have been diverted to research and data processing associated with an immediate need—response to Hurricane Sandy. This has 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.

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 have been 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 (Figure ES-1). The data we provided were used during the search and were displayed both on TV and in the print media.

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 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 an automated mechanism to perform complete three-dimensional combined transmit/receive beam-pattern measurements of transducers in a single run. Using these upgraded capabilities, a number of sonars were calibrated this year including broadband NOAA fisheries sonars and wideband transceivers and a new Reson T20-P multibeam sonar from NOAA's Office of Coast Survey. The T20-P was also used to further our work on the development of techniques to calibrate sonar systems already mounted on launches (rather than the time-consuming and difficult process of bringing the sonar to the calibration tank) and to better understand the ability of multibeam sonar systems to resolve small targets (Figure ES-2).



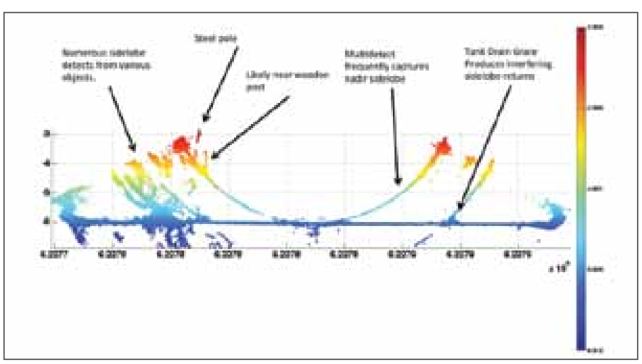


Figure ES-2. Various targets placed in the Center's acoustic test tank to test their detectability with a RESON T20-P MBES. The sonar was operated from right to left in the image (top), on the far side of the targets such that they appear in the port side of the swath. The full data set across all targets is shown on bottom side of figure.

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 in the fleet. 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. The experience gained from our MAC activities will be fed directly back into our support of NOAA mission-related research and education. 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 2014, the MAC team performed Shipboard Acceptance Trials (SAT) for newly installed or upgraded multibeam sonars on the research vessels *Nathanial B. Palmer* and *Sikuliaq*. LCDR Sam Greenaway from NOAA's OCS joined the Center MAC team for the SAT on the *Sikuliaq* to assure that the techniques and protocols developed for the UNOLS fleet are shared with NOAA. The MAC team also performed annual maintenance and checkouts 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.

In our evaluation of new sensors and their applicability to hydrographic problems, we have, through collaboration with Prof. Art Trembanis at the University of Delaware, been exploring the viability of using Autonomous Underwater Vehicles (AUVs) as a platform for hydrographic measurements. This year, several AUV surveys were undertaken in collaboration with the University of Delaware (habitat mapping off Assateague National Park and a study of the impact of dredging on scallops). The most important AUV-related activity was the Center's hosting (with Prof. Trembanis) of "AUV Hydrographic Bootcamp 2014" at UNH's coastal marine facility in New Castle, NH. AUV Bootcamp is a research and engineering workshop focused on furthering the art of hydrographic surveying from autonomous underwater vehicles (Figure ES-3). The event 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 this year's bootcamp, including 19 from industry, four from the US Navy, 11 academics, two from the UK Ministry of Defense, and eight from NOAA. Software developers from vendors that provide bathymetric

Figure ES-3. AUV Hydrographic Bootcamp 2014, held in August at the University's Marine Facility in New Castle, NH provided opportunities for engineers and developers to gain hands-on experience in hydrographic survey with an AUV. More than 45 participants from government, industry, and academia participated, working with a NOAA REMUS 600 AUV.

processing packages play a large role in AUV Bootcamp by interacting with AUV operators and hydrographers while identifying shortcomings in their processing approaches that are unique to AUV surveys.

This year also saw the initiation of an effort designed to explore the feasibility of using Autonomous Surface Vehicles (ASVs) as a platform for the collection of hydro-graphic data. Our effort has two components at this point. First, graduate student and NOAA Corps Officer LTJG Damian Manda is focusing his thesis effort on the development software that will allow a small autonomous surface vehicle to conduct hydrographic surveys. The software will allow a craft to start from a given line and complete a survey area without previous knowledge of the bathymetry. Vehicle tracks will be adapted based on detected hazards and dynamically separated depending on the depth for applicability to varying multibeam swaths. In conjunction with Damian's work, Val Smith is leading an effort to establish the capabilities of current commercial off-the-shelf ASV systems.

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, aimed at quantifying (and reducing if possible) the uncertainty associated with the measurements we make. These efforts, led by Brian Calder, are now directed on 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 work in four areas: 1) a fully-distributed version of the algorithm; 2) transition to practice of the serial and single-processor parallel versions of the algorithm in conjunction with NOAA and Center industrial partners; 3) improvements to the core algorithm to support interactive data analysis in implementation; and 4) extensions to the algorithm to allow first-order slope correction based on preliminary robust estimates of surface parameters. Most importantly the co-development model developed by the Center appears to be working and progress has been made in the implementation of CHRT with our Industrial Partners, assuring that the algorithms will be available for use by NOAA and the broader community in a timely manner.

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, with this, have been quantifying the uncertainty associated with these measurements. This year, Schmidt has been working closely with Industrial Partners Klein and Edgetech and has been able to identify conceptual errors in the way third party processing packages handled uncertainty data

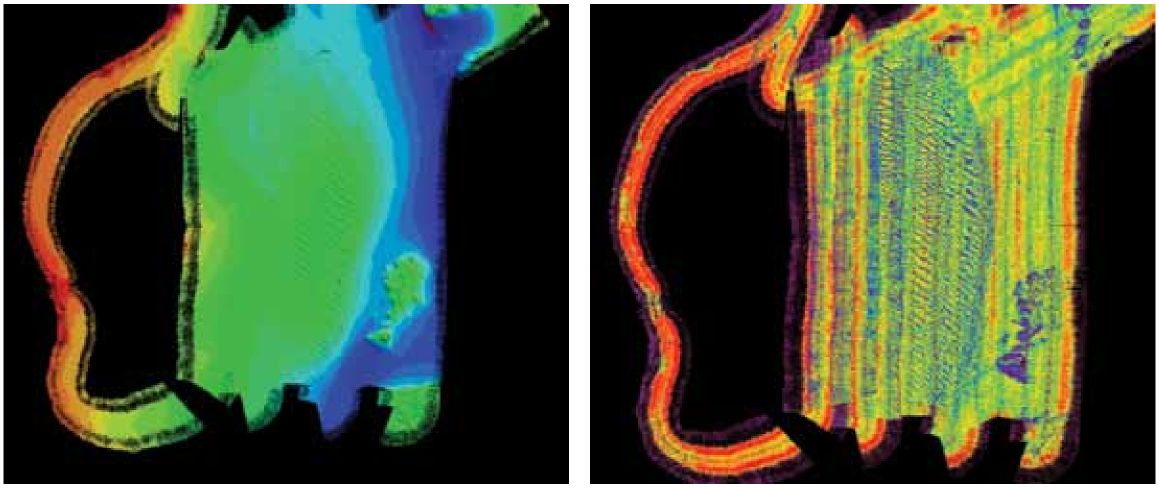


Figure ES-4. On the left, Edgetech 6205 data is shown, collected over the Portsmouth Harbor sand wave field and gridded at 0.5 m. Depths range from 1m (red) to ~28m (purple). On the right, uncertainty for this surface, 0 (red) to 0.15 m (purple), measured as the standard deviation of soundings contributing to each grid node) expressed at the 1-sigma level. IHO Special Order for these water depths is approximately 0.13 m at the 1-sigma level indicating this survey would likely meet NOAA requirements for IHO Special Order survey.

from these systems. Schmidt worked with all involved to resolve these issues, greatly increasing the potential usefulness of PMBS data for hydrographic applications (Figure ES-4) of the data produced by these systems for hydrographic applications.

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 because of the liability issues involved. To address these issues, the Center has 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 updates. The proposed approach provides a dedicated data capture device (using a small embedded processor) along with high-precision positional information and a low-cost imaging sonar. This approach, in theory, allows sufficient data to be collected to apply post-processed positioning techniques and estimate depths autonomous 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 to build services on top of the raw data. In parallel with these efforts, we are also exploring the limits of conventional Crowd Sourced Bathymetry systems; i.e., using ships of opportunity with uncontrolled bathymetric data collection systems). Working with Industrial Partner SURVICE Engineering, ARGUS data collected in Baltimore Harbor has been examined to better understand the value of these data from a charting perspective (Figure ES-5).

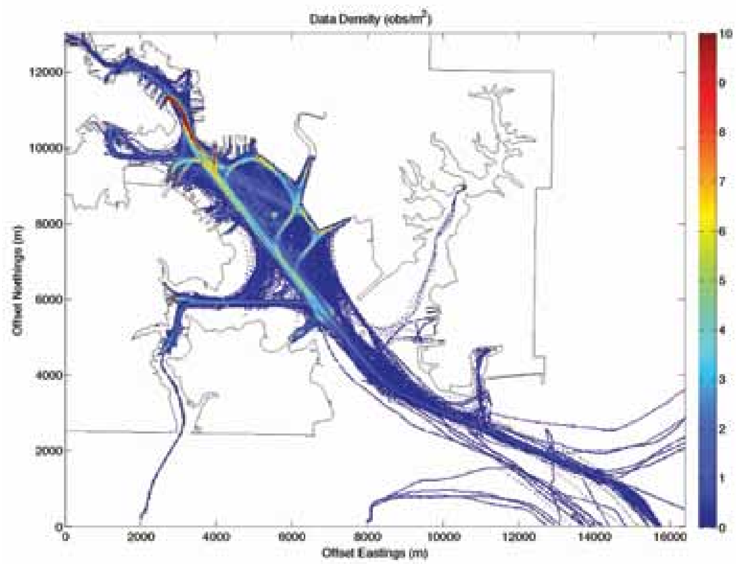


Figure ES-5.Observation density (observations per square meter) in Baltimore Harbor from ARGUS systems.

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

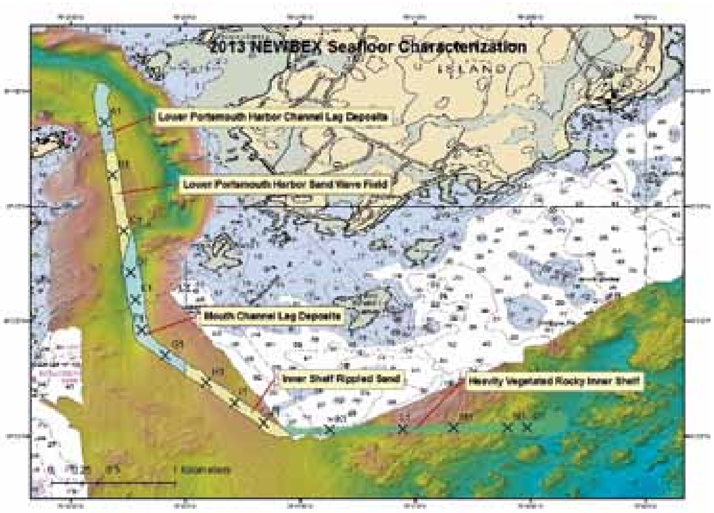


Figure ES-6. Location map of the NEWBEX transect, the 2013 sampling stations (targets), and an initial division of seafloor types.

scatter 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 new 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 (GeoCoder); 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 (be it signal processing, image processing, geology, acoustics, etc.) to quickly and collaboratively seek solutions. Tools and protocoped 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 several locations along the line. The line passes over a variety of seabed types including sand with shellhash, clean sand, sand with sand dollars, gravel, and a complicated region with a bedrock/cobble/gravel/sand mixture (Figure ES-6). 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.

Remarkably, the analysis of the 200-kHz acoustic backscatter in this region suggests that the backscatter from the entire line is stationary (Figure ES-7, left) even in the region of strong currents and bedforms. To better understand the processes that control high-frequency

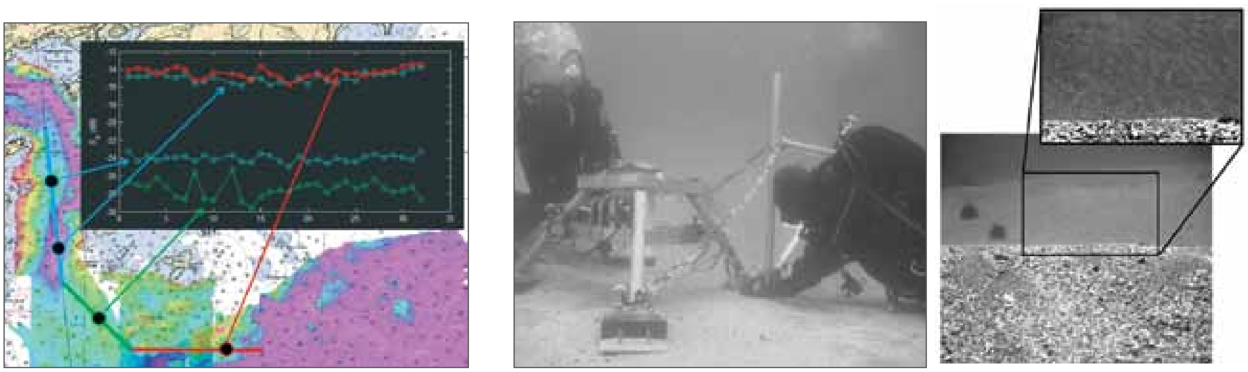


Figure ES-7. Time series of seafloor backscatter from select locations along the NEWBEX line (left) Deployment of ground-truthing system at sandwave site. Note the contrasting orientation of the sandwaves and the ripples.

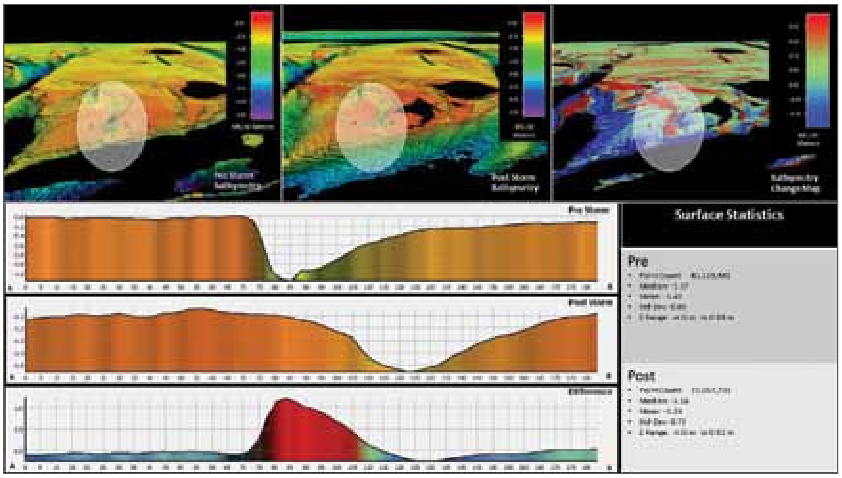


Figure ES-8. A transect across a channel in Barnegat Bay shows the creation of a new shoal, significant shift of the channel, and a change in morphology due to the effects of the storm.

seafloor backscatter, we are now collecting wide-band acoustic data at selected sites along the line, testing the hypothesis that the frequency response of the seafloor might offer another tool for discriminating between seabed types. To further investigate basic high-frequency backscatter mechanisms, we conducted a targeted field campaign aimed at a high temporal-resolution acoustic experiment in the sand wave field. In these areas, we collected calibrated acoustic backscatter over a wide range of frequencies while simultaneously collecting data that describes the temporal changes in the seabed roughness, as well as collecting bottom samples that can be used to determine grain size and shell hash content (Figure ES-7, right). The primary objective of this experiment was to gather data that can help identify the main contributor to acoustic backscatter at this site (e.g., surface roughness, shell hash, grain size).

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 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 (Figure ES-8) collected by the U.S. Geological Survey (USGS).

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 range of potential targets. An adaptive fusion algorithm (called Marine Target Detection and Object Recognition—MATADOR) is being developed that responds to changes in the environment, context, and human skills.

We have also 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, and hydrographic survey planning. This year, we worked in collaboration with NOAA to apply the techniques we have developed to derive bathymetry from Landsat and World View-2 imagery from Bechevin Bay, Alaska and Bouge Inlet, South Carolina. In Bechevin Bay, the satellite-derived bathymetry was used to map ice-induced changes in navigation channels and thus provide a guide for the location of contract surveys. This work was recognized in a letter of appreciation from the USCG. The work in Bouge Inlet demonstrated the viability of using satellite-derived bathymetry to map changes in the "Magenta Line," the line placed on NOAA charts to mark the center of navigation channels in the Intercoastal Waterway (Figure ES-9).

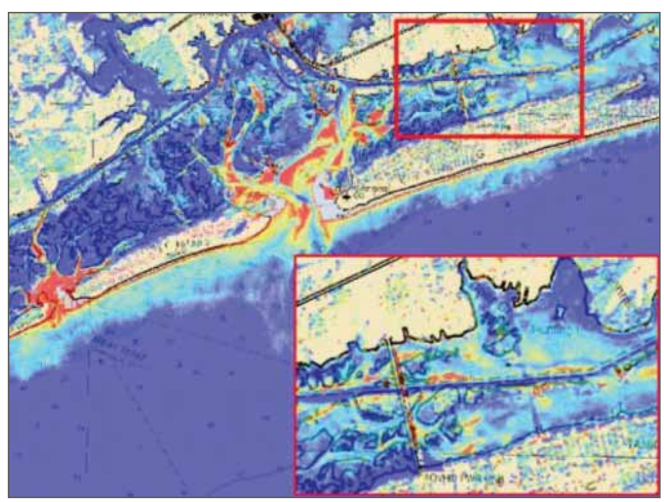


Figure ES-9. Satellite-derived bathymetry (Landsat 8) over Bouge Inlet, South Carolina superimposed on the NOAA chart. In some locations along the channel, a horizontal shift is noticeable between the charted channel and the bathymetry derived from satellite imagery.

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 production

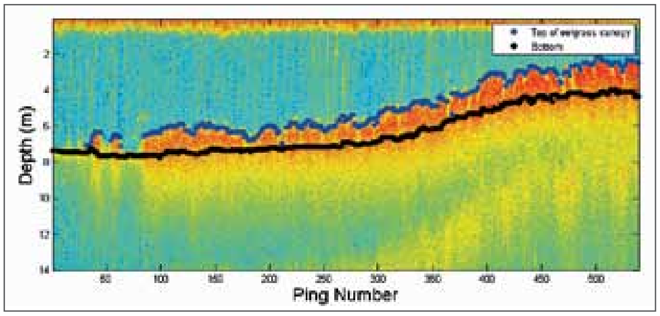


Figure ES-10. Acoustic response of eelgrass.

Figure ES-11. Instrumented goniometer. This device supports the deployment of a current meter and a video camera in fixed position relative to an eelgrass bed, as well as an echosounder focused on the same location on the seabed, but at number of different angles of incidence

of products that not only support safe navigation but can also provide information critical to fisheries management and other environmental and engineering problems. These efforts have focused on understanding and interpreting the backscatter (both from the seafloor and more recently, with the 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 (see discussion of the NEWBEX experiment above). The knowledge gained from the NEWBEX experiment will then be used to update the GeoCoder algorithms.

Beyond the identification of seafloor sediment type, we are also 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. Although mathematical models exist to predict the movement of eelgrass under varying current conditions, the relationship of these movements to an acoustic response has not been evaluated. To address this problem, graduate student Ashley Norton, under the supervision of Semme Dijkstra, is developing a catalogue of the acoustic response of eelgrass (Figure ES-10) and has built a large goniometer-like device that is placed on the seafloor over an eelgrass bed (Figure ES-11). The device is equipped with a video camera and current meter to measure all of the parameters that

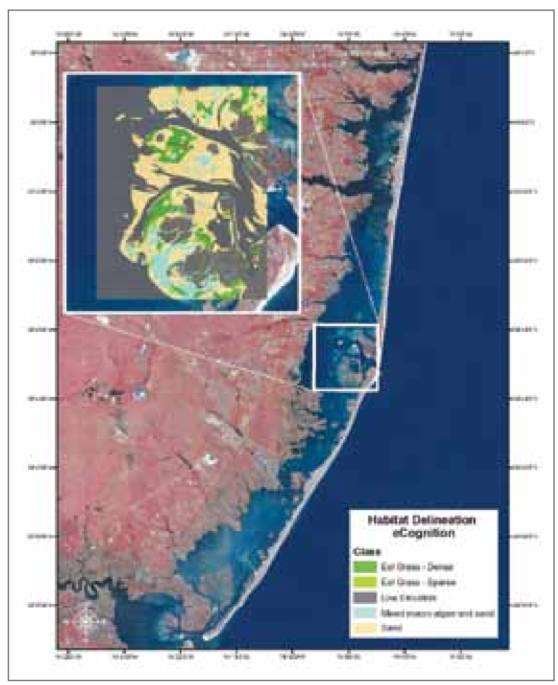


Figure ES-12. 2012 infrared image of Barnegat Bay, NJ. Inset: Map of four separate habitat types generated in eCognition by combining aerial images, waveform features, and bathymetry derived from the NOAA Riegl VQ-820-G topographic-bathymetric lidar system.

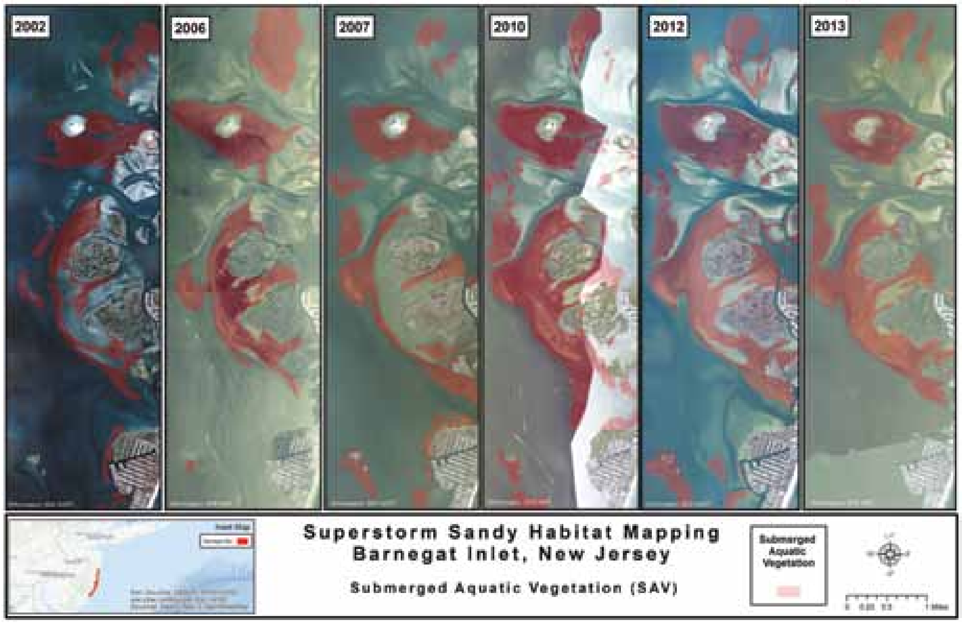


Figure ES-13. Digitized aerial imagery depicting areas of submerged aquatic vegetation in Barnegat Bay Inlet for 2002, 2006-2007, 2010, and 2012-2013.

affect the eelgrass's apparent morphology. In addition, a narrow-beam echosounder (Figure ES-11) that can step through a number of incidence angles and that is always aimed at the same patch of the seafloor is mounted on the goniometer.

Along with our work that uses acoustic data to attempt to extract critical habitat data, we are also working on techniques to quantitatively analyze lidar, hyperspectral, and optical imagery. This past year, our efforts have been closely linked to the Super Storm Sandy work where Center researchers used NOAA topo-bathy lidar data to directly map benthic habitats in Barnegat Bay and to document changes in submerged aquatic vegetation habitat that resulted from the hurricane (Figures ES-12 and ES-13).

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 report for a full description of our activities related to Deepwater Horizon). 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 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 2011, we finally had the opportunity to bring the EM302 multibeam echo sounder onboard the NOAA Ship *Okeanos Explorer* to the Gulf of Mexico and demon-strate the use of water column data for the detection and characterization of methane gas seeps over large areas. During this relatively short cruise (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—an objective that is important for both scientific and industry management perspectives—is viable.

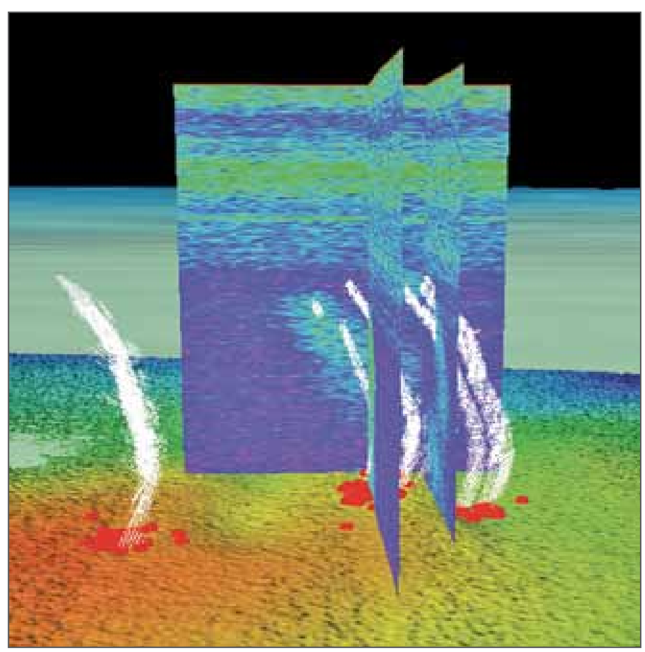


Figure ES-14. Methane seeps (vertical plumes) observed by the *Okeanos Explorer* on the western Atlantic Margin overlaid on bathymetry (ETOP02).

In 2013 and 2014, the tools we developed were used to explore for seeps in areas outside of the Gulf of Mexico resulting in remarkable finds of unknown seep activity on the Atlantic Margin (Figure ES-14). Our current efforts are focused on using our acoustic data to attempt to determine the flux of methane from these seeps, as well as the fate of the methane as it rises through the water column. To do this, we are using a newly developed broadband transceiver (a Simrad EK80) to collect wideband data that provides higher resolution detection of targets and, most importantly, allows for an estimation of the distribution of bubble sizes. Measurements of gas-seep target strengths across a wide range of frequencies can be inverted for estimates of the distribution of bubble sizes and, subsequently, estimates of free gas within the plume. Frequency-dependent changes in the target strengths of gas bubbles that rise through the water column may also help constrain models for the evolution and fate of gas bubbles as they rise to the surface and will help determine what fraction of the gas that exits the seafloor is capable of reaching the atmosphere. To date, we have collected wideband data from several Atlantic Margin seeps and from seeps in the Eastern Siberian Arctic Ocean.

While the applications of water column mapping described above have not had direct relevance to hydrographic problems, in 2014 NOAA Physical Scientist and graduate student Katrina Wyllie embarked on a thesis project designed to directly explore the applicability of MBES-derived water-column data for determining least depths on wrecks. The estimated least depths were compared from multibeam bathymetry (standard bottom detections) and multi-beam water-column data over eight different wrecks collected by NOAA vessels. Water-column least depths were determined for the wrecks and then were compared to a diver investigation (the ground truth) and the depth picked by the sonar manufacturers' bottom-detection software (Figure ES-15). The multibeam bottom-detection algorithm in both Kongsberg and Reson multibeam sonars failed to detect some of the wreck masts, as previous international studies have found. The majority of the multibeam least depths were within the calculated depth uncertainties of the estimated multibeam water-column least depths, but all of the estimated water-column least depths were shoaler than the MBES bottom detect least depths. The most significant failure of multibeam bathymetry occurred on vertical masts (high aspect ratio features) with the magnitudes of those failures in the range of several meters. As a result of this study, NOAA hydrographic vessels have demonstrated that they can collect multibeam water-column data over wrecks and that multibeam water-column data collection and processing over wrecks is the best method available to support NOAA's mission to provide accurate navigation products that ensure mariner safety.

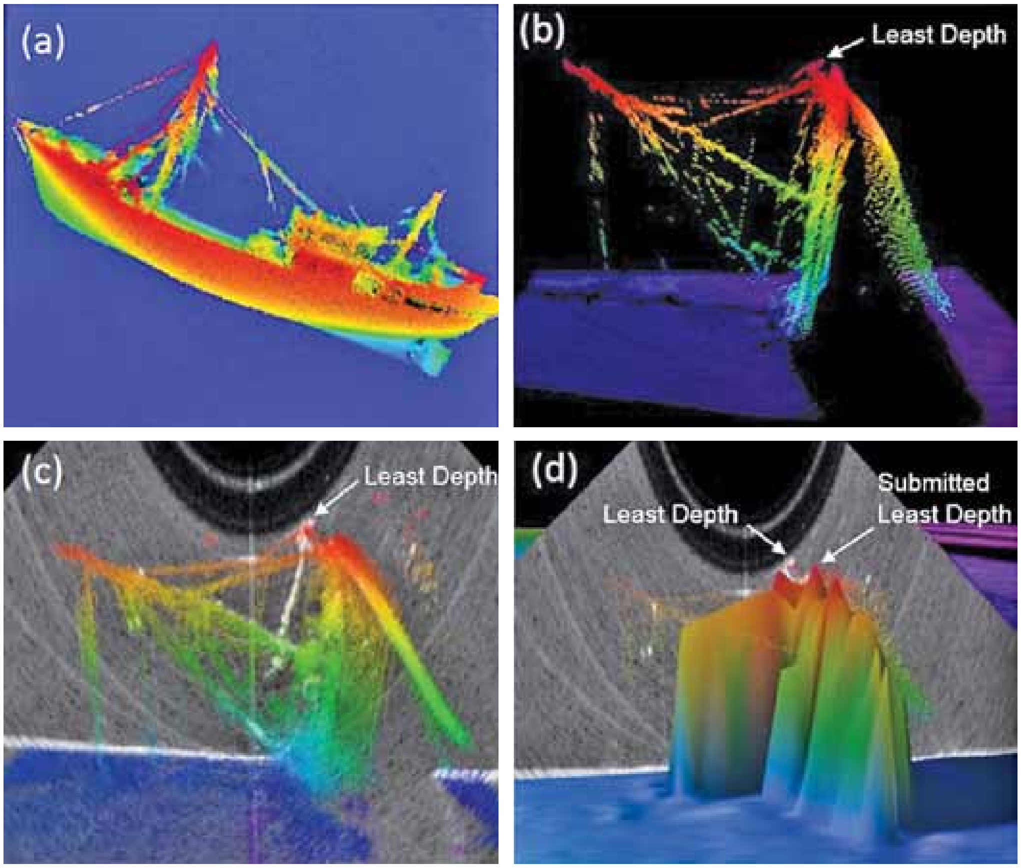


Figure ES-15. (a) Bathymetry lines collected over Women's Bay wreck. (b) Analyzed bathymetry line of wreck with least depth position indicated. (c) Water column exported point cloud of wreck with the fan at the timestamp of the least depth. (d) Verified 1m bathymetry surface with water column point cloud and fan indicating aprroximate 3m distance between designated and estimated position of wreck least depth.

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 newly 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.

Epitomizing the IOCM concept have been our efforts aboard the NOAA fisheries vessel *Oscar Dyso*n. 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—along with uncertainty and calibrated backscatter derived from the ME70—have been submitted for charting), and produce habitat maps of trawlable and untrawlable seafloor. 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 Danger to Navigation (DTON) warning. Thus, from a single fisheries sonar (ME-70) and a fisheries cruise dedicated to acoustic-trawl surveys, seafloor habitat data, bathymetric data for charting, and a specific Danger to Navigation were all derived—all from a sonar that was not purchased to map the seafloor.

Our 2014 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. 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 context of the IOCM theme.

Building on earlier work of Jonathan Beaudoin to correct backscatter problems on the NOAA Ship *Fairweather*, Sarah Wolfskehl has processed backscatter from the *Fairweather* and submitted these data to the National Geophysical Data Center (NGDC). In 2014,

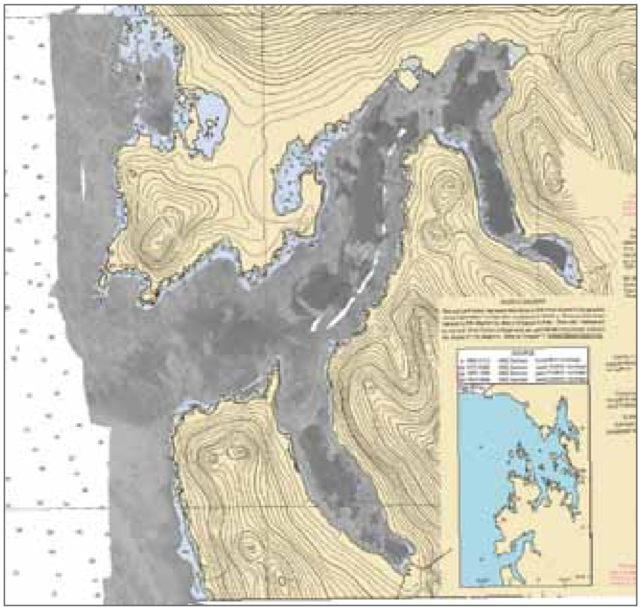


Figure ES-16. Processed backscatter mosaic from survey H11818, collected by the NOAA Ship *Fairweather* in 2010.

Sarah processed backscatter data for 13 hydrographic surveys collected by the NOAA Ship *Fairweather* in 2010 (Figure ES-16). The raw data, processed data and backscatter mosaics were archived at NGDC and are available to support seabed classification and habitat mapping for NOAA and outside organizations.

Sarah has also worked on putting the approaches developed at the Center for deriving hydrographic data from fisheries sonars into practice. Simrad ME70 fisheries multibeam echosounders (MBES) are now installed on each of five NOAA Fisheries Survey Vessels (FSV). Software developed at the Center for producing bathymetry and seafloor backscatter from these systems is now being integrated with the Hypack acquisition software that is standardly used on these vessels. This integration enables the ME70 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 May, we received a version of the integrated software from Hypack and have been working with the National Marine Fisheries Service and Office of Marine and Aviation Operations to develop a testing, training, and implementation plan. In June, we began implementation and testing aboard the NOAA Ship *Pisces*; Standard Operating Procedures were developed and will be shared with the other FSVs.

Epitomizing the concept of IOCM is the multipurpose use of "third party" data for charting. As part of our Law of the Sea Mapping efforts, Center scientists collected eight seasons of multibeam sonar data on the USCG Icebreaker *Healy* in the Bering Sea and Arctic Ocean. Sarah has performed an assessment of the USCGC *Healy* multibeam systems and evaluated the data quality from these cruises for use in application to the nautical chart in the Bering Sea and Arctic Ocean. Data from each year was compared with NOAA Ship *Fairweather* surveys in the Bering Strait. A large portion of the *Healy* transit data are in water depths that are considered the near field for the presently installed Kongsberg EM122, as well as the SeaBeam 2112 sonar the ship used in the past. The comparison with *Fairweather* data provided an assessment of the quality and accuracy of the data. In all cases, the agreement was good indicating that the *Healy* data is usable for charting purposes even though it was collected at ranges considered near field.

Continuing with the objective of evaluating third-party data for application to nautical charting, Sarah has also looked at multibeam sonar data collected by the State of Maine in support of a BOEM-funded effort to look at offshore sand and gravel resources. The operational area overlapped with previous and planned survey areas of the NOAA Ship *Hassler*. This coordination has provided a unique IOCM opportunity where the State of Maine directly benefited from existing and planned NOAA surveys, and NOAA may directly benefit from surveys conducted by the State of Maine. We are indeed mapping once and using many times, as well as formalizing the workflows and protocols established with the goal of making these processes standard aboard NOAA vessels as part of the NOAA R2R program.

Our IOCM efforts have also extended to lidar data. Although many questions still remain about the viability of using Airborne Lidar Bathymetry (ALB) data for hydrographic purposes, there is no question that this approach provides the potential for the rapid collection of bathymetric data in very shallow water where traditional multibeam sonar surveys are least efficient. In an effort to better understand the applicability of third-party ALB data, the Center is working with NOAA to look at USACE and other outside ALB data sources to compare the quality of the data collected by these systems, and their standards and operations, to NOAA MBES data and to NOAA and international hydrographic survey standards. In the past year, these efforts focused on USGS EAARL-B Topo-Bathy lidar data collected along the east coast in response to Super Storm Sandy for submission to OCS for charting.

Visualization

We continue to have a very strong focus on the development of 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 designed to address a range of ocean-mapping applications. Thomas Butkiewicz and Colin Ware 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 within 3D environments. Finally, a number of new analytical tools allow the user to leverage the predictions of these simulations to support other research projects.

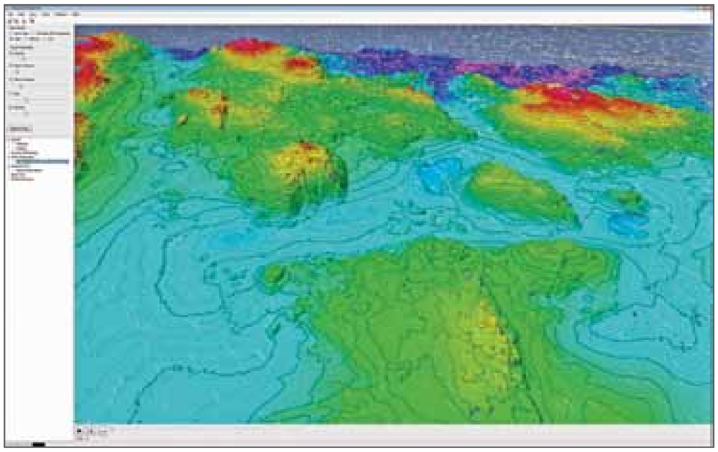


Figure ES-17. Screenshot of the VTT4D interface showing bathymetry (Isles of Shoals) and flow data.

Virtual Test Tank 4D (VTT4D) is a project that consolidates the various 3D and 4D flow-visualization techniques that Butkiewicz and Ware have developed into a single application that is intended to be shared with other researchers and the public. VTT4D replicates many of the analytic abilities and the model support found in the previous flow-visualization projects, but does so within an updated code base in an easy to distribute application. The increased flexibility of VTT4D

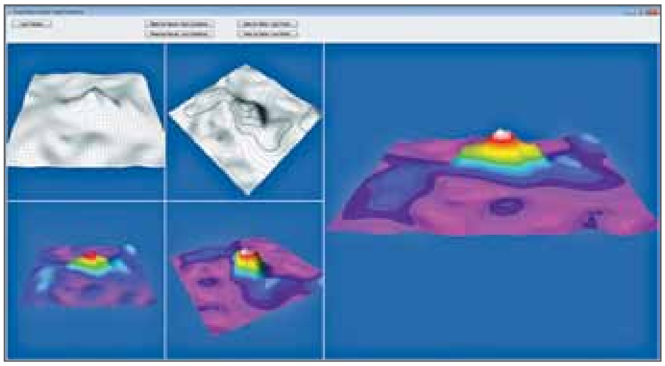


Figure ES-18. Multi-view Marine Debris Decision Tool.

allows users outside the Center to generate 4D visualizations with their own data, without the need for custom programming. It also implements many new features to support analysis and to aid presentation (Figure ES-17).

The majority of work on VTT4D this year has been to support different model/data formats, refinement of the rendering techniques and the addition of multi-threaded multi-view interfaces. There are also some new input and output modes that make it easier to import bathymetry data and raster images and to export bathymetry in various formats such as 3D.obj meshes. Support for various lidar point clouds sets has also been added to VTT4D, with these ultimately being transformed into bathymetric/terrain surfaces that can work with the existing tools. Terrain rendering and texturing has been moved into custom OpenGL vertex and fragment shaders that implement very fast, pixel-accurate contours, grid lines, color maps, banded color maps and 3D Perlin noise texturing. In addition, a slope map loader was implemented to support Super Storm Sandy research.

Figure ES-19. Zoomed view of the interactive map showing how debris objects can be queried by moving over them with mouse to get more information.

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 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. Their experiments suggest that standard rainbow color maps are not optimal but for 4D visualizations; if a rainbow color map is used, its effectiveness can be increased by switching from smooth interpolation to sharply defined bands of discrete colors. The results of this study are directly applicable to enhancing hydrographic visualization efforts at the Center and elsewhere.

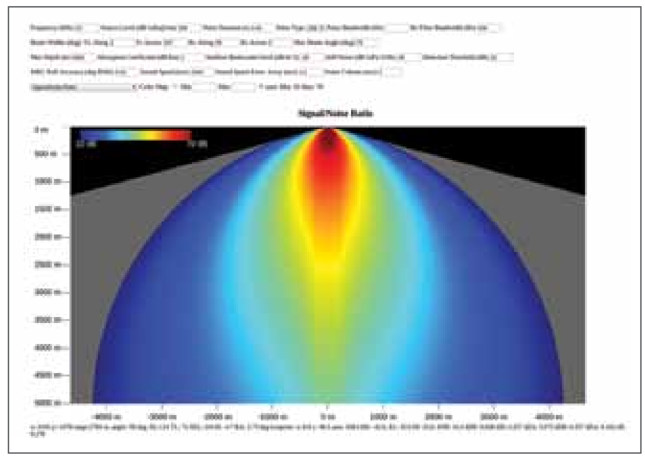


Figure ES-20. Web-based implementation of Lurton's sonar-equation based multibeam sonar performance tool.

Building on these perceptual studies and linked to our work on Super Storm Sandy, Butkieweicz has also undertaken a visualization effort focused on the determination of the optimal ways to display marine-debris targets so that the time-consuming process of human evaluation can be made more efficient. This involves the automatic generation of multiple views of the target data, with the visualization techniques, viewing angles, etc. of each view being carefully selected to best reveal and disambiguate the shape of each target. The "Marine Debris Rapid Decision Tool" (MDRDT) is actually a special multi-view version of VTT4D (Figure ES-18). Coupled with the MDRDT is a web-based, interactive tool that takes the large collections of marine-debris records received from NOAA and converts them all to a single data format, which can then be loaded and viewed on an interactive map. Users can click on polygons that denote survey/cleanup regions and then the users are presented with all the debris records for that particular region. These include obstructions, wrecks, submerged objects, etc. (Figure ES-19).

Figure ES-21. Representation of ocean currents. When animated, the flow visualization minimally interferes with other chart data.

Our visualization team is also using their skills to further our understanding of the performance of multibeam sonars. Working in collaboration with Xavier Lurton of IFREMER, Roland Arsenault, has developed a 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 that include 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 verses depth and swath width (Figure ES-20). This tool is similar to the one being distributed by the MAC (see MAC discussion under the DATA PROCESSING theme), but is web-based and interactive and thus available to a much broader audience as well as providing an excellent teaching and training tool.

Closely related to our CHART OF THE FUTURE theme (see below) is the work of our visualization group with the U.S. Navy and the International Hydrographic Organization to develop an S-100-compliant specification for the portrayal of tides and currents. Survey results of mariners overwhelmingly support the streamline-type portrayal developed by the Center. We are also looking at optimal ways to display 3D flow patterns using 3D tubes that follow streamlines with multiple cross sections or profiles. 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 (Figure ES-21). The same technologies can be used to portray wind and wave forecasts. However, determination of the best way to use an animation to portray this information has received little attention by the community.

Our visualization team has also been working with NOAA fisheries scientists to create visualizations to help interpret fisheries food-web interactions, to interactively explore ecosystem-based models of interactions between the key commercial species in the region (Figure ES-22). These visualization tools take complex model interactions and turn them into more easily interpreted results that can help inform management decisions. The tools allow for modeled long-term impacts of changes in policy to be easily seen and understood and presented to various stakeholders. Our efforts in visualizing the submerged behavior of marine mammals from tag data also continue with Colin Ware taking advantage of new low-cost tags, that now include gyroscopes, to provide more information about the angular velocity of the tagged animal and enable better estimates of energy expenditure during various phases of foraging.

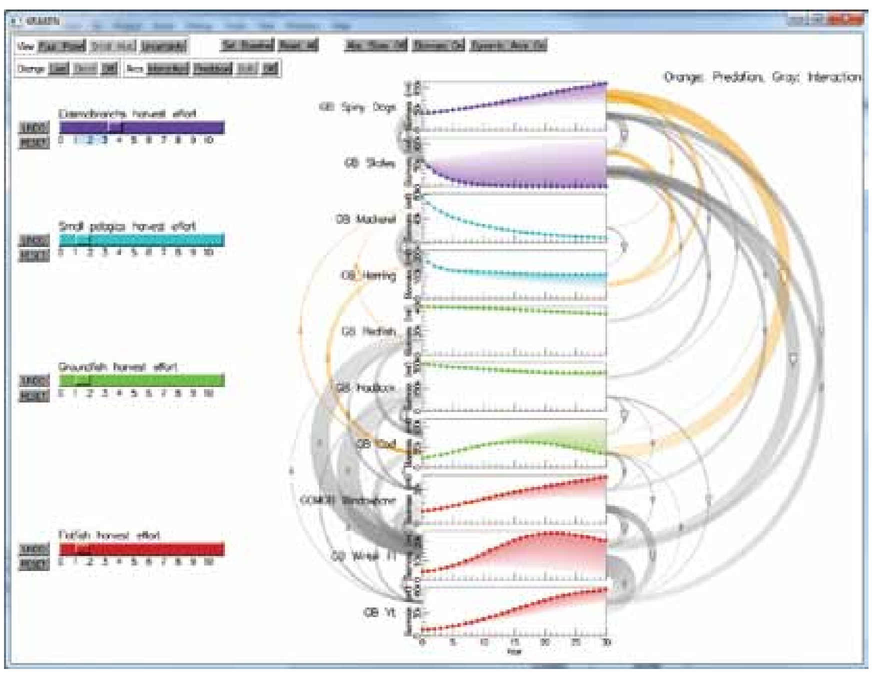


Figure ES-22. Interactive visualization of the forecast for ten Gulf of Maine species based on the NOAA KRAKEN model. The effects of increasing the catch of Elasmobranchs is visualized. The arcs show causal links in the model, with predation in yellow and species competition in grey.

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 WhaleALERT application can now be run on the iPad, iPhone, and other hand-held devices. There is now also a web-based version of the application and 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.

The revolutionary track for the Chart of the Future involves three- and four-dimensional displays and much more interactivity. In the last few years, the 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 a

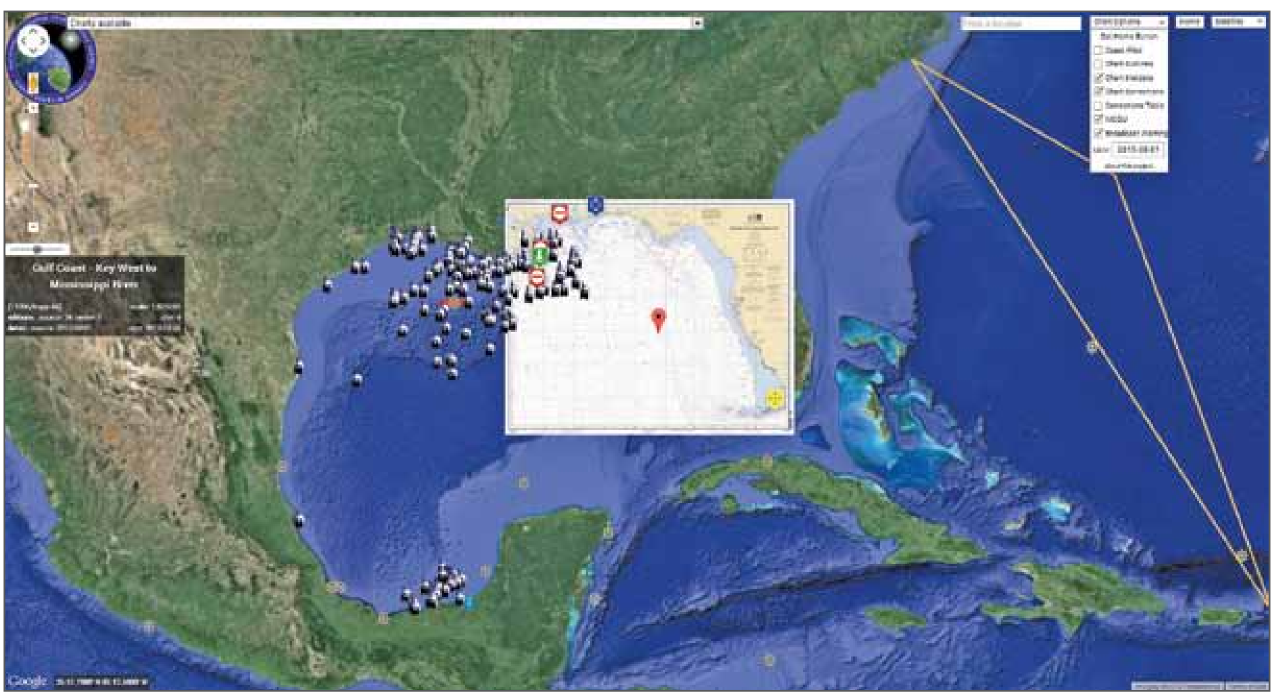


Figure ES-23. Navy version of CHuM with MODUs and Broadcast Notices.

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 a 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.

This year's efforts were focused on going beyond the prototype and working directly with OCS-derived Coastal Pilot data. Working with the OCS Coast Pilot team, Briana Sullivan is now working directly with the OCS Coast Pilot database to map out the relationships between the tables so that the next iteration of the Digital Coast Pilot will work directly on NOAA data. A component of this effort involves developing automated techniques for incorporating Local Notice to Mariners into the digital products. The project, called "Chart Update Mashup" (CHuM), involves the development of a small, specialized mashup application designed to work with Google Maps. CHuM displays the chart catalog and nautical charts in a geo-referenced environment, along with the critical corrections to the chart and the Coast Pilot with geo-referenced links. An outgrowth of this effort has been the initiation of a project with the U.S. Navy to expand the capabilities of CHuM and explore ways to serve current, tide, and meteorological data in support of the submarine fleet (Figure ES-23).

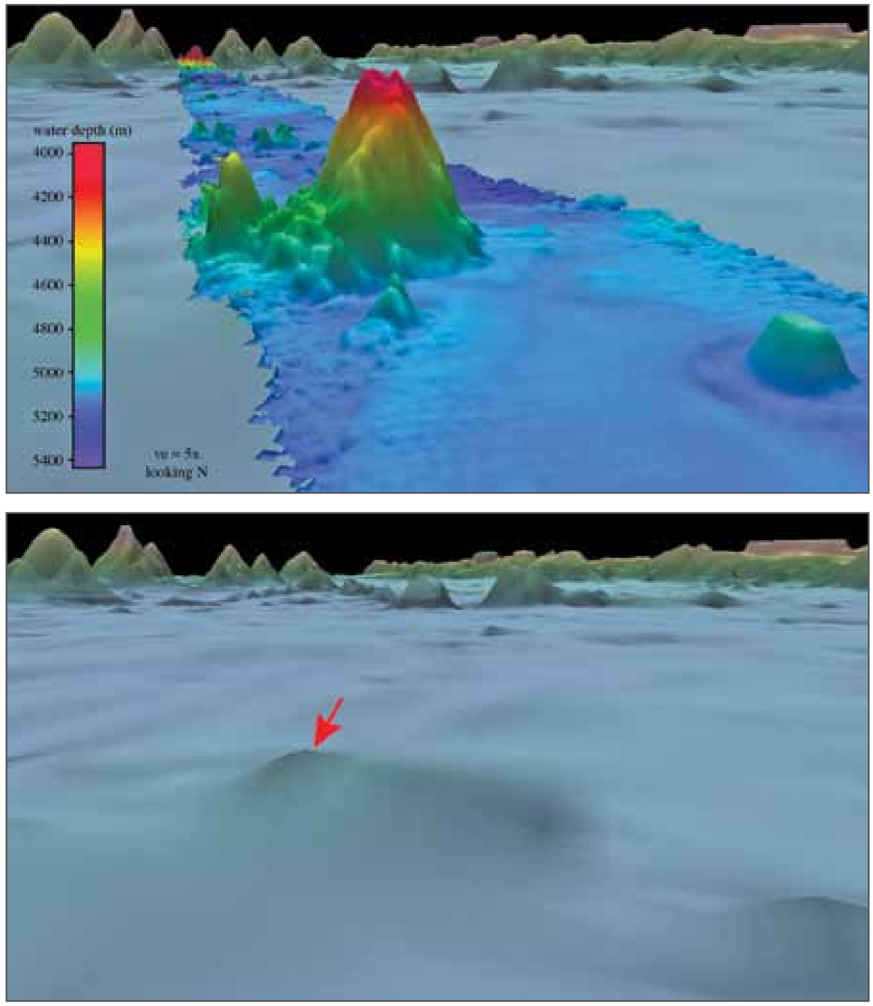


Figure ES-24. Perspective view of newly discovered seamount. Bottom panel shows the seamount from Smith and Sandwell (1997) v. 17.1 predicted bathymetry (red arrow). Top panel shows seamount in new multibeam bathymetry.

Law of the Sea

Recognizing that implementing 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, the Center has been funded, 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 surveys in 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, collecting 2,291,000 km^2 of bathymetry and backscatter data that have provided 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 2014; one in the vicinity of Johnston Atoll on the R/V *Kilo Moana* and another, a return to Mendocino Ridge, on the R/V *Atlantis* to complete mapping that started in 2009. Jim Gardner organized, planned, and led the cruise to the Johnston Atoll area in the central Pacific in August 2014. The objective of the cruise was to map a prominent gap in Keli Ridge to the south of Johnston Atoll and another gap in Karin Ridge to the east of Johnston Atoll. A total area of 97,250 km^2 was mapped during the full 13-day cruise (6275 line kilometers). A highlight of the cruise was the discovery of a prominent seamount on the multibeam monitor that only vaguely appears in the best available bathymetry of the area (Figure ES-24).

The second 2014 ECS cruise completed the mapping of the Mendocino Ridge in the eastern Pacific off the California margin that was started in 2009. The cruise, aboard the R/V *Atlantis*, began in Astoria, OR and ended in San Francisco, CA, collecting a total of 93,086 km^2 (7939 line kilometers) of high-resolution multibeam sonar bathymetry and backscatter data over a period of 19.5 days. These data have were with the 2009 data to form a single dataset that represents a coverage of 107,222 km^2 (Figure ES-25) and most likely represents all the data that will be needed in the region to address ECS issues.

Beyond the field programs, our 2014 Law of the Sea activities also included an upgrade to our Law of the Sea database, the completion of a preliminary Arctic bathymetric synthesis (Figure ES-26), analysis of ECS data, and participation in numerous Task Force, Working Group, and Integrated Regional Team meetings through the course of the year.

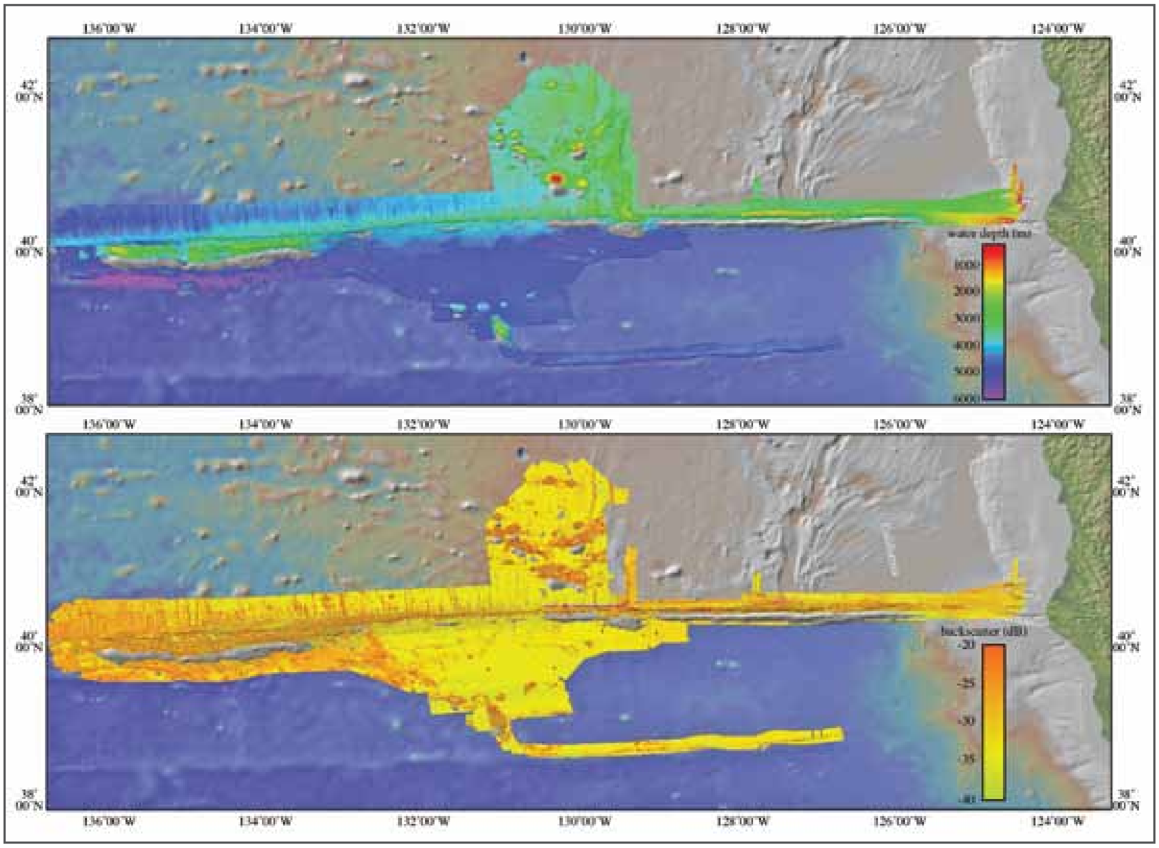


Figure ES-25. Upper panel shows merged 2009 and 2014 Mendocino Ridge bathymetry; lower panel shows merged backscatter.

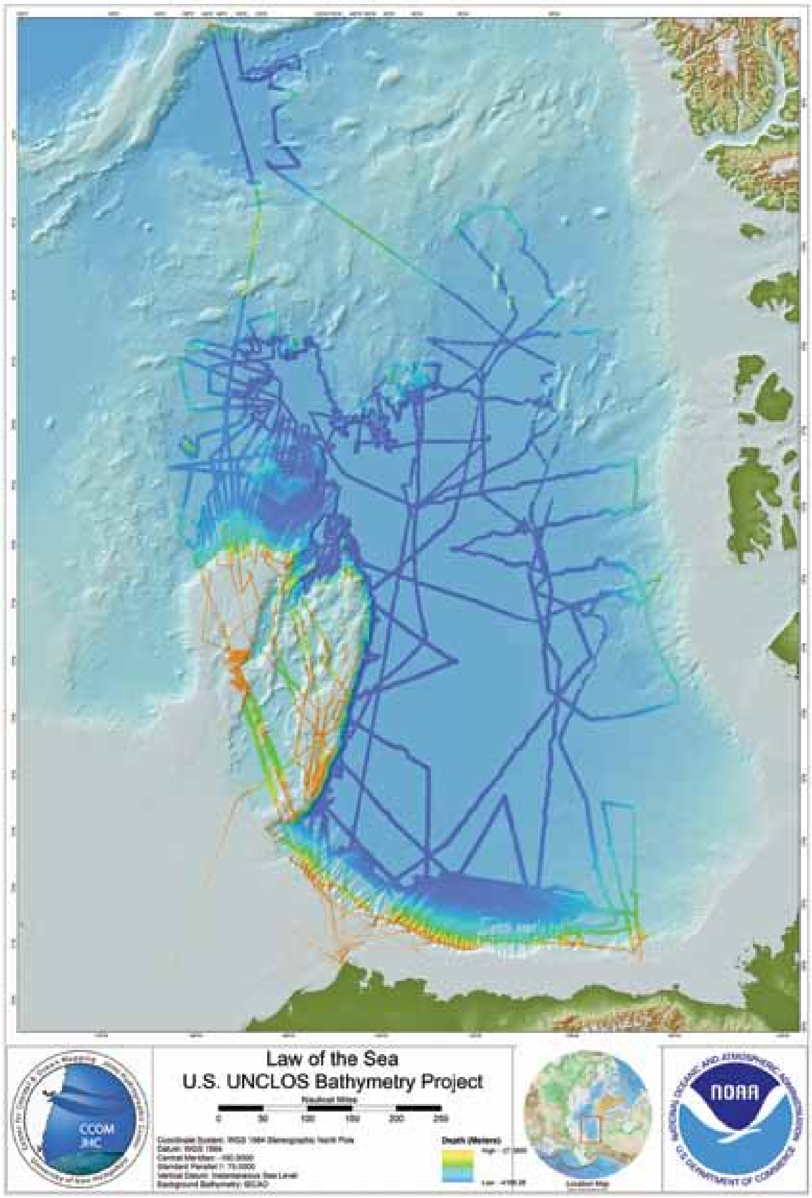


Figure ES-26. Preliminary Arctic bathymetry synthesis map. The map is generated from a single gridded dataset instead of a combined multi-year map product.

Outreach

In addition to our research efforts, education and outreach are also fundamental components of our program. Our educational objectives are to produce a highly trained cadre of students who are critical thinkers that can fill positions in government, industry and academia and become leaders in the development of new approaches to ocean mapping. Thirty-eiight students were enrolled in the Ocean Mapping program in 2014, including six GEBCO students, three NOAA Corps officers and four NOAA physical scientists (three as part-time Ph.D. students). This past year, we graduated eight master's degree students and six GEBCO students received Certificates in Ocean Mapping. A highlight of this year's educational program was the participation of some our GEBCO students in The Fifth Extraordinary International Hydrographic Conference (EIHC) that was held in Monaco from 6 to 10 October, 2014. At this event, His Serene Highness Prince Albert II of Monaco delivered the opening address and visited with our students and faculty (Figure ES-27).

We 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. There were 42,992 visits to the site in 2014 with a spike in hits associated with reports on the discovery of the new seamount near Johnston Atoll (see above). 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 also upgraded other aspects of our web presence including a Flickr stream, Pinterest page, Vimeo site, and a Facebook presence. Our Flickr stream currently has 1,988 photos with over 162,594 views since 2009, and our videos were viewed 17,599 times in 2014. Our seminar series is widely advertised and 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 SeaPerch 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

Figure ES-27. His Serene Highness Prince Albert II of Monaco meeting GEBCO program director Rochelle Wigley (second from right) and some of the alumni of the UNH Nippon Foundation/ GEBCO training program as he walked through the IHO Capacity-building exhibition.

Competition, 24 teams from New Hampshire schools, afterschool programs and community groups competed in this challenge, using ROVs that they built themselves (Figure ES-28). 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 have to navigate their ROV through five submerged hoops, a salvage course called "The Heist" where pilots must maneuver their ROV to open a door and pass through to retrieve four submerged boxes on the bottom of the pool, and a poster session where they presented posters and explained their building process to a panel of judges.

Ocean Discovery Days saw more than 1,000 students from school groups and homeschool associations from all over New Hampshire visit our facilities and learn about the ongoing research at the Center. Activities and demonstrations for all ages highlighted research on acoustics, ocean mapping, ROVs, lidar, and data visualization.

The Center also hosted a NOAA-sponsored professional development workshop focused on ocean exploration in collaboration with the NOAA Office of Ocean Exploration and Research. The NOAA Ship *Okeanos Explorer* was used as the focal point as educators from New Hampshire, Massachusetts and Maine were guided through lessons that involved innovative, modern ocean-exploration strategies and the sophisticated instrumentation and equipment used to explore our largely unknown oceans. Lesson topics included how targets are selected for exploration, mapping techniques, water-column exploration, remotely operated vehicles, and the telepresence technology that enables access to real-time ocean exploration. Participants learned how to use lessons to assist in meeting performance expectations of the Next Generation Science Standards. The participants toured the Center during the workshop and were able to communicate with the *Okeanos Explorer* at sea via the telepresence console.

Center activities have been featured in many international, national, and local media outlets including, National Public Radio, ABC News, *Huffington Post*, *Japan Times*, *Nature Magazine*, *Science World Report*, *Economic Times*, *Discovery Magazine Blog*, *Foster's Daily Democrat* and *The Boston Globe*.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2014; more detailed discussions of these and other activities of the Center can found be in the full progress report.

Figure ES-28. Teams prepare for the SeaPerch competition at the Center.

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 focus 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 nineteenth 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 2014. As such, it represents the fifth 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 14 years, from an original complement of 18 people to more than 80 faculty, staff, and students. Our faculty and staff have been remarkably stable but, as with any large organization, there have inevitably been changes. In 2014, Lee Alexander formally retired as a research associate professor with the Center though, in his retirement, he will retain an association with the Center as an Affiliate Associate Research Professor Emeritus. Dave Monahan retired from his position as the Director of the GEBCO program but also remains associated with the University as an Affiliate Professor and remains involved in the long-term planning of the GEBCO program. Rochelle Wigley, a former GEBCO student and a research scientist who has been assisting Dave for the past two years has taken charge of the GEBCO program at the Center. Jonathan Beaudoin returned to his native New Brunswick, NB to take a job with QPS. We will very much miss Jonathan but will continue to work closely with him as he works with Industrial Partner QPS to implement some of the software developed in the lab. Also in 2014, Chris Parrish, a NOAA employee who has been seconded at the lab, took a faculty position at Oregon State University. Chris will maintain his affiliate faculty status with the UNH Center. Finally, a new research scientist Erin Nagel has joined the Center team as a GIS specialist to explore new methods and best practices of using lidar and other remotely sensed data for object detection and to understand the impact of storm events like Super Storm Sandy. Outside direct funding from this grant, funding from Super Storm Sandy Supplemental funds have resulted in a large increase in personnel at the lab including Victoria Price and former graduate student Kevin Jerram who have been hired as research scientists under a Super Storm Sandy research grant (with Brian Calder as the P.I.) and Juliet Kinney, Michael Bogonko, and Cassandra Bongiovanni who are ESL employees seconded to the lab to process data related to Super Storm Sandy.

We have also had some changes in status for our personnel. As mentioned above, Rochelle Wigley is now the Director of the GEBCO program and Kevin Jerram beaome a research scientist on the Super Storm Sandy grant after his graduation. Sarah Wolfskehl who has been working for NOAA on the IOCM project, has been transferred to the Super Storm Sandy project. One of our M.S. students who graduated in 2013, Lindsay McKenna, was originally hired by the Super Storm Sandy grant but has since taken a job with NOAA's Office of Ocean Exploration and Research (although seconded to the Center). Christy Fandel, another 2013 graduate of our program, was also originally hired under the Super Storm Sandy grant but has since taken a permanent position with NOAA Office of Coast Survey in Silver Spring. NOAA hired former Center graduate student Derek Sowers as part of the OER mapping team assigned to the Center. Finally, two new post-doctoral scientists have joined the lab (both funded by external sources). Angelia Vanderlaan and Ann Blomberg are both working with Dr. Tom Weber—Angelia on the acoustic and visual detection of bluefin tuna and Ann on the detection and monitoring of gas seeps.

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 its 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 and will change his status to that of a Research Associate Professor Emeritus.

Thomas Butkiewicz received a Bachelor of Science degree in Computer Science from Ithaca College in 2005 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 Master's 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 JHC/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 in with an M.Eng. (Merit) and a Ph.D. in Electrical and Electronic Engineering in 1994 and 1997, respectively, from Heriot-Watt University in 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. 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 the 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. She has a B.A. from the University of New Brunswick in Canada, and an M.S. in Marine Biology from the University of Bremen in 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. Dr. Dijkstra 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, Dr. Dijkstra worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam-sonar data acquisition and processing. Dr. Dijkstra's current research focuses on applications of single-beam sonars for seafloor characterization, small object detection, and fisheries habitat mapping. In 2008, Dr. Dijkstra was appointed a full-time instructor and 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 JHC/CCOM.

Jim was an Adjunct Professor at JHC/CCOM from its inception until 2003 when he became a Research Professor affiliated with UNH's Earth Science Department. 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.

Jim Irish received his Ph.D. from Scripps Institution of Oceanography in 1971 and worked for 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 and Geodetic Science. Dr. Lippmann's research focuses 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.

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.

Dave Monahan is the Program Director for the Nippon Foundation's General Bathymetric Chart of the Oceans (GEBCO) training program in oceanic bathymetry. Prior to joining the Center, he served 33 years in the Canadian Hydrographic Service, working his way up from Research Scientist to Director. During that time, he established the bathymetric mapping program and mapped most Canadian waters, built the Fifth Edition of GEBCO, led the development of lidar, developed and led the CHS Electronic Chart production program, and was the Canadian representative on a number of international committees and boards. He is the past chair of GEBCO and still remains very active in the organization. In 2014, Dave retired as Program Director for the Nippon Foundation GEBCO training program but will remain active with the program and with the Center, hopefully for years to come.

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 JHC/CCOM. 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 Pe'eri is a member of the American Geophysical Union (AGU) and the Ocean Engineering (OE) and Geoscience and Remote Sensing (GRS) societies of IEEE and of The Hydrographic Society of America (THSOA).

Yuri Rzhanov is a research professor with 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. His current 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 the 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 Colin 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 Center's 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. Colin is a Professor of Computer Science and Director of the Data Visualization Research Lab at the Center. He has advanced degrees in both computer science (M.Math, University of Waterloo) and psychology (Ph.D. University of Toronto).

Thomas 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 his 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. As the Systems Manager, Jordan 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

Will Fessenden is a Systems Administrator for JHC/CCOM, and 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. is in Geophysics from the University of Western Ontario, and an M.S. from the University of Hawaii at Manoa in Geology and Geophysics, 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 the Center.

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 master's degree in Ocean Engineering from the University of New Hampshire. His master's research was the design of a methodology for field calibration of multibeam echosounders using a split-beam sonar system and a standard target. He also has an M.S. and a 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 echosounders at the acoustic tank of Chase Ocean Engineering Lab. His research focuses on the field calibration methodology for multibeam echosounders.

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) from UNH in 2012, and a Master's in marine geomatics (with honors) and a Ph.D. 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 is member of IEEE and THSOA. He has served with Italian Navy since 1999 and he has been the Operation Officer aboard the hydrographic vessels ITN *Aretusa* and ITN *Magnaghi*. Since August 2013, he has been as a 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 UN, 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, pre-production through to completion, providing technical support to the Center and wider regional projects, managing project budgets and keeping costs down, and overseeing the maintenance and operations of projects after initiation He is responsible 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 earned a B.A. in English from Nyack College in Nyack, NY and a Master's in Education from the State University of New York at Plattsburgh. She began working for the Environmental Research Group 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 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 Hurricanes 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. She oversees the day-to-day operations at the Center, as well as supervises 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 Hurricane 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 topobathy 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 bachelor's degree in Physics from the University of the South in 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 US Coast Guard Icebreaker *Healy* for several summer cruises in this role. Val completed his master's degree in Ocean Engineering in 2008 at the University of New Hampshire. 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 at 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 the R/V *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 master's 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 JHC/CCOM as Relief Captain in 2009, and was promoted to Research Vessel Captain in 2014. She came to JHC/CCOM 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 MSc 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 assistants, Linda Prescott and Maureen Claussen 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 a 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 Hurricane Sandy post-disaster research work, mostly providing support to NOAA's ICOM/JHC group in operational planning, processing practices of 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 RA and TA in the department of Civil and Environmental Engineering at UNH. Michael has an MS 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 the 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 Post Hurricane 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 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, 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 post Hurricane 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.S.. 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 the 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 who received his M.S. degree from the University of New Hampshire in 2005, has been hired by NOAA (through ERT) as a physical scientist assigned to the new NOAA vessel of exploration *Okeanos Explorer*. In this capacity, Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the . While not serving on the vessel, 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 JHC/CCOM as a Project Director for a Hurricane 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.

Christopher E. Parrish is the Lead Physical Scientist in the Remote Sensing Division of NOAA's National Geodetic Survey (NGS) and NGS's Project Manager for Integrated Ocean and Coastal Mapping (IOCM). Chris holds an appointment as Affiliate Professor of Earth Sciences and Ocean Engineering at UNH and has been based at the Center since 2010. Chris' academic background includes a Ph.D. in Civil and Environmental Engineering with an emphasis in Geospatial Information Engineering from the University of Wisconsin, an M.S. in Civil and Coastal Engineering from the University of Florida, and a B.S. in Physics from Bates College. His primary research interests include topographic-bathymetric lidar, waveform analysis, shoreline TPU, lidar geometric and radiometric calibration, and coastal science applications. Chris is active in the American Society for Photogrammetry and Remote Sensing (ASPRS), serving as Assistant Director of the ASPRS Lidar Division and Past President of ASPRS Potomac Region. He also serves as Associate Editor of the journal Marine Geodesy. In 2014, Chris Parrish left NOAA and took a faculty position at Oregon State University. He continues to maintain an affiliate faculty position with the Center at UNH.

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.S. in Ocean Engineering at the University of New Hampshire. In 2013, Glen left the NOAA Corps and became a civilian contractor to 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, and managing data and collaborating with, 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 Sandy 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. 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 where 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.

John Hall spent his sabbatical from the Geological Survey of Israel with the Center. John has been a major player 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.

Martin Jakobsson joined JHC/CCOM 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. Dr. Jakobsson 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 a 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…). 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) widely 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 worked on a range of projects including the Chart of the Future, visualization techniques for underwater and space applications, and sedimentary geology. He was particularly active in developing hydrographic applications of AIS data. Kurt is Head of Ocean Engineering at Google and an Affiliate Associate Professor at 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 and contributed this spring to a UNH course in Geodesy.

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 Master of Science and Technology in GIS Technology and a Bachelors of Science from the University of 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 related 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) was a visiting scholar from Israel Oceanographic and 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 to study 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. Photo courtesy of Rob Roseen, UNH Stormwater 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 33 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, map-storage units and two 60-inch, large-format color plotters. Users have the ability to scan documents and charts up to 54 inches using a wide-format, continuous-feed, high-resolution scanner. The Center has a full suite of printers located throughout the building, although we have 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. Included among the printers is a Canon Pixma Pro 9000 professional photo printer. All computers and peripherals are fully integrated into the Center's network and are interoperable regardless of their host operating system.

The Center's Presentation Room houses the Telepresence Console (Figure 1-2) as well as the Geowall 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" 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 had successful 2010-2014 field seasons 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

Figure 1-2. The Telepresence Console in action.

fleet in 2014-2015. The Center's IT Group expects to utilize both the Telepresence Console and the Geowall to support these additional initiatives.

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's Video Classroom also provides for web conferencing, remote teaching, and the hosting of webinars. The IT Group collaborates with the JHC/CCOM seminar organizers to provide both live webinar versions of the Center's Seminar Series, as well as video and audio archives available through the web after each event. Building on the success of the 2011 through 2014 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 the distribution of the finished product through the JHC/CCOM website, Vimeo, and YouTube.

The Center's Visualization Lab includes an ASL eye-tracking system and 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 Chase Ocean Engineering 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 available in the high bay. The wave/tow tank is approximately 120 feet long, 12 feet wide, and 8 feet 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 with a maximum amplitude of approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geo-textile construction that has

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

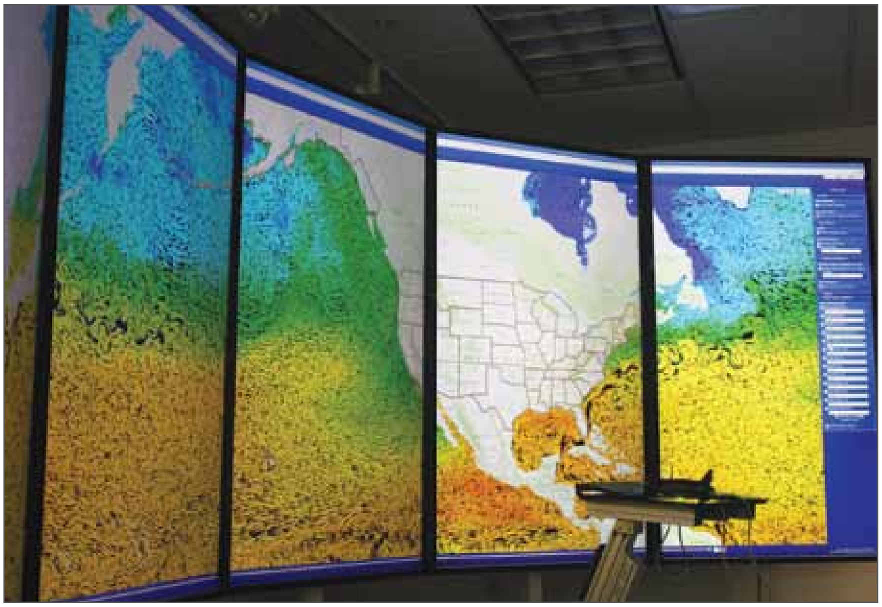


Figure 1-4. Semi-immersive, large-format tiled display.

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 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, four 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 2014, the "beach area" (wave absorbing material) was replaced but problems with the wave-generator prevented use as a wave-maker for much of the year. Nonetheless, the tank saw 143 days of operation in 2014.

The engineering tank is a freshwater test tank 60 feet long by 40 feet wide with a nominal depth of 20 feet. 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 and 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 2014, the engineering tank saw 182 days of use and, in partnership with OER, the addition of a 6-ton capacity crane to the high-bay allowing the deployment of the OER Deep Discover Remotely Operated Vehicle (ROV) and other heavy items in to the test tank.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 750-square-foot, 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 is 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 which are available to 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.

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 all of the 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 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 JHC/CCOM 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 JHC/CCOM 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.

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 and FE-227 fire suppression systems. These systems help to ensure that JHC/CCOM network services have as little downtime as possible. Additionally, the larger of the server rooms employs a security camera, as well as 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 JHC/CCOM 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 21 physical servers, 28 virtual servers, two NetApp storage systems fronting eight disk arrays, a legacy compute cluster consisting of seven nodes, and a new compute cluster consisting of eight nodes. A Cisco ASA 5520 firewall and McAfee Nitro Intrusion Prevention System (IPS) provide boundary protection for our 10-gigabit and gigabit Local Area Network (LAN). JHC/CCOM 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. In early 2013, the IT Group replaced the Foundry Big Iron RX-8 that served the south wing with a Brocade ICX 6610 switch stack, which provides 192 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, four Brocade 7131N wireless access points centrally managed with a Brocade RFS4000 management device, and a QLogic SANBox 5800 Fibre Channel switch. The PowerConnect switch handles edge applications such as the Center's Electronics Laboratory and Telepresence Console. 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 in the 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.


Figure 1-5. JHC/CCOM SAN and NAS infrastructure in the primary server room.

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 de-duplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems house 28 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's email server, Visualization Lab web server, Certification Authority server, several Linux/Apache web servers, a Windows Server 2008 R2 domain controller, version control server, two JIRA project management servers, an FTP server, and an Oracle database server.

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. The Center's IT staff also built, configured, and installed a custom-built locally-redundant NAS storage system hosting over 54TB of data as a middle-tier 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 18 months this system has been in use, it has proven a popular and reliable option for large, static data sets and as such, a second, larger array has been proposed and is expected to enter service in 2015. 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 that consists of two 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 de-duplicated 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 new hardware 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 JHC/CCOM server and workstation environments.

The Center's network is protected by a Cisco ASA 5520 firewall and McAfee Nitro Intrusion Prevention System. The firewall provides for high-performance packet filtering and the IPS performs deep packet inspection to detect application-layer threats. The firewall also serves as a mobile access gateway, providing SSL VPN access. With the mobile access solution, users are able to join their local computer to the Center's network from anywhere in the world, allowing them to use many of the Center's network-specific resources on their local computer.

The IT staff recently implemented a new eight-node compute cluster furnished by 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.

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

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 198 high-end Windows and Linux desktops/laptops, as well as 29 Apple Mac OSX computers that serve as faculty, staff, and student workstations. As of March 2014, the IT Group successfully completed the phase-out of Windows XP, ahead of schedule for the April 8th deadline. All Windows workstations at the Center are now running 64-bit versions of Windows 7 Professional or Windows 8.1 Pro, whereas MacOS users are currently migrating to Apple's OSX 10.10 Yosemite platform. Deploying the 64-bit version of these operating systems allows faculty, staff and students to take advantage of new, enhanced versions of scientific and productivity software, while maintaining interoperability with older applications.

The Center also maintains a network at the Pier Support Building at UNH's Coastal Marine Lab facility in New Castle, NH. The Center's 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 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 Center's research vessels are located at the pier adjacent to the Pier Support Building. 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 work is underway to upgrade the *Coastal Surveyor's* systems for the 2015 season.

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 is to improve bandwidth and access to Internet2 resources for scientific research. The Center's was identified in the grant as a potential beneficiary of such improved access. The project is currently in the pre-deployment stage but, when completed, the Center will have a 20-gigabit connection to UNH's Science DMZ, and from there a 10-gigabit connection to Internet2. This improvement will allow 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 network improvements are scheduled for installation and testing in the first quarter of 2015, and are planned to be operational in a production capacity by the second quarter of 2015.

Information security is of paramount importance for the IT Group. Members of the JHC/CCOM 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. Also in the works is a next-generation firewall/threat management appliance, intended to replace the Center's current firewall/IPS hardware. JHC/CCOM also 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's 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 the Center's 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 the Center's 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. The same server that hosts Nagios also runs a Syslog-ng server as a central repository for system logs and utilizes custom-built modules for event identification and report generation to meet a variety of additional logging needs. In the first quarter of 2015, the IT Group is planning an upgrade of the server currently hosting Nagios/Syslog-ng, including the implementation of a modern Security Information and Event Management (SIEM) service, which will allow for faster identification and response to possible network threats. Where physical security is concerned, Chase Ocean Engineering Lab now utilizes a biometric door access system, which provides 24/7 monitoring and alerting of external doors and sensitive IT areas within the facility.

All information security controls at the Center are independently assessed on a regular basis. Assessment reports, along with related documentation, are compiled into an Assessment and Accreditation package and submitted to NOAA's Office of Coast Survey. The package demonstrates the Center's compliance with the Department of Commerce's Information Technology Security Program Policy, as well as the host of NIST standards that form the foundation of the Policy.

The IT Group utilizes Request Tracker, a helpdesk ticket tracking software published by Best Practical. JHC/CCOM staff, students, and faculty have submitted over 7,000 Request Tracker tickets since its inception in mid-2009. Throughout 2014, the IT Staff was able to resolve 90% of tickets within three days. The software is also used for issue tracking by the Center's administrative staff, lab and facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee project.

The Center continues to operate within a Windows Active Directory domain environment and, in early 2012, migrated the majority of its domain services to a 2008 Active Directory running on Windows Server 2008 R2. A functional 2008 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 Center's IT Group maintains all low and moderate impact 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. The Center's IT Group encourages developers to use Mercurial for new projects while continuing to support Subversion for existing projects. Mercurial uses a decentralized architecture that 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.

Figure 1-7. Research vessels at the pier in New Castle, NH.

The Center's website, re-launched in 2012, utilizes the Drupal content management system as its framework. Drupal allows 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.

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 2014, for the first time, the *Coastal Surveyor* operated each month 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 Hydrographic 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. 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. This will be the fifth year that both vessels will be left in the water over the winter at the UNH pier facility in New Castle and will be the first year that we attempt to operate the vessel year-round in support of the NEWBEX Experiment. Winter mooring has reduced the winter costs and added the advantage that vessels are at the ready through the entire year. 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*—specially 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 was 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, 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 installed 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 were 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, aside from normal maintenance, 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.) were 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,* 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

Figure 1-8. R/V *Coastal Surveyor with bow ram.*

R/V *Cocheco*

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

R/V *Cocheco* (Figure 1-9) 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 Course. In 2014, *Cocheco* operated over eight months (April through December) and supported 55 days of research programs and the Hydrographic Field Course. Upgrades to the UPS-power system, wiring for 220 VAC, and instrument bench wiring for both 24 VDC and 12 VDC were also completed. In 2009, AIS was permanently installed on *Cocheco*, her flux-gate 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 2014, routine maintenance was performed (e.g., replacing fluids, filters, cleaning the bilge, inspections) and specific issues were addressed including battery problems, replacing the compass and recalibration of the compass and autopilot. New bottom paint and zincs were also applied.

Figure 1-9. R/V *Cocheco*.

R/V *Coastal Surveyor* Scheduled Research and Educational Operations for 2014

Month	Days	User
January	1	NEWBEX
January	1	WAASP
January	1	L3-Klein Hydrochart
March	2	WAASP
April	2	L3-Klein Hydrochart
April	2	WAASP
May	1	students with Klein Hydrochart
May	4	Edgetech
May	4	Novatel
May	2	Heaton research project
May	1	L3-Klein Hydrochart
June	15	Summer Hydro 2014 Field Class
June	1	Vessel Operations and Training
July	2	L3-Klein Hydrochart
July	2	Vessel Operations and Training
August	3	AUV Boot Camp
August	1	L3-Klein Hydrochart
August	2	Vessel Operations and Training
September	2	L3-Klein Hydrochart
September	1	Vessel Operations and Training
October	1	Bajor
October	1	Coast Discovery Day
October	1	L3-Klein Hydrochart
October	3	Schmidt and Edgetec
October	1	Lanzoni
November	2	Lanzoni
December	1	Pe'eri
December	1	Vessel Operations and Training
TOTAL	61	

R/V *Cocheco* Scheduled Research and Educational Operations for 2014

Month	Days	User
April	1	Lippmann - river cruise
April	1	Seamanship Course - buoy operations
May	1	Seamanship Course - boat handling
June	4	Summer Hydro Field Course - SBES
June	2	Bajor - tripod deployment and recovery
June	15	Summer Hydro Field Course - SBES, MVP, and sidescan
July	12	Summer Hydro - grab sampling and video
July	1	S. Dijkstra - video sampling
August	2	Mayer, Jerram, Weber - transducer calibration
September	2	Bajor - tripod deployment and recovery
October	2	Bajor - tripod deployment and recovery
November	1	Bajor - tripod deployment and recovery
December	1	Bajor - tripod deployment and recovery
TOTAL	55	

Figure 1-10. CBASS surveying in New River Inlet, NC.

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 developed the Coastal Bathymetry Survey System or

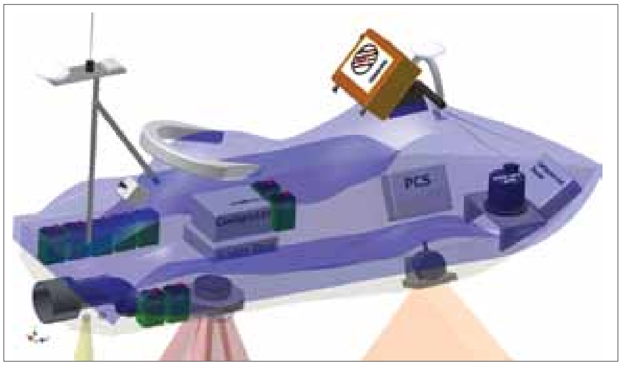


Figure 1-11. CAD drawing (right) showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery packs, GPS and RTK antennae, and navigational display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

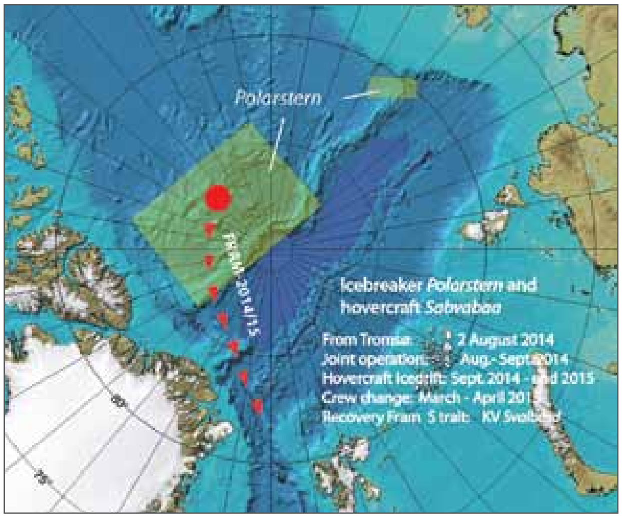
In 2012, numerous upgrades were made to the CBASS including the development of full-waveform capabilities for the 192 kHz single beam echosounder on board, the integration and field use of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) for observation of the vertical structure 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 Inlet and River Mouth Dynamics Experiment (RIVET) sponsored by the Office of Naval Research (ONR). 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 in late 2012 kept it out of the field for most of 2013, but it has been 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.

R/H *Sabvabaa (Blodgett Foundation)*

Dr. John K. Hall, a 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 been 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

Figure 1-12. Yngve Kristofferson and the R/H *Sabvabaa* drifting above Lomonosov Ridge.



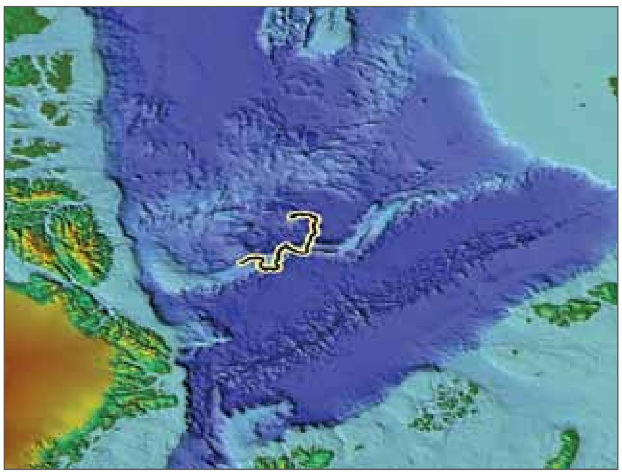


Figure 13. Proposed drift of *Sabvabaa* ice-drift (upper left) and actual drift as of 21 Dec. 2014 (lower left).

for Coastal and Ocean Mapping 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 ten 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 with enough supplies to operate from 12–16 months autonomously, making a series of scientific measurements as it drifts (Figure 1-14). Since its deployment in September, the ice-drift station has crossed back and forth across the Lomonosov Ridge several times.

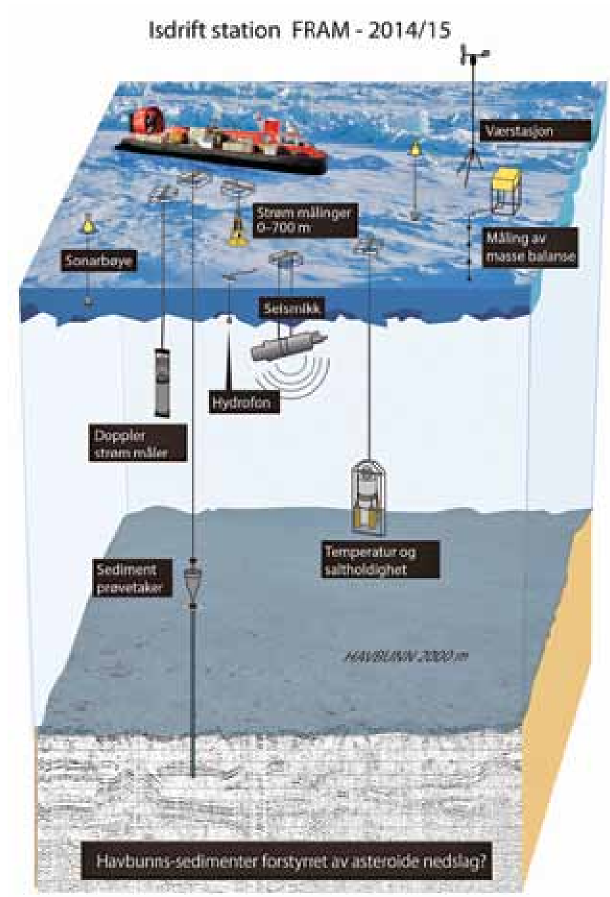


Figure 14. Overview of the scientific measurements to be made by *Sabvabaa* during its operation as an ice-drift station during 2014/2015. Figure from **http://www.geo.uib.no/polarhovercraft/index.php?n=Main.FRAM-2014-15**.

Deep Discoverer ROV NOAA OER – Maintenance Facility

The 2010 NOAA cooperative agreement includes much closer and formalized collaboration with NOAA's Office of Ocean Exploration and Research (OER). As part of this collaboration, the OER program chose to use the facilities of the Center as the staging area for the development of their new deep-water Remotely Operated Vehicle (ROV) (Figure 1-15). In support of this effort, the Center constructed a large, secure work area in proximity to our deep acoustic test tank so that, as development is underway, components or the entire system can be tested in the tank. (Figure 1-16).

The NOAA ROV system is a two-vehicle system—the ROV and a camera sled. The ROV is connected to a camera sled via a flexible electro-optical tether which is, in turn, connected to the support vessel via a standard oceanographic 0.68-armored electro-optical-mechanical cable. Each vehicle carries separate subsea computers, high-definition (HD) cameras and Hydrargyrum Medium-Arc Iodide (HMI) lighting. Both are controlled independently of the other from a topside control system. The 9200-lb. ROV operates in a traditional manner employing a large-array of LED lights, six cameras, two seven-function manipulators, thrusters, and other science equipment to explore its surroundings. The camera sled serves three primary purposes: to decouple the ROV from any ship movement, provide an alternative point of observation for ROV operations, and to add substantial back-lighting for the ROV imaging. Both systems are rated for operations down to 6000 m.

In 2011, the camera sled—christened *Seirios*—was constructed at the Center. The Center directly supported the NOAA team in the construction of the sled through machining of parts, assembly of the sled and supporting testing in the Engineering Tank. The *Seirios* was fully tested in the lab and deployed on the NOAA Ship *Okeanos Explorer* where it worked successfully for the entire 2011 season.

In 2012, construction of the ROV (now called *Deep Discoverer*) began and was ready for initial testing by early 2013. A new gantry system capable of lifting six tons was installed in the high-bay to move the vehicle directly from the work area into the acoustic engineering tank. The ability to work on the ROV in the high-bay and easily place it in the acoustic engineering tank for testing greatly facilitated the completion of the ROV, allowing it to be sent to the *Okeanos Explorer* for field testing in April 2013 and to commence mission operations in May. Since May 2013, the *Deep Discoverer* has had two very successful field seasons in support of OER work; we expect the vehicle to return to the Center for further upgrades early in 2015.

Figure 1-15. *Deep Discoverer* ROV being constructed in the Center's high-bay.

Figure 1-16. *Deep Discoverer* ROV being tested in the Ocean Engineering test tank at the Center.

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 certificate 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 collaborated with the Dean of the College of Engineering and Physical Sciences and the Department of Mathematics and Statistics to create a specialized math course, which is taught at the Center. This course is designed to provide Center students with the math skills needed to complete the curriculum in Ocean Mapping. The content of this course was designed by Semme Dijkstra and Brian Calder specifically to address the needs of our students and is taught by professors from the UNH Math Department. 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 was 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) has subsequently been 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: the continued development of the "Tools for Ocean Mapping Course" that was completely overhauled in the 2012-2013 academic year, and 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.

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

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.

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, with 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 every year since the 2007 academic year, such that 60 scholars have already graduated with the Graduate Certificate in Ocean Mapping. The 2014 class of six were selected from sixty applications, attesting to the on-going demand for this course. This year, after a meeting with Nippon Foundation, the recruiting process was further refined by adding a former Scholar to the selection committee to continue scholar interactions.

Funding for GEBCO Year 11 was received from the Nippon Foundation and the selection process followed the new guidelines of including input from the home organizations of prospective students. A shortlist of six students (Figure 2-1) from the sixty applicants representing twenty-six countries was made and these students from Japan, Venezuela, Kenya, Sri Lanka, Philippines and Indonesia (with one new coastal state represented) are currently completing their first semester at the Center.

The Nippon Foundation/GEBCO students add a tremendous dynamic to the Center both academically and culturally and funding from the Nippon Foundation has allowed us to add a valuable new member to the Center staff with Rochelle Wigley in the position of Program Director for the GEBCO bathymetric training program. Nippon Foundation/GEBCO training program students at UNH are required to visit other international ocean organizations and/or take part in a deep-ocean cruise. This requirement rounds out the students' training, helps them build networks, and puts into practice their newly-acquired theoretical knowledge. This training/internship includes familiarization with the programs that the organization being visited is engaged in, as well as directed work under supervision.

The Nippon Foundation/GEBCO training program students of Year 10 visited NOAA's National Geophysical Data Center (NGDC) and the co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO; AWI (Bremerhaven); BODC (Liverpool); Lamont-Doherty Earth Observatory (NY); Geoplus and Simrad (Spain); and OceanWise (UK). Survey cruises included the NOAA Ship *Rainier* (Alaska), surveys in the NOAA Thunder Bay National Marine Sanctuary, the E/V *Nautilus* (Windward Passage), the R/V *Atlantis* (ECS cruise to Medocino Ridge) as well as the R/V *Falkor* (Ontong Java Plateau). A poster titled, "Managing Geophysical Data in the South West Indian Ocean using GeoMapApp," generated by Hemanaden (Ravi) Runghen and based on his lab visit at Lamont-Doherty Earth Observatory (LDEO) at Columbia University was awarded a best poster prize at the Challenger Society for Marine Science 2014 annual conference in Plymouth, UK. In addition, the Year 10 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.

An ancillary project of the GEBCO program at UNH, The Indian Ocean Bathymetric Compilation (IOBC) project is ongoing with the establishment of a database comprised of >600 available single beam, multibeam and compilation grids. This project has proved to be an excellent working case study for the Nippon Foundation/GEBCO students to understand the complexities of downloading and working with publicly available bathymetric datasets.

The Second Training Workshop of the Nippon Foundation/GEBCO Indian Ocean Bathymetric Compilation project was held 5–9 May in Kuala Lumpur. The meeting objective was to utilize the skills and experience of Arndt, the Editor of the International Bathymetric Chart of the Southern Ocean (IBCSO) program, as he led the

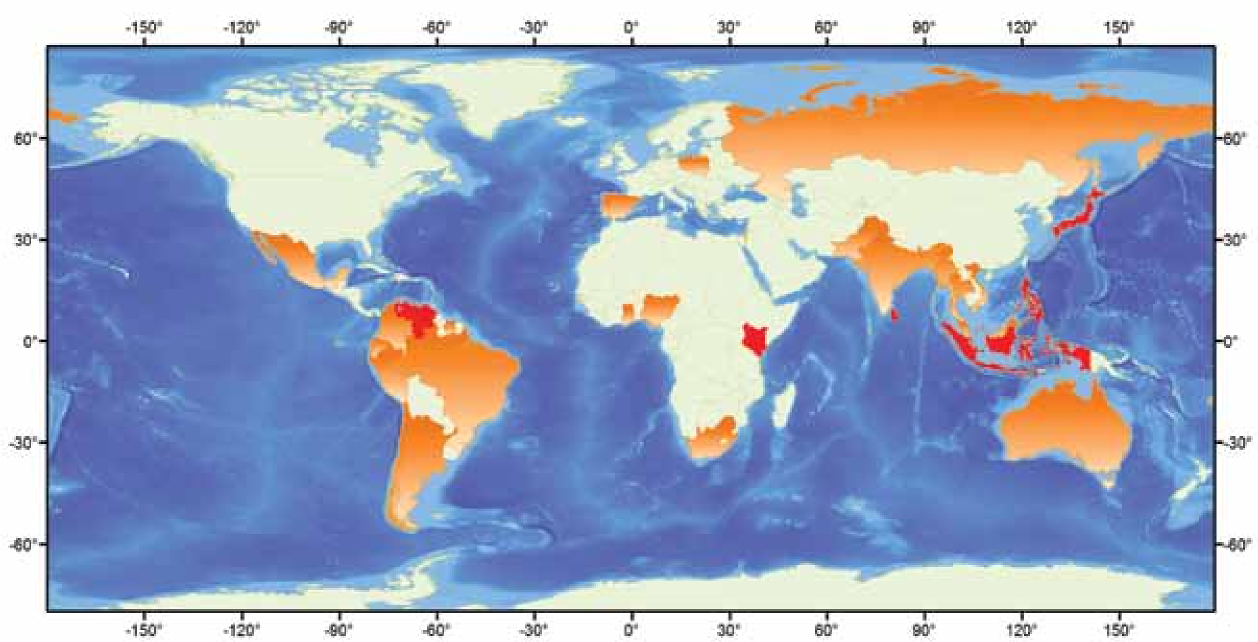


Figure 2-1. Distribution of countries from which GEBCO scholars have come (orange) and home countries of Year 11 GEBCO scholars (red).

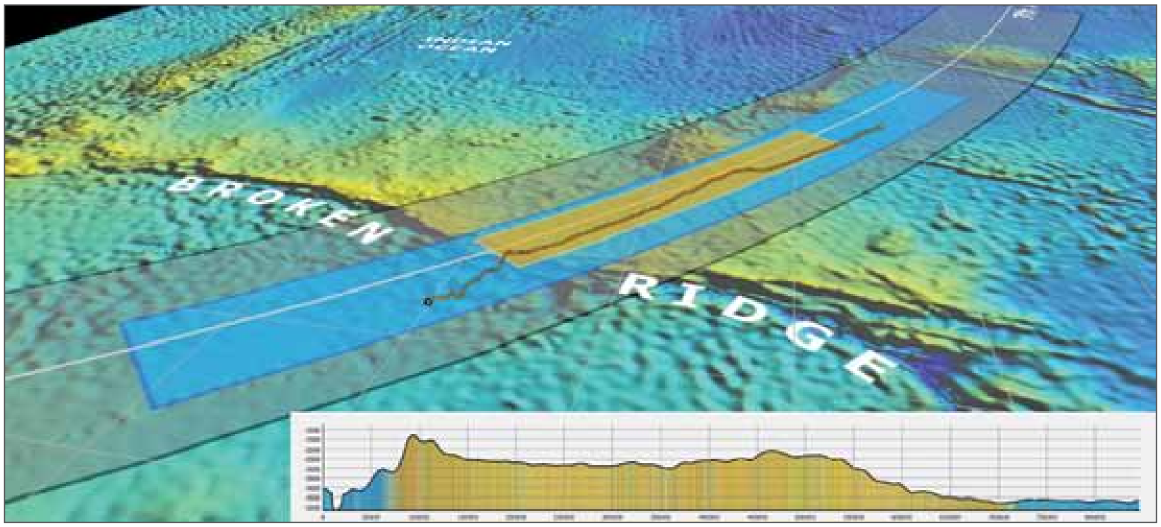


Figure 2-2. One of the images generated for journalists requesting information and an understanding of the seafloor in the vicinity of the Malaysia airline MH370 search area.

group through the work flow of the IBCSO bathymetry compilation. This provided the opportunity for training of a group of Nippon Foundation/GEBCO scholars as Jan Erik Arndt shared his knowledge (and scripts) from all aspects of the IBCSO project, including data homogenization and archiving, IBCSO data formats, the different resolution gridding algorithms and the bending algorithm to merge multi-resolution grids to produce a final product. This project was represented at the Fall 2014 AGU in a poster titled, "Nippon Foundation/GEBCO Indian Ocean Bathymetric Compilation Project," co-authored by Rochelle Wigley, Norhizam Hassan, Mohammad Chowdhury, Roshan Ranaweera, Xinh Le Sy, Hemanaden Runghen and Jan Erik Arndt.

The Indian Ocean Project proved to be a resource for both government agencies and the media as the dataset was used to produce bathymetric images (Figure 2-2) of the seafloor in the area believed to be the crash site of Malaysian Airline MH370.

The Fifth Extraordinary International Hydrographic Conference (EIHC) was held in Monaco 6–10 October, 2014. One focus for this meeting was the topical issue of capacity building. In light of this, the International Hydrographic Bureau (IHB) organized an exhibition on International Hydrographic Organization (IHO) capacity-building initiatives and invited alumni from the Nippon Foundation/GEBCO program to attend (Figure 2-3), where His Serene Highness Prince Albert II of Monaco delivered the opening address of the 5th EIHC and opened the Capacity Building Poster Exhibition. Four posters were on display for the week of the conference that summarized the Nippon Foundation/GEBCO Postgraduate Certificate in Ocean Bathymetry training program at the Center, allowing the Scholars present to expand on their experience and knowledge gained while at the Center.

Figure 2-3. His Serene Highness Prince Albert II of Monaco meeting GEBCO program director Rochelle Wigley (second from right in top photo) and some of the alumni of the UNH Nippon Foundation/GEBCO training program as he walked through the IHO Capacity-building exhibition.

GEBCO Students (2014-2015)

STUDENT	INSTITUTION	COUNTRY
Kimeli, Amon	Kenya Marine & Fisheries Research Institute (KMFRI)	Kenya
Kurita, Hirokazu	Hydrographic and Oceanographic Department of Japan	Japan
Prasetyawan, Indra	Department of Marine Science, Faculty of Fisheries and Marine Sciences of Diponegoro University, Semarang	Indonesia
Roperez, Jaya	National Mapping and Resource Information Authority (NAMRIA)	Philippines
Samarakoon, Nilupa	National Hydrographic Office/NARA of Sri Lanka	Sri Lanka
Vallee, Maxlimer	Venezuelan Foundation for Seismological Research (FUNVISIS)	Venezuela

Hydrographic Field Course

The 2014 Summer Hydrographic Field Course brought the R/V *Coastal Surveyor*, R/V *Cocheco*, 11 Center students, and several technical staff under the supervision of Semme Dijkstra to the waters off Rye, NH. The primary objective was to extend surveys southwards of the area covered by the course in 2013.

One hundred and sixty-two nautical miles of main scheme lines were collected, with an additional 14 miles of cross lines in water depths ranging from 22m to 1m below MLLW. Total areal coverage was 2.1 square nautical miles. Additionally, 12 grab samples were obtained, along with seafloor video coverage of each of the sampling sites.

Data were collected and processed using HYPACK and CARIS. A comparison with Charts 13274, 13278 and 13282 was performed and the observed depths generally matched the charted depths, but shoaler depths were observed near the various rocky outcrops resulting in four DTONS (affecting eight charts) that have been reported to NOAA. The charted contours generally align well with the automatically generated contours from the dense MBES data (Figure 2-4).

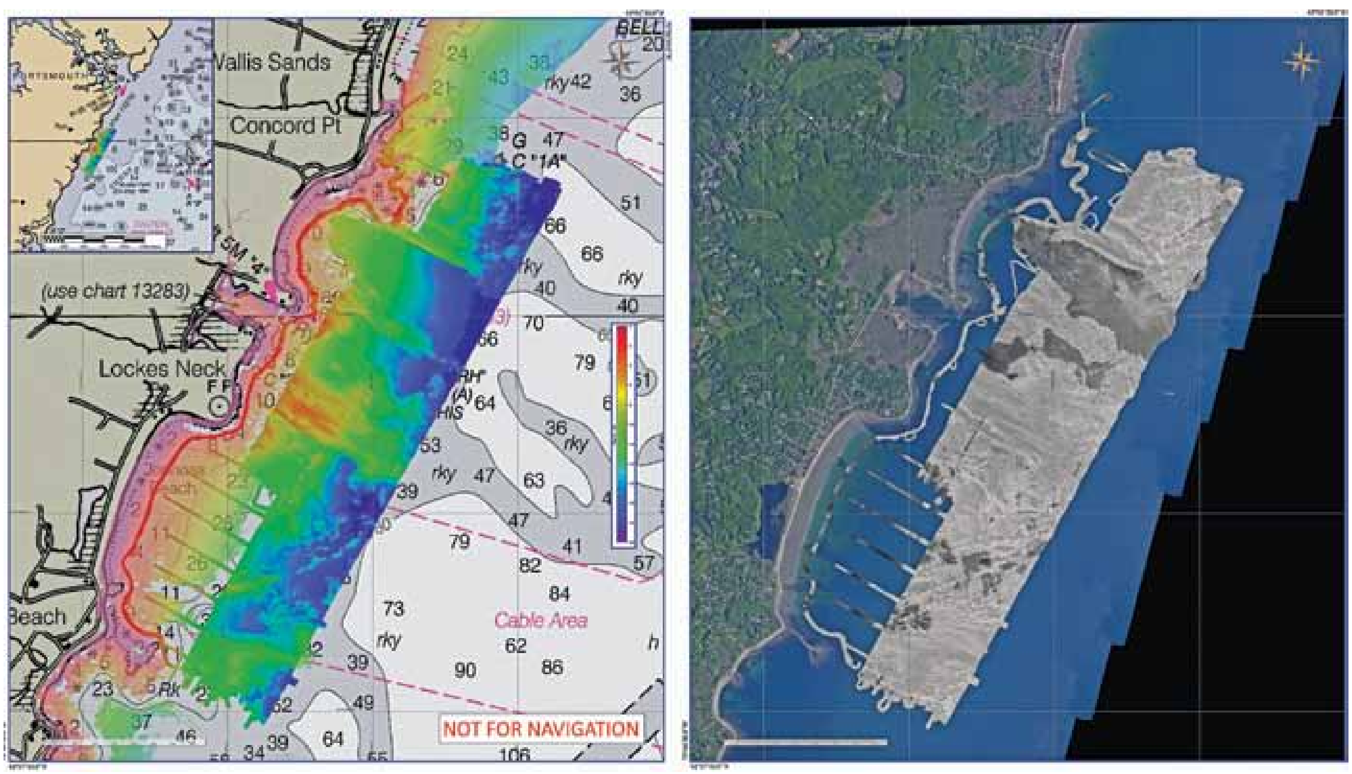


Figure 2-4. Bathymetry and backscatter products of the 2014 Hydrographic Field Course off Rye, NH.

Extended Training

With our fundamental educations 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 2014, we hosted short courses from CARIS, ESRI, QPS, GeoCAP, Rolls Royce and Edgetech. These meeting 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 and the visits of many NOAA scientists to discuss NOAA priorities for multibeam-sonar systems and surveys as part of a series of NOAA Multibeam Workshops and the developing Intergovernmental Working Group for Integrated Ocean and Coastal Mapping (IWG-IOCM).

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.

2014 SURF Fellows and Projects

Fellow: Rasha El-Jaroudi (Georgia Institute of Technology undergrad)
Advisor: Brian Calder
Project: Approaches to Crowd Sourced Data

Fellow: Zhuo Xu, (UNH undergrad)
Advisor: Val Schmidt
Project: Determination of Both Range and Angle Binning Methods with Different Binning Sizes with Regard to Their Capabilities for Object Detections

In 2014, we also hosted Hollings Scholar Lydia Auner. The Hollings Scholarship is a prestigious fellowship offered by NOAA to talented undergraduates to work with NOAA researchers at an appropriate research facility.

Undergraduate Mentoring

While most of the Center efforts are focused on graduate students, many of the Center faculty are also involved in mentoring undergraduates through the employment of students on an hourly or work-study basis. In 2014, we 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. During 2014, LTJG Damian Manda of the NOAA Corps 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. Funding for materials was provided through a grant from the Naval Engineering Education Center (NEEC).

Academic Year 2014 Graduate Students

STUDENT	PROGRAM	ADVISOR
Bajor, Eric	M.S. Mech. Eng.	Weber
Bolan, Daniel	M.S. Comp. Sci.	Ware
Borba, Caesar	M.S. E. Sci. Ocean Mapping	Armstrong
Barrios Burnett, Felipe	M.S. E. Sci Ocean Mapping	Monahan
Di Stefano, Massimo	Ph.D. OE	Mayer
Englert, Christopher	M.S. E. Sci. Ocean Mapping	Mayer
Freire, Ricardo	Ph.D. OE Mapping	Alexander
Guo, Xiao	M.S. OE Mapping	Parrish
Heaton, John	M.S. Mech. Eng.	Weber
Hu, Han	M.S. OE Mapping	Rzhanov
Humberston, Joshua	M.S. E. Sci. Ocean Mapping	Lippmann
Irish, Onni	M.S. E. Sci. Ocean Mapping	Mayer
Jerram, Kevin	M.S. OE Mapping	Weber
Kidd, John (NOAA)	M.S. E. Sci Ocean Mapping	Armstrong
Loranger, Scott	Ph.D. E.Sci Oceanography	Weber
Malik, Mashkoor (NOAA)*	Ph.D. Ocean Engineering	Mayer
Manda, Damian (NOAA)	M.S. OE Mapping	Armstrong
Miao, Dandan	M.S. OE Mapping	Calder
Mihtsentu, Mezgeb	Ph.D. Comp. Sci.	Ware
Nifong, Kelly	M.S. E. Sci. Ocean Mapping	Armstrong
Norton, Ashley	Ph.D. NRESS	Dijkstra
Pencanha, Anderson	M.S. E. Sci Oceanography	Armstrong
Pillsbury, Liam	M.S. OE Mapping	Weber
Rice, Glen (NOAA)*	Ph.D. OE	Armstrong/Calder
Sowers, Derek*	Ph.D. NRESS	Mayer
Stevens, Andrew	M.S. Comp. Sci.	Butkiewicz
St. Jean, Carmen	M.S. Comp. Sci.	Ware
Welton, Briana (NOAA)	M.S. E. Sci. Ocean Mapping	Armstrong/Weber
Wyllie, Katrina (NOAA)	M.S. E. Sci. Ocean Mapping	Armstrong
Wolfson, Monica	Ph.D. NRESS	Boettcher
Yao, Fang	M.S. E. Sci. Ocean Mapping	Parrish
Yin, Qian	M.S. OE Mapping	Rzhanov

* Part-time

Status of Research: January–December 2014

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 2013 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 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 in the upgrades to 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 to 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.

Research engineer Carlo Lanzoni, Tom Weber, NOAA Corps officer and student Briana Welton, Glen Rice, Val Schmidt, Mike Jech (NOAA NMFS), and our industrial partners were the prime users of the calibration facility in 2014. They calibrated systems for that will be used on NOAA launches, looked at the capabilities of several new systems, and continued the work begun as part of Lanzoni’s Master’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 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 3-1). 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. Components of the system were tested in the tanks in 2012, and, in 2014, Carlo Lanzoni field-tested the in-situ calibration technique using a Reson T20-P aboard the R/V *Coastal Surveyor* with help from Glen Rice and Sam Greenaway (Figure 3-1). This method utilizes a standard tungsten

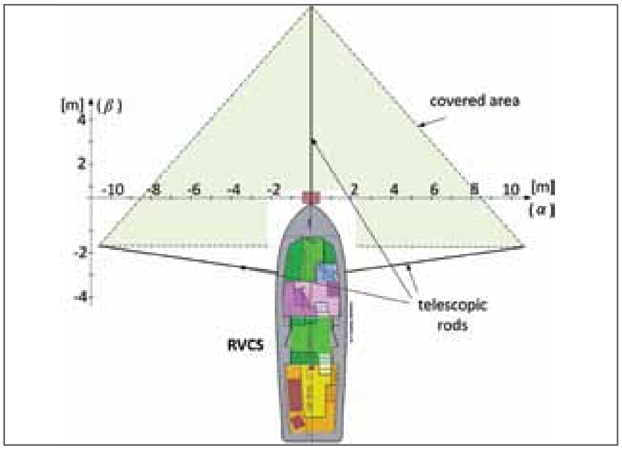


Figure 3-1. Planned and actual deployment of a calibrated target sphere on the R/V *Coastal Surveyor*.

carbide target sphere from three telescopic poles at various locations underneath the MBES, and uses a split-beam echosounder (operating in passive mode) to position the sphere within the MBES. Although there is considerable mechanical difficulty with this method, initial results from the experiments in the fall of 2014 (and in particular, the beam-pattern results shown in Figure 3-2) suggest that this method can be made to work. Developing an absolute calibration method for high-frequency MBES in the field is a tantalizing goal. Based on this initial success, we anticipate exploring ways to reduce the mechanical complexity of this field procedure.

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 2014, 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 3-3). These calibrations include measurements of radiation beam pattern, impedance, transmit voltage response (TVR) and receiver sensitivity (RS):

1. A Simrad 120 kHz split-beam sonar system operating with the newly acquired Wide Band Transceiver (WBT) in support of Chris Taylor NOAA – NCCOS). The WBT is a new product we are testing that allows sonar systems to receive signals over a much wider bandwidth than before. The WBT has important implications for better target discrimination, 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) in conjunction with the WBT to evaluate the ability of the system to detect small targets close to the seafloor.
2. A suite of Simrad split beam sonars were calibrated, including ES-18 (18kHz), ES70 (70kHz), ES 200 (200kHz) transducers.
3. Four deep water single-beam electro-acoustic transducers from Edgetech (models, DW106, DW216, DW216, Hammer Bell and 216 Stave) were calibrated along with an Edgetech PVDF transducer.

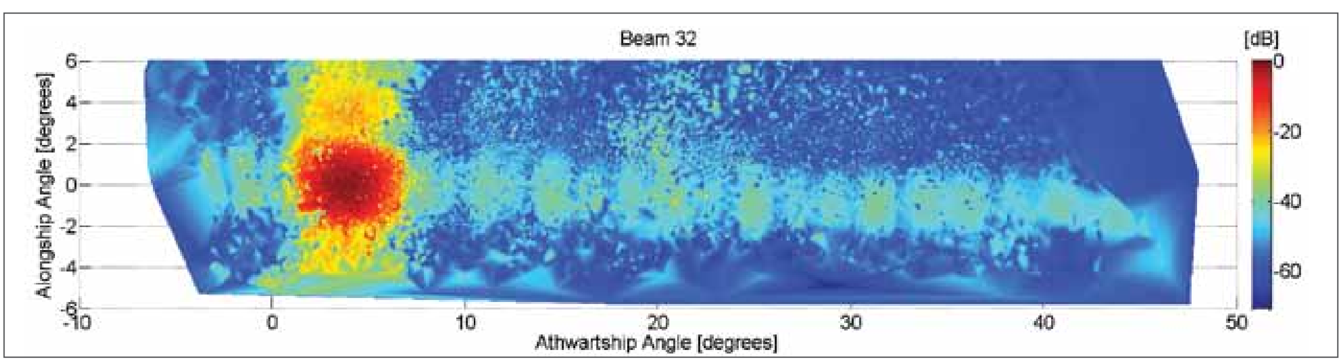


Figure 3-2. Beam pattern results from field measurements with the Reson T20-P.

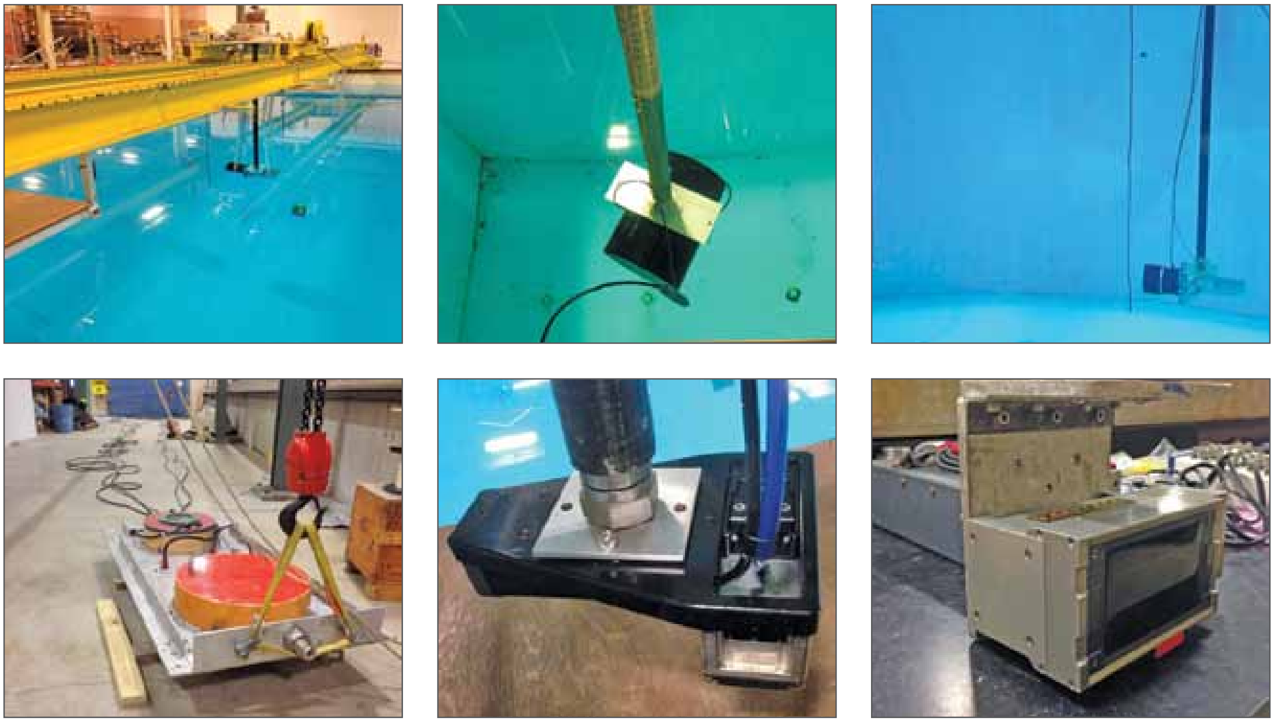


Figure 3-3. Some of the transducers tested in the acoustic tank in 2014. Left to right – top row: Edgetech DW106, Edgetech Hammer Bell, Edgetech DW216. Left to right – bottom row: Simrad ES 18 and 70, Reson T20P and Imagenex Delta-T.

4. A NOAA-owned Reson T20-P multibeam system.
5. Imagenex Delta-T model 837 B sonar.

"Standard" Extended Target for MBES Calibration

Along with the standard sonar calibration techniques described above we have also been working on developing techniques that will allow us to quickly and efficiently measure the angular response of the seafloor in a calibrated manner. As will be described later in the discussion of the NEWBEX experiment and our seafloor characterization work, understanding the angular response of the seafloor may be a critical component to remotely characterizing the seafloor. To this end we have developed a new calibration method that utilizes a "standard" extended target designed to simulate the seafloor (Figure 3-4, bottom). This standard target was used in the spring of 2014 by John Heaton to calibrate a Reson T20-P. The calibrated T20-P was subsequently used during a survey over the NEWBEX line, and the oblique incidence backscatter (45 degrees) was compared to a more-easily calibrated Kongsberg EK60 split-beam echo sounder (Figure 3-4, top). The results from the two systems closely matched, showing great promise for this calibration technique.

Target Resolution of Sonar Systems

Taking advantage of the test tank facilities, Val Schmidt began a series of studies aimed to empirically determine the ultimate resolution of the MBES systems we use. The first system tested was a RESON T20-P that was placed in the acoustic test tank with several targets in order to assess the signal processing challenges involved in varied target detection. Targets included wooden pilings, an aluminum pole, cinderblock, and an approximately 1m concrete "rock."

Care must be taken in interpreting tests like this because the scenario is generally unlike conditions experienced at sea. Tank walls and objects on the tank floor, or embedded in its surface, produce large returns relative to those of the artificial targets making them unrealistically difficult to detect. However, the exercise was useful in that it provided insight into strategies for optimizing sonar performance in a real environment. For example, when the seafloor itself has high target strength, such as when operating over coarse gravel or rock outcrops, objects proud of the seafloor are less likely to be detected, since returns from these objects may be considerably smaller than the seafloor itself. This occurs in Figures 3-5b and more specifically in 3-5c in which few, if any, detections are made on wooden pilings whose target strength is small compared to that of the tank floor. In addition, when the seafloor target strength is small relative to objects proud of the seafloor, detections on the target are often returned in adjacent beams to those actually intersecting the target due to sidelobe interference. When this occurs, soundings are often generated both above and below the actual object depth. Although the shoal-most point on the object may be captured, when averaged in subsequent gridding, the distribution of soundings may obscure small objects altogether. Software efforts focused on target detection are further discussed under the DATA PROCESSING theme.

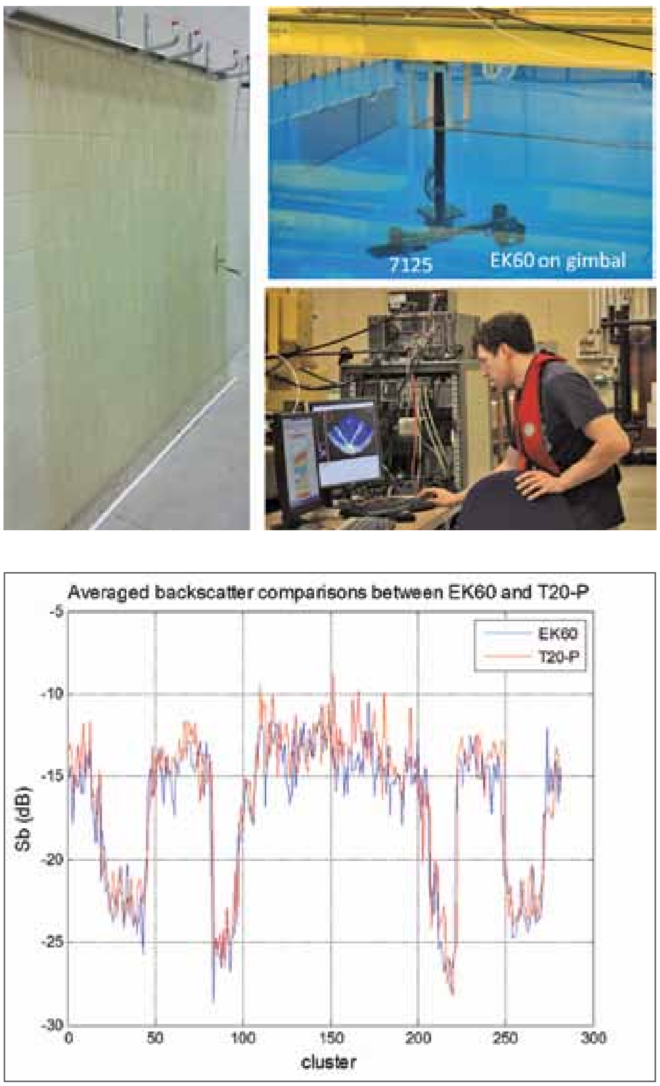


Figure 3-4.The extended calibration target being used to test a Reson 7125 in the acoustic tank by John Heaton (top). The target was subsequently used to calibrate a Reson T20-P, and the calibrated T20-P produced similar backscatter at 45 degrees to a calibrated EK60 (bottom).

EK80 Wideband Transceiver

We also began 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 fisheries echo sounder transducers (one of which the Center is using on the NEWBEX project). In support of this effort, we tested the EK80 in the acoustic tank and, in early December 2013, collected broadband acoustic data (160-260 kHz) over the standard NEWBEX line in Portsmouth Harbor.

Following up on these 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, and was rotated from -90° to +90° along its equator. The tests demonstrated that the main beam behaves as expected, 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 is relatively flat between 16-22 kHz. Field trials conducted by the Weber, Mayer and Jerram on the R/V *Cocheco* just before the departure for the

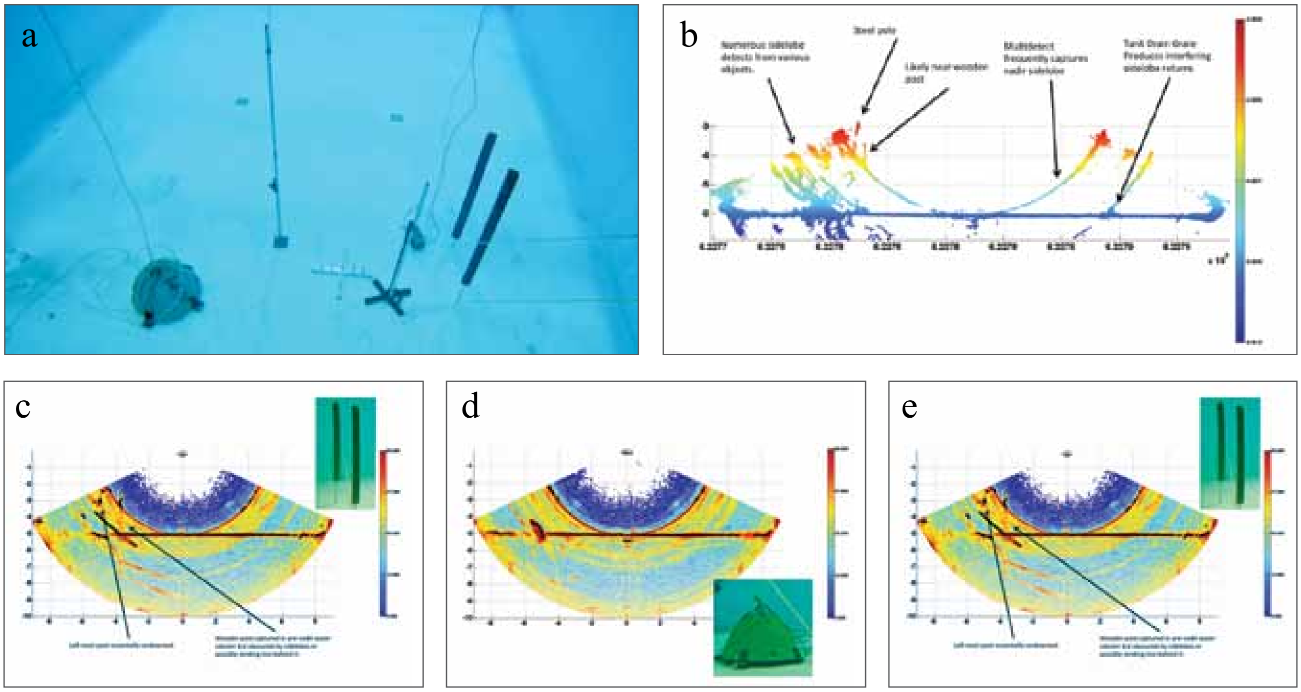


Figure 3-5. Various targets placed in the Center's acoustic test tank to test their detectability with a RESON T20-P MBES. The sonar was operated from right to left in the image (a), on the far side of the targets such that they appear in the port side of the swath. The full data set across all targets is shown in b, with water column overlain with bottom sonar detects from single pings over individual targets in plots c-e. The test showed that high target strength surfaces (tank floor and walls) can overwhelm low target strength objects and that side lobes on a high target strength object can produce soundings both above and below the object obscuring its measurement.

Arctic revealed that the WBT was capable of producing an optimal 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)

Further discussion of the results of the *Oden* and *Endeavor* cruises will be presented under the MIDWATER MAPPING theme.

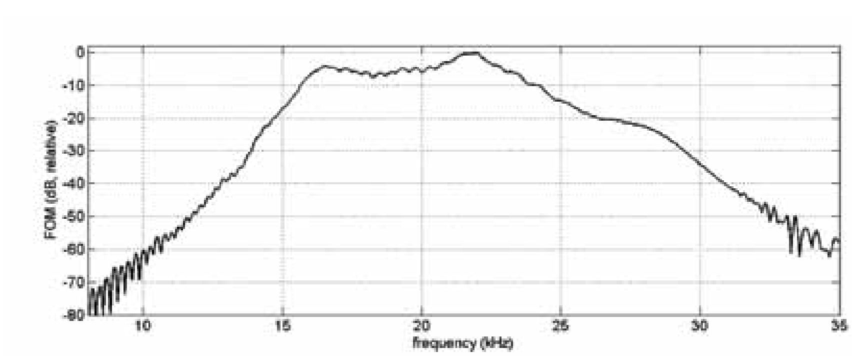


Figure 3-6. Figure of merit (combined transmit/receive response) of ES18 using WBT in decibels, relative to its peak value.

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 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.

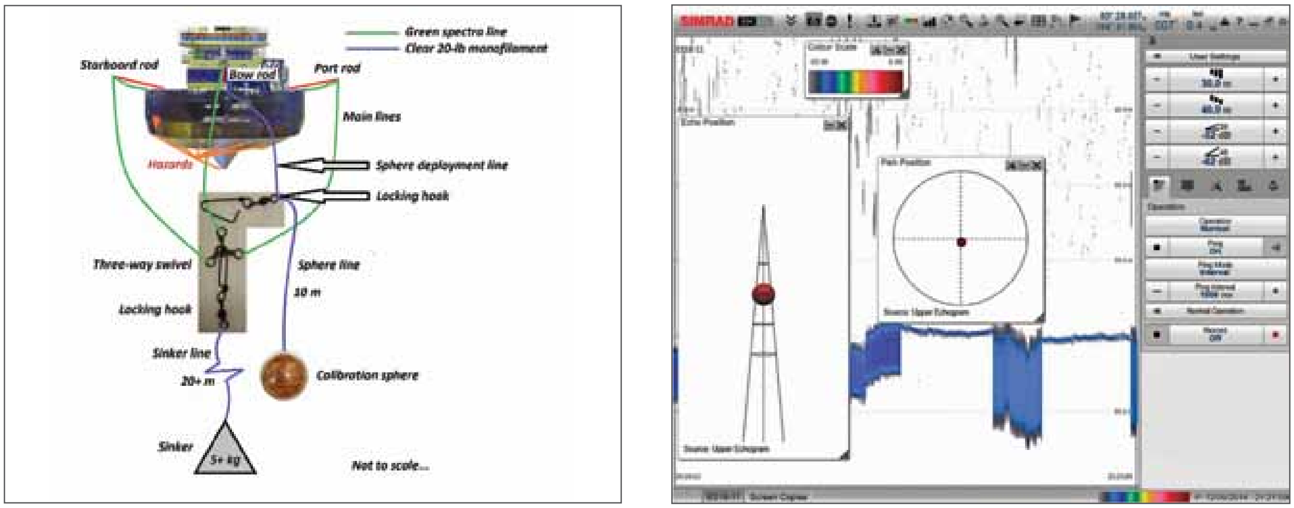


Figure 3-7. Schematic of field calibration for EK80 with18-11 transducer (left) and location of calibration sphere at acoustic center of transducer during calibration on board Icebreaker *Oden* (right).

This role of the Center in evaluating the performance of the academic communities MBES systems was formalized in 2011 with the funding by the National Science Foundation, to Paul Johnson and Jonathan Beaudoin (along with Vicky 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**.

Although Jonathan Beaudoin left the Center to work for QPS, his involvement with the MAC continues, although in a diminished role. Paul Johnson has taken on more of the responsibility of the management and operations of the MAC with Paul acting as the point person for questions submitted to the MAC's help desk from multibeam

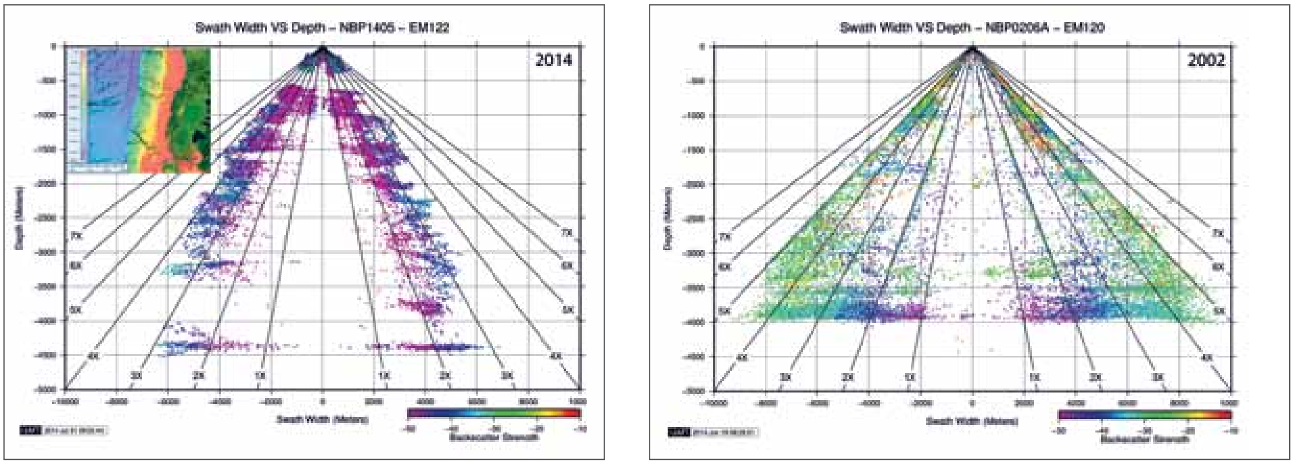


Figure 3-8. Left figure shows the R/VIB *Palmer's* EM122 swath coverage achieved during the sea acceptance trials (NBP1405). Swath widths at ~4500 meters water depth are up to 3 times water depth. Coverage of 5 to 7 times water depth was achieved, but only in depths shallower than 1500 meters. Right figure shows the R/VIB *Palmer*' EM120 swath coverage achieved during the original sea acceptance trials (NBP0206A) in 2002. Swath widths as a function of depth are almost consistently higher than those achieved during the NBP1405 EM122 trials except in relatively shallow water.

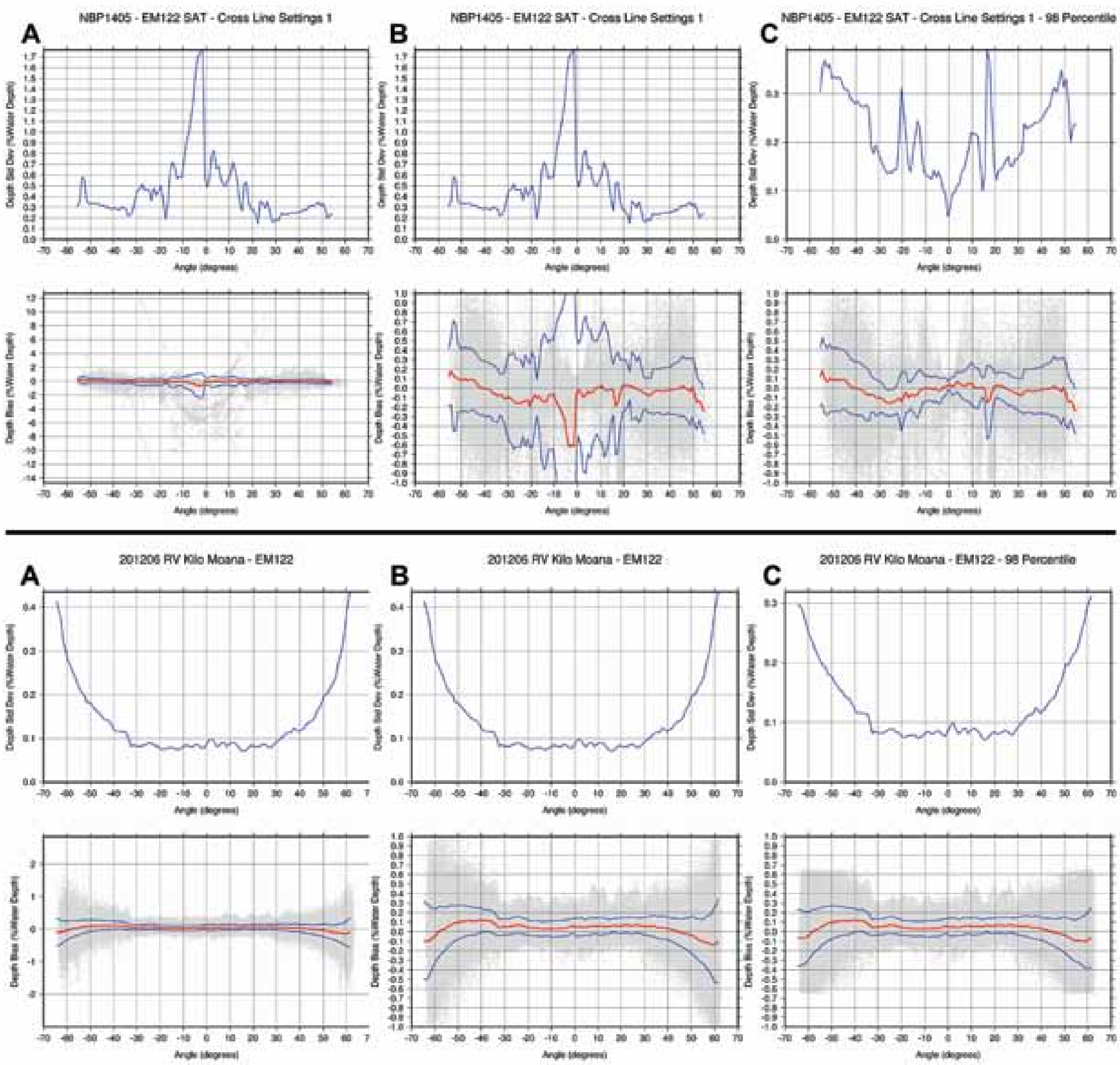


Figure 3-9. The top panel is the cross line analysis results R/VIB *Nathaniel B. Palmer* EM122 data collected during June of 2014. The bottom panel is R/V *Kilo Moana* data collected during 2012. For both plots, the red lines are the mean depth bias and the blue lines are 1 standard deviation from the mean depth bias.

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.

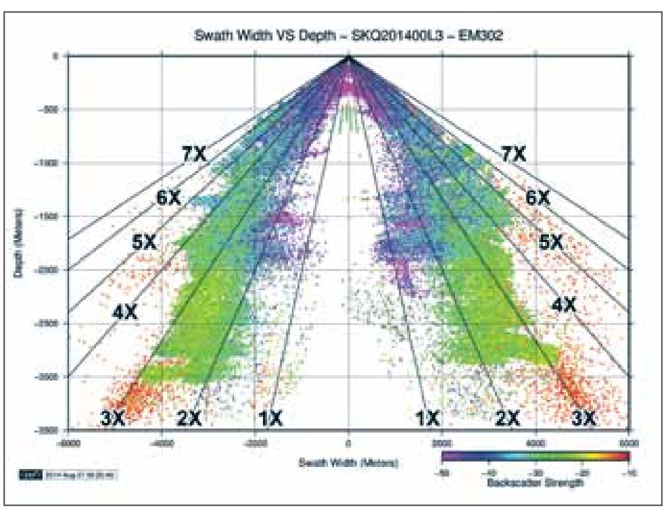
During June of 2014, Paul and research scientist Kevin Jerram sailed as representatives of the MAC to conduct a Shipboard Acceptance Test (SATs) of a new EM122 installed on the R/VIB *Nathaniel B. Palmer.* This assessment was conducted following a dry dock period, and was held during a transit from Talcahuano, Chile to Puerto Montt, Chile. This test proved challenging, as the upgrade process for the MBES only replaced the topside electronics and acquisition system, while the transmit and receive arrays that had been installed in 2002 were unchanged. Kongsberg, prior to the installation, had recognized that more than 12% of the transmit array was damaged meaning the system could not pass its built-in startup test (BIST). This led to a situation where the planned acceptance test had to be continually modified based on the quality of the data collected from different survey depths, bottom types, or sea conditions. Although the cruise was deemed successful in collecting enough data to calibrate the system, run a reference surface performance test, and to generate extinction curves, the adequacy of the data was far from ideal.

Figure 3-8 shows the swath width of the system (x-axis) as a function of water depth (y-axis) by plotting the cross track distance from nadir of the outermost sounding from the port and starboard sides against the depth of the sounding (color reflects the backscatter strength). The left image shows the results of all data collected during the 2014 EM122 SAT. The black lines in Figure 3-8 indicate that the swath width is between 3 to 3.5 times the water-depth at 3500 m deep. The right most portion of figure 3-8 shows that the EM120 shipboard acceptance test in 2002, using the same arrays as the 2014 test, had a swath width of 5 times water depth at the 3500 m water deep. This comparison clearly showed that the newly upgraded EM122 electronics were not able to reproduce a swath width performance curve equal to that of the original EM120 system. Further evaluation, including accuracy testing (Figure 3-9) showed that even the data that was being collected over the limited swath width was compromised in accuracy.

Working with the Kongsberg technicians who participated in the SAT, we advised the National Science Foundation that the transmit array was likely compromised and could not generate a ping of sufficient signal strength to accurately and efficiently map the bottom. The results of these and other tests performed by the MAC are fully documented and have been submitted to the National Science Foundation and are available for download from the MAC website (**http://mac.unols.org**).

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 MAC team was able to run a full suite of sonar acceptance tests on both systems, including a sensor geometry review prior to departure, a patch test calibration for both systems, three different sites for accuracy assessment (deep, shallow, and very shallow), self-noise testing, swath performance testing (Figure 3-10), transmit and receive impedance testing, and mid-water evaluation (Figure 3-11). They were also able to collect a full dataset to be used for backscatter equalization. The backscatter data were turned over to Jonathan Beaudoin for analysis and the generation of a work flow that will produce a correction tables (bscorr.txt files), that can be loaded into the Kongsberg TRUs for each multibeam to equalize the backscatter data in real-time.

Institutions outside of the 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. In February 2014, Paul and Jonathan organized and carried out the second multibeam "checkup" for the R/V *Falkor's* EM710 and



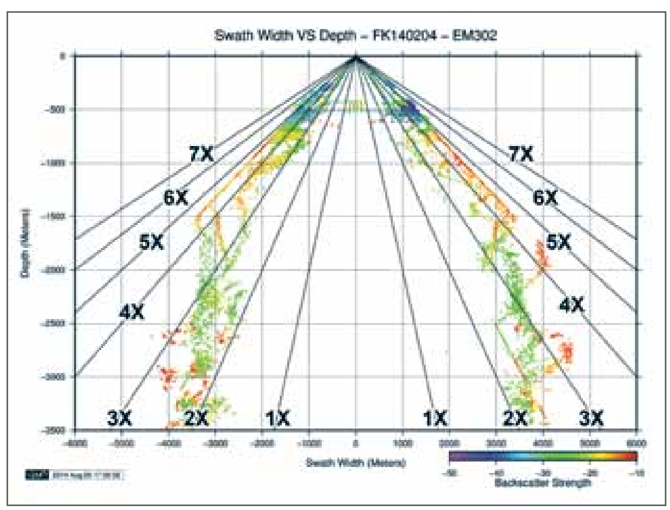


Figure 3-10. Image on the left shows the R/V *Sikuliaq's* EM302 swath coverage achieved during the sea acceptance trials. Image on the right shows the R/V *Falkor's* EM302 collected during a system evaluation test. Both system show very similar results for achieved coverage over the same range of depths.

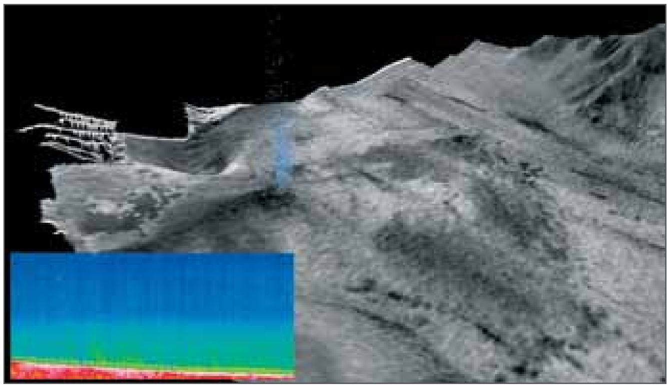


Figure 3-11. EM302 Mid-water data collected over the Hudson Canyon seep field evaluating the mid-water capability of this sonar system. The three dimensional figure shows a single seep detected during the survey. The color insert shows a stacked ping view of a line of EM302 data where multiple potential seeps were detected.

EM302 systems off the Hawaiian Islands. This review included verification of the SIS installation and setup, impedance checks of the arrays, calibration of each system, assessing each system's performance over a reference surface, and evaluation of the acoustic noise of the ship in different operating modes and sea states. These data were then compared to the previous year's checkups to determine if any significant changes had occurred to the performance of either system.

The Center was also been contracted by Dr. Robert Ballard's Ocean Exploration Trust to provide similar multibeam sonar installation guidance and long-term support for their vessel of exploration E/V *Nautilus*. In April 2014, Paul and Kevin Jerram sailed on the *Nautilus* to conduct a multibeam checkup on the *Nautilus's* EM302 off the west coast of Florida. During this visit, Paul and Kevin verified the system's installation geometry, checked the impedance values of the arrays, conducted a patch test in order to determine static offset values, and ran a system extinction and performance test.

Paul returned to the *Falkor* during September because the ship had installed a new Kongsberg Seapath MRU along with a brand new POS/MV positioning system. In order to properly calibrate each system and to make sure there had been no changes to the system during the dry dock period in Alameda, CA, a patch test was conducted on each positioning system as well as a performance check on each multibeam system to verify that they were ready for an upcoming mapping cruise.

By scheduling these types of checkups on a yearly (or more frequent) basis, the MAC team is able to look for potential changes in system performance and give the operators a warning if their systems are not collecting the highest quality data possible. These cruises also give Paul an opportunity to improve the tools and techniques developed for multibeam echosounder evaluation for the Multibeam Advisory Committee. All tools developed through the MAC are readily available to NOAA.

Besides the tools mentioned above, which are used for assessing multibeam accuracy and swath width performance, new and updated tools are currently available through the MAC website by either direct download or by request. These tools include the SVP editor developed by Jonathan, which is the most commonly downloaded utility available from the MAC and is currently used on all of the academic fleet vessels running multibeam. The SVP Editor program, Figure 3-12, bottom, supports the graphical display and editing of SVP, CTD, XBT, and XSV data. This program is designed to facilitate the editing and application of sound speed

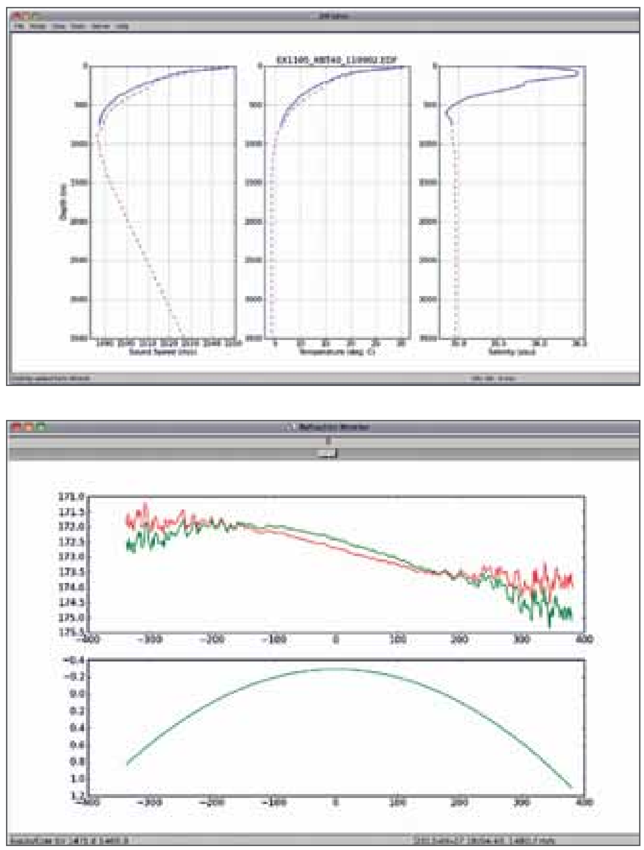


Figure 3-12. EM302 Mid-water data collected over the Hudson Canyon seep field evaluating the mid-water capability of this sonar system. The three dimensional figure shows a single seep detected during the survey. The color insert shows a stacked ping view of a line of EM302 data where multiple potential seeps were detected.

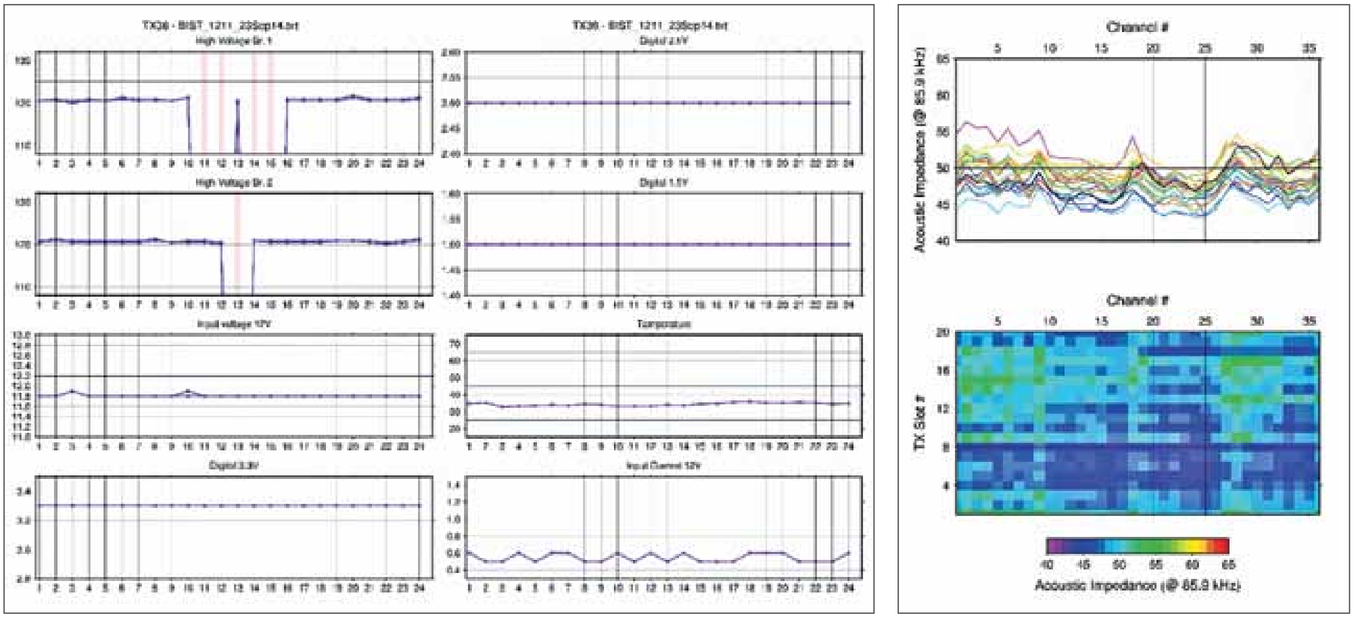


Figure 3-13. The figure on the left figure shows a cleaned XBT sound speed profile (leftmost panel, blue line) along with Temperature and Salinity profiles (blue lines) derived from data extracted from the world ocean atlas (dashed magenta line). The figure on the right shows the Refraction Monitor portion of the SVP Editor. This panel shows the current swath profile from the echosounder (red) and a calculated profile (green, top) using the currently loaded profile. The bottom green profile shows a smoothed difference between the two profiles. angle (right).

profiles for multibeam acquisition systems. It also allows for monitoring of refraction related issues in real time (Figure 3-12, top) and can also be run in a server mode where the program delivers sound speed profiles, derived from either the World Ocean Atlas or RTOFs model for the current position of the ship, to the multibeam acquisition system.

Kongsberg provides a Built In Self Test (BIST) for their sonars, offering critical information on the health of the sonar system, but the output provided by Kongberg is a difficult to interpret text file. To address this, Paul designed a tool to aid in the interpretation of the results of the BIST (Figure 3-13). Plotting is available for BIST results from TX36 tests, RX32 tests, RX channel tests, RX noise levels, RX noise spectrum, and RX noise levels vs. ship speed. With these tools, users are more readily able to understand the results of this critical test.

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 (multiple-row sidescan sonars that use phase differences from the multiple rows to determine depth as well as backscatter) for hydrographic use. 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 of rapidly collecting 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 Drs. Shachak Pe'eri and Chris Parrish) and will report on most of this effort under the HABITAT theme later in the report.

Modeling Lidar Extinction Depth as a Function of Water Quality

Lidar has proven to be an important tool for rapidly collecting data to immediately assess changes that result from major events like storms. However, water clarity is a major limiting factor in data collection. Turbidity from storm events may delay the collection of useful data, so establishing guidelines for when lidar flights are appropriate based on water quality is an important step in determining when and if lidar can be used for post-storm change assessment (and any other time). The EPA established a model in 2008 for calculating light attenuation as a function of turbidity, salinity, and chlorphyll-a concentrations for the Chesapeake Bay area, where Kd is the attenuation coefficient, T is turbidity, A is chlorophyll-a, S is salinity, and C is a regionally-dependent coefficient:

$$K_d=(x*T^{(1/1.5)})+(y*A^{1})+(z*S^{1})+C$$

Although the coefficients used in the above equation are regionally dependent, the variation in coefficient values between regions is not significant for the purposes of establishing what an adequate degree of water clarity is for emergency response purposes. Victoria Price is leading an effort to establish a geographically-independent model for lidar penetration as a function of easily measured water quality parameters that will allow managers to determine how soon data collection may be possible after a storm. To date, water quality data in conjunction with lidar flights has not been adequate (collected in such a way that the creation of a statistical model is not possible). However, we will be conducting surveys in the spring of 2015 and will establish protocols for the collection of appropriate data that are needed to create a regionally independent model.

Mobile Laser Scanner Integration

Within the context of the SENSOR theme we report on a new laser-based effort begun this year by Shachak Pe'eri in collaboration with Vitad Pradith of NOAA/OCS/NSD and Jack Riley and Bryan Murray of NOAA/OCS/CSDL. 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 3-D scanners.

Pe'eri and colleagues are exploring the concept of mounting a 2D-laser scanner on a survey vessel. Two different software configuration will be evaluated—the Hypack HYSWEEP® hardware setup and the manufacturer's open source software that allows measurements of range and intensity to be integrated with navigational information. From an operational perspective, the goal is be able to detect dangers-to-navigation (including piers, piles, air gaps and overhanging cables) from a small survey vessel.

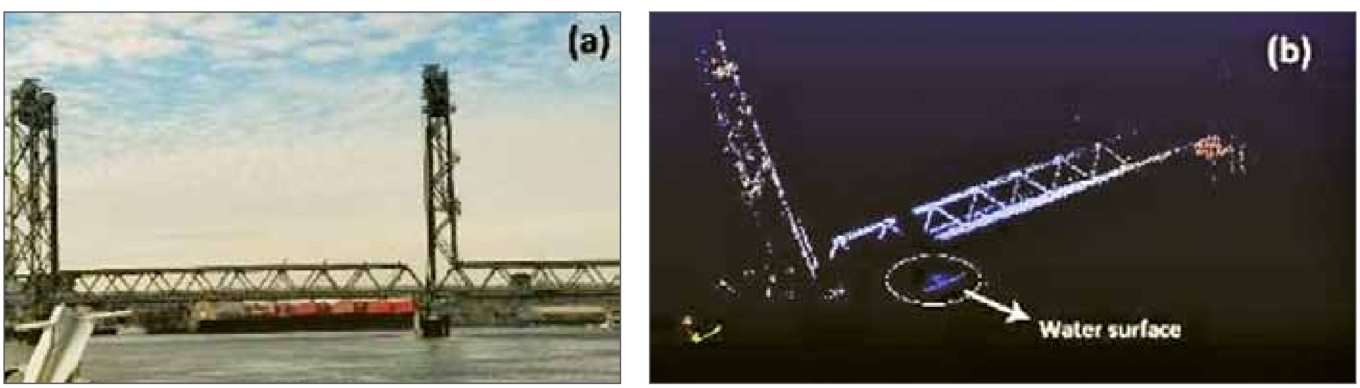


Figure 3-14. Mobile laser scanner results of the Memorial Bridge, Kittery, ME: (a) image of the bridge (12/1/2014) and (b) point cloud of 14 frames (scans) showing the bridge structure and the water surface.

Figure 3-15. AUV Hydrographic Bootcamp 2014, held in August at the University's Marine Facility in New Castle, NH provides opportunities for engineers and developers to gain hands-on experience in hydrographic survey with an AUV. More than 45 participants from government, industry and academia participated.

In 2014, a market survey was conducted that resulted in the selection of an HDL-32E Velodyne laser scanning system for evaluation. The system was evaluated in laboratory conditions in the Center's Ocean Engineering tank facilities as well as in the field (at the UNH Coastal Marine Laboratory) mounted on the R/V *Coastal Surveyor.* Data were collected using the Hypack HYSWEEP® hardware setup and VeloView, an open source software. Data was collected in Portsmouth Harbor (Figure 3-14) and are currently being analyzed.

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 (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, salinity (derived), 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.

In 2014, the Center's AUV-based collaboration with Art Trembanis at University of Delaware continued. Schmidt provided engineering and mapping support for two field projects, the first involving habitat mapping off Assateague National Seashore as part of the National Park Service's post-Hurricane Sandy assessment, and the second was the product of a "Research Set-Aside" grant awarded to Trembanis from NOAA fisheries to

Figure 3-16. An EMILY ASV during training at Stennis Space Center

investigate incidental scallop mortality during dredging operations. From a technical perspective these projects focus on the use of the AUV's downward-looking camera for habitat mapping and ground-truthing of acoustic reflectivity maps. The high image overlap required by these missions may also afford the ability to re-navigate missions from collocated imagery.

In addition, Schmidt and Trembanis hosted the AUV Hydrographic Bootcamp 2014 in August 2014 at UNH's coastal marine facility in New Castle, NH. AUV Bootcamp is a research and engineering workshop focused on furthering the art of hydrographic survey from autonomous underwater vehicles (Figure 3-15). The event 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 this year's bootcamp, including 19 from industry, four from the U.S. Navy, 11 academics, two from the U.K. Ministry of Defense and eight from NOAA. Developers from software vendors that provide bathymetric processing packages (e.g., Caris, Hypack, Leidos, and MB-System this year) play a large part at AUV Bootcamp by interacting with AUV operators and hydrographers while identifying shortcomings in their processing approaches that are unique to AUV surveys. An issue identified at this year's Bootcamp was the failure of standard AUV post-processing to compensate for atmospheric pressure and actual density characteristics of the water column. The magnitude of these errors was calculated and approaches to compensate for them were explored so that more accurate AUV-derived bathymetry can be produced.

In other AUV collaborations, discussions began late 2013 between the Center and Bluefin Robotics regarding the suitability of their AUVs and associated systems for hydrographic survey. These discussions continued into the spring of 2014 with a visit to CCOM and field trials of a Bluefin 9" survey vehicle in late October 2014. Bluefin Robotics became a corporate partner this May affording the Center an opportunity to more routinely use their systems in research and instruction in the coming months. Bluefin has also expressed interest to underwrite the next AUV Bootcamp workshop.

ASVs

2014 also saw the initiation of an effort designed to explore the feasibility of using Autonomous Surface Vehicles (ASVs) as a platform for the collection of hydrographic data. Our effort has two components at this point. First, graduate student and NOAA Corps Officer LTJG Damian Manda is focusing his thesis effort on the development of a small autonomous surface vehicle with hydrographic surveying targeted behaviors. The platform uses a BeagleBone Black embedded Linux computer, which controls the vessel in conjunction with an Arduino microcontroller. The BeagleBone 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. This control system is intended to be flexible for installation on platforms of opportunity and for this research will be implemented on an existing NOAA EMILY small autonomous boat

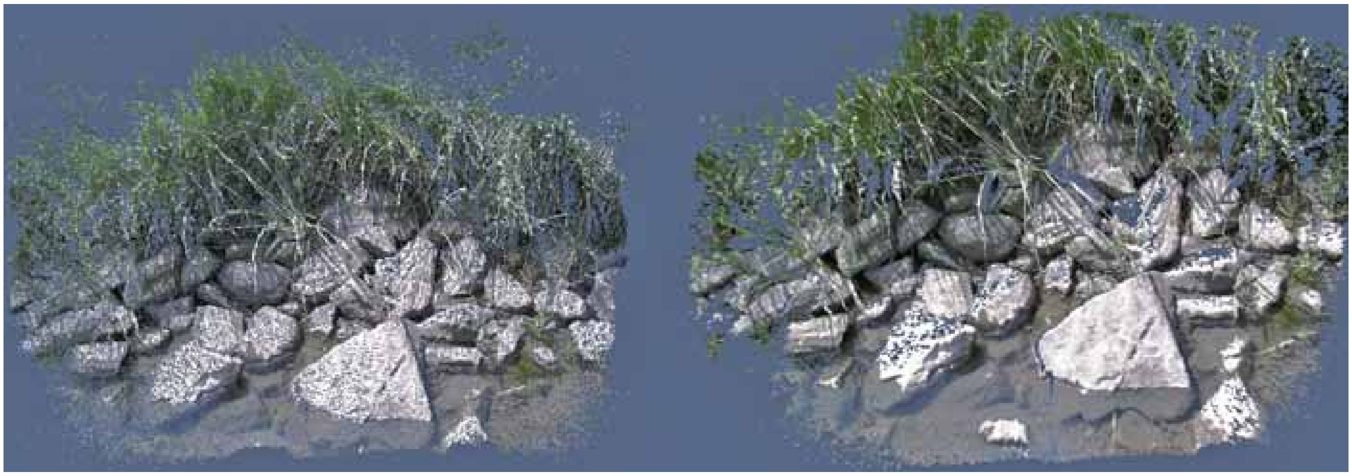


Figure 3-17. Single point cloud frame captured with Kinect2 under worst possible lighting conditions (left). Meshed version of image on right.

(Figure 3-16). Most of the components for this control system were integrated and tested during 2014 but final testing awaits boat delivery.

In conjunction with Damian's work, Val Smith is leading an effort to establish the capabilities of current commercial off-the-shelf ASV systems. Val will be visiting manufacturers and producing a summary report that we can then compare with survey requirements.

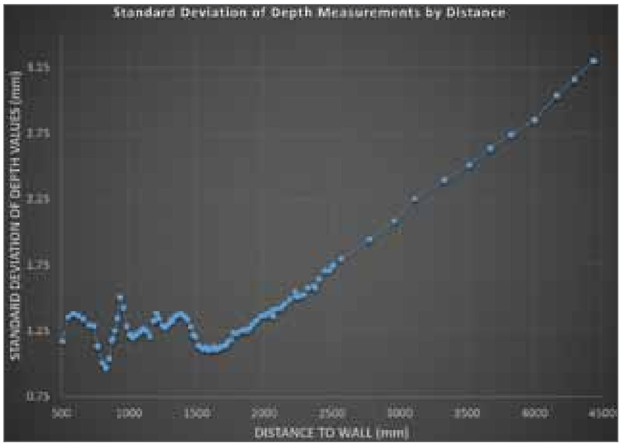


Figure 3-18. Error characteristics of Kinect2: StdDev of depth measurements vs. distance.

Other Sensors

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

Tom Butkiewicz has been investigating the potential for using the new 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. 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 found that the Kinect v2 can capture 3D imagery through and underwater (Figure 3-17). This allows it to capture 3D data that are continuous above and below the waterline, and may also enable certain underwater applications. Tests indicate it has a maximum underwater range of ~1 m, due to the high attenuation of the infrared wavelength and proximity of the light source to the camera (causing significant early returns; Figure 3-18). There is unreleased firmware which supposedly increases this near range performance, and it may be possible to retrofit the device with better-penetrating green laser diodes for underwater usage. Butkiewicz developed the "Kinect2 Map Kit," a freeware software package that enables users to capture their own 3D point cloud datasets using a Kinect v2 device. It also provides numerous diagnostic and analysis modes to assist proper calibration and usage. This software has been freely released to the public via the Center's website.

A detailed evaluation of the Kinect v2's suitability for coastal mapping, performance, and error characteristics have been published in a paper entitled "Low-Cost Coastal Mapping using Kinect v2 Time-of-Flight Cameras," which was presented at IEEE OCEANS '14 in September 2014. Since that publication, Butkiewicz has added a new feature to his Kinect2 software, which allows users to track arbitrary surfaces for changes over time. This was developed to support an oil spill research project at UNH, in which blobs of viscous oil were placed in a flume. Their existing method for measuring the deformation and erosion of an underwater blob was to take video of the blob and have a student watch the captured video and note each event and make other qualitative observations. Butkiewicz's software allows a user to select any arbitrary surface in view of the Kinect2 to be tracked. The software calibrates for that surface and then monitors and transforms all future 3D observations into the coordinate system of the surface. The end results are time-lapse images calculated at specified intervals that present the surface's shape as a height field (Figure 3-19). The process produces both human-viewable color mapped images, as well as machine-readable raw images, that have 1-to-1 pixel to millimeter mapping as well as intensity values that can be imported directly into analysis packages such as MATLAB.

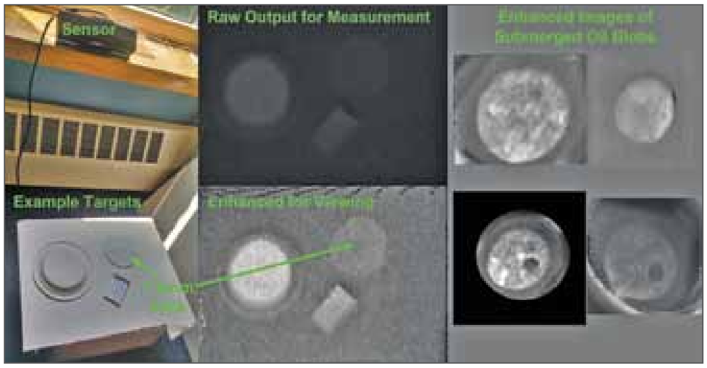


Figure 3-19. Testing setup with Kinect Sensor and targets (left). Transformed images of targets (middle). Captured images of actual submerged oil blobs (right).

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 that we are involved with, 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" and explore the usefulness of existing datasets and suggest new directions that might be take. 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 – 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

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, Alaska; Woods Hole, Massachusetts; and Valdez, Alaska) 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 multi-beam 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 2014 is described below.

Multiresolution Grids—CHRT

Calder's efforts with respect to CUBE in 2014 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 four areas: a fully-distributed version of the algorithm (major effort); transition to practice of the serial and single-processor parallel versions of the algorithm in conjunction with NOAA and Center industrial partners; improvements to the core algorithm to support interactive data analysis in implementation; and extensions to the algorithm to allow first-order slope correction based on preliminary robust estimates of surface parameters.

The CHRT algorithm extends the CUBE estimator by providing a nested grid data structure that allows the resolution of data representation to adapt to prevailing conditions throughout the survey area of interest, and through robust estimation techniques that predict automatically the required resolution based on the observed data. In a two-pass approach, CHRT starts with a coarse resolution estimate of depth and data, computes the appropriate resolution for data representation at regular intervals across the area of interest and replaces the coarse grid with piecewise-constant finer resolution grids. A second pass through the data at the (varying) finer resolution completes the process and automatically preserves the appropriate level of detail in the source data for inspection by a human operator. Appropriate metrics are provided to key the operator's attention to areas of the data that likely require further work. In addition to better preserving the details in the source data, CHRT also removes significant amounts of operator interaction and uncertainty in setting up the computational problem, and avoids many common operator errors that could be problematic in CUBE usage. The result is a simpler, more efficient and significantly more robust environment for computer-assisted hydrographic data processing.

An area of focus in 2014 was the problem associated with implementing CUBE in regions of steep slopes (i.e., Alaska). We have investigated a number of approaches to the problem of steep slopes in bathymetry when processed with CUBE and CHRT. For example, in the initial development of CUBE the ability to adjust sounding depths according to a rough estimate of regional slope was included, but was rarely used because of to the difficulty of achieving reliable estimates of slope from raw data. In a previous reporting period we also described a method to iteratively estimate the regional slope from the outputs of multiple runs of the CHRT algorithm and iterates slope estimates to convergence over time. Both of these options can be effective, but require either some significant pre-computation (first method), or iterative computation (second method), which is a significant time investment. As an alternative approach, in the current reporting period Schmidt and Calder have been investigating a method that adapts the essential idea of the CUBE/CHRT algorithms to include the potential for covariance between uncertainties in all coordinate axes for each observation and to estimate, by the same methods as CUBE/CHRT, the parameters for a low-order polynomial fit to the raw data in a region, while preserving the core robustness of the CUBE/CHRT methods (e.g., multiple hypotheses and uncertainty estimates, multiple metrics on algorithm performance).

The fundamental issue is that while the CUBE algorithm provides an extraordinary and efficient tool for managing outliers and optimizing what is known about the seafloor it suffers from an inability to handle soundings whose errors are correlated. Although correlated soundings may result in many ways, they most frequently result when the seafloor is sloped and the resolution of the sonar is high enough to detect it. In this case, CUBE's assumptions regarding the local flatness of the seafloor are violated. CUBE attempts to compensate for this effect by artificially inflating the uncertainty of soundings as a function of distance from the grid node, but the method is imperfect. This forces CUBE to be exceedingly conservative in its estimation of the uncertainty of the depth of the seafloor, reporting uncertainty of the soundings that contribute to the depth hypothesis rather than the uncertainty of the hypothesis itself. The result is that, as soundings are added to a hypothesis, the uncertainty of that hypothesis will tend to increase, rather than decrease as might otherwise be expected. Because of the imperfect knowledge of the data's correlation one is forced to consider the worse-case scenario, accepting no statistical power in the depth estimation process.

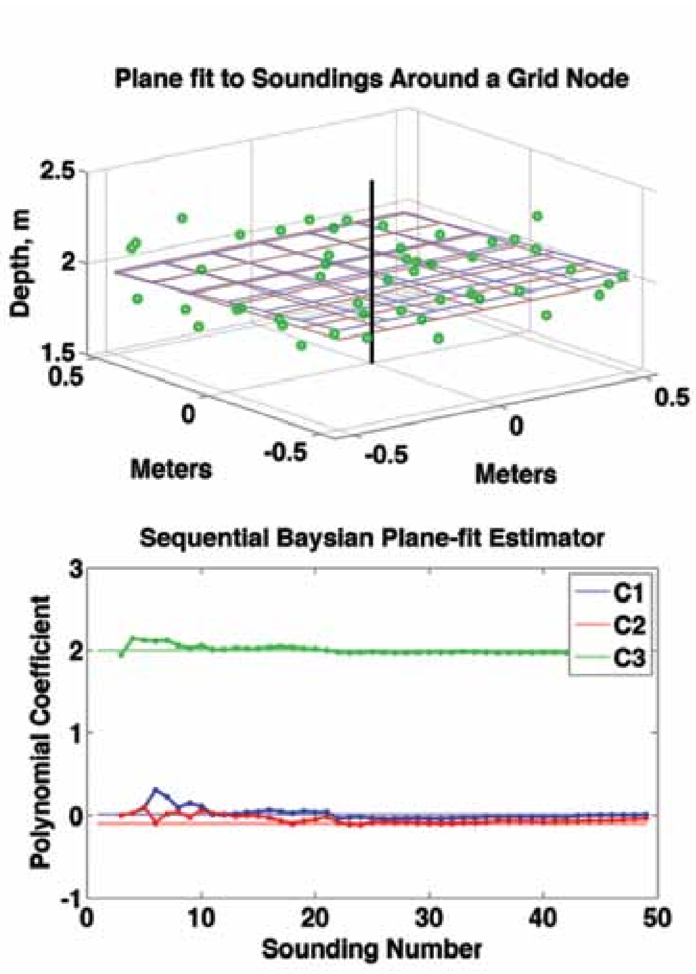


Figure 4-1. In an initial implementation of the new algorithm, the scalar estimation of depth at each grid node is replaced by a plane fit (z = C1x + C2y + C3). The plots above illustrate the process. A plane fit to soundings around a grid node (upper plot) is adjusted incrementally through the sequential estimation process (lower plot).

The work of Schmidt and Calder in 2014 attempts to address this problem by estimating the extent to which the data is correlated, such that addition of more data to a hypothesis results in a reduction in depth hypothesis uncertainty when soundings are estimated to be statistically independent. The initial approach is to replace the scalar estimation process within CUBE with a 2D polynomial estimation (a plane fit), such that both the depth and the slope of the seafloor (and the extent to which soundings are likely correlated) can be estimated simultaneously (Figure 4-1). From this information an uncertainty metric can be generated that both decreases with addition of more data when soundings errors are statistically independent (i.e., when the seafloor is flat), but increases when the sounding errors are correlated (i.e., when the seafloor is sloped). As such, the resulting hypothesis uncertainty is more somewhat akin to "risk," capturing both the knowledge of the seafloor's mean depth and the extent to which the data failed to meet the flat seafloor assumption. The advantage of this technique is that it preserves the core methods of CUBE/CHRT, while upgrading the model of uncertainty in the depth observations and implicitly allows for a higher-order model of the local seafloor properties, without significantly increasing the complexity of the computations required, and preserves the incremental nature of the CUBE/CHRT algorithm.

Additional efforts during 2014 primarily focused on consolidation of the code distributed to our Industrial Partners so that it is easier for them to develop, test, and adopt. This has included (primarily through the work of Giuseppe Masetti in collaboration with Calder) the distribution of a significantly improved OpenGL interface, a much more sophisticated and cleaned-up build system, and a new exception handling system that provides for much better control over exceptional circumstances in the code. The code has also been successfully built on Ubuntu and Fedora Linux distributions as well as 64-bit Windows 7 and MacOS 10.9. In addition, the slope correction code developed in the last reporting period has now been integrated into the public distribution of the source code so that Industrial Partners can see how this will be implemented once fully adopted.

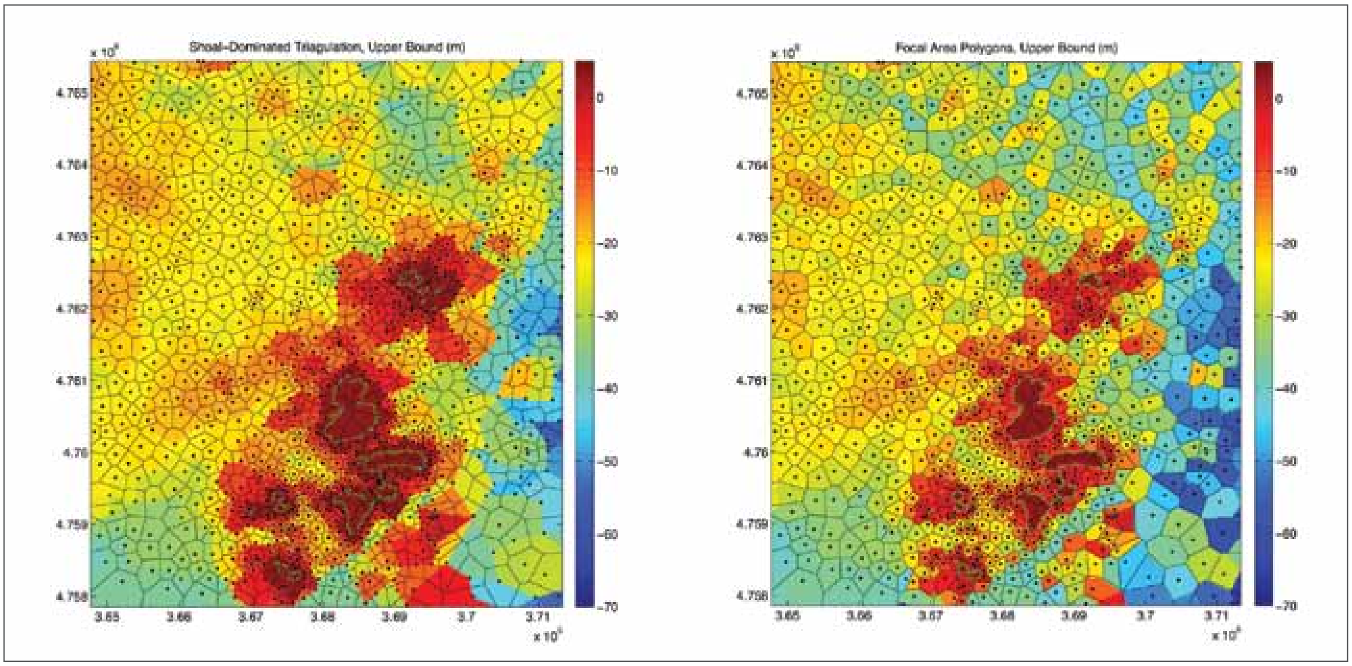


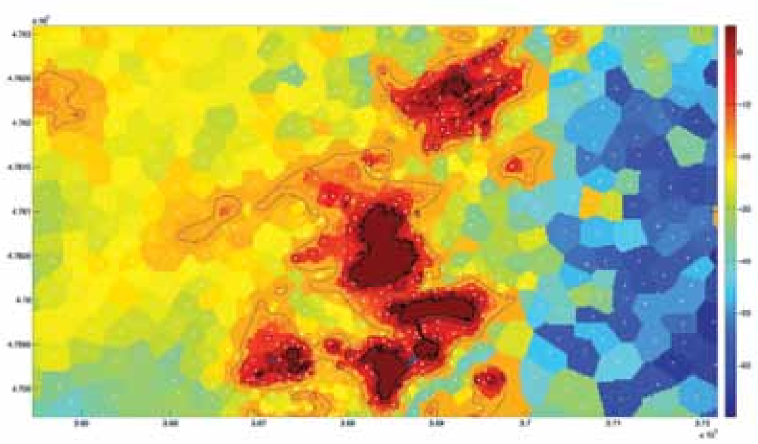
Figure 4-2. Comparison of Shoal-Dominated Triangulation (left) and Focal Area Polygons (right) in the vicinity of the Isles of Shoals, NH. The Shoal-Dominated Triangulation reflects the cartographic expectation that there should be nothing shoaler in any triangle than the shoalest point on the vertices; this significantly expands shoals, as can be seen in the shoreline area. The Focal Area Polygon reconstruction attempts a more balanced estimate based on a perceived 'area of influence' about each sounding. Here, the areas are purely the Voronoi polygons, but a hybrid version balancing between these two extremes is shown in Figure 4-3. Green lines: ENC-derived land area boundaries; black dots: sounding locations; black lines: Voronoi polygons about the soundings.

Interval Bathymetric Reconstructions from Sparse Data

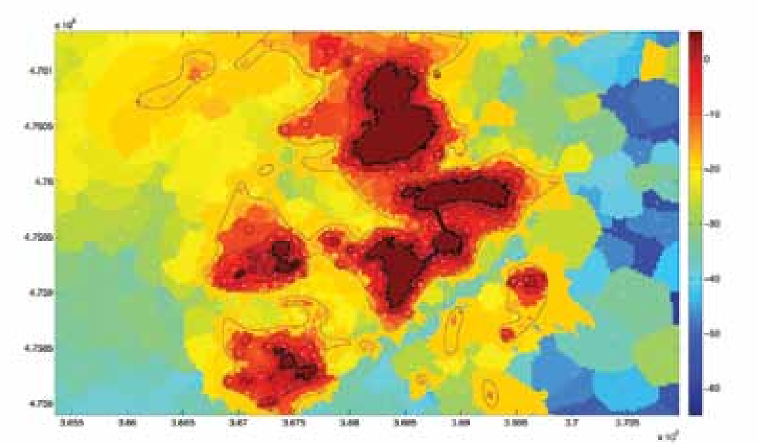
(For information only – funded by other sources)

What do you do if you need to know the depth in detail at a particular location for planning purposes, but all you have is a chart? Worse, how do you compensate if you have multiple charts that (a) are mutually incompatible, and (b) do not contain the depth curve you need? With funding from the Office of Naval Research, Calder has initiated a project to consider the problem: Given a collection of charts of an area at different scales, and only the charts, how much can you say about the depth in the area, and with what confidence? While focused on a specific Navy-related problem (submarine navigation), the analysis of these issues offers insight into just how representative charts are as a function of scale and underlying data density.

Recognizing that with very sparse data the most significant source of uncertainty is the lack of knowledge in predicting the depth between the observations (modelling uncertainty), the method under development attempts to minimize assumptions about the depth between observed values by estimating the boundary limits of the possible depths, rather than attempting to estimate a mean depth and dispersion (such as a standard deviation). This allows for fewer assumptions on the distribution of uncertainty within the affected regions and a more flexible modelling structure that can include objects with only vaguely estimated depths such as wrecks, rocks, and obstructions, where the information might be provided relative to waterline (e.g., "rocks awash") so that a depth range has to be imputed. This is, however, achieved with wider bounds on the depth than might otherwise be expected. This model is probably a more truthful statement of what is known purely from the charted data, and admits alternative methods of reconstruction such as shoal-dominated triangulation and focal area polygons (Figure 4-2), or a combination of both (Figure 4-3), where the algorithm expands from focal area polygons to shoal-dominated triangulations according to a metric that assesses the relative importance of the point being reconstructed. That is, if the data appears to be especially significant – for example, a shoal rock – then its influence over the reconstruction can be skewed towards the maximal shoal-dominated triangulation; however, if the area is deep and other points in the vicinity are shoaler, a focal area reconstruction might be preferred. The algorithm currently uses a measure of local shoalness (i.e., the number of neighbors that are



(a) Isles of Shoals, reconstructed using focal area method.



(b) Isles of Shoals, reconstructed by variable polygon method.

Figure 4-3. Reconstructions of the area around the Isles of Shoals, NH, showing the influence of depth areas, land areas, depth contours, wrecks, rocks, and obstructions. The basic focal area reconstruction (a) gives each sounding as much space as possible; the variable polygon reconstruction (b) emphasizes the areas around soundings or other features that are considered more significant.

deeper than the point being reconstructed), but other factors could also be applied. Whichever method is used, the reconstruction methods represent uncertainty by establishing a best estimate of upper and lower depth bounds (Figure 4-4).

Combining multiple source datasets from charts at different scales covering the same area was found to be sub-optimal at the source-data level; a more useful solution was to generate a reconstruction individually from each source, and then composite the results. Due to the coarse information (both spatially and in the vertical) available in small scale charts, simply taking the shoalest reconstruction at each point is not useful, and trying to preserve the highest resolution data while also preserving shoals is also difficult. A more useful solution, is to use the reconstruction with the best uncertainty estimate (i.e., smallest gap between upper and lower bound), which naturally preserves the higher resolution large scale chart information where available.

The data generated by this combination rule was intended to be used to assist in passage planning, an illustration of which is provided in Figure 4-5. Here, a simple trajectory over the image (in white at left) showing legs and waypoints has been translated into depths along track (upper right) with vertical lines marking waypoints. A 10m safety contour has been constructed on the depth reconstruction (solid black line at left), and this is reflected in the solid red line (top right), with the solid orange line representing a 20% buffer below this intended to be a warning level. The broken red and orange lines represent a "safety buffer" of 60 feet (18.3m) and its 20% warning buffer. Only the upper envelope of depth interval is shown here, but the stepwise nature of the "curve" clearly indicates the quality of the data available, and should be a useful warning to the user as to its reliability.

In many situations, simple visual warnings about the trajectory are more useful than detailed data. As an example of what is possible with this type of data, the bottom right panel of Figure 4-5 shows a traffic-light warning of depth to the safety contour in color: red if the predicted depth is above, orange if in the warning zone, or green if the depth is more than the warning level. Inset to this is a grayscale representation of similar data, but with respect to the "safety buffer" with black for depth less than the limit, grey for depths between the limit and the warning, and white for depths below the warning. The vertical axis in this panel is a log-scale of distance orthogonal to the current track from the position of the vessel to the nearest point of bathymetry that is above the "safety buffer" (i.e., the width of the safe corridor to port [positive axis] and starboard [negative axis] about the current track). Using a logarithmic scale provides more detail close to the track, where it counts, but provides a wider dynamic range packed into the same plot. A plot like this can be useful in planning when attempting to provide alternative scenarios for maneuvering while under way.

Although these depth reconstructions are necessarily low resolution due to the nature of the source data,

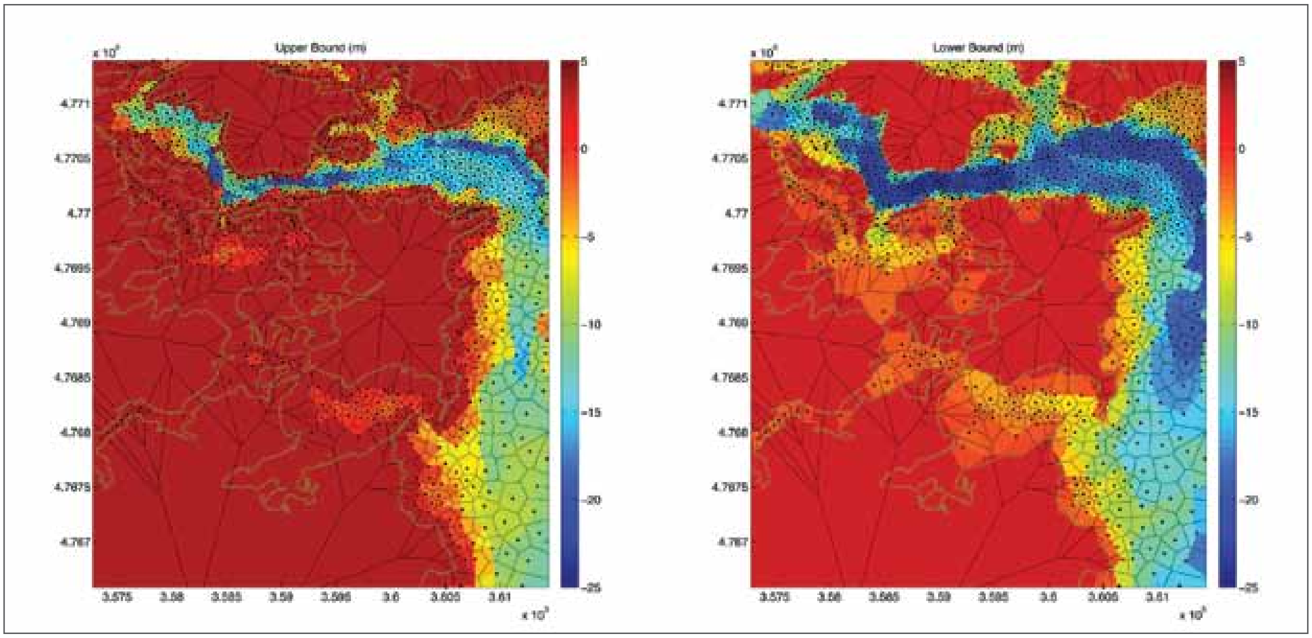


Figure 4-4. Shoal-dominated triangulation reconstruction for the Portsmouth Harbor, NH region. Colored regions are zero order reconstructions of depth for shoalest (left) and deepest (right) likely depth, forming an interval estimate for the depth in each area. Black dots are sounding reconstruction points with their associated Voronoi polygons; green lines are shoreline derived from ENC land area polygons.

they provide a new means to assess the uncertainty of planning products. This has the significant advantage in that it admits sources of depth information which can either only be specified up to a range, or for which the available description is more qualitative, and therefore cannot be specified more precisely than a range without over-stating what is known about the measurements. The advantage of this method, however, is that the results of the reconstruction remain essentially grids at some suitable resolution, and therefore they can be processed by all of the methods in common use for grids, and they can also be communicated and archived using conventional techniques.

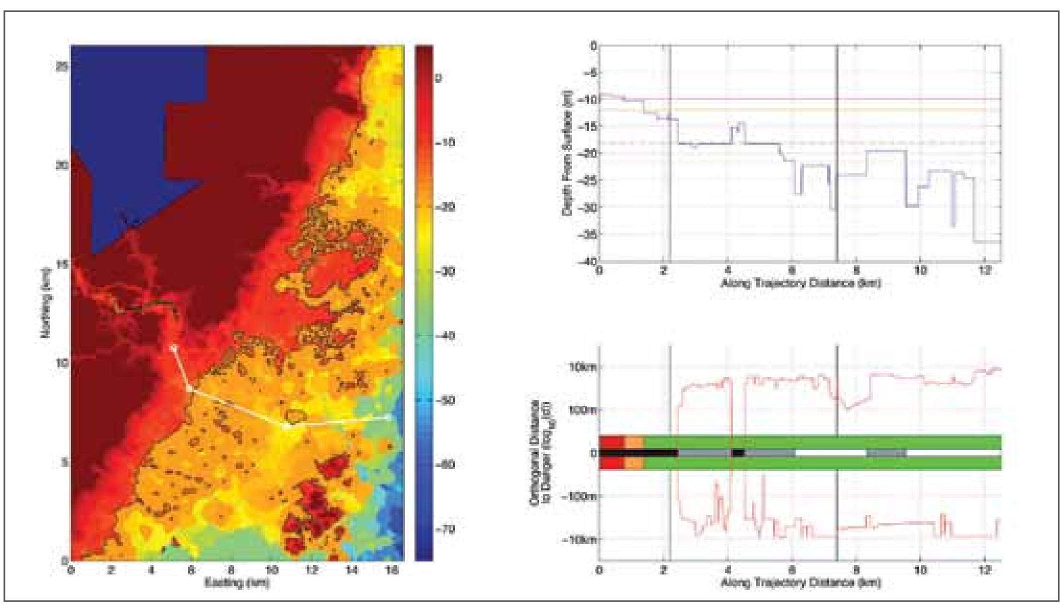


Figure 4-5. Trajectory construction and visualization using the uncertainty combined data. The visualization of the trajectory and safety bands on the right provide planning information on depth safety, closest approach to a shoal area, and potential danger of violating a ship safety boundary.

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. The system, Figure 4-6, 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. In addition, ellipsoidal depth estimation allows for static and dynamic calibration, Figure 4-7, which can be conducted automatically without user intervention, greatly increasing the quality of the data as well as allowing for long-term health monitoring of the collection system for quality assurance purposes. Development of the concept, and the system, is on-going.

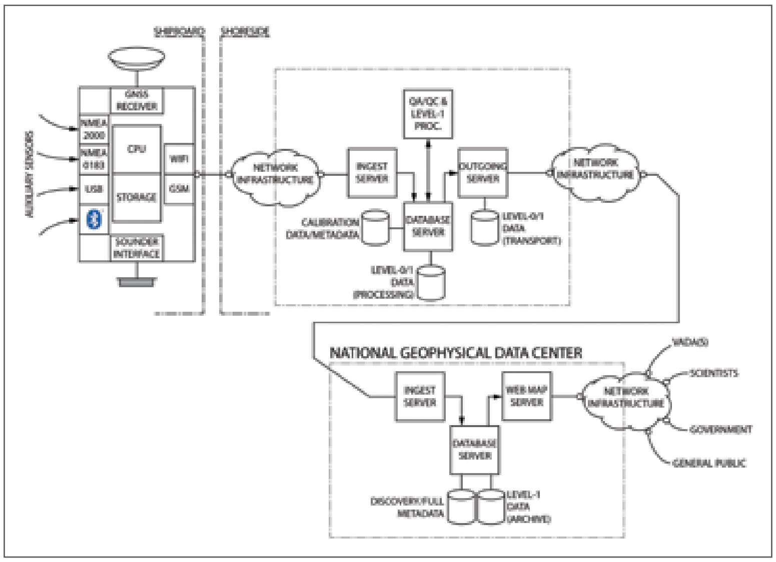


Figure 4-6. Design of a Trusted Community Bathymetry collection system, and associated data flow paths

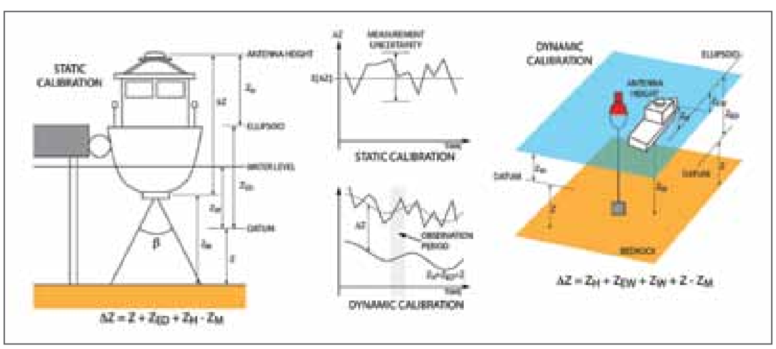


Figure 4-7. Static and dynamic calibration models for the Trusted Community Bathymetry data collection platform, based on ellipsoidally referenced heights constructed from post-processed GNSS data. Static calibration, conducted alongside a dock or other fixed point, allows estimation of measurement uncertainty and potential bias against a known reference; dynamic calibration, conducted against a known reference point allows for an estimate of the dynamic effects of water line as a function of speed through water.

In parallel with these efforts, Calder and SURF student El Jaroudi explored the limits of conventional Crowd Sourced Bathymetry systems (i.e., using ships of opportunity with uncontrolled bathymetric data collection systems). Working with Industrial Partner SUR/VICE Engineering, they investigated the ARGUS data from Baltimore Harbor in order to determine a baseline for the CSB concept. The basic premise of CSB is that a crowd of observers do not repeat each other's mistakes, and therefore the combination of the data from all observers should effectively estimate the mean depth, and efficiently cover most of the area of interest. However, examination of the Baltimore Harbor data show that while the overall data set has areas of significant density (Figure 4-8), the data is not uniformly distributed between the observers. In this case, the vast majority (almost 90%) of the data is contributed by a single observer, which results in biases from that observer being disproportionately represented in the overall depth reconstruction, Figure 4-9. In effect, there is no crowd in this area: there is a single observer, with a few "outliers" contributed by the other ships.

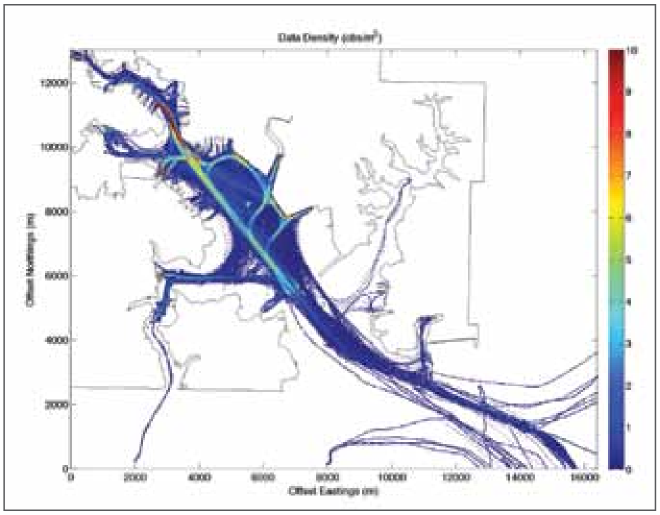


Figure 4-8. Observation density (observations per square meter) in Baltimore Harbor from ARGUS systems.

The analysis also showed that observers are not necessarily consistent. Figure 4-10 shows the behavior of the primary observer in the channel region. Here, the observations from different times are sufficiently different that they cause offsets in the reconstructed mean depth, primarily due to the limitations of data density available from a single observer. While the resolution of estimation could be reduced to address this issue, the ability of the system to capture small details would be impaired; further processing could also be attempted to reduce these effects, but since metadata is limited it would be difficult to apply most common techniques (and more sophisticated techniques also result in higher costs for verification and post-processing quality control).

Consequently, it would appear that there are limitations with the implementation of the crowd-sourcing paradigm applied to bathymetric measurements. Particularly, it appears that providing sufficient diversity in the crowd of observers to ensure that observation errors cancel out may be difficult, and that the data density in all regions of even heavily trafficked areas (like Baltimore Harbor) may be less than optimal for determination of depth. Comparison of the CSB data to a reference set from NGDC, Figure 4-11, shows that changes in the depth in the area are evident, particularly in the channel dredged in the middle of the region (alongside a new dock) since the reference set was surveyed. Determining whether the differences are significant, however, is more difficult. If normalized z-scores are computed, then much of the area is considered significantly different. Determining the extent to which differences between observed data and reference can be considered 'real' is therefore difficult.

The observations are, strictly, only valid for the data set used for analysis, and in other more diverse settings, more consistent results might be observed. It appears, however, that there is still some question as to the utility of CSB data for hydrography, and that further assessment of CSB methods is required, particularly with respect to uncertainty of estimation and qualification of results. It may be possible, for example, to qualify the information associated with any individual measurement, and therefore determine how many measurements in an area are required before an observed difference from the reference data is considered significant. Research is on-going.

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

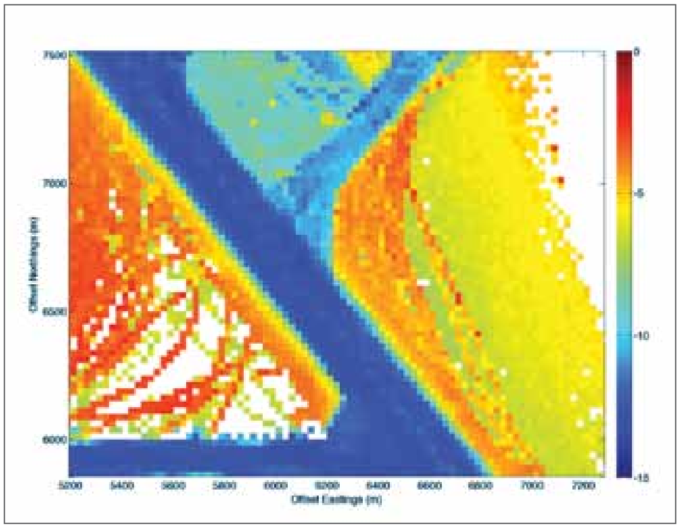


Figure 4-9. Mean depth estimates (meters) from all data sources, focusing on an area of the main channel into Baltimore Harbor. Because the data is dominated by a single observer, offsets from other observers can show up as stepwise differences associated with their particular observation trajectories.

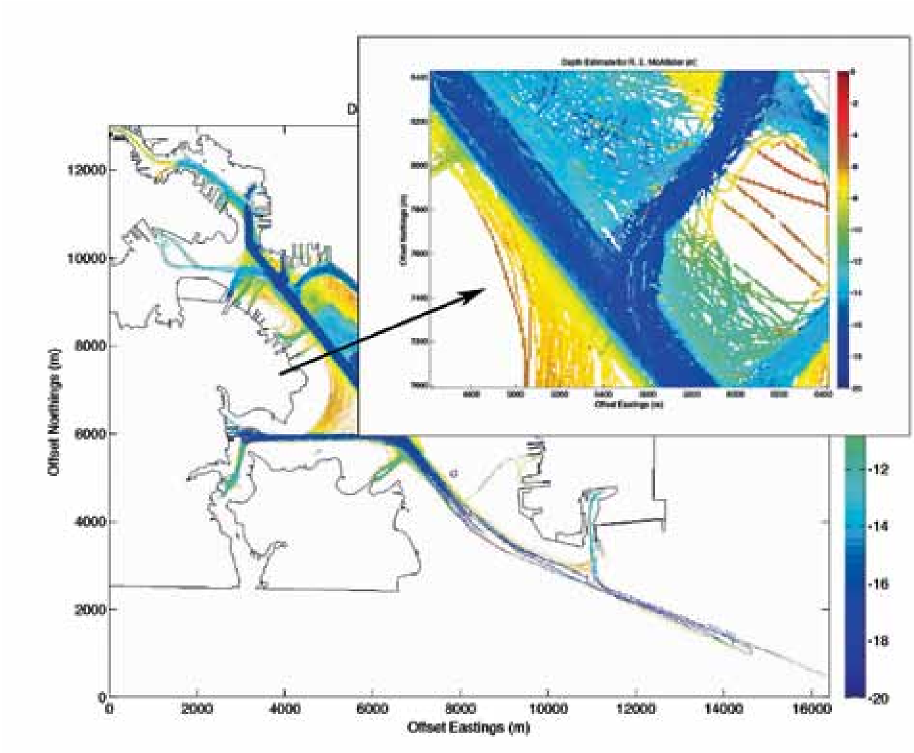


Figure 4-10. Example of data from a single observer, showing that observations even from the same observer can be sufficiently inconsistent to cause observable effects in the mean depth in an area (primarily due to limitations on data density).

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. Working with data collected by the 500-kHz GeoSwath system aboard the Gavia AUV (see AUV section), he has collaborated with Tom Weber and others to understand the uncertainty associated with PMBS data and develop robust processing tools. GeoSwath data is particularly difficult to process, because no filtering is done during data acquisition that might mitigate the volume and complexity of data. The system produces almost 4000 raw measurements per port/starboard ping pair. It is not surprising that data from phase differencing systems appear to be noisy when compared with multibeam system because multibeam systems average many measurements with each bottom detection. The volume and quality of PMBS data make the processing task lengthy, error prone and almost impossible to repeat when standard methods are used. Therefore we have endeavored to create a semi-automated, physics-based processing package capable of filtering the PMBS data for outliers, estimating the uncertainty of the remaining measurements and combining the measurements in an optimal way to produce seafloor sounding estimates similar to that of multibeam systems.

Schmidt's algorithm, written in MATLAB begins with the Most Probable Angle Algorithm including a despiking routine for filtering. Uncertainty is estimated for each sounding using a method similar to the Quality Factor method proposed by Xavier Lurton (visiting scholar from IFREMER) for multibeam systems (see discussion above). Then, given a user-specified maximum depth uncertainty, individual measurements are combined in a weighted mean until their combined uncertainty falls below the desired depth uncertainty. Sounding estimates are then written to GSF files for further processing in CARIS or other similar software packages.

Because data are processed to meet a depth-uncertainty requirement, this new model inverts the goals of traditional survey methods. Rather than producing a survey and subsequently inspecting the survey to see what portion meets the desired IHO requirement, one may specify the IHO requirement and process the data to meet it (though it may not meet other requirements such as resolution). Such a method may be extensible to standard multibeam systems and is a subject of ongoing research.

To better understand the issues associated with the use of PMBS data for hydrographic purposes, the Center has been working with various Industrial Partners who manufacturer PMBS systems and are collaborating with them in their development, assisting with their integration into common data processing packages, and developing work-flows for processing data. For example, the Klein Hydrochart has been a sonar of particular interest to NOAA because they regularly operate these systems as sidescan sonars for object detection. Use of their bathymetry data could lead to great efficiencies in NOAA's survey efforts. However in the process of evaluation of the Klein Hydrochart bathymetric systems, the Center was able to identify processing and conceptual errors in the handling of Klein's uncertainty data by commercial software packages that had the effect of completely omitting sonar uncertainty from their calculations. Sonar uncertainty data is critical to creation of data products and quantification of survey quality for meeting IHO survey requirements. Schmidt worked collaboratively with Klein to identify and resolve the software issues.

Similarly, Schmidt visited Edgetech in February, 2014, to assist them in the development of a real-time uncertainty metric for their systems. Again, he discovered issues with commercial bathymetric data-processing packages that led to interpretation problems and other errors. In May, under the Center's Industrial Partnership agreement, Edgetech provided a model 6205 bathymetric sidescan for a 3-day evaluation by the Center. Figure 4-12 shows preliminary results from this field trial that illustrates the system's ability to capture IHO special order survey products in shallow water. While real-time sonar-estimated sounding uncertainty was not available at the time of this trial, with Schmidt's assistance Edgetech began in the fall of 2014, to provide real-time sounding uncertainty estimates for their systems.

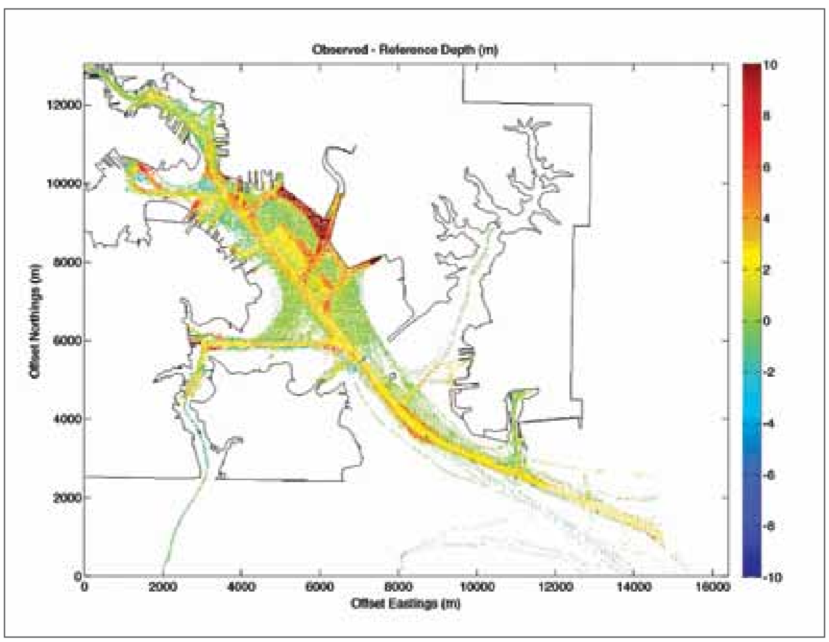


Figure 4-11. Difference in depth between observations and the reference data for the area sourced from NGDC.

This work on resolving problems with PMBS processing software and optimizing the processing pipeline have been transferred to practical application as Kevin Jerram has been working with Val to create processing guides for the Geoacoustics Geoswath, Klein Hydrochart and Edgetech 4600/6205 PMBS systems. These are systems that are being used by NOAA and others to evaluate the impact of Super Storm Sandy in a hydrographic context. Specifically, Jerram has been identifying data processing paths to rapidly generate bathymetric surfaces that require minimal additional editing and is evaluating these rapid data-processing methods for their ability to preserve objects (e.g., marine debris) in the resulting gridded bathymetric surfaces. These methods employ existing commercial off-the-shelf software and could be integrated with NOAA's existing workflows. For more immediate and general use, data processing guides are presently in development for several manufacturers of PMBS systems likely to be used in future storm response surveys.

Recent efforts include assessment of objects in bathymetric surfaces generated from post-Sandy PMBS datasets collected offshore Long Island and Delaware. These datasets include objects on the seafloor ranging in size from small fish haven structures (1-2 m in any dimension) to a barge (approximately 50 m long, 10 m wide, and 3 m in relief above the seabed). Figure 4-13 shows a cross-section of soundings on a barge, indicating some of its structural details and illustrating the noise in the data that could confound identification of smaller objects. These assessments show that, barring significant blunders or gaps in swath coverage, objects larger than 1 m in all dimensions are generally detectable in the gridded bathymetric products. In most cases, however, closer inspection of the raw soundings is necessary to provide enough detail for identification of an object. The smallest example objects (approximately 1 m in all dimensions) were readily detected but not clearly identified in the PMBS bathymetry data, representing an ongoing challenge and area of research for these systems. This work, funded in part by Super Storm Sandy funds (see below), will help to provide guidance for all operators of PMBS systems ensuring that both their bathymetric and sidescan data is of hydrographic quality.

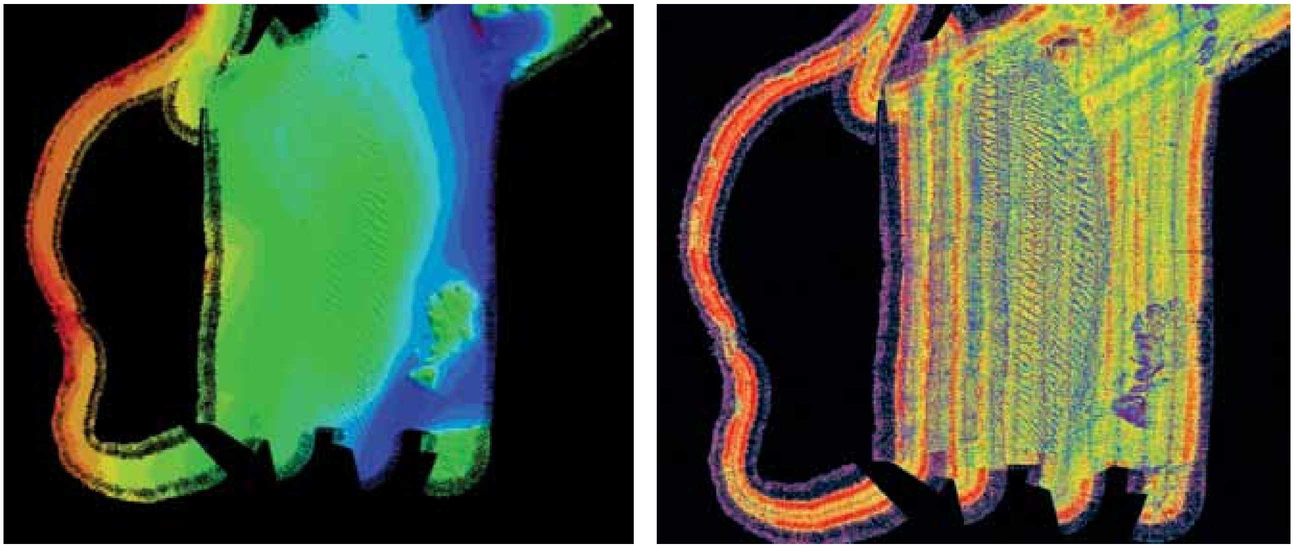


Figure 4-12. On the left, Edgetech 6205 data is shown, collected over the Portsmouth Harbor "thumbprint" sand wave field and gridded at 0.5 m. Depths range from 1m (red) to ~28m (purple). On the right, uncertainty for this surface, 0 (red) to 0.15 m (purple), measured as the standard deviation of soundings contributing to each grid node (the Caris "Std Dev" layer) expressed at the 1-sigma level. IHO Special Order for these water depths is approximately 0.13 m at the 1-sigma level indicating this survey would likely meet NOAA requirements for IHO Special Order survey.

In addition, Xu, an intern under the Center's Summer Undergraduate Research Fellowship (SURF) program tested several binning strategies for PMBS systems to evaluate the tradeoff between resolution and uncertainty when bin sizes are fixed, as is the standard approach (as opposed to the dynamic methods proposed by Schmidt, Weber and Lurton – see below). Xu's findings show that for objects approaching 1m in dimension, the resolving capability of PMBS systems tends to be limited by subsequent gridding processes more than the sounding resolution itself and as such systems may be safely operated to reduce sounding uncertainty in lieu of higher resolution.

Balancing Resolution and Uncertainty in Bathymetric Sonar Systems

Bathymetric sonar systems used for hydrographic survey must continually balance the trade-off of achieving high resolution to meet target detection requirements

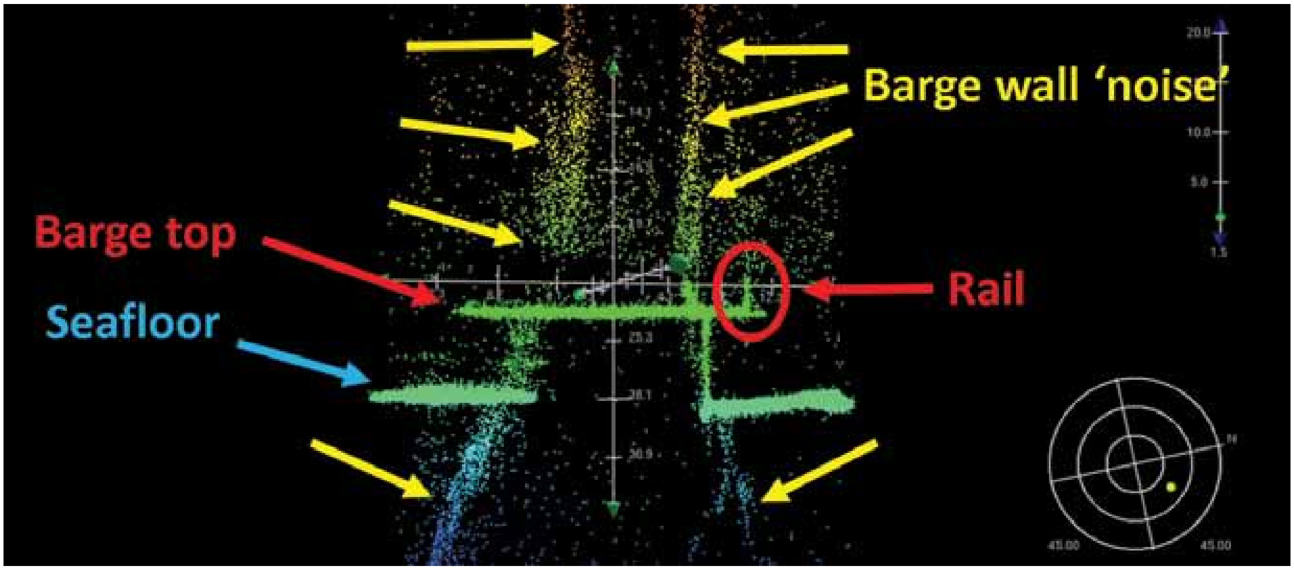


Figure 4-13. Cross-section of PMBS soundings on a barge approximately 3 m high and 10 m wide. This subset includes soundings from several survey passes and illustrates the capability of PMBS echosounders for detailed representation of hazards with the trade-off of data noisiness associated with these systems. Object detection and identification using PMBS is an area of ongoing research under the Center's Super Storm Sandy Supplemental grant.

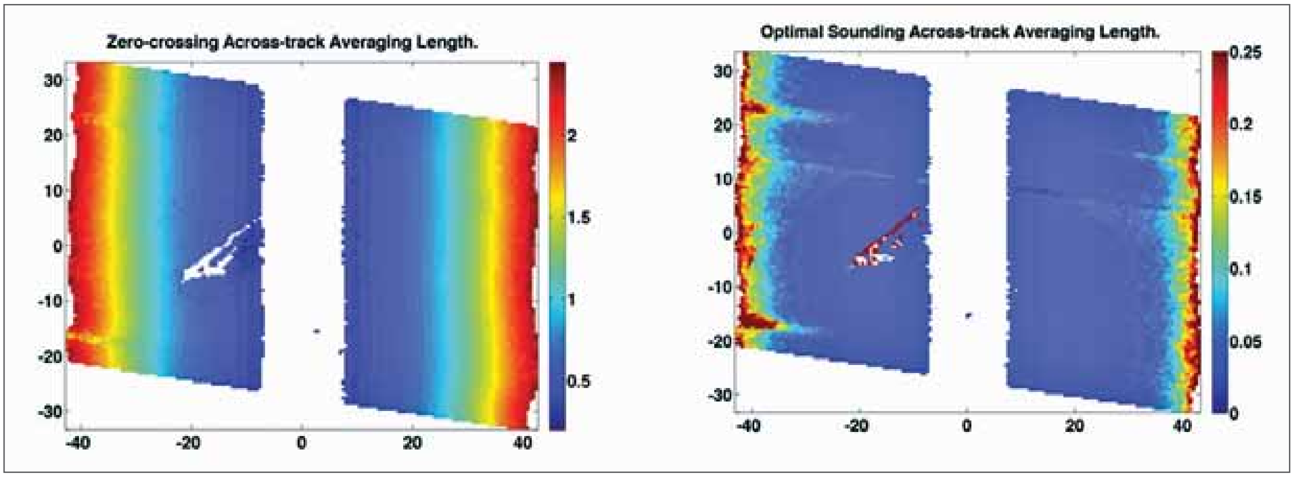


Figure 4-14. Raw data from a RESON 7125 MBES was reprocessed for zero-crossing phase detects as well as the new method for optimizing resolution and uncertainty. Across-track averaging length is plotted above for both cases showing that higher resolution (smaller length) can be obtained across more of the swath with the new method.

and simultaneously, low uncertainty to meet survey uncertainty requirements. To this end, work continues at the Center on a new method for the production of bathymetric soundings from phase-measuring bathymetric sonar systems. Developed by Schmidt, Weber and Xavier Lurton (IFREMER), the algorithm (the "SWL" method) seeks to balance the trade-off between uncertainty and resolution in these systems by fixing the uncertainty in soundings and varying the resolution dynamically. Individual measurements and their associated individual uncertainties are combined in a Bayesian estimator until the associated a posteri-eri variance drops to a desired level and no more. The estimator then becomes a "sounding," and the process is repeated with the remaining measurements across the swath. Because no two measurements contribute to a single sounding the resulting values are statistically independent (unlike soundings produced from most bathymetric echosounders). Moreover, as the quality of the measurements vary, the effective across-track resolution changes dynamically, allowing the system to achieve the full resolving capability of the system (for a given beamwidth and bandwidth) when SNR and other conditions permit.

Figure 4-14 illustrates the increase in across-track resolution that is possible by comparing the across-track extent of measurements contributing to each sounding for both zero-crossing detects and those generated by the SWL method. Uncertainty was limited to 0.1% of the full water depth, approximating the uncertainty in the standard zero-crossing detections. Figure 4-15 illustrates qualitatively the difference in zero-crossing and "optimal" soundings producing a higher density of statistically independent soundings over the wreck where the modeled uncertainty is low.

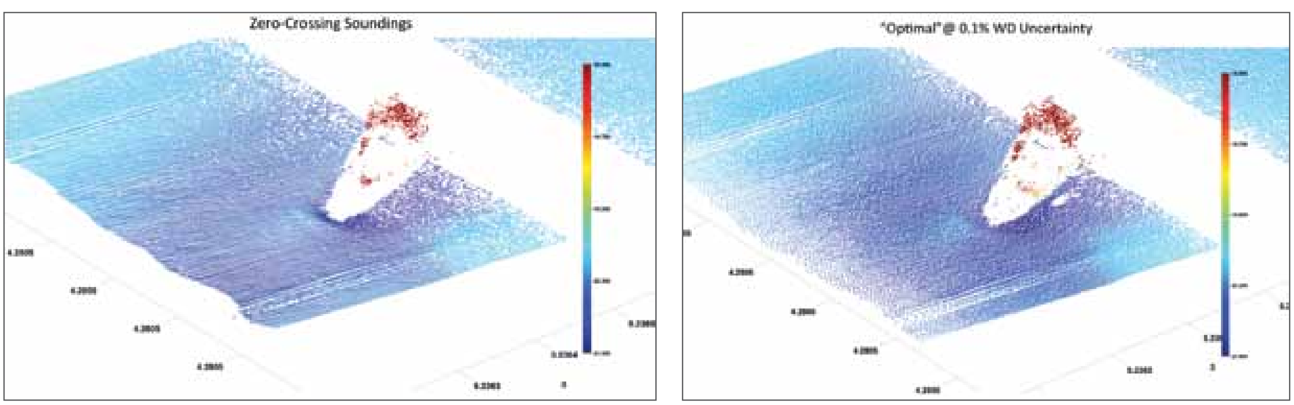


Figure 4-15. Raw data from a RESON 7125 MBES was reprocessed for zero-crossing phase detects as well as the new method for optimizing resolution and uncertainty. Here sounding uncertainty is estimated from theoretical models. An increase in sounding density and resolution is seen over the shipwreck using the SWL "optimal" method with a decrease in sounding density in outer portions of the swath where SNR cannot support it.

Evaluation of Uncertainty in Bathymetry, Navigation and Shoreline Data from 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 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) though they also draw on personnel and efforts supported under this grant. We briefly report on these efforts here and refer the reader to **http://sandy.ccom.unh.edu** and references therein for more detailed descriptions of the work done under the Super Storm Sandy grant. Super Storm Sandy-related efforts are also reported on under the HABITAT and IOCM themes.

Modelling Uncertainty in Photogrammetry-Derived National Shoreline

Tidally-referenced shoreline data serve a multitude of purposes, ranging from nautical charting, to coastal change analysis, wetland migration studies, coastal planning, resource management and emergency management. To assess the suitability of the shoreline for a particular application, end users need to use the best available shoreline and also reliable estimates of the uncertainty in the shoreline position. NOAA's National Geodetic Survey (NGS) is responsible for mapping the national shoreline depicted on NOAA nautical charts. To date, previous studies on shoreline extraction from remote sensing have focused on modeling the uncertainty in NGS shoreline derived from airborne lidar data, but these methods have not been extended to aerial imagery and photogrammetric shoreline extraction, which remain the primary shoreline mapping method used by NGS. The aim of this effort is to develop a rigorous total propagated uncertainty (TPU) model for shorelines compiled from both tide-coordinated and non-tide-coordinated aerial imagery using photogrammetric methods. The work for this study was conducted by Fang Yao as part of her Masters graduate work under the supervision of Shachak Pe'eri and Chris Parrish.

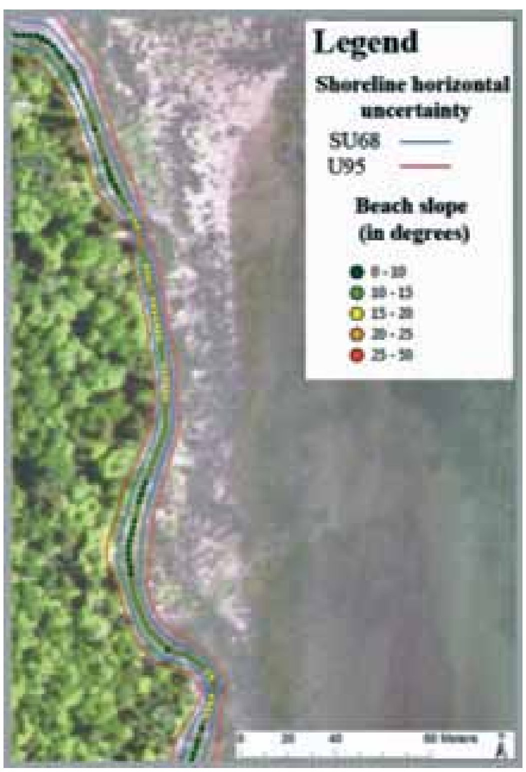


Figure 4-16. The uncertainty boundaries of a photogrammetric shoreline. The blue lines and the red lines represent the uncertainties at standard deviation (68% confidence level), SU68, and 95% confidence level, U95, respectively. The colored circles represent the beach slope in degrees.

The study found that the main uncertainty components for tide-coordinated and non-tide-coordinated compilations are the offsets between MHW/MLLW and actual water level and human compilation uncertainty, respectively. The TPU model developed in this study (Figure 4-16) can easily be extended from the test area to other areas and may facilitate estimation of uncertainty in inundation models and marsh migration models. The details of the findings of this effort have been reported in a paper published in Marine Geodesy (Fang Yao, Christopher E. Parrish, Shachak Pe'eri, Brian R. Calder and Yuri Rzhanov (2015) Modeling Uncertainty in Photogrammetry-Derived National Shoreline, *Marine Geodesy*, 38:2, 128-145, DOI: 10.1080/01490419.2014.957792).

Morphological Change After Hurricane Sandy

(For information – funded by another NOAA grant)

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. 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. She has created a preliminary work flow for the Sandy team to unzip raw lidar files, analyze point cloud data, create lidar data collection boundary files, create header files, and merge multiple raw files into more manageable files that can be used in NOAA's Vertical Datum Transformation for ellipsoid and tidal datum transformations and eventually gridding the data and creating digital terrain models (Figure 4-17). The lidar sensors used are USGS EAARL-B before the storm in October 2012 and after the storm November 2012 -2013, NOAA NGS Riegl VQ-820-G flown in September 2013, and Chiroptera I flown in April 2014. Nagel has obtained, managed and processed bathymetric lidar data for the JHC/CCOM Sandy team to use in their specific area of research and to provide practical examples of bathymetric lidar sensor capabilities in terms of depth, resolution, feature detection and possible consideration for input into NOAA's nautical charts.

In July 2014 the USGS provided the Center with an updated version of the pre- and post- Super Storm Sandy EAARL-B topo-bathymetric data set, which was

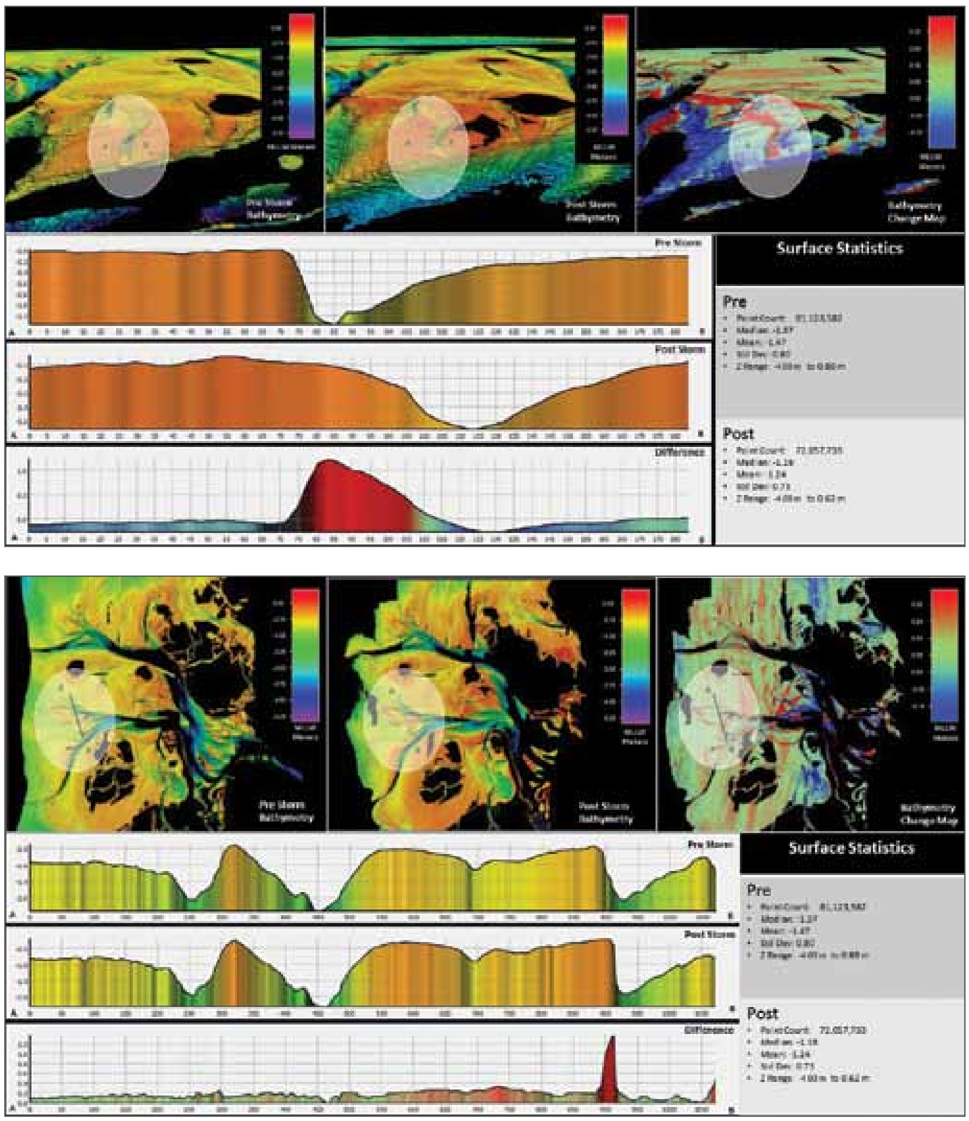


Figure 4-17. (top) A transect across a channel in Barnegat Bay shows the creation of a new shoal, significant shift of the channel, and a change in morphology due to the effects of the storm. (bottom) The mouth of Barnegat Bay Inlet, shows remarkably little change after the storm, except for a distinct localized change in the location of a channel edge at approximately 900m along transect. Data derived from EAARL-B surveys, courtesy of the U.S. Geological Survey.

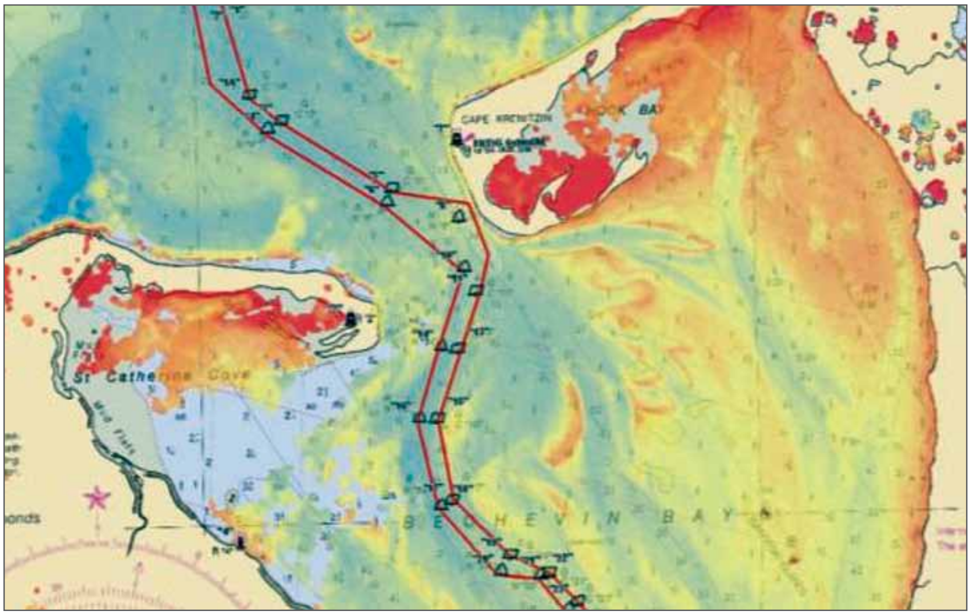


Figure 4-18. Satellite-derived bathymetry (Landsat 8) from March 2014 over Bechevin Bay, Alaska. The bathymetry is overlaid on a NOAA chart and the channel (red outline) from 2013 is depicted using USGC's aid-to-navigation (ATONs).

corrected for an early calibration issue and was filtered to remove flight line artifacts. While the topographic shoreline data remained unchanged, it was necessary to re-process the bathymetry data. Deposition and erosion analyses were performed on the new surfaces using raster math in ESRI ArcGIS and several areas of interest with full overlap of data pre- and post-storm were selected for the creation of profiles in QPS Fledermaus (Figure 4-16). Slope maps were also created using ArcGIS. Comparing NOAA charts to this lidar data highlights areas that may be dangers to navigation and areas of concern that may then be further surveyed and adjustments made to the charts. In October 2014, the USGS indicated that another data set with an additional -0.16 m offset would be released; the point cloud data and surfaces were publicly released in November.

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. Also, the accuracy of the results was 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. The approach developed for single images involves the following steps:

- Pre-processing– Satellite imagery is downloaded based on the geographic location and environmental conditions (e.g., cloud coverage and sun glint).
- Water separation– Dry land and most of the clouds are removed.
- Spatial filtering– 'Speckle noise' in the Landsat imagery is removed using spatial filtering.
- Glint/cloud correction– Contributions from sun glint and low clouds are radiometrically corrected.
- Applying the bathymetry algorithm– The bathymetry is calculated using the blue and green bands.
- Identifying the extinction depth– The optic depth limit for inferring bathymetry (the extinction depth) is calculated.
- Vertical referencing– A statistical analysis between the algorithm values to the chart soundings references the Digital Elevation Model (DEM) to the chart datum.

The great potential for Satellite Derive 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 demonstrated 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, a number of new areas and applications were explored.

Bechevin Bay, Alaska

An area of collaboration between NOAA and the U.S. Coast Guard (USCG) is the update of several key channels along the Aleutian Islands, Alaska. An update is required during the spring season every year after the sea ice has melted. Many of these areas are shallow mud flats that are highly impacted by the ice and thus the location of navigation channels can significantly change each season. In order to provide the contractors with a clear survey plan, satellite-derived bathymetry was used in its traditional single-band method for mapping the bathymetry as well as by using comparison of the green and red bands to indirectly map the channels (through their increased turbidity). Both Landsat imagery and WV-2 imagery were used for the evaluation. This approach proved to be very useful and led to the identification of clear changes in the channel location. The work was recognized in a letter of appreciation from the USCG for helping them more efficiently survey the channel (Figure 4-18).

Updating the Magenta Line (Intracoastal Waterway)

The magenta line was first placed on navigation charts by The U.S. Coast and Geodetic Survey, a NOAA predecessor agency, during the 1910s to mid-1930s in order to mark the center of the channels. Over the years, mariners started to use the line as a guide for navigation. However, the magenta line on NOAA charts have rarely been updated over the past 70 years. Since last year, MCD has been updating the Magenta Line to horizontally match the navigation channel rather than the geographic center of the channel/lagoon using topo-bathy lidar surveys and AIS records. The challenge in this approach is that surveying with topo-bathy lidar systems requires many resources (time, man-power and funding resources) and the AIS position records are too sparse and provide only the position of the vessel (including when it anchors or runs aground). As a demonstration, a satellite-derived bathymetry approach was applied to Bouge Inlet, South Carolina as a means to provide horizontal positioning of the channel without the need to reference the bathymetry to the chart datum (Figure 4-19).

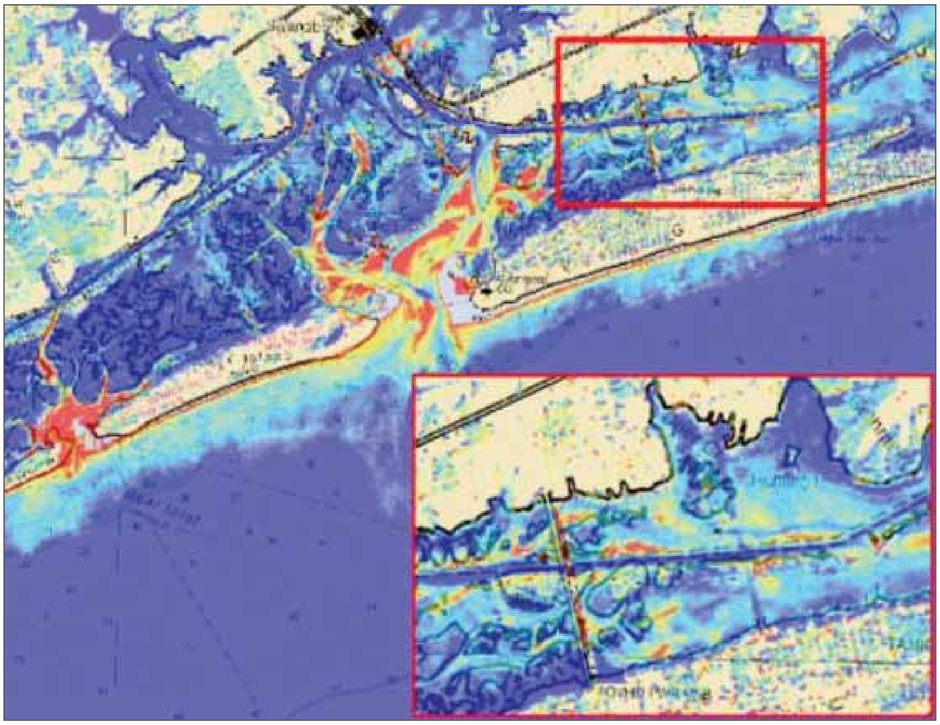


Figure 4-19. Satellite-derived bathymetry (Landsat 8) over Bouge Inlet, South Carolina. The bathymetry is overlaid on a NOAA chart. In some locations along the channel a horizontal shift is noticeable between the charted channel and the bathymetry derived from satellite imagery.

Chart Adequacy Using Publicly Available Data

Under the leadership of Shachak Pe'eri, Center researchers 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-

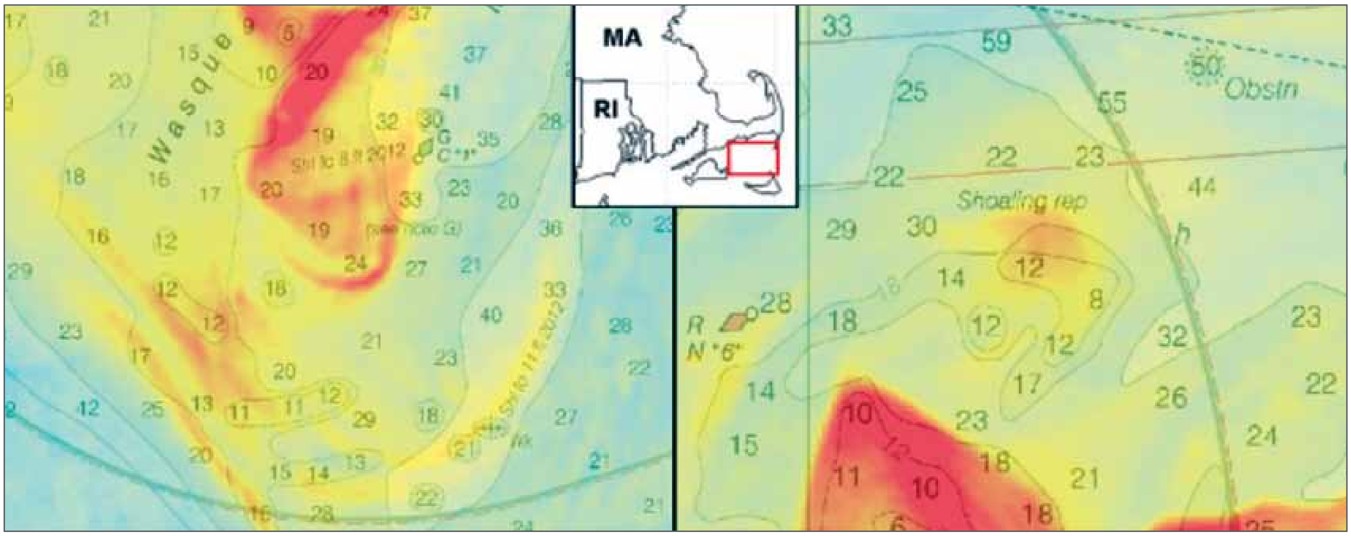


Figure 4-20. Bathymetry derived from Landsat 8 imagery confirming reported shoals offshore of Cape Cod, MA.

derived bathymetry (SDB), and airborne-lidar bathymetry (ALB) for evaluating the adequacy and completeness of information on NOAA charts. Procedures for combining these data sets were developed and two study sites that were evaluated: Cape Cod – Nantucket Sound, MA, and Terrebonne Bay and Barataria Bay, LA. These areas were selected because they have not been surveyed since the 1960s. Based on the publicly available datasets it was possible to identify differences between the charted depths and the measured depths from SBD and ALB and to develop a reconnaissance procedure to monitor these changes on a yearly basis (Figure 4-19).

Enhancing Satellite Imagery Using 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 will allow the production of hydrographic products (e.g., shoreline and satellite-derived bathymetry) at a higher resolution that the original satellite imagery.

Super-resolution (SR) is an image processing approach that is used to enhance the resolution of an imaging system (Figure 4-21). This approach is typically used for cameras that are mounted on a fixed platform with the ability to collect a large amount (i.e., hundreds or thousands) of images (e.g., video cameras). However, this approach might pose a challenge for satellite imagery because the push-broom scanner on a fast moving platform collects only a small number of images over a stable area. The two key conditions to evaluate the potential use are: 1) geometrical referencing between all images, and; 2) image quality due to the ambient illumination of the performance of the scanner.

During the past twelve months Ricardo has been evaluating the geo-referencing of Landsat 8 images based on publications and empirical work. By comparing satellite images using phase correlation, it is possible to evaluate the registration quality to a sub-pixel resolution. Preliminary result confirm that the co-registration of the satellite imagery is on a sub-pixel level (NASA's reported horizontal referencing accuracy is $1\sigma = 17$ m for a 28.5 m pixel). Ricardo was also able to show that the shift is uniform across the image and an affine transformation can be used (Figure 4-22).

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.

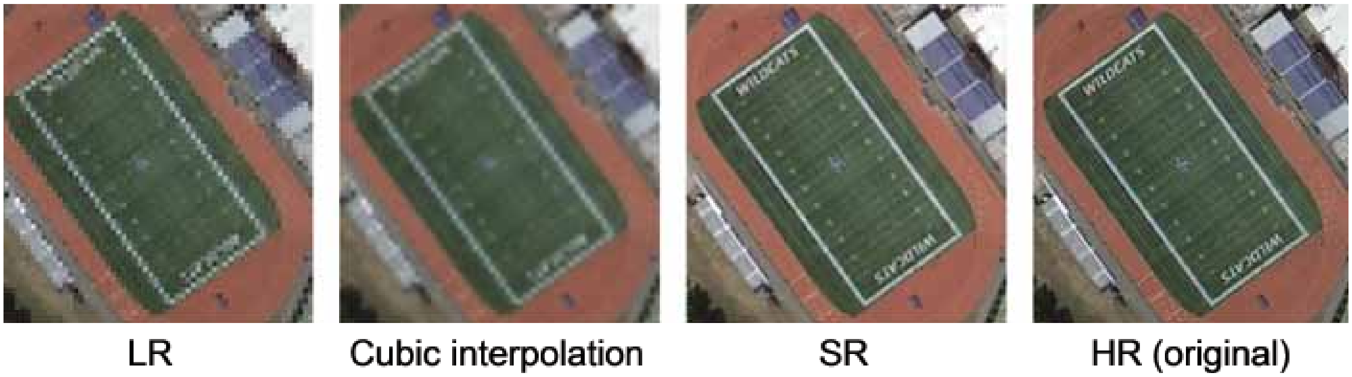


Figure 4-21. Demonstration of SR reconstruction. Image on far right (HR) is full high-resolution image of UNH football field. Image at left is degraded by 17-fold (LR). Image labelled Cubic Interpolation represents standard approach to improve resolution using single low-res image. Image labelled SR represents reconstruction of image from 16 low-resolution images that have been randomly rotated and translated.

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 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. Mashkoor 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 description 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

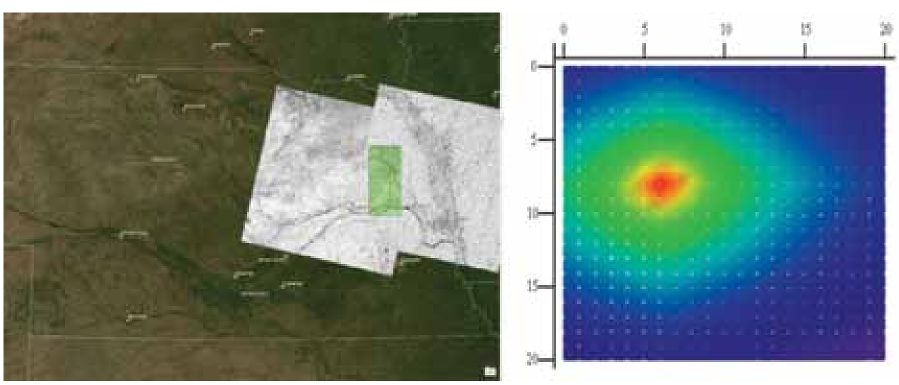


Figure 4-22. Preliminary results using Landsat 8 imagery from two adjacent trajectories (satellite paths) (left) Infrared bands used in the geometric referencing evaluation and (right) the phase correlation result. It is important to note that an intentional 6 pixel shift in the easting and 8 pixel shift in the northing were added in order to validate the algorithms and the results.

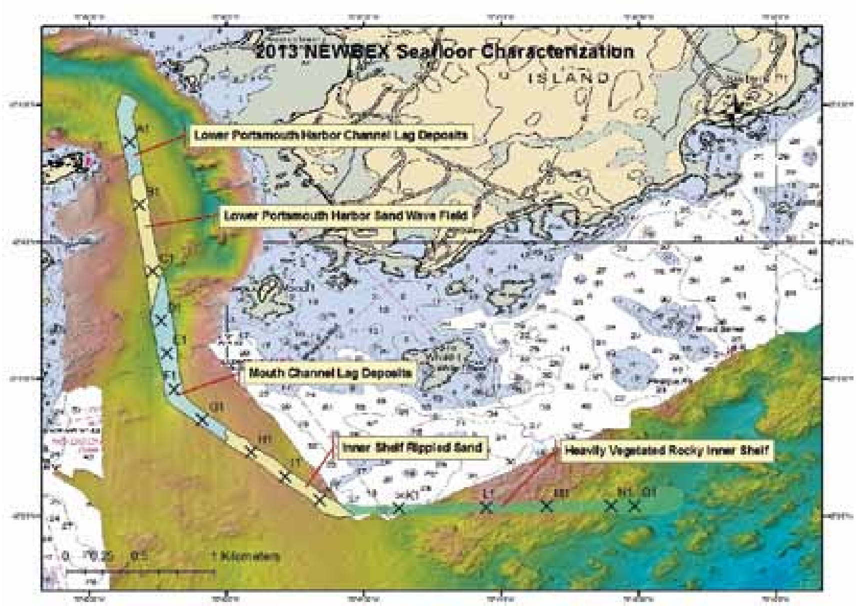


Figure 4-23. Location map of the NEWBEX transect, the 2013 sampling stations (targets), and an initial division of seafloor types.

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 of the details of the NEWBEX experiment were presented in the 2012 and 2013 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. Analysis of all of these data are underway. Larry Ward has finished gain size analysis and a preliminary (but still extensive) analysis of all samples collected along the NEWBEX line. The line, which was chosen in coordination with NOAA OCS and the NOAA Ship *Hassler* officers (at the time), passes over a variety of seabed types including sand with shellhash, clean sand, sand with sand dollars, gravel, and a complicated region with a bedrock/cobble/gravel/sand mixture (Figure 4-23). The variety of sediment types provides an excellent test-bed for studying high-frequency acoustic backscattering of a range of seafloor conditions. The grain size analysis completed by Larry Ward suggests that the sediment composition of each of these regions is very stable (Figure 4-24).

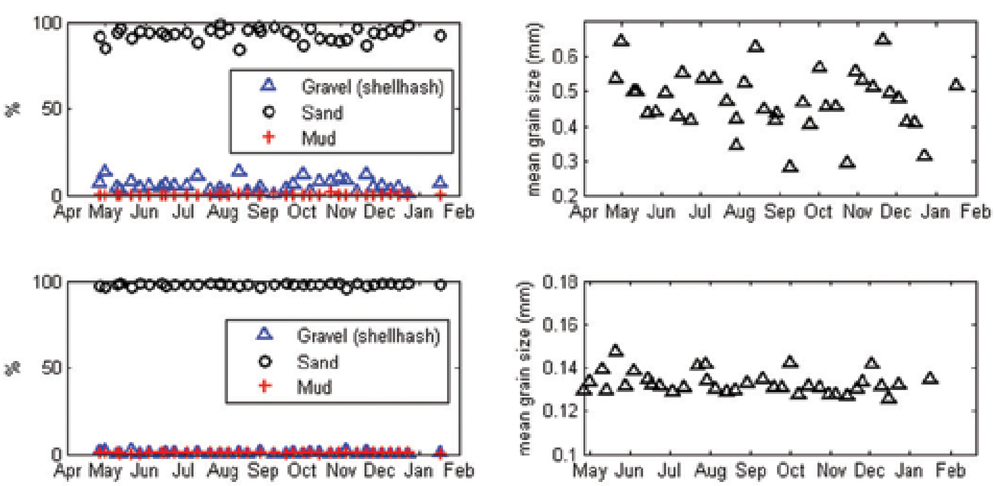


Figure 4-24. Sediment analysis results for two weekly stations on the NEWBEX line, including % gravel, % sand, and % mud (left column); and mean grain size in mm (right column). The northern weekly station (top row) is in the sand wave field, where the gravel portion is mostly shellhash, and the southern weekly (bottom row) station is in an area with much smaller bedforms.

The preliminary analysis of the 200-kHz acoustic backscatter in this region suggests that the backscatter from the entire line is stationary (Figure 4-25). Processing of these data is currently being refined by Glen Rice as part of his PhD work, with a focus on slope and footprint corrections. The stability of the acoustic backscatter along the NEWBEX line was not expected, particularly on the northern portion where there is a sand wave field and currents of up to a few knots. As we begin to investigate the processes controlling high-frequency (> 100 kHz) seafloor backscatter, one of the avenues we are investigating is wideband acoustics. The frequency response of the seafloor might offer another tool for discriminating between seabed types, and to successfully investigate this it is important to understand the basic mechanisms for seafloor scatter at high frequencies (e.g., how important is grain-size induced roughness vs. shell hash?). In December 2013, we ran our 200-kHz EK60 in wideband mode using a prototype version of the Kongsberg EK60 (Figure 4-26). Preliminary data show some changes in the frequency response of the seabed between regions, so a more extensive analysis of these data is underway.

To further investigate basic high-frequency backscatter mechanisms, we have also conducted a targeted field campaign aimed at a high temporal-resolution acoustic experiment in the sand wave field. This effort was led by graduate student Eric Bajor. The focus was on collecting calibrated acoustic backscatter over a wide range of frequencies while simultaneously collecting data that describes the temporal changes in the seabed roughness, and also collecting bottom samples that can be used to determine grain size and shell hash content. The main objective of this experiment was to gather data that can help identify the main contributor to acoustic backscatter at this site (e.g., surface roughness, shell hash, grain size). To this end, a preliminary experiment was conducted in early summer of 2014 where a single camera and an ADCP were deployed in the sand wave field (Figure 4-27). Both instruments collected data with a period of ~1 minute, with the objective of understanding the gross currents responsible for sediment motion as well as the time scales at which the bedforms are changing. The results of this preliminary study suggest changes occur on very short time scales, and the changes were used to 'tune' a follow-on acoustic experiment conducted in October 2014. During the October experiment, broadband acoustic data (approximately 100-250 kHz) were collected over the sand wave field and the adjacent (and presumably stationary) gravel thalweg, while a stereo camera was deployed to quantify the surficial roughness spectrum of the seabed. A sampling rate of one image every 10 seconds was set for the stereo camera that was constructed over the course of the summer by Eric Bajor and Carlo Lanzoni, with help from Yuri Rzhanov. Bottom samples were also collected during the stereo camera work. Under the guidance of Han Hu, Eric Bajor has been reconstructing height maps from the stereo camera data (Figure 4-28). These results will eventually be analyzed to find the roughness spectrum of the seafloor. Analysis of the acoustic data and bottom samples is just getting underway. The anticipated outcome is a better understanding of the processes controlling acoustic backscatter in this environment, which in turn should help determine the capabilities of high-frequency mapping sonars for seafloor characterization.

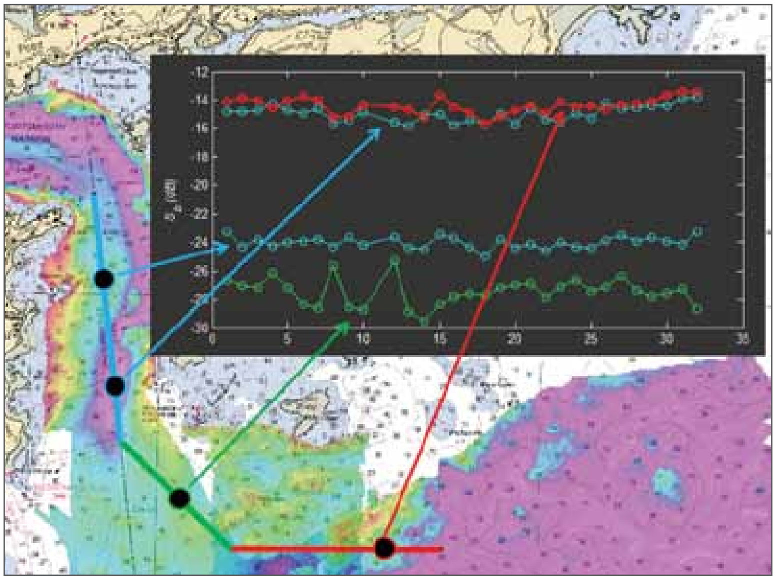


Figure 4-25. Time series of seafloor backscatter from select locations along the NEWBEX line.

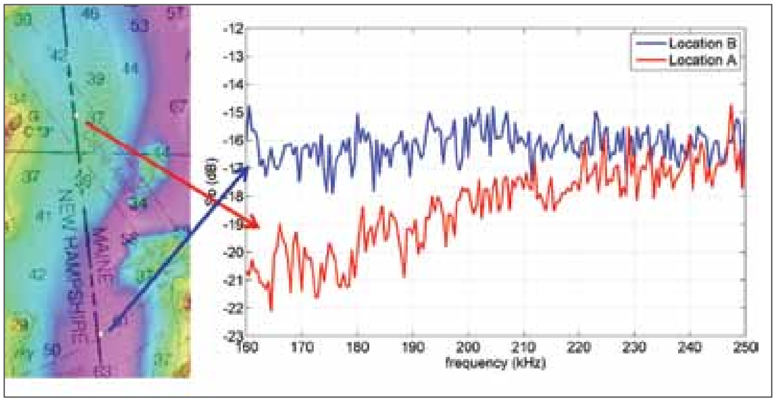


Figure 4-26. Wideband acoustic backscatter collected from two locations along the NEWBEX standard line in December 2013.

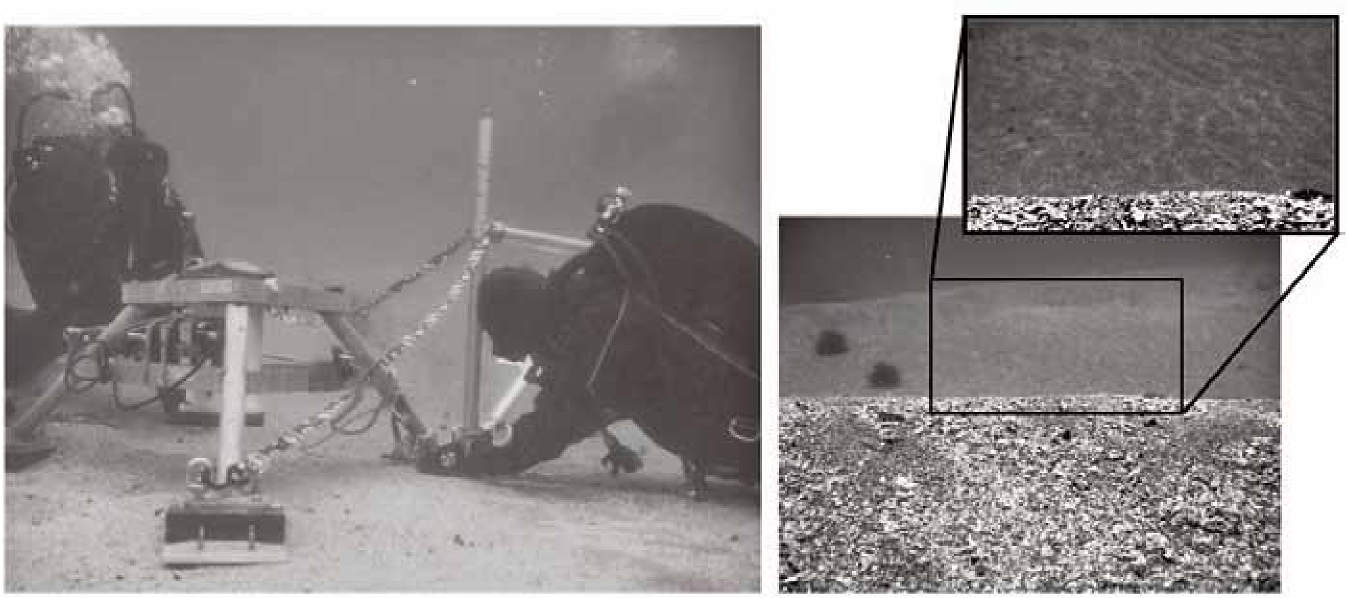


Figure 4-27. Deployment of ADCP, Aquadop, and camera. Note the contrasting orientation of the sandwaves and the ripples. Picture credit: Liz Kintzing.

The NEWBEX experiment has built upon Mashkor Malik's thesis work attempting to identify and quantify the uncertainty sources associated with MBES backscatter survey. 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 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. In Figure 4-29, and making several simplifying assumptions, individual uncertainty sources were propagated for an EM302 MBES to compute uncertainty in backscatter measurement (left) and seafloor incidence angle (right).

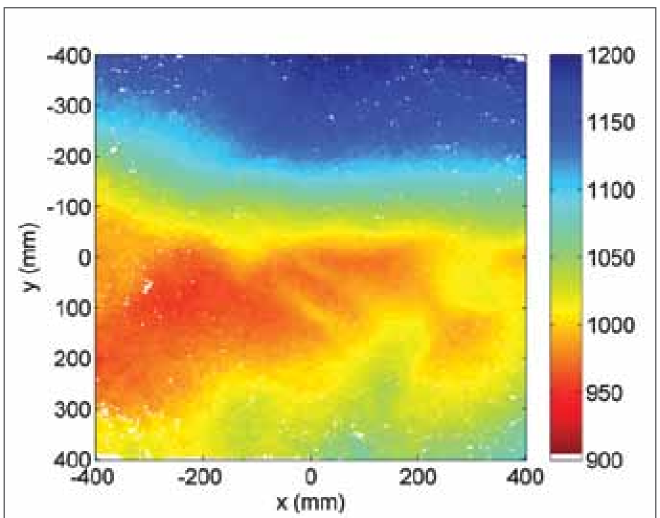


Figure 4-28. Preliminary analysis of the stereo camera data by Eric Bajor, with help from Han Hu. Depth below the stereo camera (in mm) is mapped to color.

Backscatter Working Group

The interest in establishing efficient and optimal workflows for generating high-quality backscatter data has gone far beyond NOAA. At the international Geohab 2013 Conference (a conference that focuses on techniques for mapping habitat), a "Backscatter Working Group" was formed to define a set of best practices and guidelines for backscatter acquisition and processing for those who use multibeam echosounders. Many members of the Center are represented on this working group (Jonathan Beaudoin, Brian Calder, Mashkoor Malik, Larry Mayer, Glen Rice, Val Schmidt, Tom Weber, and Briana Welton); Glen Rice has been selected to represent the Center on the chairing group. He will be coordinating the backscatter acquisition chapter of the planned document. The final document is scheduled for publication in 2015; further information about the Backscatter Working Group can be found at **http://geohab/org/BSWG**.

Marine Target Detection and Object Recognition (MaTaDOR)

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 has now 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. Masetti's 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 (called Marine Target Detection and Object Recognition—MATADOR) is being developed that appropriately responds to changes in the environment, context, and human skills.

MATADOR is a modular software package that has been developed to provide an adaptive fusion algorithm that is able to quickly and effectively detect the presence of marine debris. Such a task involves some degree of modeling and approximation to make the analysis computationally efficient and sufficiently effective in practice. The scope of the detector has been specifically tailored to analyze products commonly available from surveys (mainly, bathymetric digital terrain models (DTMs) and backscatter mosaics) with several associated data sets, such as statistics derived from the raw or processed data. The algorithms are designed to be quickly integrated into existing workflows easing their application during an emergency response situation.

Current research is focused on the identification of the most appropriate analytical tools for different types of targets. For example, a threshold-based algorithm is best suited for flat targets like a submerged barge whereas an edge detector is better suited for targets characterized by more irregular and varying surfaces (Figures 4-30 and 4-31). An additional topic currently

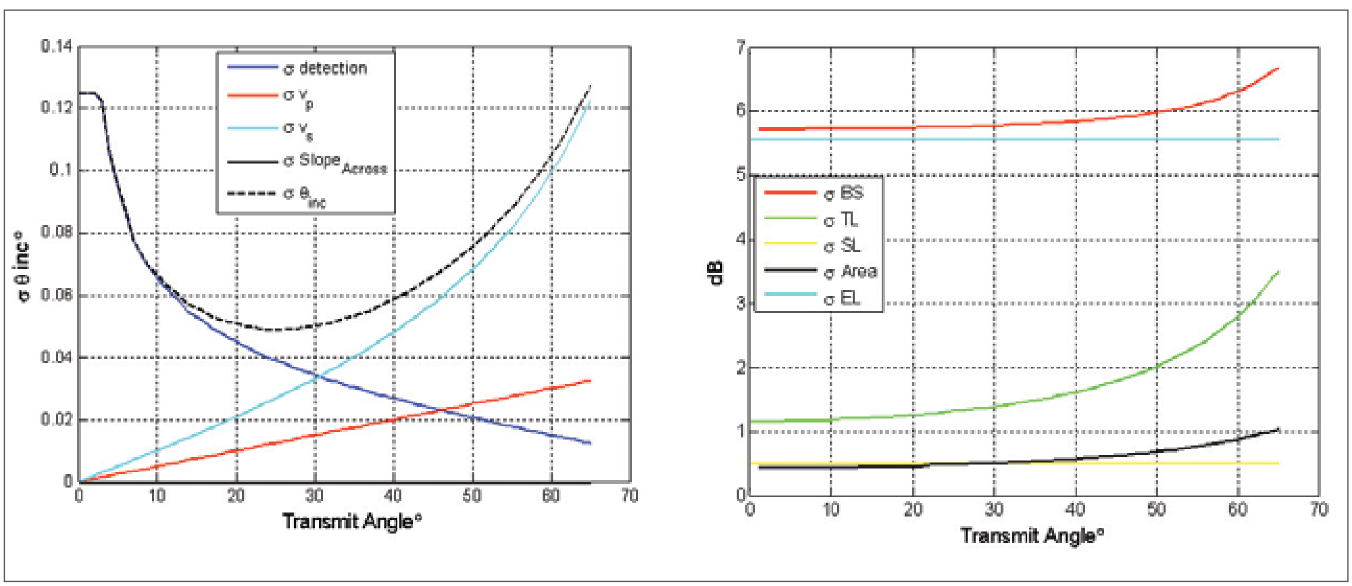


Figure 4-29. (left) Backscatter uncertainty estimation using 30 kHz EM 302 in water depth of 500 m in nominal operating conditions. Individual uncertainty sources were propagated to estimate uncertainty in ensonified area (Area), source level (SL), transmission loss (TL), echo level (EL) and final backscatter measurement (BS). (right) Combined uncertainty estimation of seafloor incidence angle (30 kHz, EM 302) based on predicted uncertainty due to detection uncertainty, sound speed at surface, sound speed profile, and seafloor slope uncertainty (assumed zero) in 500 m water depth under nominal operating conditions.

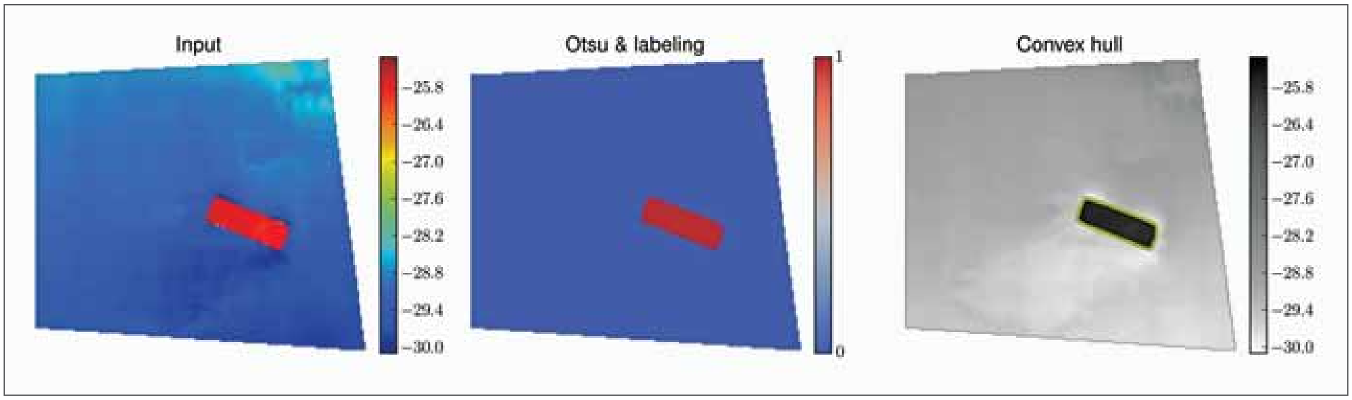


Figure 4-30. A DTM characterized by the presence of a barge (left pane) is processed using an algorithm that applies Otsu threshold (middle pane) and convex hull techniques to identify the shape (in yellow) of the target (right pane).

under investigation is the multi-scale nature of marine debris (ranging from the finest resolution of the acquisition system to scales of tens of meters). A regional minima approach at variable scale provides a possible solution to create a hierarchy of spatial areas. Such a multi-scale solution also provides a means to split the computational burden thus enhancing efficiency.

For both backscatter and bathymetry, the adoption of classical estimation techniques generates only a point estimate or a confidence interval that becomes important when attempting the fusion of target information from different products. In order to provide appropriate distributions for exploitation, Bayesian methods were adopted because they permit the use of multiple-source asymmetric and discontinuous posterior distributions that may be carried into further analysis. A hierarchical scheme is proposed where a series of modeling tasks are implemented through a probabilistic model, casting the debris detection problem as one of estimating properties of the posterior distribution describing the probability of objects occurring given the observed data products. Pragmatic advantages of the proposed Bayesian framework are the opportunity to include prior knowledge (e.g., a geological context) as well as developing an extendible robust scheme for estimating the probability of an object that occurs at any point in the area of interest, making detection simpler. A Markov chain Monte Carlo (MCMC) system is used to estimate probability of object presence on a per pixel/node basis. The data probability under the hypothesis of having marine debris is produced by the detector from different types of products, related both to bottom detection (depth)

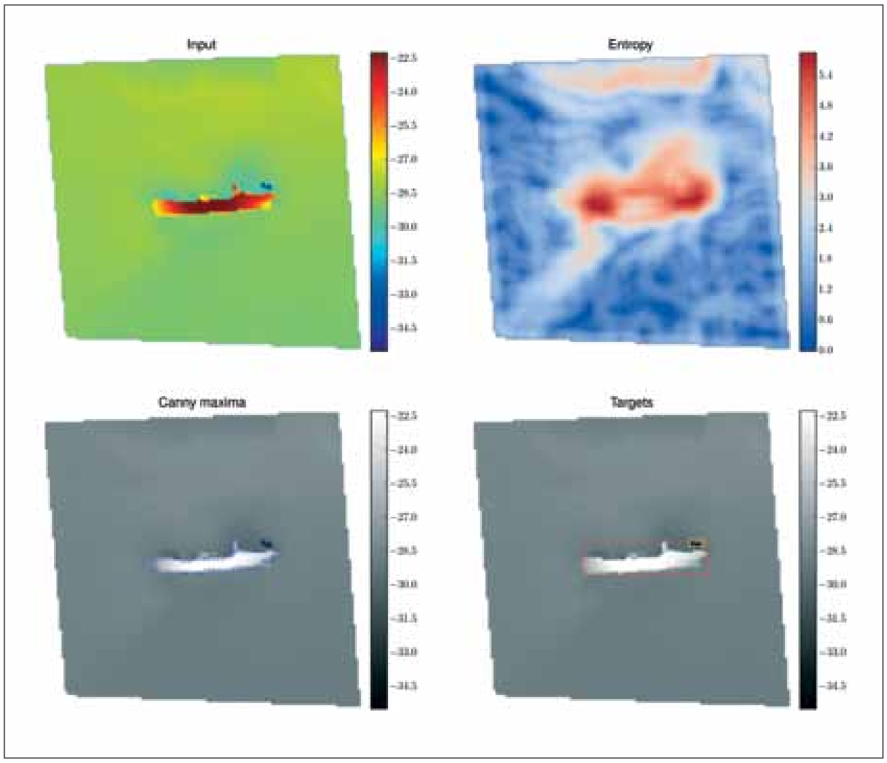


Figure 4-31. A DTM characterized by the presence of a wreck (top-left pane) is processed using an algorithm that first prepares the data applying entropy (top-right pane) and Canny edge (bottom-left pane) operators, then defines the bounding box of possible targets (bottom-right pane).

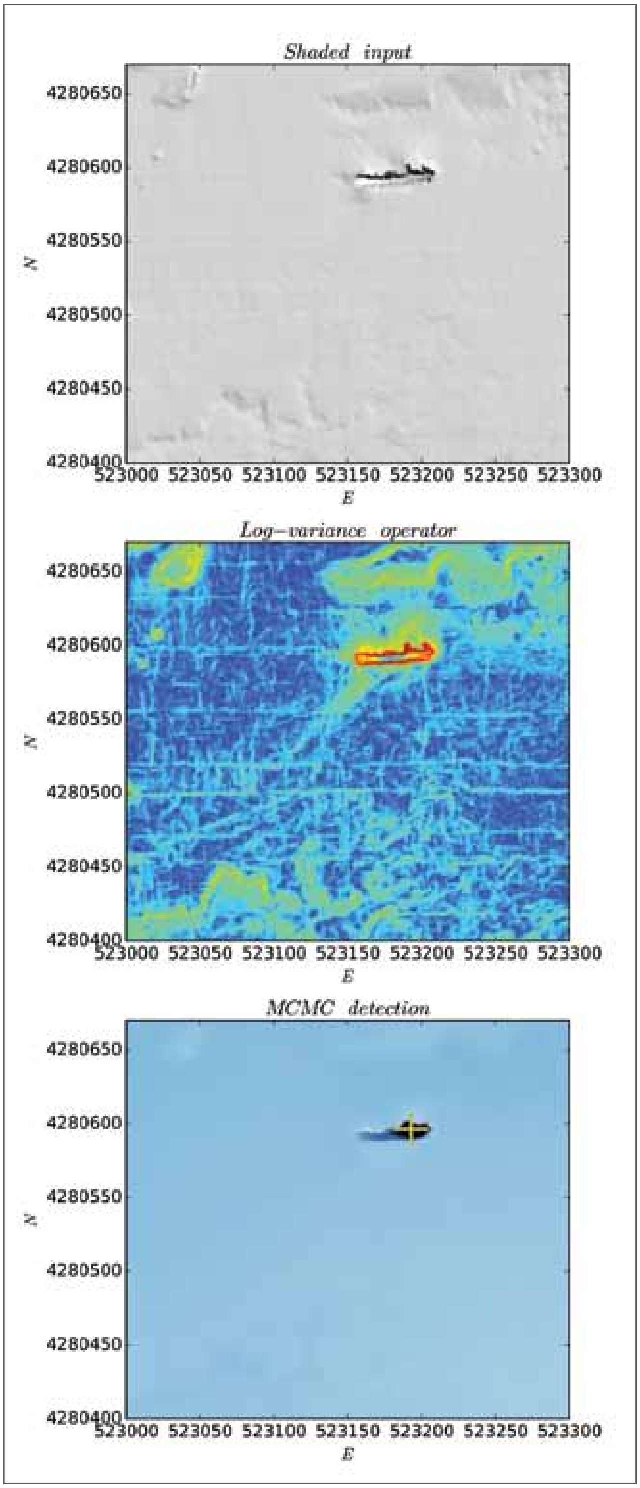


Figure 4-32. A DTM characterized by the presence of a wreck (top pane) is first processed to calculate the log-variance (middle pane), then a Markov Chain Monte Carlo (MCMC) is applied. On the bottom pane, the resulting positional traces are plotted together with the Maximum a Posteriori (MAP) (yellow 'plus' symbol). Although simple as targets go, the wreck provides a good test-bed for the development of more complex situations.

and to the intensity time series usually collected over it (backscatter). In order to avoid over-fitting and to maintain reasonable computation times, the hierarchical model is made as simple as possible. For instance, taking advantage of the clustering division observed by applying a log variance operator, the process involved in the data creation around a target was modeled with only two components: the position and the mass. In such a specific case, a Markov Chain Monte Carlo (MCMC) was applied and the target position is identified as the maximum a posteriori probability (MAP) to minimize the loss function (Figure 4-32).

The expected outcome of the overall fusion approach is the reduction of inter-algorithmic cross-correlation and, thus, the probability of false alarm. Because the framework provides sufficient flexibility to integrate additional source of information, the extension of the detector with a set of ad hoc hydrographic products is also being investigated with the intent of improving the detection performance.

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 of our largest databases—the eight seasons of Arctic multibeam sonar data collection (see LAW OF THE SEA theme), and 13 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 of 2014 Paul began the process of transitioning the Center's web based dynamic map services from a very simplistic JavaScript implementation, with very few interactive features, to a much more feature-rich version. The initial migration started by redesigning the Law of the Sea's Arctic Ocean bathymetric maps to include features such as layer control, distance measuring, selectable basemaps, and bookmarking (Figure 4-33—middle and bottom). Examples of

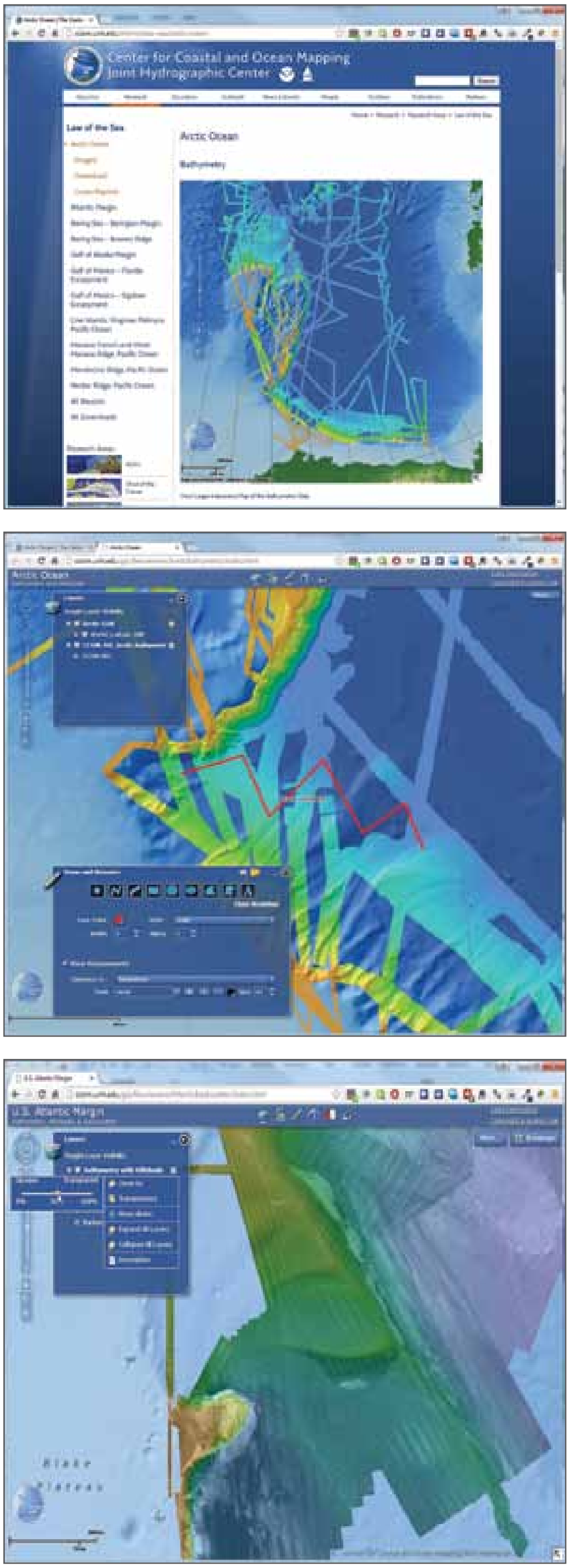


Figure 4-33. Examples of the current dynamic maps served through the Center's website which are implemented using the Flex API. These maps allow full interaction with the data including being able to change layers, measure distances, and bookmark views.

these features and the Arctic data base in action can be found at **http://ccom.unh.edu/gis/flexviewers/ArcticBathymetry**). Following the release of the new Arctic dynamic maps, the Atlantic Margin bathymetry and backscatter maps were then revised and released (Figure 4-33—top). The Atlantic database served under this mode can be found at **http://ccom.unh.edu/gis/flexviewers/AtlanticBathymetry.**

These initial implementations were done using an ArcGIS API, developed by ESRI, based on the Adobe Flex framework. This method allowed Paul to develop a very feature-rich web map interface to data already loaded and served from the Center's GIS server. However, the downside of this method proved to be that the Flex framework had slow initialization and loading speeds and did not work with many mobile platforms, meaning both the new Flex version and the older less-capable JavaScript version had to be maintained. These issues, coupled with ESRI's eventual decision to end support of the ArcGIS API for Flex this year has meant that the Center once again needed to look in a new direction.

To address these issues, Paul began development of new feature rich dynamic maps based on ESRI's ArcGIS JavaScript API. The new maps have the same features and functionality as the former Flex version, but do not suffer from slow loading speeds and incompatibility with mobile browsers. A very early implementation of this version can be seen in Figure 4-34 and by visiting **http://ccom.unh.edu/gis/jsviewers/GulfOfAlaska**.

Like the current Flex based interface, the new JavaScript implementation allows transparency effects on layers (Figure 4-34—middle image), measurement of features (Figure 4-34—right image), bookmarking of regions, the drawing of shapes and annotations, and the printing of viewed areas. Improvements will continue on the new interface and it will eventually be deployed to replace all of the Center's web-based dynamic maps during early spring 2015.

The improvements with the interface continued during the fall of 2014, with Johnson migrating the Great Bay Estuary and Gulf of Maine datasets (see discussion below) to the new web interface. This migration integrated the bathymetry and backscatter into a single dynamic web map for each site. This new style also gives the user the ability to toggle between datasets and to adjust the transparency of the datasets on the fly.

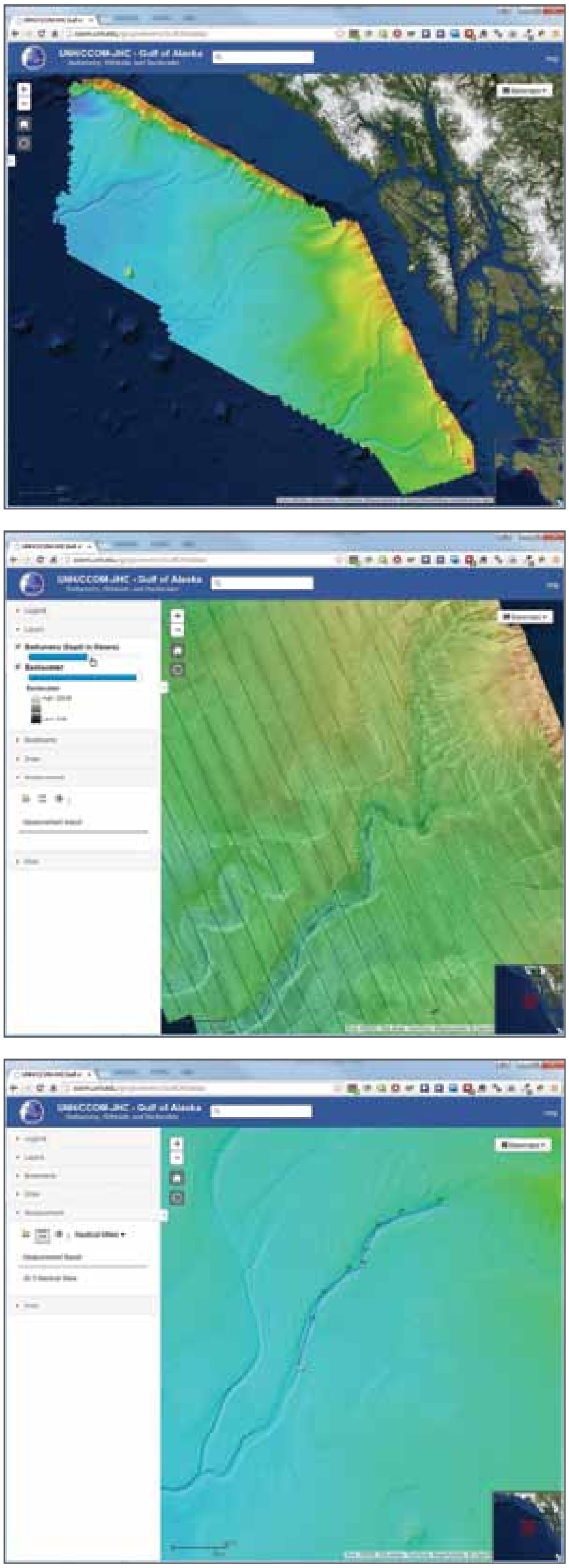


Figure 4-34. Examples of the prototype dynamic map pages based on a JavaScript implementation. The maps have similar capabilities as the existing Flex versions, but are also compatible with mobile clients.

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 many years of data from the region and numerous requests for these data. The 14 years of collection of these data 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.

In 2014 work continued on the aggregation, evaluation, assembly, and visualization of all available bathymetry (NOAA BAGs, field sheets, xyz files, SD files, etc.) and backscatter data from the Great Bay Estuary and the Gulf of Maine. The overall bathymetric coverage within the synthesis was significantly improved this fall with the inclusion of the data from the NOAA Ship *Ferdinand R. Hassler*. As part of the synthesis assembly, Paul constructed a "seamless" multi-resolution ESRI raster composite of the Great Bay Estuary and Gulf of Maine bathymetric data. This composite allows multiple gridded datasets of variable resolution to be displayed and worked with as though they were a single grid. Paul assigned a prioritization value to each gridded datasets so that data of the highest resolution and of the highest data quality will be displayed to users interacting with the dataset at each appropriate zoom level.

Figure 4-35 shows a series of zoomed images of the bathymetric synthesis. The upper left figure (A) shows an overview of the data where most of the data is displayed at a 400-meter grid cell size and is predominately composed of coarse regional datasets. As the user progressively zooms in on the synthesis (from panels A to B to C to D), the bathymetry displays higher and higher resolution data until the user reaches the bottom right panel (D) where the data is now displayed at a 1 m grid cell size. The beauty of this type of interface is that users who interact with the grid are unaware of the transitions between the various gridding resolutions and the data appear as a single unified grid at all zoom levels.

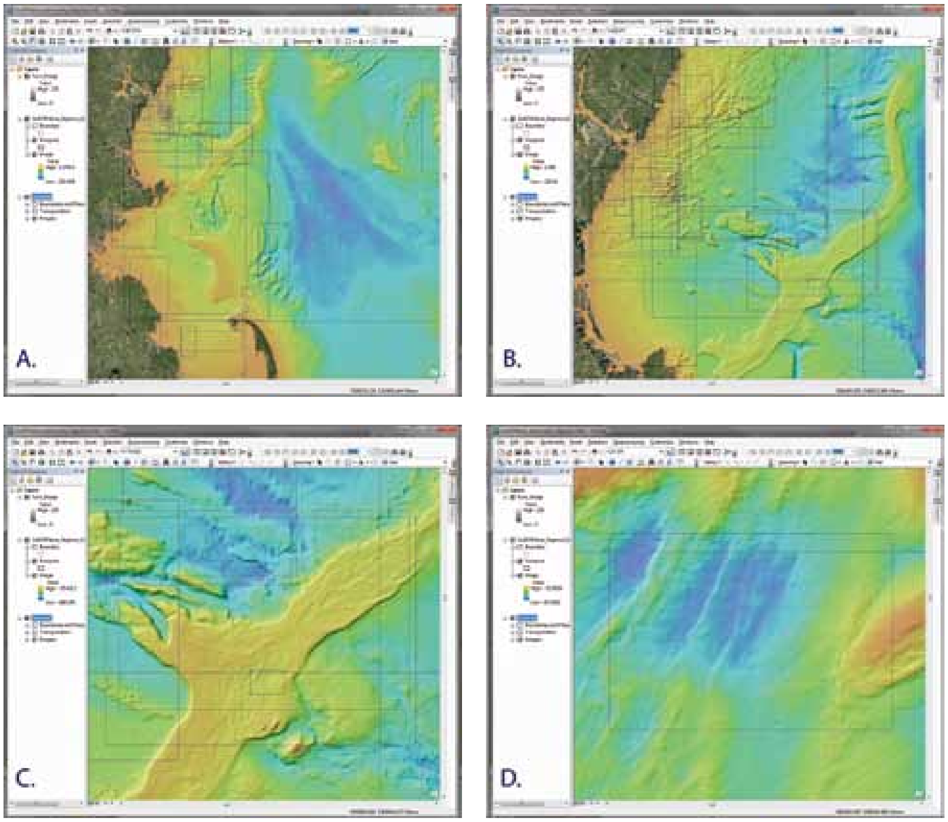


Figure 4-35. Various zoom levels showing the ever increasing level of information of the new Gulf of Maine bathymetric synthesis.

Part of the process of generating the bathymetric synthesis required Paul to transform all of the bathymetric data with their varied coordinate systems into a single common coordinate system, WGS 1984 Web Mercator/Auxiliary Sphere. This coordinate system is used by many mapping products, including Google Earth and ArcGIS.com. Enforcing this single common projection has allowed the Center's GIS Server to rapidly distribute data through web mapping services without the need for reprojection, meaning little slow-down when interacting with the data over the internet. This process, has also allowed the Center's server to support the distribution of the data through standard OGC services (WMS, WFS, etc.).

Paul released two different "beta" versions of the synthesis for distribution through the Center's GIS server in November of 2014. One beta version contains only the high resolution multibeam data and thus has gaps in areas of no-data (Figure 4-36, left). The second beta version of the synthesis contains both the high-resolution data as well as the low-resolution regional data (Figure 4-34, right). These datasets can be viewed at **http://bit.ly/1ArSSg2** or **http://bit.ly/1xaJZtU,** respectively.

In addition to the bathymetric and backscatter data, a sedimentological and photographic database has been developed for the UNH Study Area at Jeffreys Ledge, This database is based on work undertaken from 2002-2005 (funded by several agencies including JHC/CCOM). The database consists of sediment classifications based on grain size data from samples collected at 124 stations (Figure 4-37), sediment classifications based on video analysis from 141 stations (Figure 4-38), and more than 700 seafloor images (photos extracted from archived video) from the 141 stations where video was collected. The photographs depict the bottom sediments, epifauna, and a variety of seafloor features. Therefore, a rich and useful database exists for the UNH Study Area on Jeffreys Ledge that has value to a number of users. The application of this database will be discussed further under the HABITAT theme.

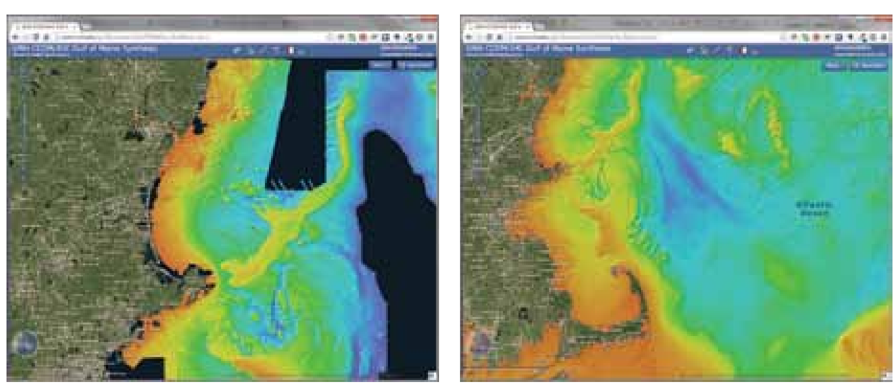


Figure 4-36. Examples of the dynamic maps pages serving the Gulf of Maine bathymetric synthesis. The figure on the left shows the synthesis composed of only high resolution bathymetric data. The figure on the right includes the same high resolution bathymetric data, but in areas of no data display a low resolution regional grid in to have a seamless dataset.

Incorporation of USN Submarine-Derived Bathymetry into Arctic Database

For the past few years, the Center has been the recipient of U.S. Navy submarine-derived bathymetric data collected under the auspices of the SCICEX (SCientific ICe EXperiment) program. These data are sent to the Center in various formats and then processed by Paul Johnson to derive position and seafloor depth data. We have received data from two 2011 SCICEX missions (the USS *Connecticut* and the USS New *Hampshire*), one from a 2012 SCICEX mission (the USS Topeka), and two from 2014 (the USS *Hampton* and the USS *New Mexico*). Initial processing of 2011 and 2012 data was conducted in 2013 and final processing and submission of the 2011 and 2012 data was completed during the spring of 2014. The Center finalized the 2014 data in December of this year. Figure 4-39 shows location of bottom sounder points collected during the 2014 USS Hampton mission. Inset into the map is the profile of the data collected compared to the IBCAO depths over the same points. Good correlation to IBCAO data where high-quality source data exist for IBCAO imply that the submarine-derived data is of good quality and in those areas where IBCAO has no source data offers the opportunity to update Arctic bathymetry.

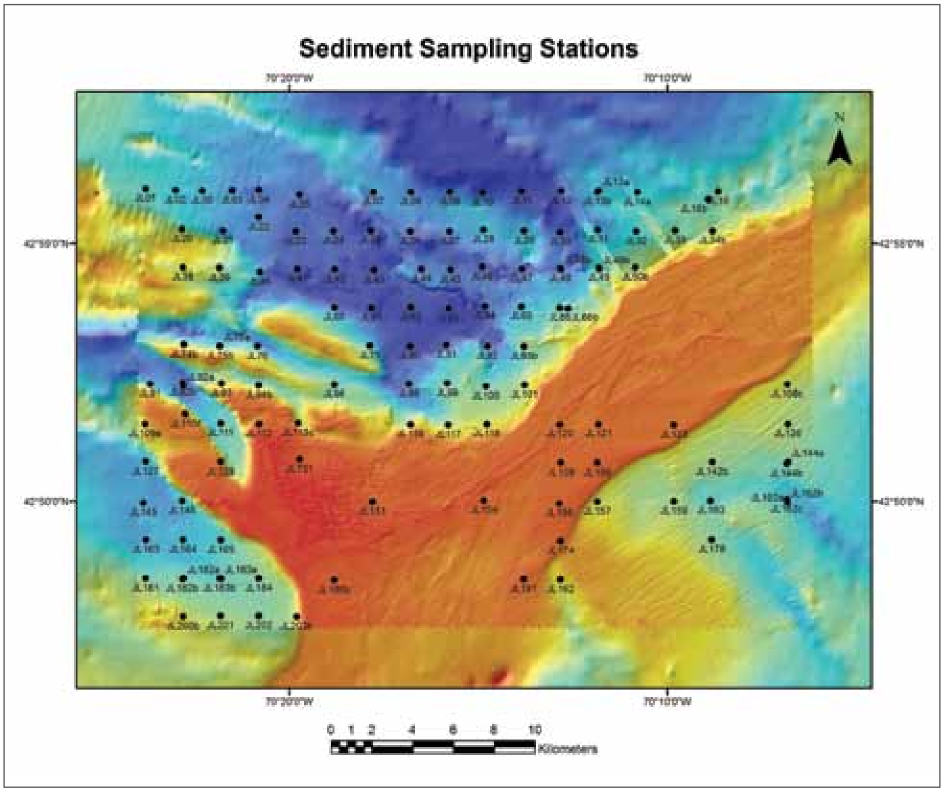


Figure 4-37. Location of sediment stations on Jeffreys Ledge.

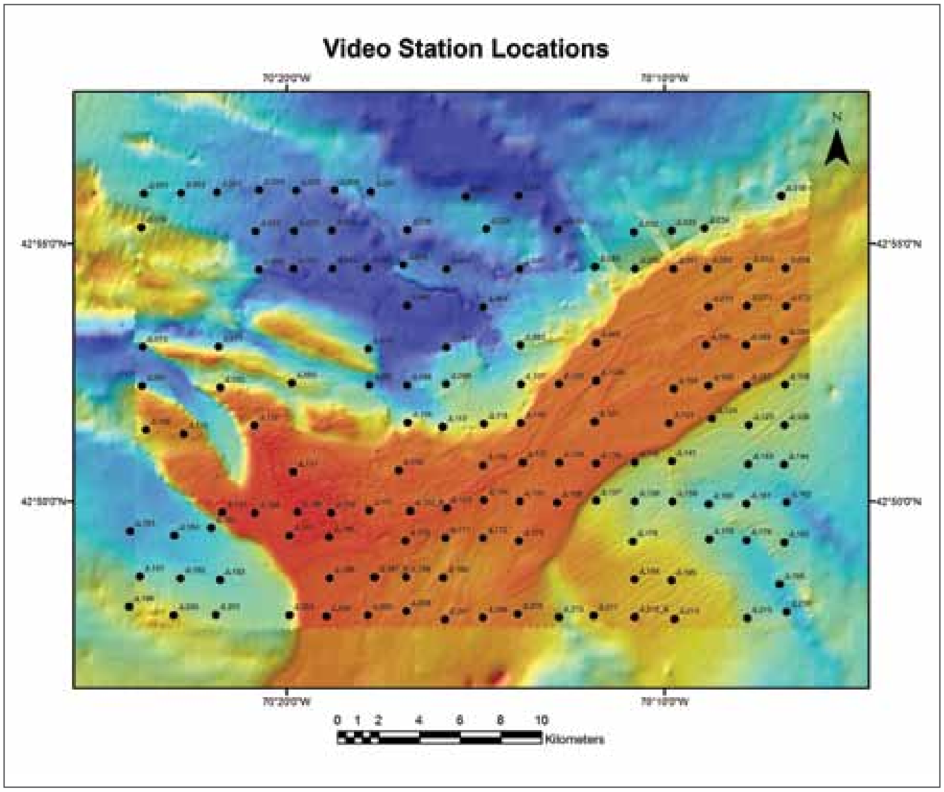


Figure 4-38. Location of video stations on Jeffreys Ledge.

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 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 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. As additional downstream benefits, this would 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 (Figure 4-40).

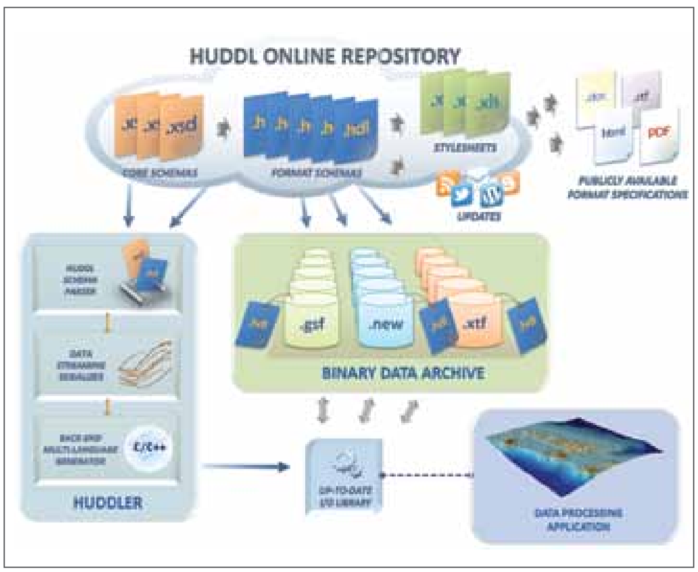


Figure 4-40. HUDDL framework: the online repository is used both for public provision of format specifications (in different formats) and as source for HUDDLer that parses the descriptive schemas, serializes the information and creates an I/O library. Data processing applications can thus use this library for access to the binary data.

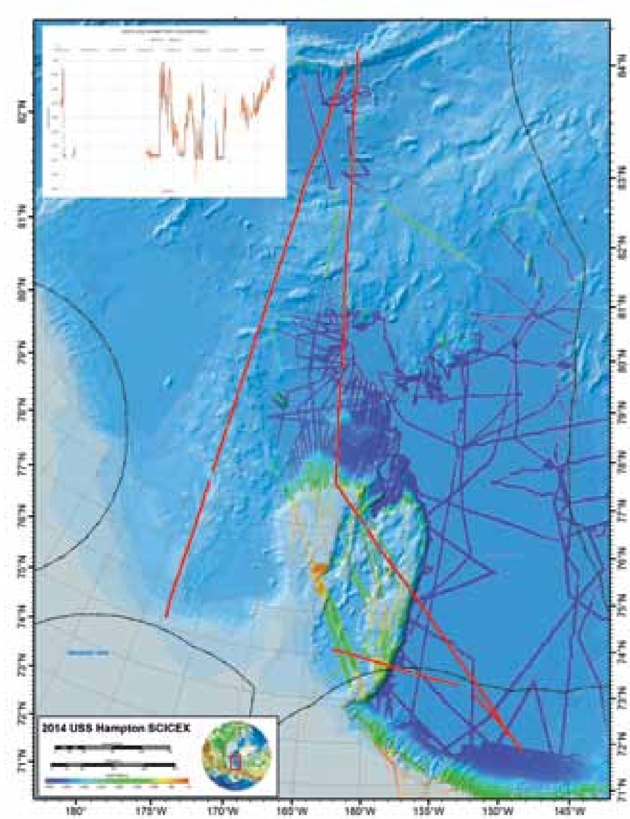


Figure 4-39. USS *Hampton* SCICEX bottom sounder track line overlaid on the IBCAO and CCOM Arctic basemaps. Inset shows the profile of the bottom sounder data as well as the depths at the same points extracted from the IBCAO grid.

Currently, Calder and Masetti have developed the XML interface for HUDDL, and constructed a code-generator application in C++ that allows multiple language back-ends to be implemented, so that the output code can be generated in different computer languages. Code in C and C++ is generated directly; code in Python and MATLAB is generated through a C++ library with SWIG bindings. Example data formats for Kongsberg and HyPack data files have been built as demonstrations of the technique, and a website has been developed to support and describe the project. The HUDDL project was described in a paper at the Canadian Hydrographic Conference, which will also be published in Lighthouse; a paper for International Hydrographic Review on the application layer of HUDDL (known as HUDDLer) is in preparation.

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 sonar development 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 is not well defined. Our response to this question is to focus on the development of approaches for characterizing the seafloor through the analysis of data we can derive from the sensors we work with (sonars, 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 is the NEWBEX experiment (described above). Once proper corrections are made, the resulting backscatter values should be much more representative of true seafloor variability.

Seafloor Characterization and Habitat Studies and Resource Studies Offshore New Hampshire

Jeffreys Ledge

Jeffreys Ledge, a major morphologic feature in the Gulf of Maine, is extremely important to regional bottom fisheries – a large portion of Jeffreys Ledge is inside the Western Gulf of Maine Closure Area. Knowledge of the seafloor characteristics and controlling geologic processes is important for evaluating bottom habitats on Jeffreys Ledge, which in turn are important to fisheries management. In addition, insights into the morphology and sedimentology of Jeffreys Ledge are important to the overall understanding of the evolution and geology of the Gulf of Maine. Previously (2002-2005), a major field campaign by a multidisciplinary group was conducted at Jeffreys Ledge including high-resolution bathymetry, extensive bottom sampling for sediment and benthic infauna analysis, and videography for assessment of bottom type and benthic epifauna. A

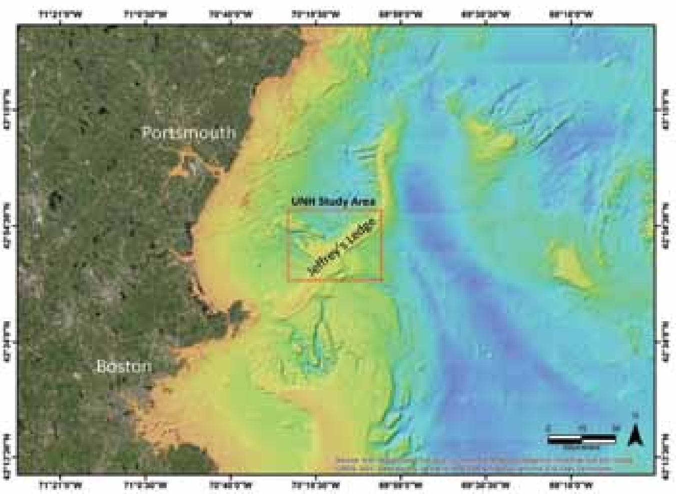


Figure 5-1. Location map of Jeffreys Ledge and the UNH Study Area. The western half of the UNH Study Area is outside, while the eastern half is inside, the Western Gulf of Maine Closure.

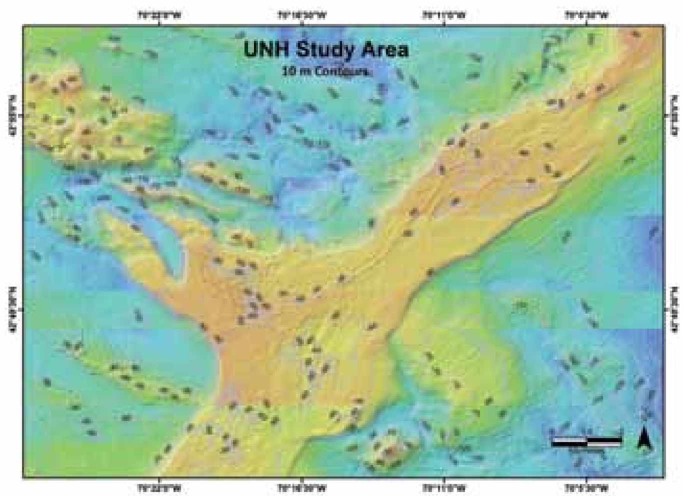


Figure 5-2. Bathymetry of the UNH Study Area.

significant portion of this work was presented in an M.S. thesis and two scientific journals (Malik 2005, Malik and Mayer 2007, and Grizzle et al. 2009). As a result of these studies, a rich database including high-resolution bathymetry, sediment grain size, videography, and subbottom seismics exists for Jeffreys Ledge. In the past year, a significant effort was invested in continuing the analysis of the Jeffreys Ledge data including a review and upgrade of the sediment sample database (~125 locations) and re-analysis of bottom video from ~150 stations for seafloor characteristics and grain size classification. In 2014, bottom images were extracted from the video from each station to enhance the seafloor coverage and a database of nearly 700 images was developed to directly accompany the seafloor classifications and descriptions from the sediment and video (see Data Management section of DATA PROCESSING theme). This database, now complete, provides a clearer understanding of the seafloor characteristics of the study area and associated habitats and provides an excellent test bed for future habitat studies.

Additionally, in 2014 the JHC/CCOM Western Gulf of Maine (WGOM) database was used to develop detailed surficial sediment maps for a section of Jeffreys Ledge (UNH Study Area), a major physiographic feature in WGOM (Figure 5-1). These maps, based on the integration of high resolution bathymetry (Figure 5-2), bottom videography, and direct bottom-sediment sampling, depict major sediment types (classifications) and morphologic features. They will help further our understanding of seafloor habitats in the WGOM and are relevant to fisheries management as the UNH Study Area bridges a section of Jeffreys Ledge that lies within the WGOM Closure (an area closed to ground fishing since 1998).

The difficulty of directly sampling gravel has produced a lack of sediment samples and grain size data for sections of Jeffreys Ledge. Consequently, a new sediment classification based pm archived video was developed primarily for gravel environments. The descriptive classification is based on visual inspection of the video and an estimation of grain size (with the aid of laser references). A portion of the video transect that typically extended ~25 to ~50 m in length was isolated at each station for analysis. Bottom sediment viewed in each frame was first described as mud-sand or gravel. If the gravel size clasts were largely in contact, then the bottom was classified as a gravel with the appropriate modifiers (see Table 5-1). If the gravel clasts were separated by sand or granule material, then the seafloor was classified as a sandy gravel with the appropriate modifiers.

Development of a bottom sediment classification based on video for the gravel dominated environments, coupled with standard sediment classifications based on complete grain size analysis for sandy or muddy regions, provides a comprehensive coverage of the project area. This approach was required because of the variety of depositional environments that range from gravel platforms to muddy basins. The resulting surficial sediment map is shown in Figure 5-3 (left) with Figure 5-3 (right) showing the major features observed in the study area.

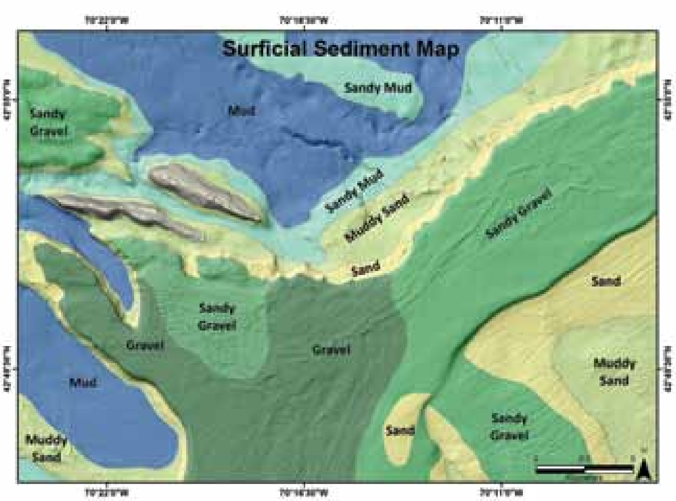
Seafloor Classification	Gravel in Contact or Separated by Sand	% of Frames With Pebbles	% of Frames With Cobbles	% of Frames With Boulders
Pebble Gravel	Gravel in Contact	> 50 %	> 10 %	> 10 %
Pebble Gravel with Cobbles	Gravel in Contact	> 50 %	10 – 50 %	> 10 %
Pebble Gravel with Cobbles and Boulders	Gravel in Contact	> 50 %	10 – 50 %	10 – 50 %
Pebble and Cobble Gravel	Gravel in Contact	> 50 %	> 50 %	> 10 %
Pebble and Cobble Gravel with Boulders	Gravel in Contact	> 50 %	> 50 %	10 – 50 %
Pebble Cobble and Boulder Gravel	Gravel in Contact	> 50 %	> 50 %	> 50 %
Sandy Pebble Gravel	Separated by Sand	> 50 %	> 10 %	> 10 %
Sandy Pebble Gravel with Cobbles	Separated by Sand	> 50 %	10 – 50 %	> 10 %
Sandy Pebble Gravel with Cobbles and Boulders	Separated by Sand	> 50 %	10 – 50 %	10 – 50 %
Sandy Pebble and Cobble Gravel	Separated by Sand	> 50 %	> 50 %	> 10 %
Sandy Pebble and Cobble Gravel with Boulders	Separated by Sand	> 50 %	> 50 %	10 – 50 %
Sandy Pebble Cobble and Boulder Gravel	Separated by Sand	> 50 %	> 50 %	> 50 %

Table 5-1. Classification of gravel bottoms based on videography from Jeffreys Ledge. Note that the actual percentage of the area of a frame composed by a class size (pebble, cobble, or boulder) was not determined, rather simply if any pebbles, cobbles, or boulders were present in that frame.

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 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. The project will also take advantage of the new WGOM Bathymetry Synthesis developed by the JHC/CCOM Data Manager Paul Johnson (see Database section of DATA PROCESSING theme). Sediment property characteristics, existing seismic reflection profiles, and bottom video data, will be fused with high-resolution MBES bathymetry and backscatter data compiled in the WGOM Bathymetry Synthesis. When available, the



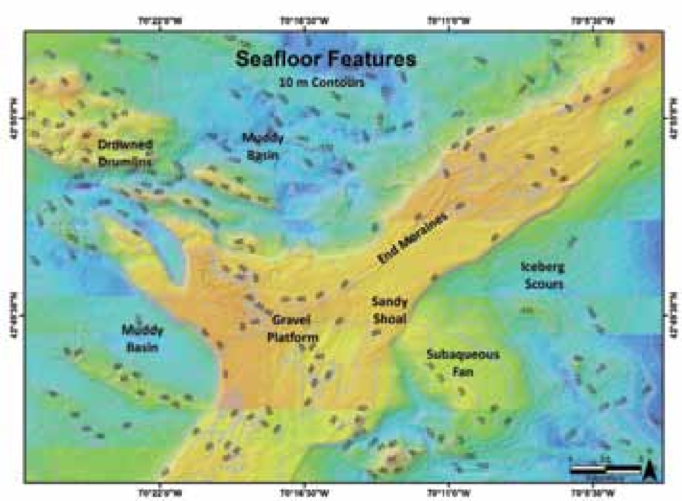


Figure 5-3. Surficial sediment map draped over the bathymetry of the UNH Study Area (right) and major features of area (left).

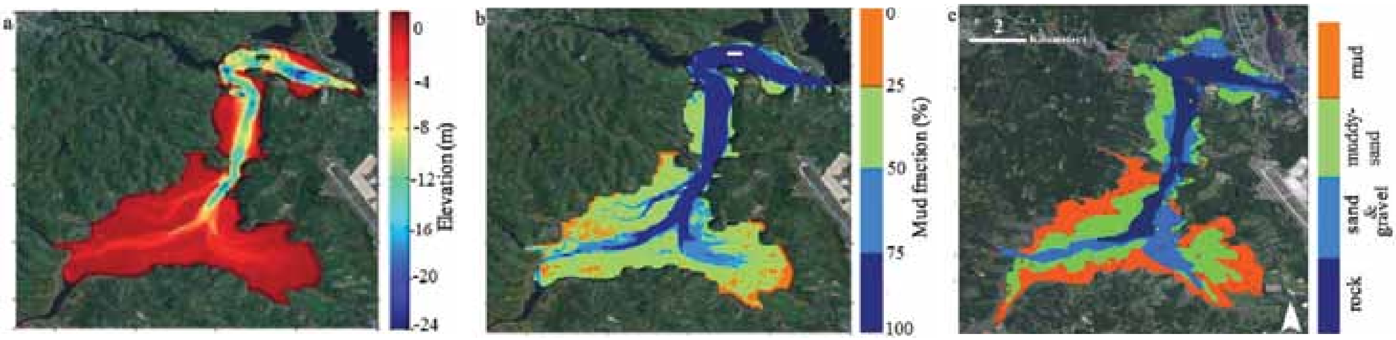


Figure 5-4. (a) Bathymetry of the Great Bay estuary including the Little Bay with water depths relative to NAVD88 (approximately mean sea level). (b) Sediment distribution map of the Great Bay system determined by the depth model developed from Little Bay data. (c) Sediment distribution map of the Great Bay system as determined by qualitative interpolation (filled blocks) from existing historical sediment data (filled points; Poppe, et al. 2003).

MBES backscatter data will be interpreted to the extent possible and utilized in the seafloor mapping and identification of sand and gravel deposits. To date, the major efforts of the project have been focused on upgrading the database, especially the seismic reflection data that are largely analog records. The upgrading involves the conversion of the analog seismics records to digital (segy) files.

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. Tom Lippmann and graduate student Joshua Humberston have been using a dual frequency (24 and 200 kHz) single beam echo sounder mounted on either the CBASS (see **FACILIITIES** section) or a small survey launch. A comparison between sediment samples collected in the summer of 2013 and single-beam echo-sounder bathymetry and backscatter intensities collected in the winter of 2013 allows for a first-order evaluation of the distribution of mud fraction in Little Bay Estuary. Particle size distributions were characterized by the fraction of silts and clays (muds) of the surficial sediments and ranged from 1 to 75% silt/clay, indicating regions of predominantly mud or sand, and areas with a mixture of the two. The samples were collected in water depths that range from 1 to 18 m, and show a reasonably strong (logarithmic) relationship of increased mud content as the depths shallow. This relationship was not surprising considering that the strong currents that flow down the center portion of the deep channel tend to winnow out the fine particles and deposit them on shallower mud flats that border the Bay. Comparisons between sediment mud fraction and the 24 kHz intensities do not show any appreciable correlation, most likely because of the effects of volume scattering from the lower frequency acoustic pulses. The lower volume scattering from the 200 kHz signal correlated more favorably to the type, particularly for the total intensity returns from the bottom.

It should be noted that despite its skill the logarithmic model is likely much too simple for widespread application to the Little Bay. The sediments were sampled in the summer months and, although the evolution of the Bay during that time period is not large, there could have been some changes to the surficial sediments. Sediment samples collected near the outflow of the Bellamy River on the north end of Little Bay generally do not follow the same trend as the data from other parts of the Bay. These samples are likely influenced either by coarser material that emanate from the Bellamy River, or by increased flows out of the Bellamy River and across the mud flats that remove a higher percentage of the fines. Estimates of the bulk density of the surficial sediments along one cross-estuary transect show that the acoustic response is affected by the porosity of the surficial sediments, as expected, and that the variability of the predicted mud fractions are likely a result of variations in sediment bulk density throughout the estuary. It is clear that a more complex model is needed to accurately represent local variations in sediment distribution (this is being pursued as part of ongoing research). Nevertheless, the logarithmic relationship between 200 kHz backscatter intensities and sediment size provides a gross, first-order approximation of the mud fraction in surficial sediments in Little Bay and that a simple application of the model to the Great Bay region qualitatively captures the gross properties of mud fraction reasonably well (Figure 5-4). Graduate student Joshua Humberston has developed a more complex model that involves empirical orthogonal functions of backscatter waveform properties. This model works well in Little Bay and was also found to work quite well when applied to data from Great Bay as a test of the application of the results to other areas not included in the development of the model.

Figure 5-5. Instrumented goniometer. This device supports the deployment of a current meter and a video camera in fixed position relative to an eelgrass bed, as well as an echosounder focused on the same location on the seabed, but at a number of different angles of incidence.

Mapping and Characterizing the Eelgrass Canopy

Eelgrass ecosystems are remarkably diverse and productive and create important habitats for a wide range of species. Understanding the distribution of eelgrass and other submerged aquatic vegetation is of critical importance in the health of critical coastal regions. Acoustic mapping of eelgrass has been a long-sought goal of marine scientists, although it is recognized that the response of eelgrass to constantly changing current conditions makes their characterization difficult by acoustic means. Although mathematical models exist to predict the movement of eelgrass under varying current conditions, the relationship of these movements to an acoustic response have not been evaluated. To address this problem, graduate student Ashley Norton, under the supervision of Semme Dijkstra, has built a large goniometer-like device designed to be placed on the seafloor over an eelgrass bed. The device is equipped with a video camera and current meter so that all parameters that affect the eelgrass' apparent morphology can be measured. In addition, a narrow-beam echosounder that can be stepped through a number of incidence angles and that is always aimed at the same patch of the seafloor is mounted on the goniometer (Figure 5-5). The device was first deployed late June 2014.

The initial study reveals that the existing model for the prediction of eelgrass movement as a function of current speed does not appear to scale well to the larger size plants that were observed. Experiments to confirm this contention will be performed in the summer of 2015 by repeating the experiment earlier in the eelgrass growth cycle when the plants are smaller. If the model does work well for the smaller plants, then mapping will have to be done early in the growth season to use the model. It currently appears that a more useful approach may be the creation of a catalogue of eelgrass posture under different current regimes for different size plants.

A catalog of acoustic responses of eelgrass in a range of current environments and grazing angles was initiated by the collection of multibeam sonar data over eelgrass beds at three different sites in Great Bay estuary NH over a period of five days. The different sites represent slightly different environments; open coastal eelgrass beds (Portsmouth Harbor), up-estuary eelgrass beds (Great Bay proper) and a part of the estuary where, in the past, eelgrass detection from aerial imagery has been difficult because of the dense boat traffic and high turbidity (Little Harbor). The data were collected using an Odom MB1 multibeam sonar mounted on the vessel *Orion* from Substructure Inc. Ashley is currently in the process of evaluating these data (Figure 5-6).

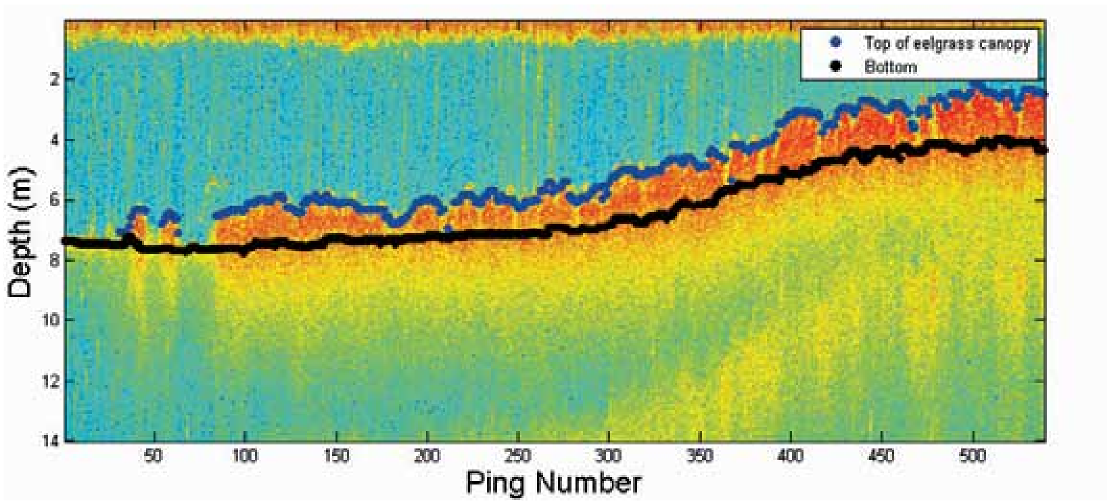


Figure 5-6. Along-track plot of water column backscatter amplitude at nadir from a survey line over an eelgrass bed in Portsmouth Harbor

Lidar, Hyperspectral and Optical Approaches to Habitat 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

Remotely sensed datasets that can be used to generate benthic habitat maps and other products are becoming increasingly available for a number of environmentally sensitive coastal areas around the U.S. The source data can include lidar bathymetry, lidar-derived seafloor reflectance (or pseudo-reflectance) and aerial imagery in addition to acoustic data, such as MBES and calibrated backscatter. These data are of great interest to a number of NOAA program offices and their partners, but there are several challenges that currently inhibit their wide-scale use in the generation of the required products. The challenges include:

- Demand for the products currently exceeds resources and capabilities needed to generate them.
- Downstream users typically lack specialized software and training to be able to generate end products.
- Existing procedures are specific to certain sensors or sensor types.
- Lidar return amplitudes have not been fully radiometrically-calibrated.
- Products often contain a number of artifacts.

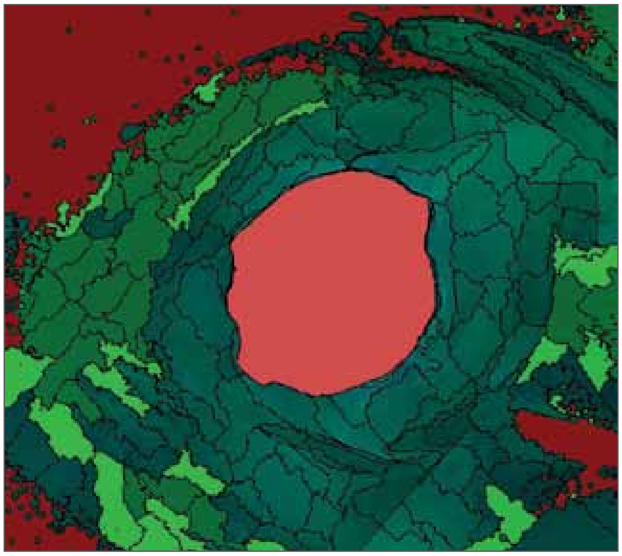


Figure 5-7. Subset of a habitat classification map for Barnegat Bay, NJ created using eCognition. The pink area in the center is a small island; the total area covered in the image is roughly 0.7 km2. Dark green indicates dense eelgrass, light green indicates sparse eelgrass, teal indicates sand, and red indicates areas of deep water.

To address these challenges, Center researchers have initiated a research project in collaboration with Steve Rohmann of the NOAA Office of National Marine Sanctuaries (ONMS) to develop tools and workflows that will enable wide-scale use of remotely sensed data for the production of the required habitat-relevant products without the need for expensive, specialized software, training or additional resources. The primary goal of this work is to build upon existing benthic-habitat mapping procedures developed by the NOAA National Centers for Coastal Ocean Science (NCCOS) and overcome the challenges listed above. In particular, we seek to develop and test standardized, sensor-independent (e.g., LADS, SHOALS, CZMIL, EAARL-B, VQ-820-G, Chiroptera) processing procedures, using open-source and/or low-cost COTS software to produce benthic-habitat maps to support conservation and management of marine ecosystems and associated organisms. The procedures must be designed to work with readily available data and must not assume access to data types that would not typically be provided (e.g., raw lidar waveforms or interim downstream products). Another key goal is to ensure that the products generated from these procedures are consistent with existing benthic-habitat maps developed by NCCOS and others, so that change analysis can be performed.

Although earlier work has focused on regions of interest to NCCOS (e.g., Marquesas Keys, FL.), much of our habitat-based efforts this past year have focused on regions impacted by Super Storm Sandy, with some of the work funded by separate Super Storm Sandy-related funds.

Habitat Mapping and Change Analysis in Sandy-Impact Area

(For information – funding through another NOAA grant)

Ongoing research at the Center has enabled 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. A Center research team that includes Chris Parrish, Jenn Dijkstra, Victoria Price, Erin Nagel and Shachak Pe'eri

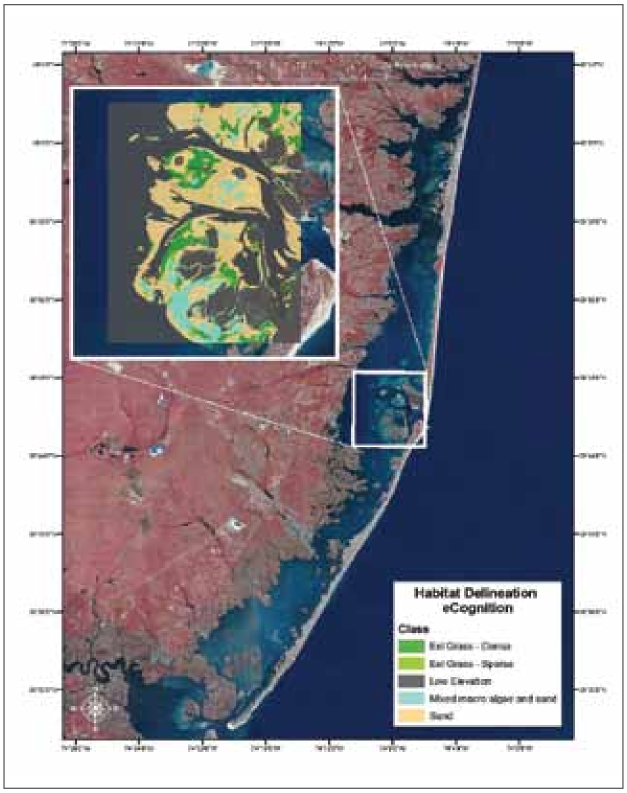


Figure 5-8. 2012 infrared image of Barnegat Bay, NJ. Inset: Map of four separate habitat types generated in eCognition by combining aerial images, waveform features and bathymetry derived from the NOAA Riegl VQ-820-G topographic-bathymetric lidar system.

is investigating the use of NOAA topo-bathy lidar data to document changes in submerged aquatic vegetation habitat 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.

Seagrass beds were mapped using aerial imagery, lidar bathymetry, and lidar waveform features (specifically from the NOAA Riegl VQ-820-G system) using the software package eCognition (Trimble, Sunnyvale, CA) in collaboration with Jarlath O'Neil-Dunne (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. 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. Imagery and lidar bathymetry, reflectance and pulse shape deviation were used for this project as the data layers and a map for the Barnegat Bay inlet was created that delineates areas of dense eelgrass, sparse eelgrass, mixed submerged aquatic vegetation (SAV) and sand. The accuracy of the resulting map was 84% when compared to ground-truth samples collected from the area (Figures 5-7 and 5-8.)

Aerial imagery from 2002, 2006, 2007, 2010, 2012–2014 are currently being curated and analyzed for seagrass, mixed Submerged Aquatic Vegetation (SAV), and sand-only habitats so that pre- and post-storm habitat maps can be compared to historical data (Figures 5-9 and 5-10). eCognition is currently being used to create a habitat map in the Barnegat Bay area from the USGS EAARL-B data as well as the David Evans and Associates Chiroptera lidar data so that the three systems may be compared and assessed for accuracy and ease of use in a post-storm emergency response scenario.

Mapping the Condition of Coral Colonies Using a Spectral Approach

Corals are recognized as an essential component of the marine ecosystem and are particularly sensitive indicators of the health of the ocean. Most remote-sensing studies of corals have focused on the identification of their presence or absence, but few studies have used remote-sensing data to directly determine the health

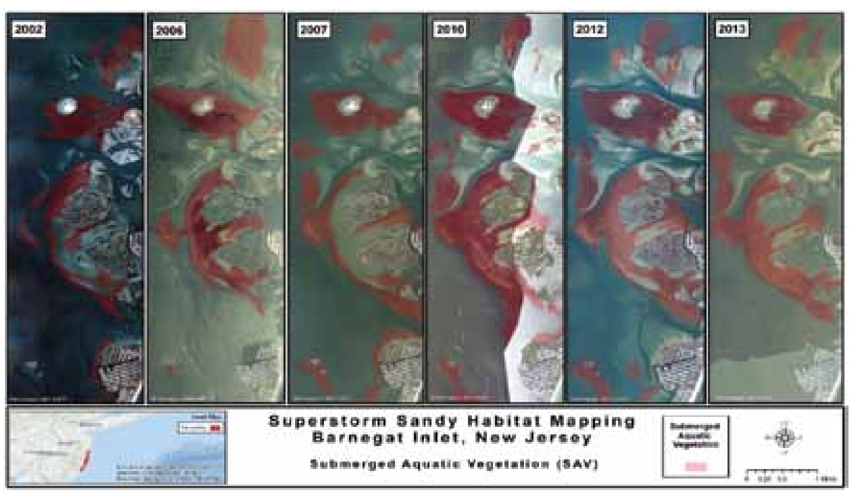


Figure 5-9. Digitized aerial imagery depicting areas of submerged aquatic vegetation in Barnegat Bay Inlet for 2002, 2006-2007, 2010, and 2012-2013.

of the coral. Here, we explore a proof of concept using in-situ measurements of reflectance and fluorescence excited from a tungsten lamp and colored lasers to directly measure the health of coral colonies. The results of this study may be of value to coastal managers in to define environment sensitivity indices (ESI) and habitat mapping and monitoring programs that use hyperspectral and airborne lidar bathymetry (ALB) data.

When illuminated with a white tungsten lamp (for reflectance) and with blue (460 nm), green (532 nm) and red (655 nm) lasers (for fluorescence) excited pigments in coral tissues (e.g., chlorophyll and fluorescent protein pigments) produce an inelastic scattering (light emitted at a different wavelength). Pe'eri and colleagues have demonstrated in the laboratory that this scattering can be used to discriminate between healthy and sick corals. They then moved to a site in the Gulf of Elat to see if the technique could be applied in the field.

During the months of May and June 2014, Shachak Pe'eri collected a set of spectral measurements on healthy and sick coral branches (from base-to-tip). In addition, he investigated different larvae at the release stage and after a few days (swimming, settled or dead). Preliminary results show systematic spectral differences based on the coral tissue condition and the pigments of the tissue (e.g., chlorophyll and fluorescent protein pigments). A preliminary review of the results from the ground-truth survey conducted in the Gulf of Elat (June 16, 2014) supported the laboratory results (Figures 5-11 and 5-12).

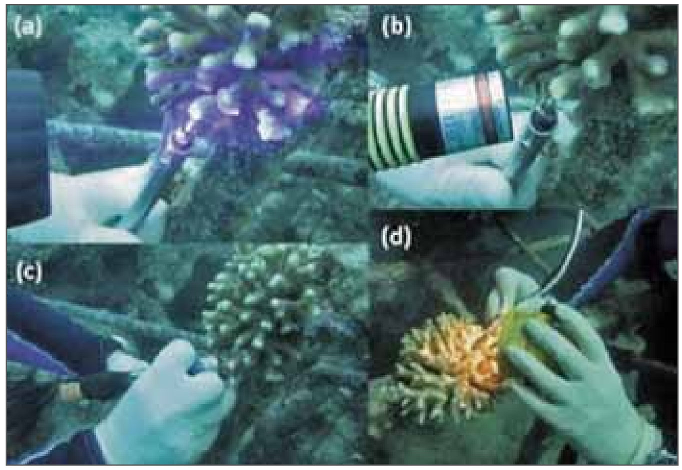


Figure 5-11. Ground truth work conducted in the Gulf of Elat (June 16, 2014): (a) fluorescence measurements using a blue (460 nm) lamp, (b) fluorescence measurements using a green (532 nm) laser, (a) fluorescence measurements using a red (655 nm) lamp, and (d) reflectance measurements using a white tungsten (black body temp. 2900K) lamp.

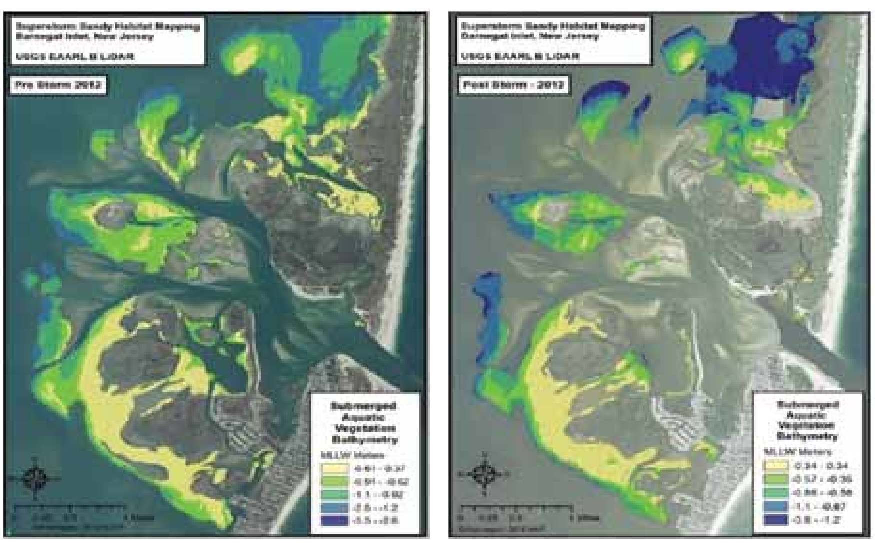


Figure 5-10. Pre-and post- Super Storm Sandy EARRL-B bathymetric lidar clipped to areas digitized as submerged aquatic vegetation.

Instruments to Ground Truth Sonar, ALB, Hyperspectral 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 upon, and water column within which we are making our measurements, we have developed a suite of tools and approaches.

Optical Collection Suite (OCS and BUGS)

In order to better understand the environmental factors that influence optical remote-sensing data and extend ground-truth capabilities for NOAA platforms, the Center has developed several ground-truthing sensor suites. The Optical Collection Suite (OCS) is a ground-truthing system that enables researchers to collect underwater imagery with real-time feedback while, at the same time measure the spectral response and quantify the clarity of the water

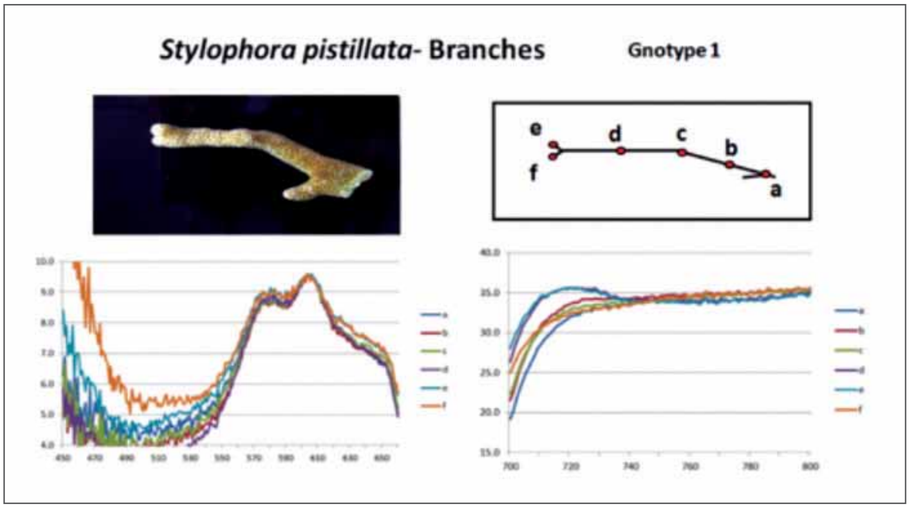


Figure 5-12. Preliminary results of coral reflectance from base (point "a") to tip (point "e" and "f"). (Top left) image of the coral branch, (Top right) schematic illustration of the point of measurement. (Bottom left) Normalized reflectance measurement ranging from 450 to 700 nm. (Bottom right) Normalized reflectance measurement ranging from 700 to 800 nm.

with simple and relatively inexpensive instruments that can be hand-deployed from a small vessel (see details in earlier progress reports). The OCS system has been operational since 2009 and has been used in several ground-truth missions that supported airborne lidar bathymetry (ALB), hyperspectral imagery (HSI), and swath-sonar bathymetric surveys in the Gulf of Maine, southwest Alaska and the U.S. Virgin Islands. Based on the success of the OCS, an autonomous system, the Benthic Underwater Ground-truthing System (BUGS) was designed for deployment from AUVs or ROVs.

In contrast to the OCS, the Benthic Underwater Ground-truth Spectrometer (BUGS) is designed for underwater operations without top-end monitoring. The current design is self-contained and can be added to an AUV as an additional section or towed from a ship (as a tow-fish). The two key sensors in BUGS are a spectrometer (to collect upwelling radiation) and a camera (to acquire the texture of the seafloor). LED panels on the system are used to provide controlled downwelling irradiation. In addition, the system includes a computer for data storage, auxiliary sensors (e.g., attitude, pressure and temperature), and a Wi-Fi network with the ability to connect to the computer and transfer the logged data without the need to open the system. We are also planning to incorporating a laser range finder to the system in the future.

In 2014 the electronics and mechanics of BUGS were designed and tested in a controlled environment, where data streaming from all the sensors are synchronized. A major limitation to the tests is the operation time that was limited to two hours (mainly because of power consumption and memory) is incompatible with a typical REMUS mission of six to eight hours. Accordingly, the memory capacity of the system was expanded to 128 GB and we are currently looking for batteries that can last eight hours. In addition, we have converted a land rangefinder (Fluke 410D) to communicate with a computer and also tested its operation underwater in a waterproof fixture. The current operational range is 3 m, which is in the desired altitude of the BUGS module from the seafloor.

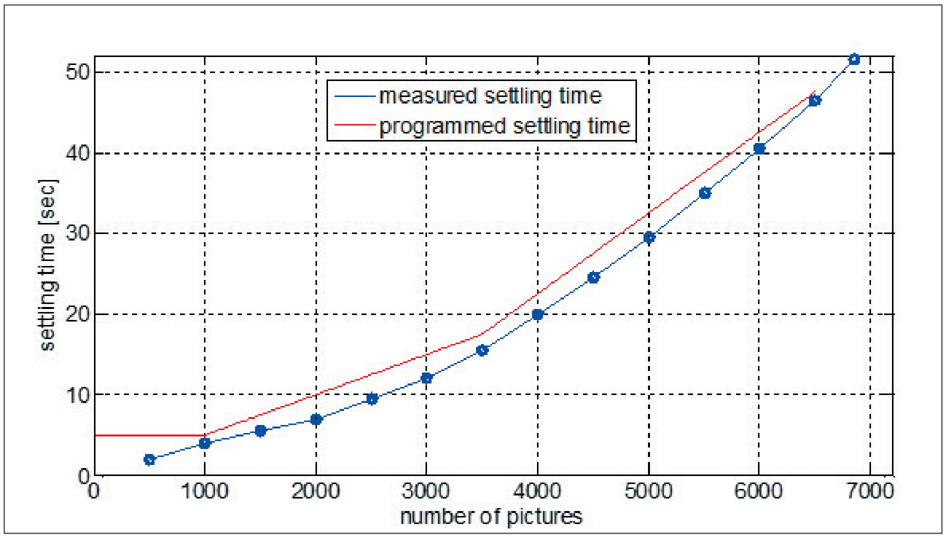


Figure 5-13. Evaluation of camera settling time. This evaluation is used to program the microcontroller to turn on the camera and wait until it is ready for taking the picture before the trigger signal is applied.

Underwater Cameras—Single and Stereo

Although we constantly strive to derive as much information as possible from our acoustic remote sensing systems, acoustic systems will never provide the resolution offered by optical imagery of the seafloor. Thus, we often resort to either photos or video to provide the ultimate "ground-truth" about the nature of the seafloor. The lab has been developing several low-cost, high-resolution camera systems to support a number of our seafloor mapping projects. Led by research engineers Carlo Lanzoni and Paul Lavoie, both a stereo and a single-camera were developed this year with the capability of remote deployment and automated time-lapse imagery.

The single underwater camera system was designed and built to operate underwater to continuously take high-resolution pictures of the seafloor at a rate of one picture per minute for a period of five days. This system employs a microcontroller that operates a HackHD camera that controls the camera trigger and also turns the camera on to take the picture and turns it off after each cycle to optimize battery performance. The system uses a LED light panel as the camera flash that is also controlled by the microcontroller. Tests were performed in the field with successful results regarding the system operation (Figure 5-13).

A prototype of the stereoscopic underwater-camera system was built and tested that employed two HackHD cameras that can be simultaneously fired by a microcontroller to send a trigger simultaneously signal to the cameras. The cameras are required to be at a static position and optically calibrated to ensure proper performance during the operation. These requirements are accomplished by using SD memory cards with 'Eye-fi' technology, which allows pictures to be downloaded from the cameras in a wireless fashion without the need of opening the camera cases to remove the memory cards.

The proper operation of the system requires the difference in trigger times from the two cameras (trigger-time offset) was evaluated for the two cameras and found to be within the acceptable range (below 100 ms) (Figure 5-14).

Reconstruction of 3D Underwater Scenes

A constraint on the use of underwater imagery is the limited field of view afforded by most optical systems. Yuri Rzhanov has developed a number of techniques for the automatic mosaicking of underwater imagery (see previous progress reports). His efforts on image rectification in 2014 focused on the reconstruction of three-dimensional scenes, in support of the ground-truthing of backscatter data collected during the NEWBEX project as part of Eric Bajor's thesis work (see discussion of NEWBEX under DATA PROCESSING theme). Image pairs acquired by a calibrated stereo system built for Eric Bajor's thesis work allow for dense reconstruction of the imaged surface. The technique that performs best for underwater images is the so-called Semi-Global Matching (SGM). This technique is an extension of a classical dynamic programming procedure, but although the classic approach is aggregated only along the epipolar lines, the SGM technique aggregates from a number of directions (typically, eight or sixteen). Matching cost is calculated using a mutual information approach and involves calculation of local entropies of the input images and their joint entropy. The standard aggregation process uses two penalty parameters,

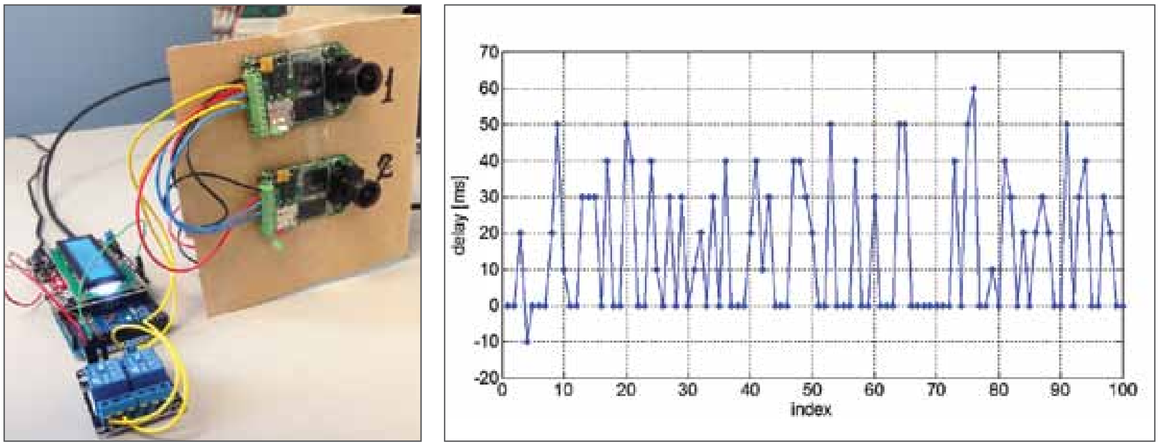


Figure 5-14 – Trigger time offset evaluation tests for stereo camera system.

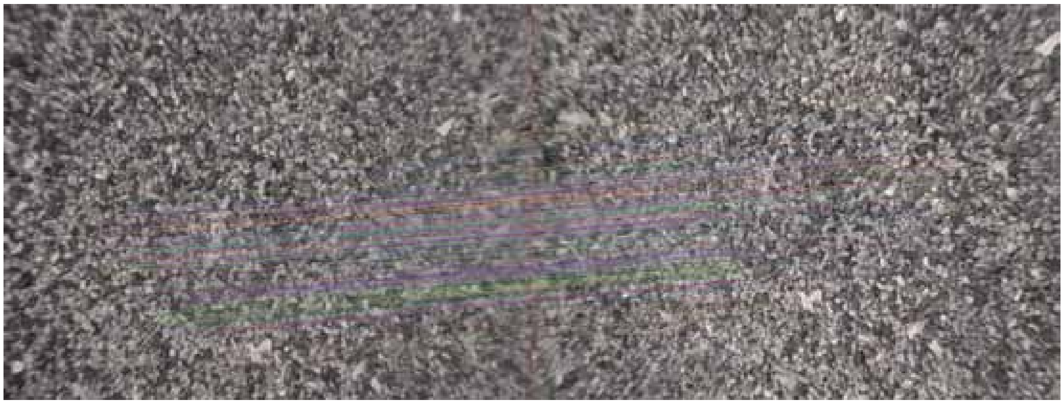


Figure 5-15. Pair of stereo images.

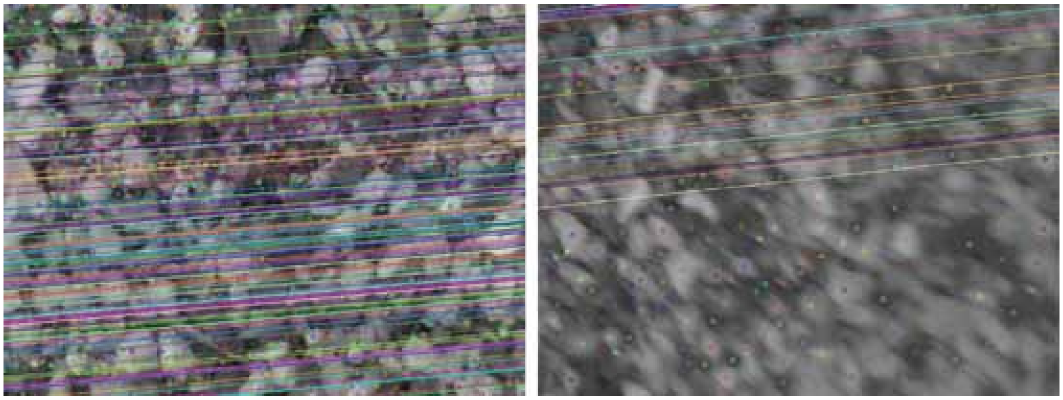


Figure 5-16. Left: central part of left image. Right: bottom-right part of the left image.

but we have proposed the use of a number of penalty parameters with values that depend on strength of the edge a particular pixel is located on. Stronger edges add larger penalties, and vice versa. The reasoning is that edges that appear in the imagery are more likely to correspond to abrupt changes in range and occlusions. Currently, the experiments have involved only three penalty parameters. The simple edges were detected using the classical Canny detector. Even this modification has shown substantial improvement in accuracy on benchmark datasets with little added overhead. The next step is the use of a hierarchical segmentation algorithm where higher pyramid levels represent more pronounced (stronger) edges.

The quality of the acquired imagery dramatically affects the matching (and hence reconstruction) results. Figure 5-15 shows stereo images next to each other separated (for ease of visualization) by a red vertical line. Small circles show the detected special points and slanted lines connect matched special points. It is clear that only the central part of the image has sufficiently good quality for matching (see the difference in the Figure 5-16; the central part of the image is far sharper because it contains many more detected special points).

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 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 sediment lab for grain-size analyses. A procedure to determine the CaCO3 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.

Water Column Mapping

Although fisheries sonars have imaged the water column for some time, this capability is 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 included Jonathan Beaudoin, Glen Rice, Kevin Jerram and Maddie Schroth-Miller, mapped 17,477 km2 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.

Figure 5-17. Oil droplet making apparatus with camera mount, oil tank and water tank.

Another aspect of this work is the variability of the observed seeps, both in terms of the seep presence and absence and also in terms of the variations in flux. Graduate student Kevin Jerram worked to improve the localization of plumes and the estimation of associated seep source locations on the seafloor by employing attitude-compensation and refraction-correction methods similar to those used in multibeam echosounder processing routines. Estimates for installation offsets of the EK60 transducer relative to the vessel inertial navigation system are of critical importance for accurate seep localization.

Jerram's Master's thesis (under the supervision of Tom Weber) focused on the estimation of angular offsets by comparing seeps observed with the split-beam EK60 to simultaneous 'benchmark' observations made with the *Okeanos Explorer's* Kongsberg EM302 multibeam echosounder (for which all offsets have been determined by patch testing). He has been able to localize seeps within the split-beam's 11° beam to an accuracy that is similar to that achievable with the 1° x 0.5° EM302. Seep locations in approximately 1600 m water depths were estimated using the resulting EK60 transducer offsets agreed to within ~15 m of those determined from patch-tested EM302 data and fell within the 'scatter' of EM302 location estimates of seep for repeat observations.

Jerram has also developed routines for seep characterization that include beam-pattern corrections for true target strengths of sample volumes in bubble plumes. These methods are cornerstones of Jerram's M.S. thesis and are presently being used to evaluate spatial and temporal variability of positions and target strength profiles for seeps observed repeatedly during EX1105 and EX1202 Leg 3.

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, the M.S. defense of Kevin Jerram early in the 2014 spring semester and the recent submission of his master's thesis for possible publication in G3 (revision submitted). These data still maintain rich opportunities for further work, but this will likely be done using funding external to the NOAA grant. 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.

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 set to begin in early 2015 (Figure 5-17). The generated will be ensonified with a Simrad EK-60 operated at 200-kHz and the acoustic response will be evaluated to empirically determine the relationship between droplet size and density and the target strength recorded by a relatively low-frequency sonar. Subsequent tests will be performed with a broad range of frequencies to characterize the size, density and frequency-dependent target strengths of oil droplets. The intent of this research is to enable vessels equipped with shipboard echosounders to monitor and map dispersed oil plumes, which often result from oil spills at sea.

Fate of Methane Emitted from Dissociating Marine Hydrates

(For information – funded by non-NOAA sources)

As part of a DOE-funded project, we are making measurements on plume heights and plume morphologies for newly-discovered U.S. Atlantic margin methane plumes. We have received raw data, previously archived on tape at the National Geophysical Database Center, which contain the newly-discovered seeps along the U.S. Atlantic margin (Skarke et al., 2013). These data, which were collected in recent years by the NOAA Ship *Okeanos Explorer*, are comprised of both split-beam-echosounder (SBES) and multibeam-echosounder data. Both SBES and MBES data will be examined to extract parameters related to the evolution of the methane bubbles as they rise through the water column (e.g., the minimum observation depth) (Figure 5-18). Vertical target-strength profiles will be extracted, building on the techniques used by Weber et al. [2014] as well as the M.S. work of graduate student Kevin Jerram. The first step in this process is to catalog what subset of seeps have been observed with both the SBES and MBES in order to gain an overall sense of the data, and to extract seep 'profiles' from both the SBES and MBES data for subsequent analysis. This first step is almost complete and in the spring we will begin to explore what the seep-profile data suggest about the fate of methane bubbles from deep, mid-depth and shallow-water sites.

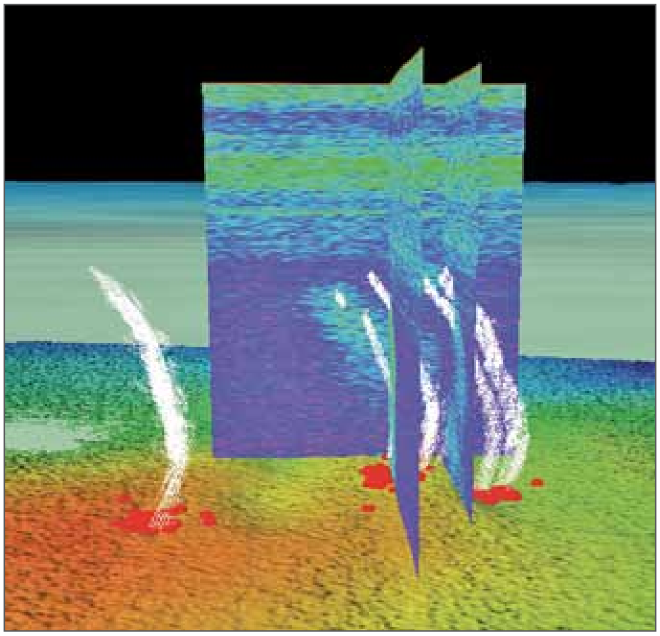


Figure 5-18. Methane seeps (vertical plumes) observed by the *Okeanos Explorer* on the western Atlantic Margin overlaid on bathymetry (ETOP02)

Figure 5-19. Shiptrack for SWERUS-C3 expedition. Center team participated on second leg, departing from Barrow, Alaska on 17 August 2014 and arriving in Tromso Norway on 4 October 2014.

As part of this effort, we also revisited the seeps located in the Hudson Canyon in July, 2014 aboard the the R/V *Endeavor* on a cruise led by John Kessler (University of Rochester). We brought a 38-kHz EK60 with a new Kongsberg wide-band transceiver and were able to collect data over several gas seeps in ~500 m water depth. This same site was revisited by the R/V *Sikuliaq* during its SAT (with Paul Johnson aboard—see MAC discussion) in August, 2014 and collected EM302 water-column data and multiple-frequency EK60 data. Together, these data provide a rich level of information that we anticipate mining in order to help empirically constrain the fate of methane rising through the water column.

Mapping Gas Seeps in the Eastern Siberian Arctic Ocean Using a Wide-Band Transceiver

(For information – funded by non-NOAA sources)

The summer of 2014 found Larry Mayer, Tom Weber and Kevin Jerram on an invited, 45-day expedition in the Eastern Siberian Arctic Ocean aboard the Swedish Icebreaker *Oden* as part of the SWERUS-C3 Expedition (Figure 5-19). SWERUS-C3 is a multi-disciplinary program with base funding supported by the Swedish Knut and Alice Wallenberg Foundation (KAW) that aims to investigate the linkages between Climate, Cryosphere and Carbon release from the sediment, with addition of greenhouse gases (GHG) to the atmosphere. The Center team's objective was to map the spatial distribution and geologic context of gas seeps in the East Siberian Arctic Ocean as well as attempt a new approach to

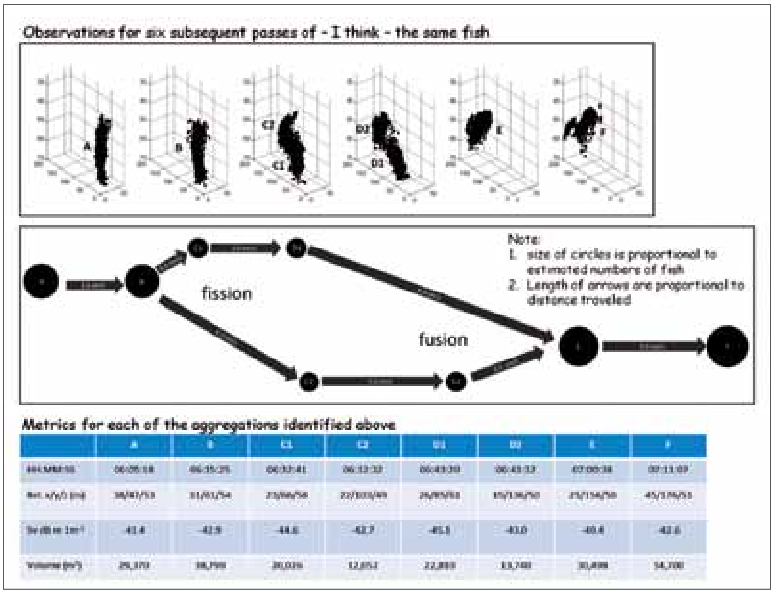


Figure 5-20. Repeat pass (~15 minute intervals) observations of pollock in Eastern Bering Sea colleced during 2012 (data made available courtesy of Chris Wilson, NOAA AFSC).

enhance the estimates of the flux of gas that emanates from the seeps by providing acoustic estimates of the distribution of bubble sizes.. The team used an array of tools to address these objectives that include the EM122 multibeam sonar, the SBP 120 high-resolution subbottom profiler and a new EK80 broad-band split-beam sonar.

The new EK80, installed at the start of SWERUS-C3, added a new dimension to gas-seep mapping. We replaced the *Oden's* EK60 transceiver with a newly developed broad-band transceiver (EK80) and calibrated both the original EK60 and the new EK80 with a calibration sphere (see discussion under SENSORS theme). The calibration process makes it possible to quantify the acoustic target strength of gas bubbles within an ensonified volume such as a plume of gas bubbles rising from a seep. These observations can be used to examine the spatial (and temporal, for seeps observed multiple times) variability of gas seep 'strength'. With knowledge of the distribution of bubble-sizes, the observations of target strengths can be used to estimate gas flux.

The advantage of the EK80 is that its broad-band information provides higher resolution detection of targets and most importantly, allow for an estimation of the distribution of bubble sizes. Measurements of gas-seep target strengths across a wide range of frequencies can be inverted for estimates of the distribution of bubble sizes and, subsequently, estimates of free gas within the plume. Frequency-dependent changes in the target strengths of gas bubbles that rise through the water column may also help constrain models for the evolution and fate of gas bubbles as they rise to the surface and will help determine what fraction of gas that exits the seafloor is capable of reaching the atmosphere. Participation of the Center team was funded by the National Science Foundation and the Sloan Foundation. At present, processing of the seep data is awaiting its release by the Russian government.

Midwater Mapping of Fish Behavior

(For information – funded by non-NOAA sources)

We briefly report on this ONR-funded project because of its relevance to many NOAA fisheries issues and its use of NOAA sonar systems (the ME-70). The goals of the project are to develop new models of the behavior of fish aggregations, including the fission/fusion process, and to describe the echo statistics associated with the random fish behavior using existing formulations of echo statistics. To do this, ME70 data collected aboard the NOAA Ship *Oscar Dyson* that describe pollock aggregations are being exploited to help ground-truth models of fish behavior. The ME70 data analysis is focused on data collected in the Eastern Bering Sea (EBS) during 2010 and 2012 (data made available courtesty

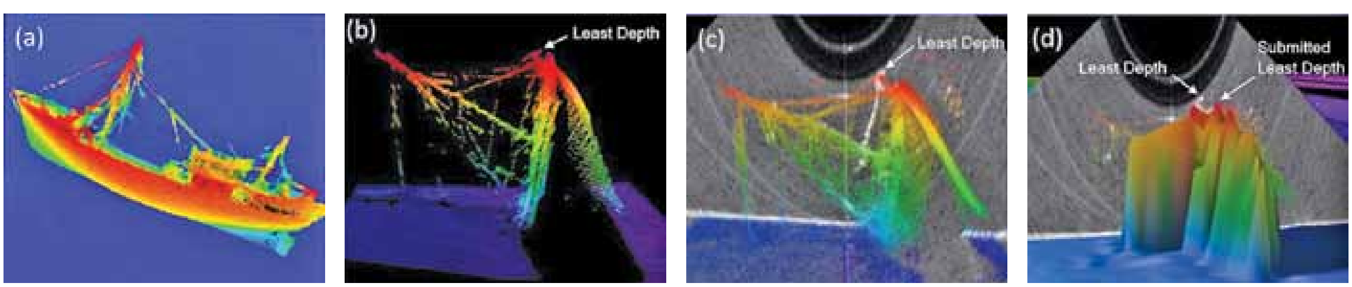


Figure 5-21. (a) All bathymetry lines collected over Women's Bay wreck displayed in CARIS HIPS subset editor. (b) Analyzed bathymetry line of wreck with least depth position indicated. (c) Water column exported point cloud of wreck with the fan at the timestamp of the least depth. (d) Verified 1m bathymetry surface with water column point cloud and fan indicating aprroximate 3m distance between designated and estimated position of wreck least depth.

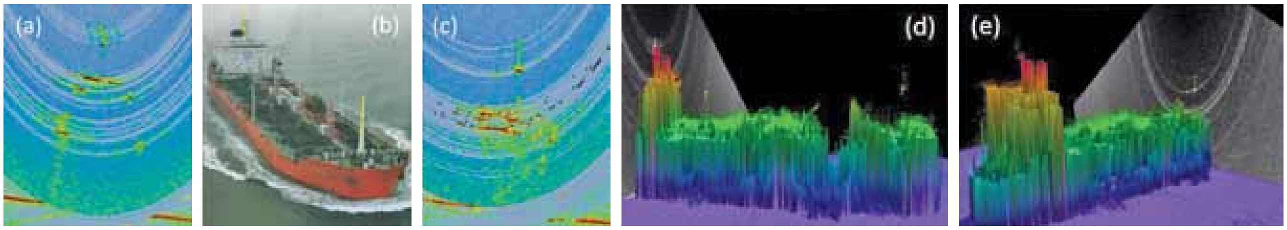


Figure 5-22. (a) FMMidwater fan view of water column solution over least depth of wreck *Bow Mariner*; (b) *Bow Mariner* image with bow and least depth masts highlighted in yellow; (c) FMMidwater fan view water column solution over bow mast of wreck; (d) *Thomas Jefferson* 50cm bathymetry grid with *Ferdinand Hassler's* filtered exported water column point cloud and water column fan located at timestamp of wreck least depth mast; (e) *Thomas Jefferson* 50cm bathymetry grid with *Ferdinand Hassler's* filtered exported water column point cloud and water column fan located at timestamp of bow mast.

of Chris Wilson, NOAA AFSC). Most of the data were collected along widely spaced (~40 km) transects, and for the purposes of this research, are considered to represent a 'snapshot' of the pollock aggregations present in the EBS. NOAA-AFSC conducted repeat transects during the 2012 data-collection effort on two occasions, at our request and with our guidance. The repeat transects resulted in ~1 nmi long transects that were repeated every 10-15 minutes, with 24 transects on the first occasion and 14 transects on the second occasion. Recent data analysis has been focused on fission/fussion events that were observed during repeat-pass survey work with the *Dyson*. A school of pollack was observed with the ME70 in this analysis on six subsequent passes as the school broke apart and then recombined (Figure 5-20); these type of observations offer insights into the rate and spatial scales over which fission and fusion may occur in aggregations of fish.

Using MBES Water Column Data for Least Depths on Wrecks

While the applications of water column mapping described above have not had direct relevance to hydrographic problems, in 2014, NOAA Physical Scientist and graduate student Katrina Wyllie embarked on a thesis project designed to directly explore the applicability of MBES-derived water column data for determining least depths on wrecks. The estimated least depths were compared from multibeam bathymetry (standard bottom detections) and multibeam water-column data over eight different wrecks collected by NOAA vessels. Water-column least depths were determined for the wreck *Troydon* using both FM-Midwater and CARIS HIPS software and then compared to a diver investigation (the ground truth) and the depth picked by the sonar manufacturers' bottom-detection software (Figure 5-21). The multibeam bottom-detection algorithm in both Kongsberg and Reson multibeam sonars failed to detect some of the wreck masts, as previous international studies have found. The majority of the multibeam least depths were within the calculated depth uncertainties of the estimated multibeam water-column least depths, but all of the estimated water-column least depths were shoaler than the MBES bottom detect least depths (Figure 5-22). The most significant failure of multibeam bathymetry occurred on vertical masts (high aspect ratio features) and the magnitude of those failures were several meters (Figure 5-23).

The ability of commercial software was examined to analyze and process wreck water-column data and it was found that the contextual benefit is invaluable as compared to a bathymetry point cloud. The currently available water-column workflows are not complete but pieces of the workflow exist and will hopefully be realized soon by both software vendors. The sonar acquisition settings of wreck developments are important and a hydrographer should ensure that high-quality water-column data is recorded. As a result of this study, NOAA hydrographic vessels have demonstrated that they can collect multibeam water-column data over wrecks and that multibeam water-column data collection and processing over wrecks is the best method available to support NOAA's mission to provide accurate navigation products that ensure mariner safety.

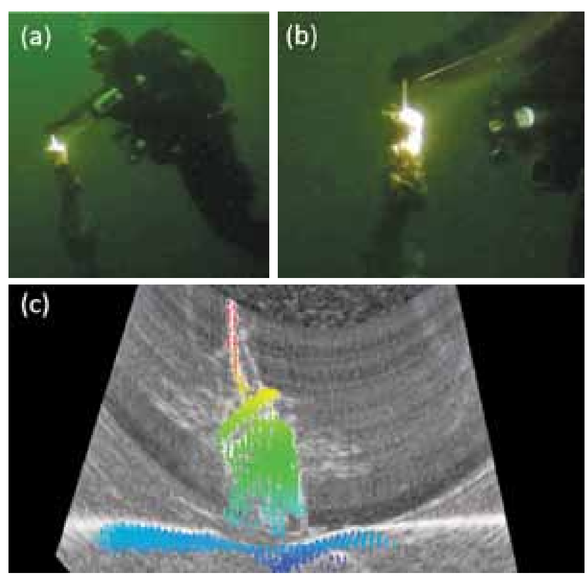


Figure 5-23. (a and b) Diver least depth measurement on *Troydon* forward mast; (c) NOAA Ship *Thomas Jefferson* water column point cloud with fan at location of *Troydon* forward mast.

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 new proposal was 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 new 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. Eventually, we envision that nine to eleven NOAA employees will be assigned to the IOCM Processing Center.

Representing the Office of Coast Survey at the Center, Glen Rice and Sara Wolfskehl have been partnering 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 context of the IOCM theme.

In 2014 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; below we focus on those projects that, for the most part, have been specifically incorporated into NOAA's IOCM projects.

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 (see Backscatter section of DATA PROCESSING theme) 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.

Building on the work of Jonathan Beaudoin to correct backscatter problems on the NOAA vessel *Fairweather* (see 2012 progress report), Sarah Wolfskehl has been processing backscatter from the *Fairweather* and submitting these data to the National Geophysical Data Center (NGDC) for archiving. In 2014 Sarah processed backscatter data for 13 hydrographic surveys collected by the NOAA Ship *Fairweather* in 2010 (Figure 6-1). The raw data, processed data and backscatter mosaics were archived at NGDC and are available in support of seabed classification and habitat mapping for NOAA and outside organizations. During processing she also updated the Backscatter Processing Standard Operating Procedure (SOP) used by the OCS processing branches

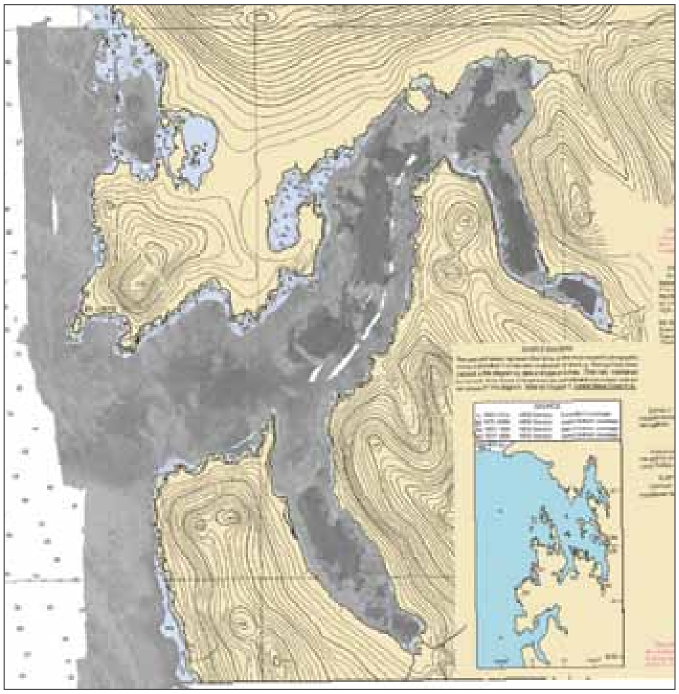


Figure 6-1. Processed backscatter mosaic from survey H11818, collected by the NOAA Ship *Fairweather* in 2010.

and worked with QPS to improve processing software in order to streamline the processing of backscatter data and gain efficiency at the branches.

Bathymetry from the NOAA FSVs

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 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 May of this year we received a version of the integrated software from Hypack and have been working with the National Marine Fisheries Service and Office of Marine and Aviation Operations to develop a testing, training and implementation plan. In June we began implementation and testing aboard the NOAA Ship *Pisces*. Sarah installed Hypack onboard the *Pisces* and wrote SOPs for installation and operation to share with the other FSVs. Testing continued throughout the year as issues presented themselves and ship time became available. In September this project was passed to NOAA OCS Physical Scientist Michael Annis, as Sarah became part of the Sandy IOCM Team. In December, shipboard testing aboard the NOAA Ship *Pisces* resulted in near operational software (Figure 6-2).

Sarah also attended an ME70 User Group meeting at the National Geophysical Data Center that brought together acousticians from the six Fisheries Science Centers to discuss archiving of EK60 and ME70 water-column data. She introduced the concept of integrating the ME70 with Hypack acquisition software. Later in the year, Sarah gave a presentation at a NMFS Vessel Coordinator meeting and to OMAO about the ME70/Hypack Integration project.

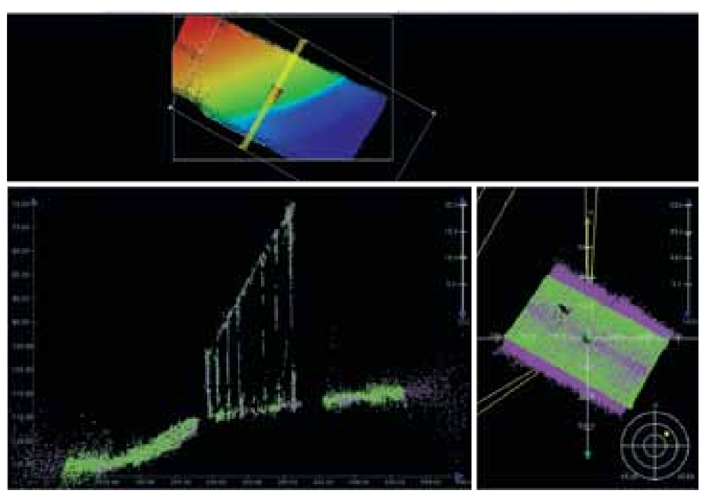


Figure 6-2. Image demonstrates the agreement between ME70 bathymetric data recorded with Hypack (green) vs the ME70 water column data processed with Tom Weber's bathymetry algorithm aboard the December testing cruise. Image courtesy of Mike Annis - HSTP.

Third Party Bathymetric Data

One of the primary mandates of the IOCM effort is to establish protocols and tools for the use of data collected by non-hydrographic vessels for hydrographic purposes. A challenge of this mandate is the reality that, often times, non-hydrographic vessels have not collected appropriate environmental data (i.e., sound speed) or performed appropriate sonar calibrations (e.g., patch tests) to make the data useable for hydrographic purposes. The Center has been working for some time now to develop tools to help address these challenges (see DATA PROCESSING theme) and the NOAA IOCM team is now evaluating the use of several third party data sets for use in hydrographic products.

USCG Icebreaker *Healy* Data Assessment for Application to NOAA Charts

Epitomizing the concept of IOCM is the multipurpose use of data collected by Center scientists in support of establishing the limits of a potential extended continental shelf as defined by article 76 of the Convention on the Law of the Sea (see LAW OF THE SEA theme). As part of our Law of the Sea Mapping efforts, eight seasons of multibeam sonar data were collected by Center scientists on the USCG Icebreaker *Healy* in the Bering Sea and Arctic Ocean. Sarah Wolfskehl has performed an assessment of the USCGC *Healy* multibeam systems and data quality from 2005 to 2013 for evaluating their use in application to the nautical chart in the Bering Sea and Arctic (Figure 6-3). NOAA would benefit from the use of USCGC *Healy* data in these areas, as they are difficult to access and lack modern multibeam coverage. The assessment included discussions with Center staff who sailed aboard the *Healy* and with NSF funded technical representatives who were responsible for the operation of the scientific equipment onboard.

Data from each year were compared with NOAA *Fairweather* surveys H12228 and H12229 in the Bering Strait. A large portion of the *Healy* transits data are in water depths that are considered the near field for the EM122 and SeaBeam 2112 sonars the ship used in the past. The comparison with *Fairweather* data provided an assessment of the quality and accuracy of the data. In all cases, the agreement was good indicating that the *Healy* data are of a high quality even though they were collected at ranges considered near field.

The *Healy* data were also assessed for use within the USCG Bearing Sea Port Access Route (PAR). The USCGC *Healy* plans to work with OCS to collect data along this route while they transit to and from their research sites in the Arctic. However, little of the prior data collected by the *Healy* aligns with the PAR. The final report will be used by NOAA to determine which, if any, surveys are suitable for charting or where additional survey work is needed.

State of Maine Multibeam Data Processed for Application to the Nautical Chart

Continuing with the objective of evaluating third-party data for application to nautical charting, Sara Wolfskehl has looked at multibeam sonar data collected by the State of Maine in support of a BOEM-funded effort to look at offshore sand and gravel resources. The operational area overlapped with previous and planned survey areas of the NOAA Ship *Hassler*. In the spirit of IOCM, the agencies worked together to not duplicate each other's efforts. Sarah and Cassie Bongiovanni have received the first set of data from the State of Maine and are reviewing and processing it for submission to OCS for charting. This coordination has provided a unique IOCM opportunity, where the State of Maine directly benefited from existing and planned NOAA surveys and NOAA may directly benefit from surveys conducted by the State of Maine.

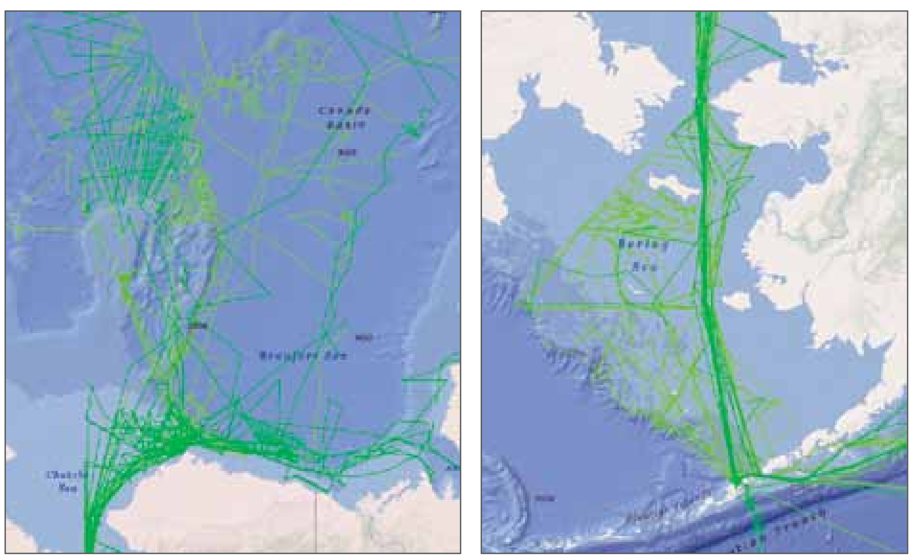


Figure 6-3. Green lines represent *Healy* survey tracklines in the Arctic (left) and Bering Sea (right) from 2005 to 2013. Sarah's report assesses the quality of these data for use within OCS for charting.

Evaluation of Lidar Topobathy Data for Incorporation into NOAA Charts, Development of Super Storm Sandy Lidar Database and Maintenance of the ESRI SeaSketch Website

USGS collected EAARL-B topo-bathy lidar data along the east coast in response to Hurricane Sandy. The NOAA Sandy IOCM team, under the leadership of Juliet Kinney, are processing these data for submission to OCS for charting. The data cover shallow water close to shore that can be difficult to access for typical hydrographic vessels and require a large amount of time to collect. In addition to bathymetry, the IOCM Center plans to process reflectivity from the lidar waveform data. Chris Parrish, while at the Center, developed algorithms to process lidar waveforms. His algorithms have been incorporated into ALPS software, a USGS lidar-specific processing software. We are currently establishing a partnership between the Center and USGS to gain access to Alps and their EAARL-B Topo-bathy Lidar data.

Michael Bogonko is establishing a GIS database for the Super Storm Sandy affected project region to support this and other lidar efforts related to the Super Storm Sandy effort. He has acquired high-resolution lidar data sets for the U.S. East Coast region hit by Super Storm Sandy from U.S. Army Corps of Engineers, New York Environmental Services, NOAA and the USGS. He currently has created and maintained a GIS lidar database for the project area to manage and account for these multiple datasets (Figure 6-5, left).

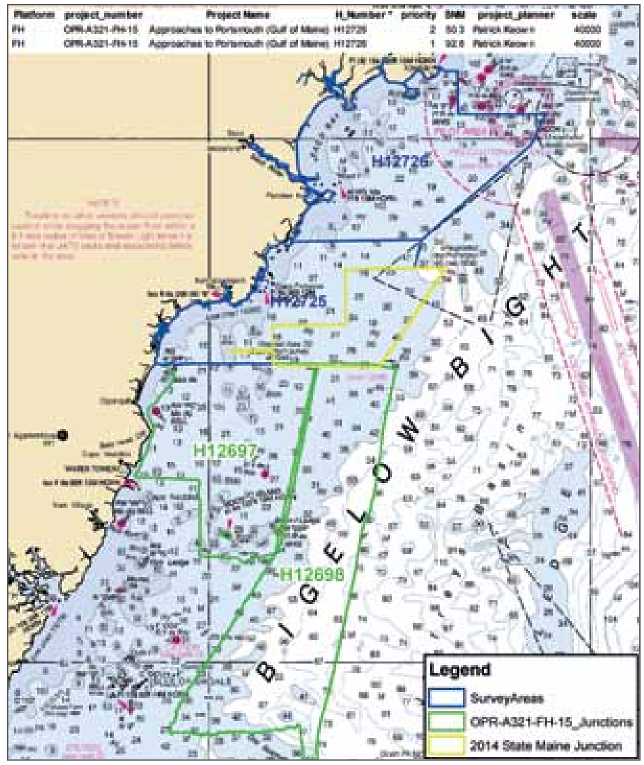


Figure 6-4. Project Instructions for the NOAA Ship *Hassler*. The yellow polygon represents the data collected by the State of Maine that will not need to be collected by NOAA. Conversely, some of data collected by *Hassler* will meet State of Maine's needs. A win-win for all.

To further ensure that the Center Sandy IOCM team coordinates their efforts with broader NOAA IOCM efforts, Cassie Bongiovanni will make certain that all data acquired and processed by the Center is entered, with appropriate metadata, into the ESRI SeaSketch site that is used on an inter-agency basis to manage and plan all IOCM-related mapping efforts (Figure 6-5, right).

Figure 6-5. (left) GIS of lidar data available in Super Storm Sandy area. (right) NOAA IOCM Seasketch site.

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, Plumlee, St. Jean, Mihtsentu, Schwehr, and Sullivan), under the supervision 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 (see earlier progress reports). Efforts this year have focused on the further development of a new interactive 3D/4D visualization environment (Virtual Test Tank 4D–VTT4D) specifically designed to help oceanographers, hydrographers, ocean engineers, biologists and others interpret complex data from a variety of sensors, models and data sets.

Interactive Exploration/Visual Analysis System for Complex Time-Dependent Flow and Other Models—Virtual Test Tank 4D (VTT4D)

Thomas Butkiewicz and Colin Ware continue to refine their advanced flow-visualization techniques with the development of tools to better communicate the complex output of today's increasingly high-resolution oceanic and atmospheric forecast simulations. They apply well-founded perceptual theory to the design of visual representations so that the contents of these models can be effectively illustrated without overwhelming the viewer (e.g., Figure 7-1). 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 within 3D environments. Finally, a number of new analytical tools allow the user to leverage the predictions of these simulations to support other research projects. The power of these tools was clearly demonstrated in 2014 with their application to the work conducted by the Super Storm Sandy team (see below).

Virtual Test Tank 4D (VTT4D) consolidates various 3D and 4D flow-visualization techniques that Butkiewicz and Ware have developed into a single application intended to be shared with other researchers and the public. It is not as full-featured as commercial software but provides otherwise unavailable visualization capabilities to researchers. VTT4D reduces dependencies on specialized hardware and can support, but does not require, 3D OpenGL Quad-buffer Stereo, multi-touch displays, and Microsoft Kinect interaction. Whereas previous visualization research applications were hard-coded to support loading particular models, VTT4D can import many common data models and formats.

The software also serves as a test bed for other visualization research projects, such as analysis and presentation of sediment-transport simulations that produce tightly integrated dynamic flow models and dynamic bathymetry models. These simulations are the perfect application for 4D visualization, because all the parameters change and the temporal relationships are significant. The software also supports the interfaces used in some of the lab's human-factors studies and provides multi-view capabilities for research into marine-debris target evaluation.

An example of VTT4D's analytical usage is its support of the ongoing research between the Center and University of Delaware that involves the Redbird artificial reef site off the coast of Delaware Bay. The Redbird reef site is unique in that high-resolution multibeam data were collected of the site just a few days before and then a few days after Super Storm Sandy and the data clearly document the impact of the storm. Subsequent surveys of the site after Super Storm Sandy document

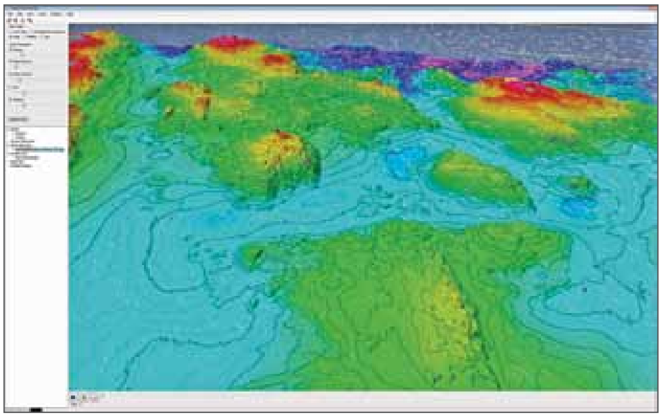


Figure 7-1. Screenshot of the VTT4D interface showing bathymetry (Isles of Shoals) and flow data.

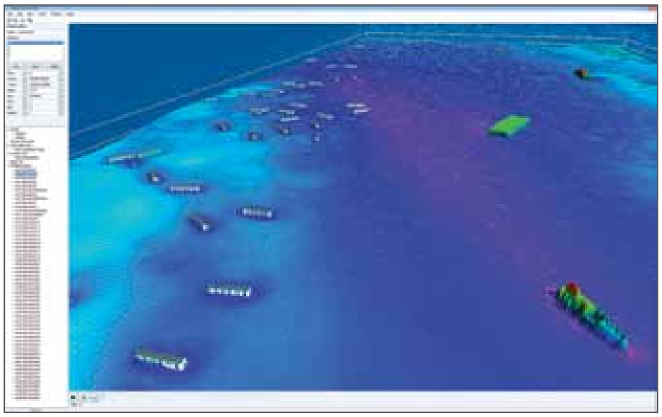


Figure 7-2. Screenshot of the VTT4D interface showing a collection of bathymetry, modeled objects, and flow data around the Redbird Artificial Reef Site, Delaware.

the recovery of the seafloor back to a "baseline" state. VTT4D has been used to display the collected data to provide intuitive and easy to interpret views of the damage to the seafloor and the artificial reef structures (mostly subway cars) caused by the storm. Analysts can import standard-format digital terrain models (e.g., .bag files) from each of the survey missions. These files were used to generate dynamic bathymetry models that were designed to highlight temporal changes through smooth animations. High-resolution models of the reef debris can be superimposed on the bathymetry to document the details of the morphological changes observed around the debris (Figure 7-2). This collection primarily consists of subway car models that have been semi-automatically aligned with the bathymetry in the Redbird site. The models can be dynamically moved and broken apart during playback of time-series data to enhance the presentation.

The majority of work on VTT4D during this period has been behind-the-scenes work to support different model/data formats, refinement of the rendering techniques and the addition of multi-threaded multi-view interfaces. There are also some new input and output modes that make it easier to import bathymetry data from Fledermaus and raster images and to export bathymetry in various formats such as 3D .obj meshes.

Support for various lidar point clouds sets has also been added to VTT4D, with these ultimately being transformed into bathymetric/terrain surfaces that can work with the existing tools (Figure 7-3). Terrain rendering and texturing has been moved into custom OpenGL vertex and fragment shaders that implement very fast, pixel-accurate contours, grid lines, color maps, banded color maps and 3D Perlin noise texturing. In addition, a slope map loader was implemented to support Super Storm Sandy research. See below for an image of dynamic surface created in VTT4D from pre- and post-storm slope calculations that were received from Shachak Pe'eri's group (Figure 7-4).

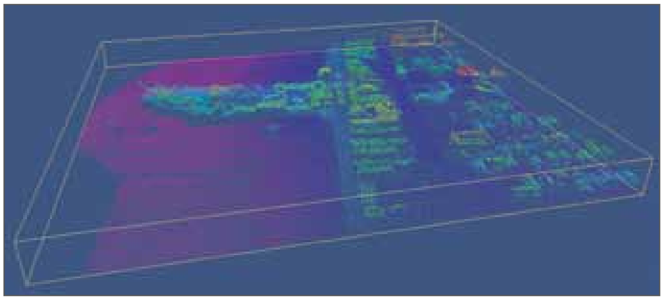


Figure 7-3. Post-Super Storm Sandy EAARL lidar point set of wrecked New Jersey pier loaded into VTT4D.

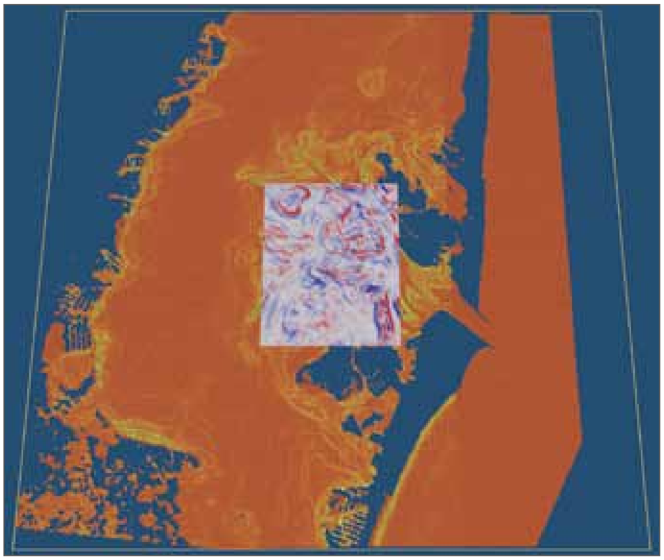


Figure 7-4. (orange) Pre-storm slope map of Barnegat Bay (center) dynamic slope surface showing areas of accretion (blue) and erosion (red) between pre- and post-storm surveys.

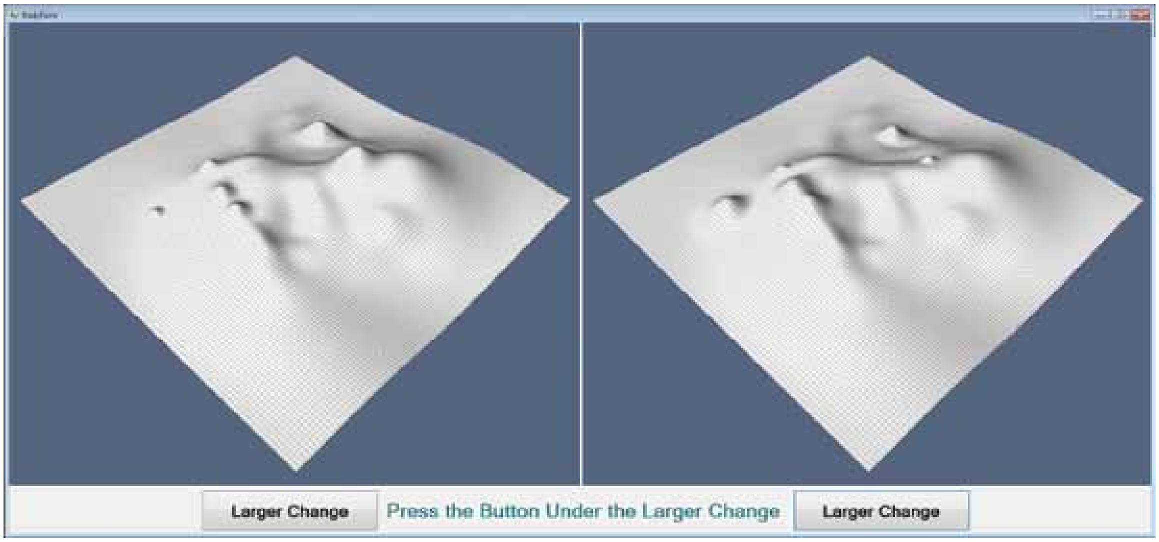


Figure 7-5. An example comparison task, in which subjects watch side-by-side animations and choose which side exhibited a larger change.

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 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 7-5). This task helped determine what technique is more effective at differentiating the relative sizes of changes, Then, in detection tasks, subjects monitored a rotating (to ensure continuous movement) randomized terrain model, which occasionally exhibited small changes (Figure 7-6). 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.

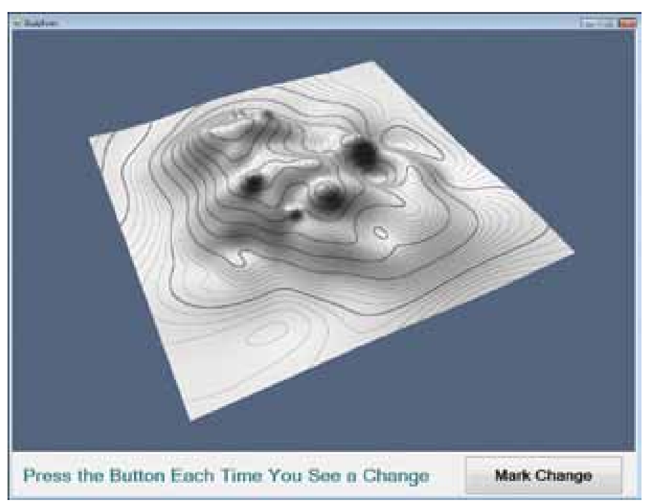


Figure 7-6. An example detection task, in which subjects monitor a rotating terrain model and indicate each time they notice it exhibiting subtle changes.

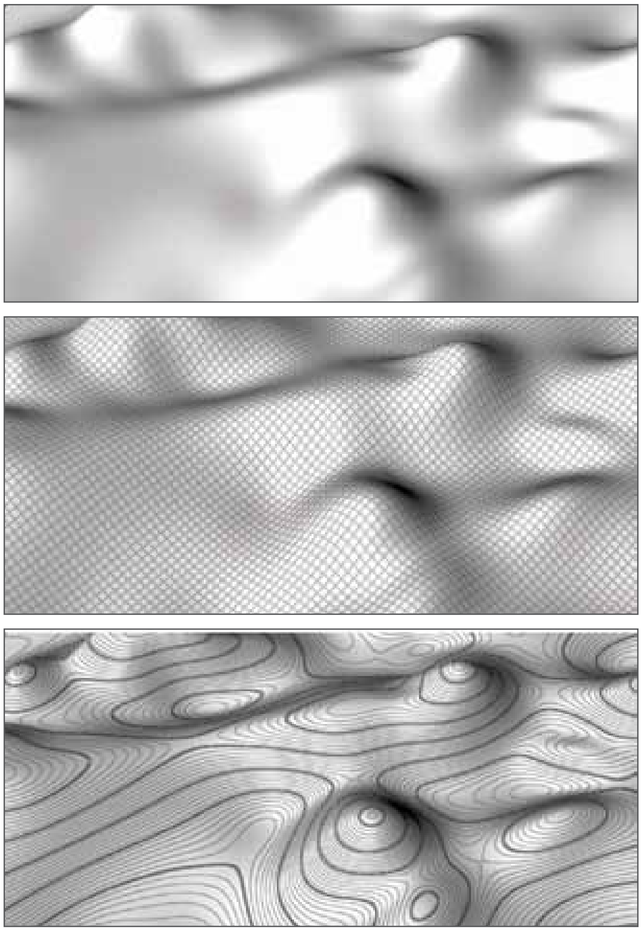


Figure 7-7. The basic texturing techniques. (top) plain shading, (middle) grids, (bottom) contours.

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 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 7-7).

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 7-8). 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. This research has been written up into a paper entitled "Effectiveness of Structured Textures on Dynamically Changing Terrain-like Surfaces" that is almost ready for submission for publication, which will most likely be to IEEE Vis 2015 in March.

Marine Debris Visualization

Butkiewicz has also produced visualizations in support of the Super Storm Sandy grant. The visualizations efforts focus on the determination of the optimal ways to display candidate marine debris targets so that the time-consuming process of human evaluation can be made more efficient. This involves the automatic generation of multiple views of the target data, with the visualization techniques, viewing angles, etc. of each view being carefully selected to best reveal and disambiguate the shape of each target. The "Marine Debris Rapid Decision Tool" (MDRDT) is actually a special multi-view version of VTT4D (Figure 7-9). MDRDT loads

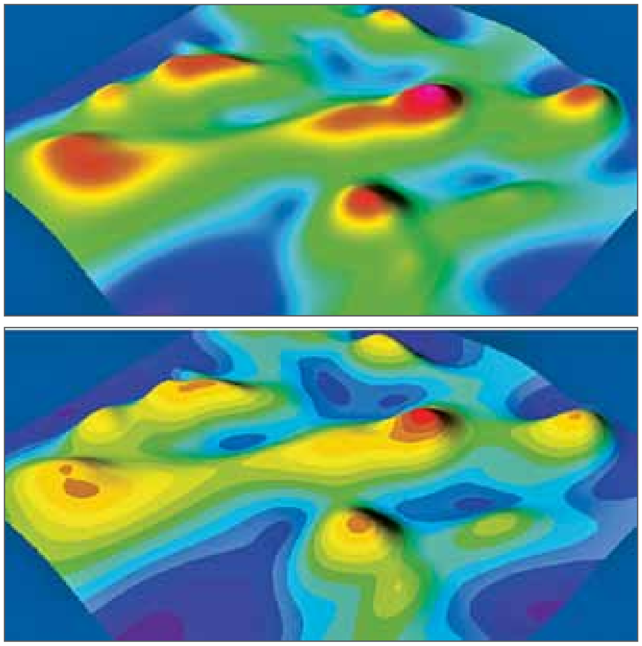


Figure 7-8. (top) Standard smooth rainbow color map, (bottom) banded rainbow color map.

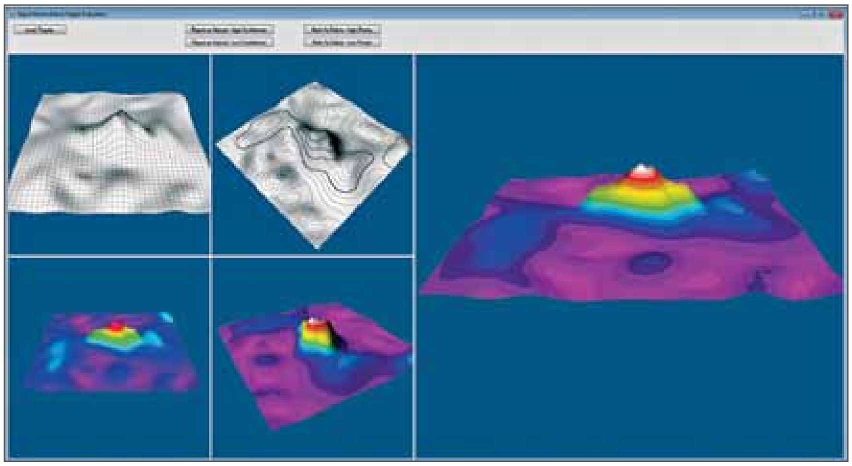


Figure 7-9. Multi-view Marine Debris Decision Tool.

potential marine-debris targets (currently as .bag files, but soon will be able to input multiple formats if available, e.g., .bag sonar + lidar point cloud) and displays them automatically in a number of views. Currently development is centered on the creation of a scoring system that can determines the possible views of a bathymetric model are most likely to be helpful to the user without the need for navigation/rotation/etc. This is accomplished by calculating metrics for each view such as the percentage of yet unseen faces revealed, the prominence and continuity of silhouette edges and the benefit of different texturing techniques.

In addition to the Marine Debris Decision Tool, Butkiewicz has also worked with graduate student Andrew Stevens to develop interactive maps for the Sandy project website (Figure 7-10). Software was developed that takes the large collections of marine-debris records received from NOAA and converts them all to a single data format, which can then be loaded and viewed on an interactive map. Users can click on polygons that denote survey/cleanup regions and then the users are presented with all the debris records for that particular region. These include obstructions, wrecks, submerged objects, etc. This allows the public to easily see where cleanup efforts occur, as well as to zoom into a particular portion of the coast to see what has been found there. Further discussion of this website as well as a series of infographics created (with Colleen Mitchell) for the Super Storm Sandy project will be presented under the OUTREACH theme.

Ecosystem Visualization Project

In collaboration with Sarah Gaichas, Robert Gamble and Michael Fogerty of NOAA's Northeast Fisheries Center, Colin Ware has begun two related initiatives to visualize fisheries-related ecosystem components for the Northeast U.S. As these tools evolve, they will be directly linked to our habitat mapping efforts.

Fisheries Model Visualization Evaluation Study

Michael Fogarty and Robert Gamble of Northeast Fisheries Center are developing an ecosystem-based model (called Kraken) of the interactions between key commercial fisheries species in the northeast region. The Center team is developing an interactive visualization component for this model that can be used as a planning tool by NOAA fisheries and the New England Fishery Management Council in order to make better-informed decisions that relate to tasks such as setting fishing quotas. The model will allow for long-term impacts (as modeled) of changes in policy to be easily visualized, understood, and presented to various stakeholders.

Ware reported in 2013 work done in collaboration with Center M.S. student Carmen St Jean and NOAA fisheries scientist Robert Gamble. This work was aimed to create visualization of fisheries models to make it easier for fisheries managers and other stakeholders to understand the work of modelers. St Jean and Ware developed a graphical method they called Dynamic

Figure 7-10. Zoomed in view of the interactive map showing how you can query debris objects by moving over them with mouse to get more information.

Change Arcs as a way to portray both the outcomes of management decisions as well as to portray the inner workings of the model in the form of interspecies interactions (Figure 7-11). The interactive visual interface enables stakeholders to adjust catch quotas for different modes of fishing, such as trawling or longlining. The by-catch mix can be included in the model, as well as climate variables. The model can show both direct and indirect effects. For example, sometimes a reduction of one species can result in a large change in the abundance of an apparently unrelated species. The sliders on the panel enable a user to adjust the level of a particular kind of fishery and see the effects on the long-term trends of all species.

Dynamic Change Arcs make it possible to interpret the complex causal chains and interaction effects. An evaluation study was performed in 2014 to determine whether or not Dynamic Change Arcs improve the understanding of species interactions. An experiment was carried out to evaluate three alternative forms of arcs that portray causal connections in the model. The results show that all linkage representations enabled participants to reason better about complex chains of causality than not showing linkages.

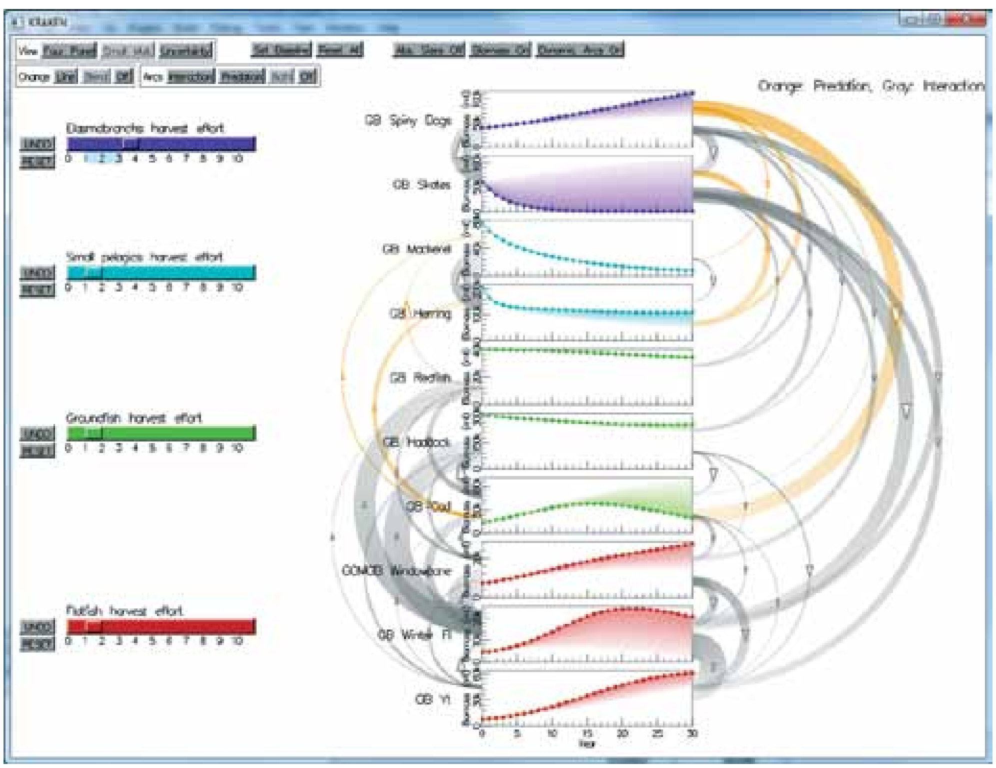


Figure 7-11. Interactive visualization of the forecast for ten Gulf of Maine species based on the NOAA KRAKEN model. The effects of increasing the catch of Elasmobranchs is visualized. The arcs show causal links in the model, with predation in yellow and species competition in grey.

Marine Mammals and Open Tag

The Center has had a long history of innovative visualization of the submerged behavior of marine mammals determined from sophisticated and expensive tags that contain accelerometers, magnetometers, pressure sensors, and hydrophones. Recently, low cost tags for marine mammals are becoming available that also contain gyroscopes in addition to the other sensors. The low cost of the new tags should encourage the deployment of many tags, with tag loss not being regarded as catastrophic. The gyroscopes will, in addition to giving more accurate angular velocity information, provide a means of decomposing acceleration measurements far more accurately. This in turn will enable better estimates of energy expenditure during various phases of foraging.

Building on the work reported last year that related fluid dynamics drag to propulsive forces in swimming Steller sea lions, Ware has begun a new study with tags attached to four foraging California sea lions. Each animal spent approximately one week at sea before returning to the haul-out where the instruments were retrieved. These animals were instrumented with an accurate pressure recorder, fast-lock gps and open tags supplied by UNH. The open tags contain accelerometers, gyros, magnetometer and pressure sensors.

The UNH part of the project is to extract propulsive accelerations from flipper strokes and thereby determine more accurately the kinematics of foraging maneuvers (Figure 7-12). Previous tags have not included gyroscopes, and because of this animal rotations are confounded with accelerations. The gyroscopes provide an inertial reference frame, enabling much more accurate estimates of accelerations, speed, and turns.

Figure 7-12. A California sea lion equipped with three tags, the middle one supplied by JHC/CCOM. This animal spent one week foraging.

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. Ware has been leading a team including Roland Arsenault and Briana Sullivan.

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; 1) it can be used to portray dynamic changes in flow patterns over time and 2) 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 either on the moving elements or the static elements.

Work by Ware includes a novel representation of flow data from a high-resolution Navy Coastal Ocean Model (NCOM) as shown in Figure 7-13. Although the printed figure is static, the actual display consists of animated transparent streamlets. The point of this is that the visualization allows the flow information to be clear while minimally obscuring other chart data. The user can either chose to focus on the flow or focus through the flow to see chart data.

Ware has also developed an alternative method for portraying data from the Wavewatch III model. Figure 7-14 shows an interactive inset to show swell waves and sea state in context with vessel heading. The background shows the modeled region. Swell waves are shown with wavelength relative to vessel length. Wind waves are shown in a separate inset. Numbers give wave height and period. The red dot at the end of the white line shows the vessel position.

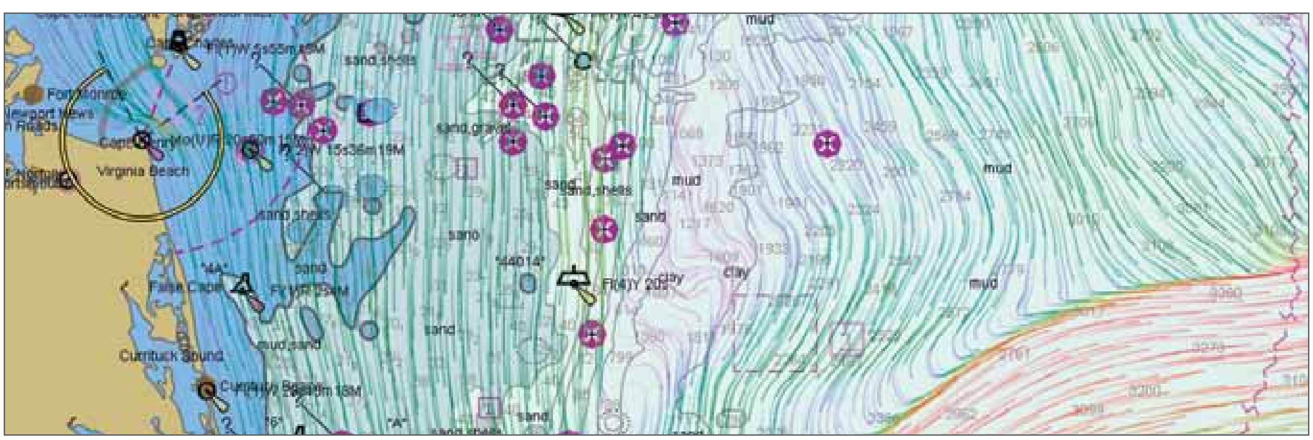


Figure 7-13. Representation of ocean currents. When animated the flow visualization minimally interferes with other chart data.

Multibeam Sonar Performance Visualization

Working in collaboration with Xavier Lurton of IFREMER, Roland Arsenault has developed an 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 verses depth and swath width (Figure 7-15). 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 and an excellent teaching and training tool.

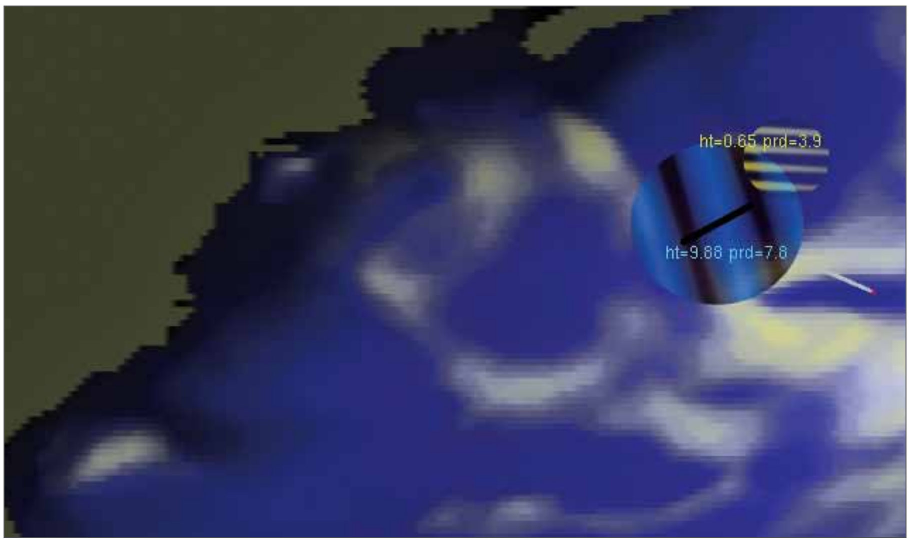


Figure 7-14. Portrayal of Wavewatch III model data. In the background swell waves are shown in blue and wind waves in yellow. This insets show Swell waves to scale (blue bars) for the bar representing a Los Angeles class submarine at the location of the red dot. The yellow bars represent wind waves traveling in a different direction. The sinusoidal patterns of waves are animated to show direction.

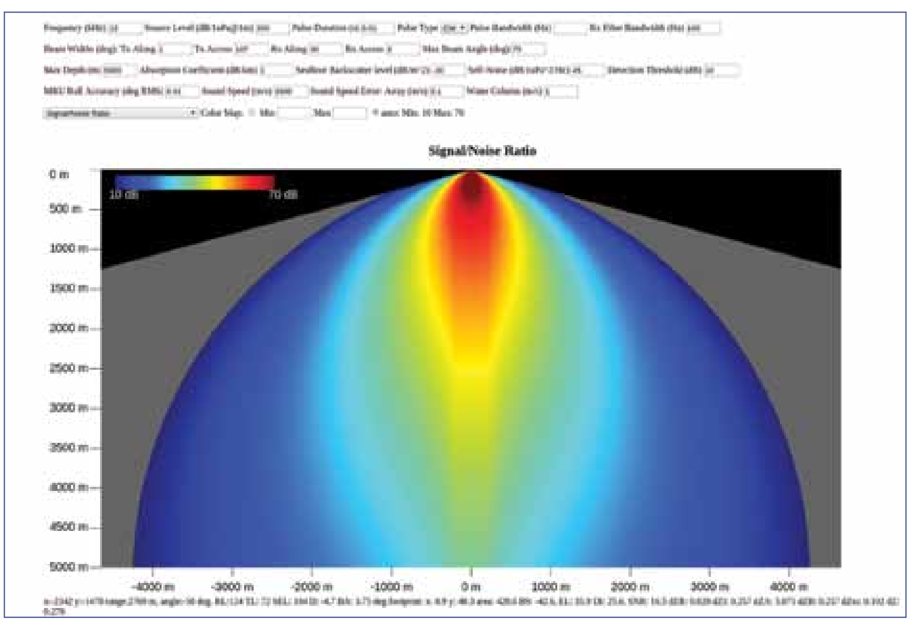


Figure 7-15. Web-based implementation of Lurton's sonar-equation based multibeam sonar performance tool.

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 faculty member Lee Alexander) 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).

Lee Alexander is leading our effort to support current ECDIS and ENCs with new data layers through his work with our industrial partners on a prototype "Tide Aware" ENC and his work with US Coast Guard, Canadian Coast Guard, and the International Association of Lighthouse Authorities (IALA), looking at the role that electronic charting will play in the e-Navigation concept of operations. E-Navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth-to-berth navigation and related services, for safety and security at sea and protection of the marine environment. As Chair of the IALA Information Portrayal Working Group, Alexander facilitated a review of existing performance standards for ship-borne and shore-based equipment, systems and services that have been adopted by the International Maritime Organization (IMO), International Hydrographic Organization (IHO), and IALA to determine their compatibility with the e-Navigation concept of operation. Particular attention was given to IMO performance standards on the "Presentation of Navigation-related Information on Ship-borne Displays." Criteria for evaluation will be the "Guiding Principles" recently adopted by IMO for Automatic Information System (AIS) Application-Specific Messages (IMO SN/1/Circ.290). The IALA Guideline on the Shore-side Portrayal Ensuring Harmonization with e-Navigation related Information was completed in September 2013. In recognition of these and other efforts, Dr. Alexander was awarded the 2014 Lloyd's List Maritime Services Award for North America.

Additionally, Alexander is working with NOAA's John Kelley to investigate the process and infrastructure required to broadcast NOS and NWS meteorological and hydrographic information to ship-borne maritime users in major U.S. ports and coastal areas via the Automatic Identification System (AIS) Application Specific Messages (ASM). This includes meteorological and hydrographic data, dangerous cargos, safety and security zones, recommended routes, status of aids-to-navigation and other time-sensitive safety information. This information will be broadcast in U.S. waters from AIS shore stations and received by ship-borne AIS equipment is are mandatory onboard ocean-going SOLAS vessels. AIS ASMs have also been identified as a means to achieve key elements of e-Navigation. An ongoing reviewis related to the data contents/parameters that are currently used to convey NOAA PORTS and nowCoast (met/hydro) information. The review will include the recent initiative by U.S. Army Corps of Engineers to provide AIS ASM broadcasts in major U.S. rivers and inland waterways, and the AIS Broadcast Service that was implemented in 2002 by the St. Lawrence Seaway Authority and U.S. Coast Guard for the Great Lakes/Seaway System. Specific recommendations will include:

a. What PORTS/NowCoast data parameters can be used or need to be modified to conform to the international data standard on AIS ASMs (IMO SN.1/ Circ. 289).

b. The four basic means of displaying NOAA PORTS met/hydro AIS ASMs (alphanumeric; graph; point, line, or polygon; symbol/ icon) as specified in the new IMO standard for displaying AIS ASMs (IMO SN.1/Circ290).

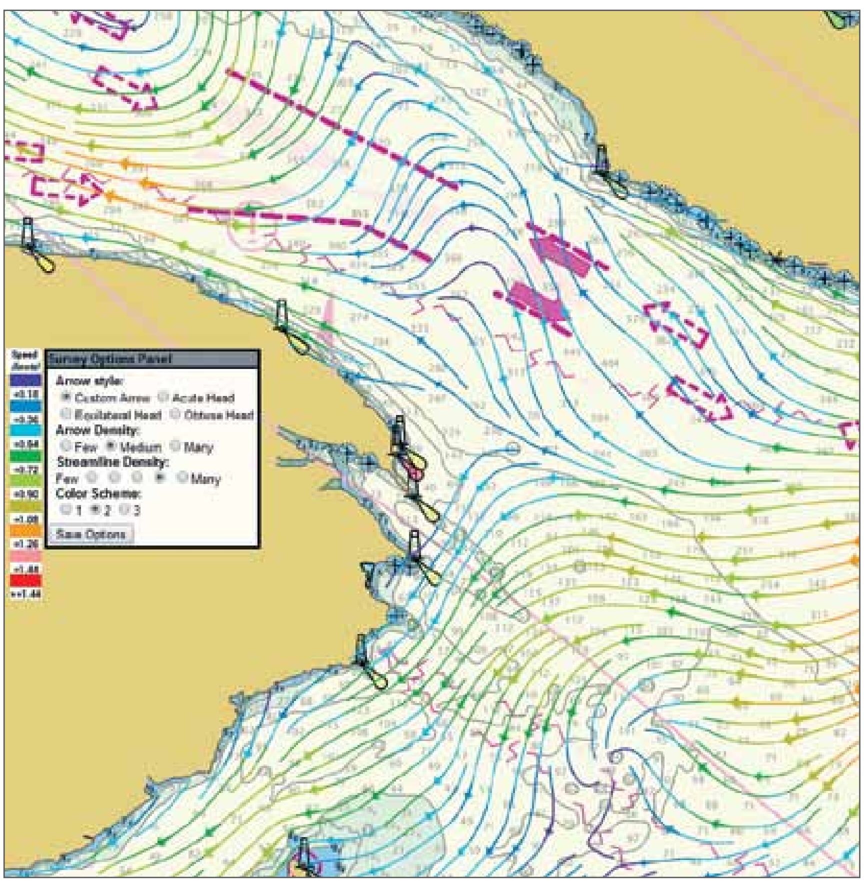


Figure 8-1. Designing Surface Currents interactive on-line survey.

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.

The current release of the library supports only a single-resolution surface. However, in conjunction with the development of CHRT and the variable-resolution grid technology, the ONSWG is currently working on a specification for BAG files that will allow them to contain variable-resolution grids (initially, at least, to support CHRT output), which will likely form the basis for the next major release of the library in the early part of 2015.

Right Whale AIS Project

The Right Whale AIS Project that the Center has supported for a number of years provides Liquid Natural Gas (LNG) carriers with real-time input on the presence of right whales in their vicinity through a series of permanent, hydrophone-equipped buoys, a right-whale vocalization system, and the transmission of the confirmed presence of a right whale to the vessel via AIS. The Center's role has been the AIS transmission and interface with the electronic chart aboard the vessel. Last year an iPhone app, WhaleALERT, was developed to augment existing ship navigation tools that inform mariners of the safest and most current information to reduce the risk of right whale collisions.

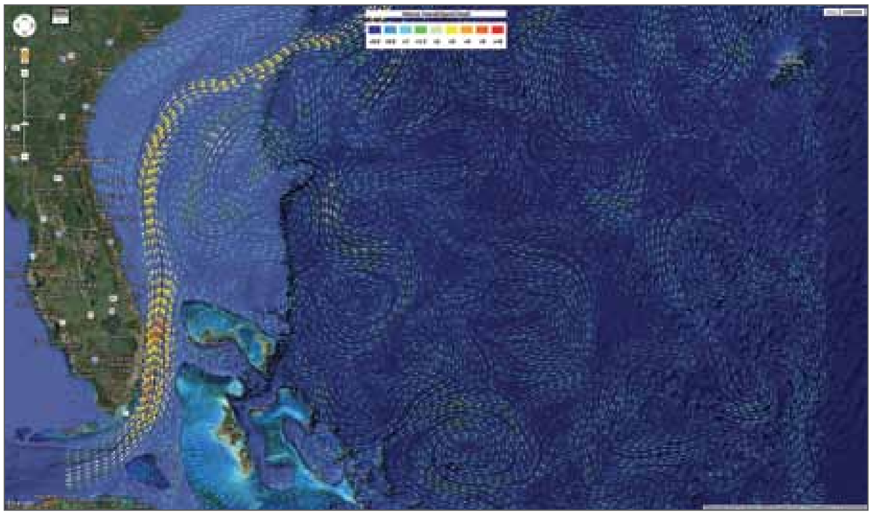


Figure 8-2: Current forecast from the Navy's regional NCOM model displayed as streamlines over Google Maps.

The Center's role is to aggregate buoy data from Cornell University and sightings and Dynamic Management Areas (DMAs) from NOAA and transmit them via both Automatic Identification System and the Internet using the IMO Circ. 289 Area Notice message format. For many years, Kurt Schwehr laid the groundwork for this project. Last year, Roland Arsenault took over the management of the Center's infrastructure and expanded the system to support DMAs and sightings. The availability of the AIS based notices was expanded with the development and support of the message transmission to provide a debugging tool and code to display area notices. This improvement contributed to OpenCPN, a cross-platform open-source chart-display application. The system became fully operational in 2014 and has been operating autonomously without intervention.

IHO Compliant Current and Tide Display

As discussed in the VISUALIZATION theme, Colin Ware has been exploring new and enhanced ways of visualization current data. The basic research has manifested itself in several projects that apply new visualization approaches to hydrographic and other navigation problems. One aspect of this research is the involvement of Briana Sullivan with the IHO's Surface Current Working Group (SCWG) with the goal of developing an S-100 compliant product specification for the portrayal of tides and currents. Sullivan designed a very well-received survey that allowed mariners to explore (and vote on) various methods of presenting current data in an ENC. Following up on this survey, in the past year Briana has created a second, more sophisticated survey that uses code written by Roland Arsenault to view streamlines in the Gulf of Saint-Lawrence area overlaid on various versions of nautical charts and satellite data. The survey is unique in the world of on-line surveys in that the user is able to make design decision in real-time and see the results combined with other changeable options (Figure 8-1). The results of this survey will contribute to the findings of a sub-group of the SCWG that is tasked with looking at the initial draft of the S-111 document. In the fall, Sullivan finished the official first draft of the portrayal section of the S-111 document. It was agreed to keep streamlines in the draft but to minimize their dominance. Thus, the subject will appear at the end of the portrayal section with a note that it needs further investigation. It will be brought up again before the entire SCWG at the 3rd meeting in May 2015.

Wave and Current Visualization in Navy Mission Planning Application

(For information – funded by another grant)

The fundamental research on current and wave display described under the VISUALIZATION theme has also attracted the interest of the U.S. Navy. The Office of Naval Research has funded the Visualization Lab to develop a web-based prototype for current visualization to be implemented as a component of the Navy's Mission Planning Application (MPA) for the submarine fleet. The migration involves the adaption of the software to a web-based service-oriented framework that produces KML files for use in a WorldWind plugin (Figure 8-2). A component in the form of a Python script has already been delivered and is currently being integrated into the MPA.

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. This year, working closely with the OCS Coast Pilot team, Sullivan received a copy of the Oracle database that contains information used to generate the Coast

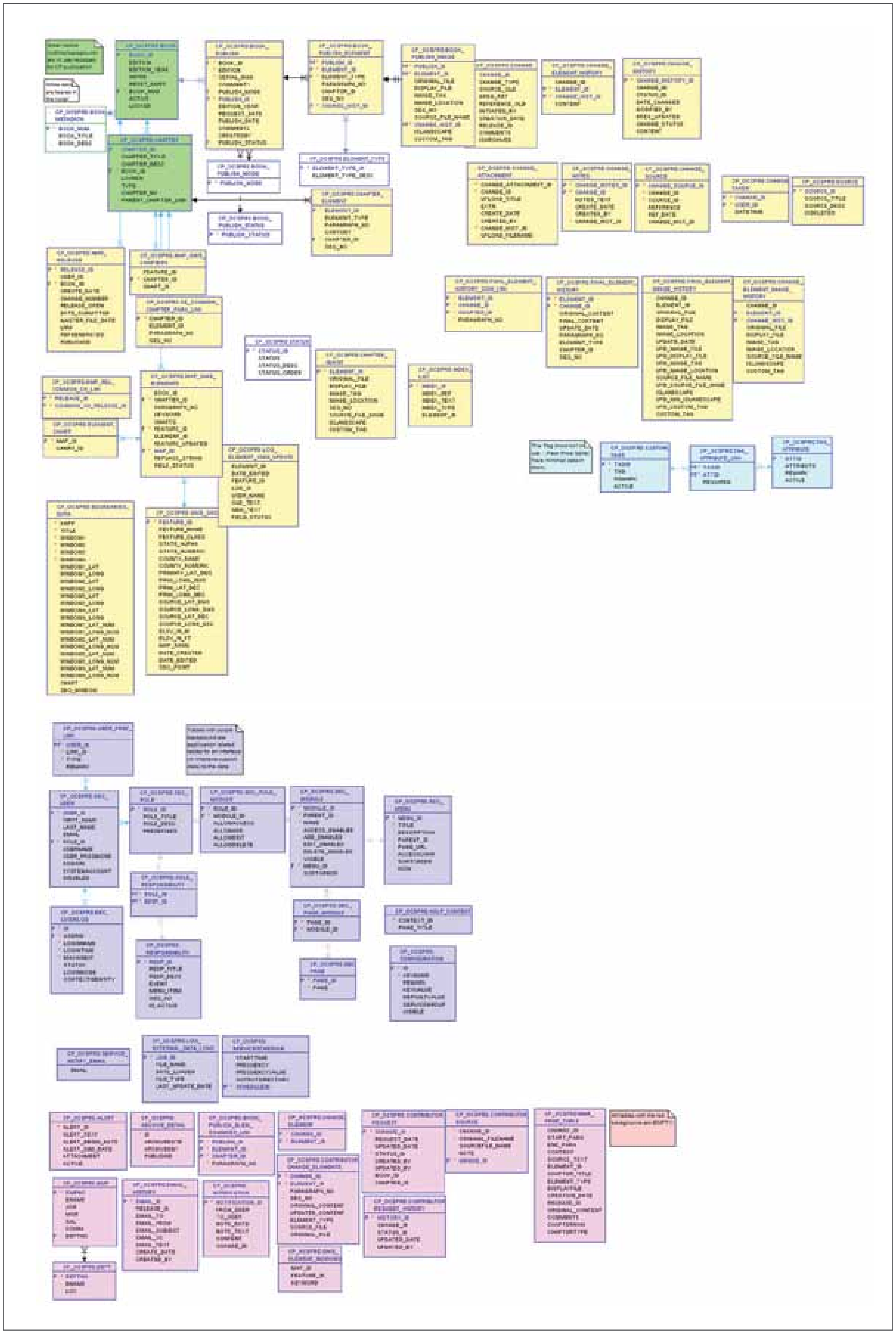


Figure 8-3. Layout of Coast Pilot database.

Pilot. She spent time mapping/laying out the relationships between the tables and getting familiar with the data contained within each table (Figure 8-3). She is finally in a position to work directly with the same data and in the same format/layout as the OCS Coast Pilot team. This is a great opportunity to create more useful tools with this data that would not only be proof-of-concepts, but will also be done using the technology that OCS is already using, so porting the prototypes to OCS in the future will be much easier.

Risk Models for Hydrographic Resurvey Priority Determination and Real-Time Risk Prediction

Many hydrographic offices have difficulties in determining how best to allocate limited resources to the task of resurveying their area of responsibility. Most often, this is done through educated guesswork, or in response to user complaints, and is a very subjective process. Similarly, there is current international interest in understanding representation of uncertainty in some form for charted data and to provide a mechanism to use this to support decision-making for underway transit.

In response to these concerns Calder is looking at how what is known about a charted area, i.e., the age and quality of the underlying survey data, the amount and type of traffic in a region, the seafloor and environmental conditions etc., can be represented to the end user in a manner that is readily accessible, intuitive, and useful, while still remaining hydrographically accurate, computable, and compatible with current delivery mechanisms. Current implementations of uncertainty representation in hydrographic end products, such as source diagrams, reliability diagrams, and CATZOC (on ENCs) are known to be inadequate descriptors, where they even exist, and therefore the Center has been developing new methods for uncertainty estimation, categorization, and representation with a particular eye on end-user compatible methods.

Previous work reported by Calder (2014) focused on a risk-based model of uncertainty, whereby risk is determined for a given ship conducting particular maneuvers in a given area by considering the properties of the ship, the properties of the environment (including the bathymetry), and the dynamics of the actual maneuvers themselves, taking into account at each stage the level of uncertainty in each of the input variables. Thus, for example, by considering the possibility that an archive survey conducted with earlier technology might be the primary source of bathymetric information available on a chart, the model can include the potential for objects of navigational significance that might not have been found by the survey (e.g., glacial erratics not picked up by sparse vertical-beam echosounder surveys), or can factor in the potential for extreme weather events such as tidal extremes or motion effects that might potentially cause the ship's hull to approach the bottom more than expected. When appropriately calibrated, such models can be used to estimate either simple statistics for the maneuvers, such as the probability of grounding either instantaneously during the transit or in total across the entire transit, or can be combined with a model of the severity, or loss, caused by various behaviors, leading to a more general (mathematical) risk model.

A particular use of the technology being considered is how to determine when to re-survey a particular area, or more generally, how to choose which of a given set of survey areas should be granted priority for a re-survey. The risk model is designed to be used for general hydrographic purposes such as chart-uncertainty expression or to determine where to survey first within a given area, and when to conclude that a survey is complete. Calder initiated a new project to develop a means to prioritize re-survey efforts. The goal of the project is to use measures of hydrographic risk and the reduction in risk that might be achieved with a new, survey of any given area, to determine where a survey would be most beneficial and, therefore, to assign a priority to subsets of an area for re-survey projects. Figure 8-4 shows an example of a risk model applied to a synthetic bathymetry that is shallow and is analyzed at full resolution, as would happen after a modern survey, and then at a reduced resolution constructed as the data would appear after an archive-scale survey; i.e., only contains data that would be available from an archive at a fixed scale, in this case 1:20,000. The lower-resolution data is re-interpolated using a geospatial model. The probability of grounding and the cumulative probability of grounding show that the effect of a survey here is approximately half of the cumulative probability of grounding for the given trajectory over the seafloor.

The magnitude of the effect before and after survey depends on both the environment and the vessel conducting the transit. Figure 8-5, for example, shows the same model as Figure 8-4 applied to a different bathymetry, where the resulting cumulative probability of grounding is different before and after surveying by a factor of approximately three. In this circumstance, therefore, it might be more useful to survey in this area before surveying in the area shown in Figure 8-4 (that is, the benefit in terms of overall reduction in risk to surface traffic is higher by surveying in the area of Figure 8-5 than the area of Figure 8-4, and therefore the area of Figure 8-5 should be of higher priority).

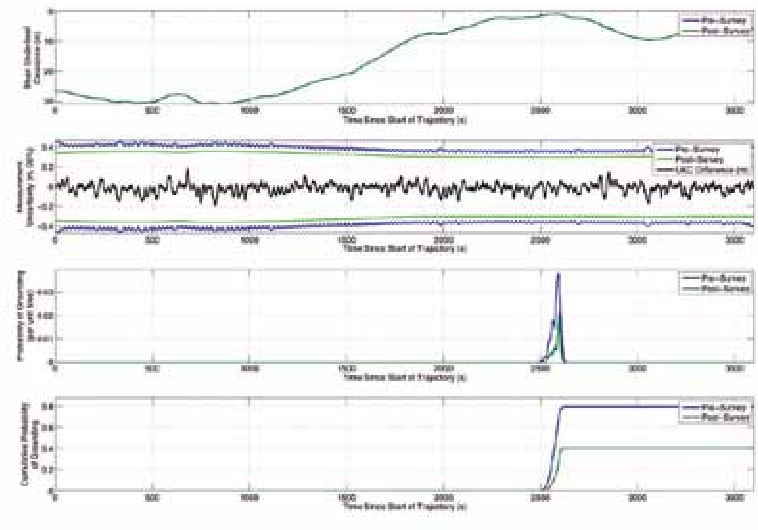


Figure 8-4. Example of the resurvey priority model applied to a synthetic bathymetry. Top panel: bathymetry at full resolution; Second panel: difference between full resolution and interpolated sub-sampled bathymetry, and their uncertainty estimates; Third panel: estimated instantaneous probability of grounding during transit over the bathymetry; Bottom panel: cumulative probability of grounding. Resurveying in this case would half the cumulative probability of grounding during the transit.

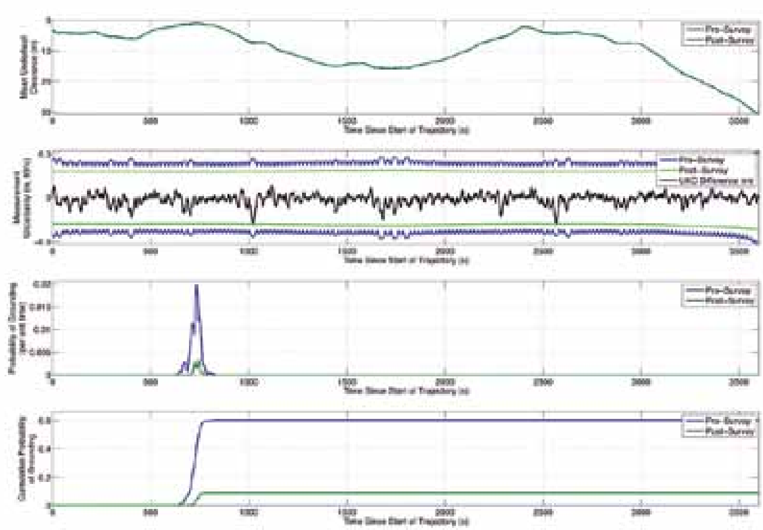


Figure 8-5. Example of the risk model of Figure 8-4 applied to a different bathymetry (panels are the same as Figure 8-4). The different bathymetry in this case, and its interaction with the ship carrying out the transit results in a much higher differential between pre-survey and post-survey cumulative probability of grounding compared to Figure 8-4.

Determining how to compare areas is, however, not entirely straightforward. Figure 8-6 shows a series of possible comparisons between the results from Figure 8-4 and Figure 8-5. If the difference between the pre- and post-survey cumulative grounding probability is computed (bottom left panel), which is a reasonable model for the scale of significance, it appears that the difference between pre- and post-survey behavior in Figure 8-4 is more significant that than in Figure 8-5. If, on the other hand, the ratio of cumulative grounding probability is taken (bottom right panel), which is also a reasonable model for the scale of significance, the opposite is true. Consequently, a more nuanced model for the significance of pre- and post-survey grounding probabilities (or any other metric of interest) will be required to ascertain the importance of any area for resurvey efforts. This is the subject of on-going research.

In collaboration with the United Kingdom Hydrographic Office and Maritime and Coastguard Agency of the United Kingdom, Calder developed a collaborative research program to construct a technology demonstrator for this methodology. The study will focus on two study areas, around the coast of the UK (Figure 8-7). The area in the southeast, from the southern North Sea through the Straits of Dover to the Isle of Wight consists of high-density survey areas with highly variable seafloor dynamics and high traffic density; the area in the northwest, from Islay through the northern Celtic Sea to Anglesey, has only low-density archive data, but has dense traffic, including many passenger ferries. The areas have been chosen as models of data rich and data poor environments so that they have more general applicability.

The effort this year has primarily been on development of conceptual models of involved risk, data discovery and collaborative project development. The project now has agreed bounds, data provision is under way and the code-base for the risk-based models has been re-structured to allow for more efficient processing. The code is also being re-developed from MATLAB to C++ so that significantly faster analyses can be carried out on the larger-scale problems that are required to demonstrate this technology in a realistic setting.

Revolutionary

Within the context of the "revolutionary" effort, Colin Ware, Tom Butkiewicz, Matt Plumlee, Briana Sullivan and Roland Arsenault have been developing specific applications for the Chart of the Future. Many of these capabilities were described in past progress reports; we will only highlight 2014 developments here.

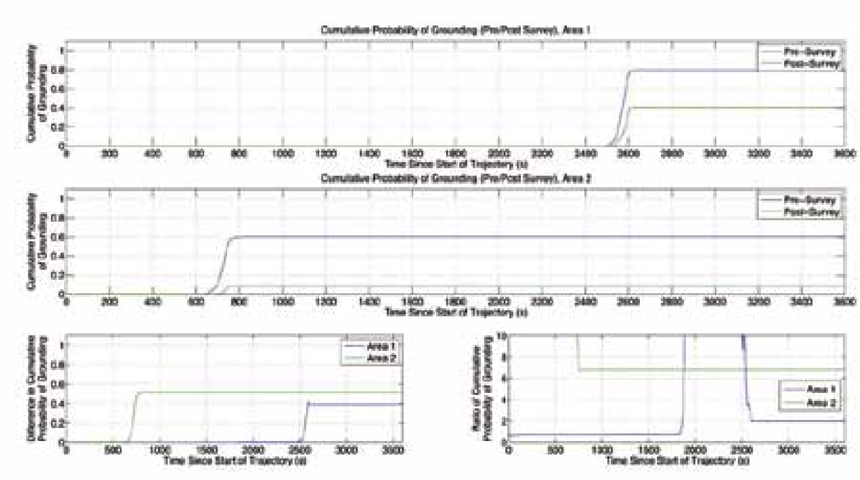


Figure 8-6. Examples of comparisons between the analyses of Figures 8-4 and 8-5. Depending on the metric chosen to compare the pre- and post-survey cumulative probability of grounding (top two panels), the significance of each area (bottom left and right panels) can appear to be different.

Local Notice to Mariners—Chart Update Mashup (ChUM)

The Local Notice to Mariners (LNM) contains information that relates to navigational aids, bridges, construction, local events and at least 11 other related topics. It is a rich and useful resource for all types of mariners. One of the biggest challenges in working with the LNM is the form (either as a PDF file or as online tables) that it is presented to mariners. Although the PDF LNM updates and online tables (and the Coast Pilot) all provide essential information to the mariner, these documents can be cumbersome to use. This was clearly demonstrated by a survey on the use of LNM conducted in 2011 by the Alliance for Safe Navigation. That survey showed that 70 percent of the boaters that responded said that they were aware of LNMs but they did not download or use them.

Of the two sources of LNM available, the PDF version is more difficult to read than the table view (provided by OCS) of the same information. Because the OCS table allows the mariner to filter on a specific chart and various views of historical data, it greatly reduces the overload of information shown, but offers no visual spatial context for the information. Each item in the table is geo-referenced, which means that a display of the table within the context of a nautical chart is the logical way to present it, but currently the mariner would need to manually plot each point on a nautical chart. The fundamental drawback to both the PDF and the table version of the chart corrections is that the user cannot interact with them.

To address these issues, Briana Sullivan has developed the Chart Update Mashup (ChUM), a small, specialized mashup application designed to work with Google Maps. ChUM was created to effectively display the chart catalog and nautical charts in a geo-referenced environment, along with the critical corrections to the chart and the Coast Pilot with geo-referenced links. ChUM is a web application that uses and combines data, presentation, or functionality, from two or more sources to create a new service. To create ChUM, Google style controls, the Nautical Charts API, Google Maps API v3 and the Nautical Charts APIUI have been integrated to seamlessly work with each other.

The result is the integration of NOAA nautical charts, the NOAA chart catalog, critical chart corrections from the LNM and the Coast Pilot in a georeferenced web-based environment.

Figure 8-7. Areas to be used for re-survey priority estimation highlighted (green) against the United Kingdom survey area of responsibility (purple). The southeast area is a highly dynamic environment with high traffic density but supported by high-resolution modern surveys; the northwest area still has significant traffic density, but has only limited survey data, making for a more challenging environment.

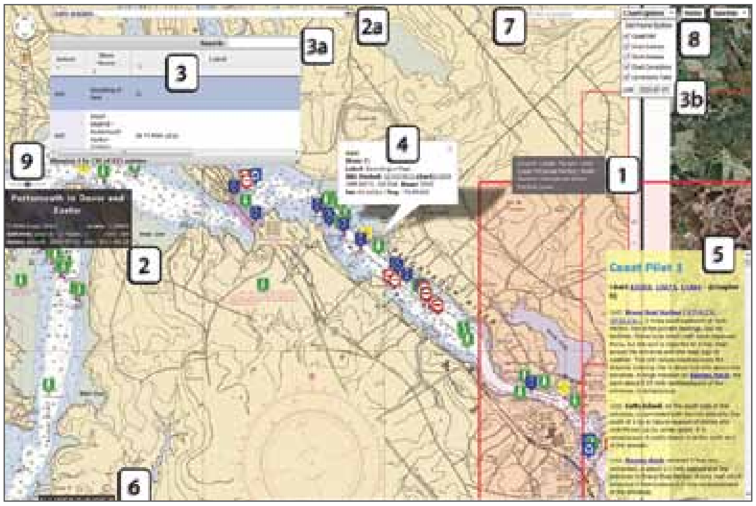


Figure 8-8. Overview of ChUM capabilities. Numbers on figure refer to items in list below.

ChUM features include (see Figure 8-8):

1. Integration of NOAA chart catalogs
2. Integration of NOAA nautical charts
   a. Ability to filter charts depending on viewport
3. Integration of critical chart corrections from OCS as a dynamic/interactive table
   a. with the ability to filter data
   b. with the ability to view historical data
4. Integration of critical chart corrections as geo-referenced markers within the context of the chart
5. Integration of Coast Pilot with Geo-coded places
6. Geo-referenced environment
7. Ability to search place names
8. Ability to save a location bookmark
9. Ability to set the chart transparency

ChUM can assist with quality assurance and quality control for OCS/USCG internal use as well as help to raise awareness of the numerous changes made to a nautical chart, helping the mariner to effortlessly visualize corrections with an intuitive interface in a web-based geo-referenced environment.

Updates to ChUM include adding MODUs (mobile oil drilling units) and Broadcast Notices for version requested by the U.S.Navy (Figure 8-9). Sullivan has also been working on adding other information from NGA to the Navy version of the mashup.

The ChUM project has now been recognized as useful and beneficial to the Marine Chart Division of the Office of Coast Survey. Mark Griffith has been a champion in the effort to get the concepts behind it used both internally and on the public website as a better way to display the critical chart corrections. To support this, Sullivan has written a white paper on the inner workings of ChUM for distribution at MCD. This report, distributed at an MCD meeting in June 2014, led to the implementation at MCD of some of the features of ChUM.

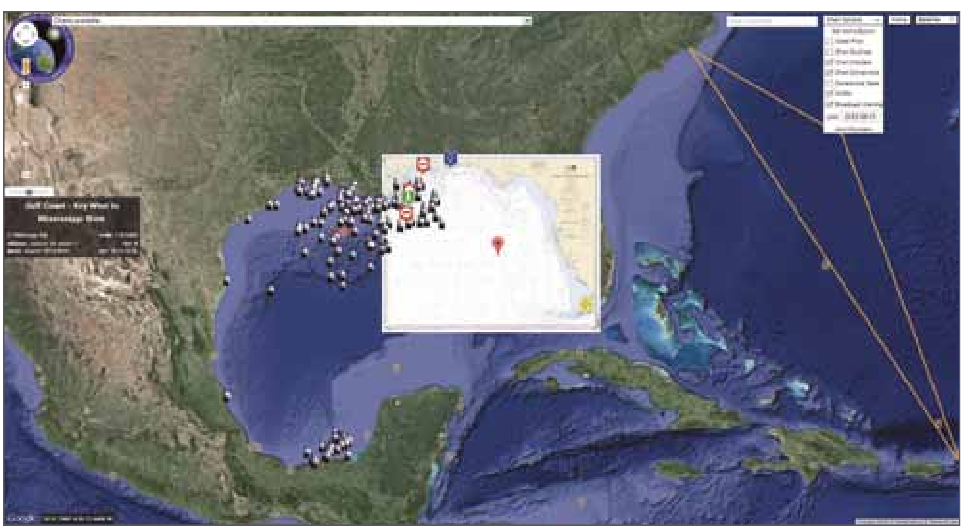


Figure 8-9. Navy version of ChUM with MODUs and Broadcast Notices.

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 began in 2003. Since then, the Center has collected more than 2.2 million square kilometers of new high-resolution multibeam sonar data on 26 cruises, including eight in the Arctic, four 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, two 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 annual 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.

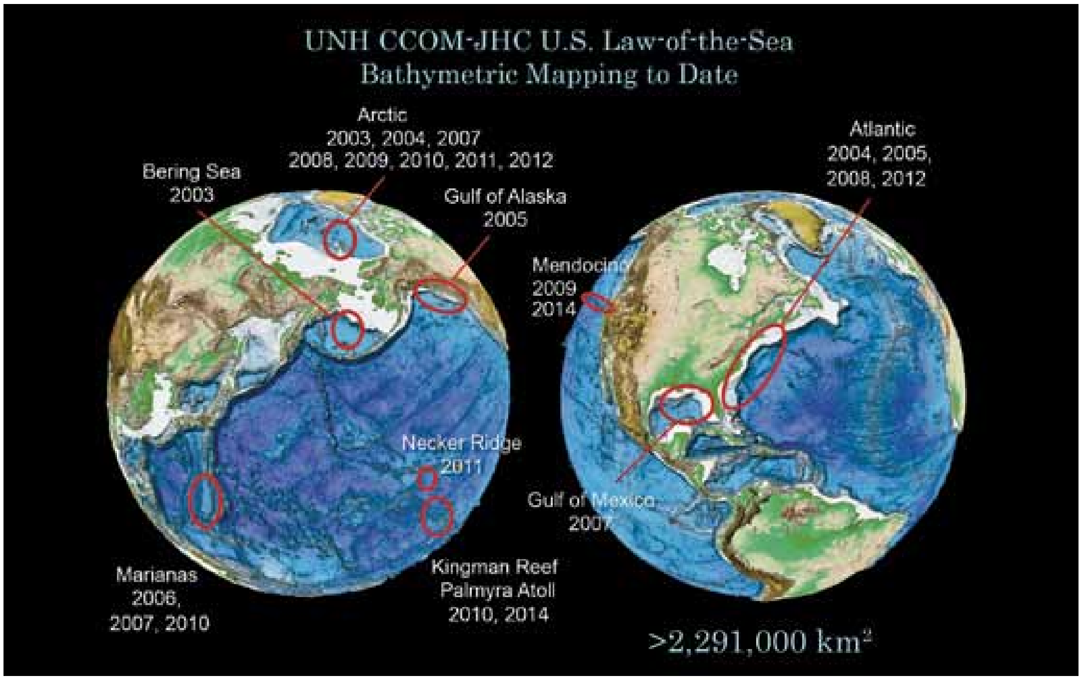


Figure 9-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center. To date, more than 2.29 million square km of data have been collected.

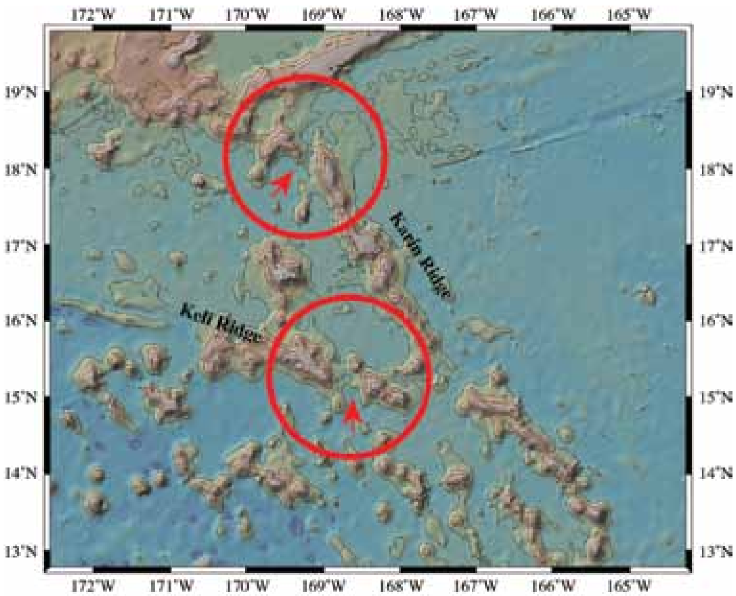


Figure 9-2. Location of ridge gaps in Keli and Karin Ridges.

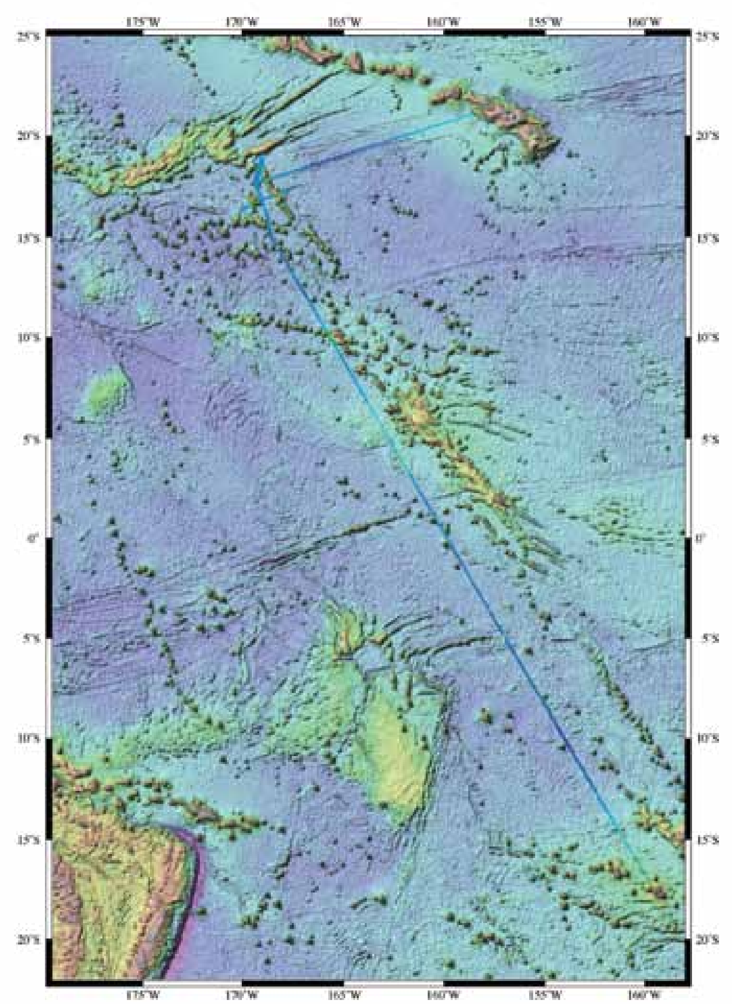


Figure 9-3. Full cruise track of Johnston Atoll cruise.

2014 Law of the Sea Activities

Two ECS cruises were competed in 2014; one in the vicinity of Johnston Atoll on the R/V *Kilo Moana* and the second a return to Mendocino Ridge to complete mapping that started in 2009.

Johnston Atoll

Jim Gardner organized, planned, and led the cruise to the Johnston Atoll area in the central Pacific in August 2014. The objective of the cruise was to map a prominent gap in Keli Ridge to the south of Johnston Atoll and another gap in Karin Ridge to the east of Johnston Atoll (Figure 9-2). The cruise used the University of Hawaii's R/V *Kilo Moana* because the ship had a planned dead-head transit from Papeete, Tahiti to Honolulu. Jim negotiated with the University of Hawaii to only pay for the four additional days that the mapping would add to the scheduled 12-day transit. The R/V *Kilo Moana's* Kongsberg Maritime EM122 multibeam echosounder, Knudsen 3260 Chirp subbottom profiler, and Bell BGM-3 gravity meter all performed to expectations during the cruise. A total area of 97,250 km^2 was mapped during the full 13-day cruise (6275 line kilometers) (Figure 9-3).

A highlight of the cruise was the discovery of a prominent seamount on the multibeam monitor that only vaguely appears in the best available bathymetry of the area (Figure 9-4). The newly discovered seamount is located at 2°38.72114'S 158°25.07171'W in water depths of 5125 m. The seamount stands 1061 m above the adjacent seafloor, is 7.1 km x 5.7 km at its base and has slopes that range from 22° to 33°. A lively debate occurred during the cruise concerning the name we should give to the seamount. They unofficially named it Humuhumunukunukuiapuaa Seamount after the official state fish of Hawai'i, but they doubt the name will stick.

The cruise reached the area of Keli Ridge and mapped the gap with a single line (Figure 9-5). The gap in the ridge spans 18.3 km at its base but extends 45 km across the breadth of the ridge and stands at least 300 m above the adjacent basin depths. The bathymetry shows a broad saddle that is punctuated with numerous conical volcanic pinnacles, some have summit calderas whereas others have sharp peaks, and yet others are not conical but squat, flat summit features. The multibeam backscatter (Figure 9-6) shows the bare rock of the

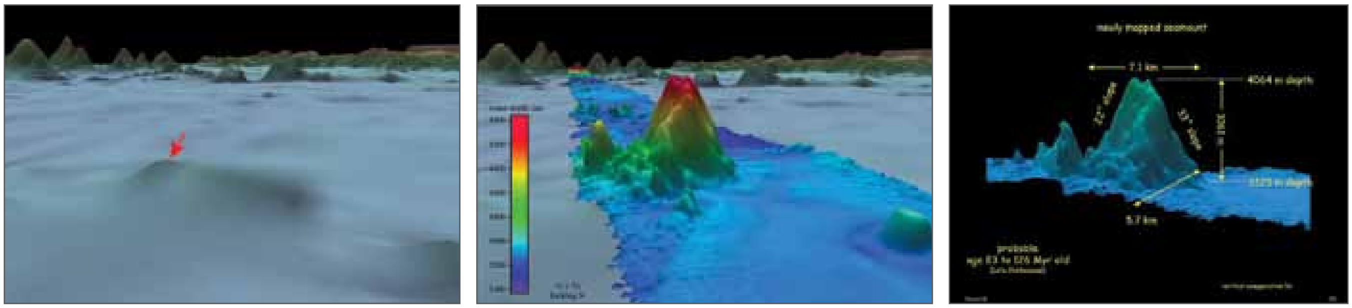


Figure 9-4. Perspective view of newly discovered seamount. Left panel shows the seamount from Smith and Sandwell (1997) v. 17.1 predicted bathymetry (red arrow). Middle panel shows seamount in new multibeam bathymetry.

volcanic features (-30 to -25 dB) compared to the sediment cover (-48 to -32 dB) that comprises the seafloor of the gap. Both the bathymetry and the backscatter demonstrate that the gap is an area where increased volcanic activity occurred compared to the adjacent seafloor.

The Karin Ridge gap (Figures 9-7 and 9-8), located 340 km north of Keli Ridge gap, occurs along en echelon trends between the northern nose of Karin Ridge and a southern platform of the Mid-Pacific Mountains (MPM) to the west. The width of the gap required two passes to acquire a complete picture of the bathymetry of the gap area. The base of the gap is only 4.2 km across but occurs as a broad shelf that extends 13.5 km with a WNW-ESE trend 24˚ to the trend of the ridge. The floor of the broad shelf is very smooth and appears to be an archipelagic apron shed off the western flank of Karin Ridge. The western edge of the shelf rises abruptly from abyssal depths with slopes of ~6˚. A knife-edged ridge (red arrow in Figure 9-7) trends SE away from the eastern flank of the MPM platform, parallel to the trend of Karin Ridge and out across the Karin Ridge gap, providing a buttress that the archipelagic apron has banked up against.

The flanks of Karin Ridge that form the gap are composed of a series of stacked volcanic flows and a few isolated volcanic pinnacles. The volcanic flows of both the MPM platform and Karin Ridge separate basin depths of 5500 m to the SW from basin depths of only 5250 m depth to the NE (Figure 9-8).

Mendocino Ridge

A second ECS cruise in 2014 completed the mapping of Mendocino Ridge in the eastern Pacific off the California margin (Figure 9-9) that was started in 2009. The 2014 cruise on the R/V *Atlantis* began in Astoria, OR on September 23 and ended in San Francisco, CA

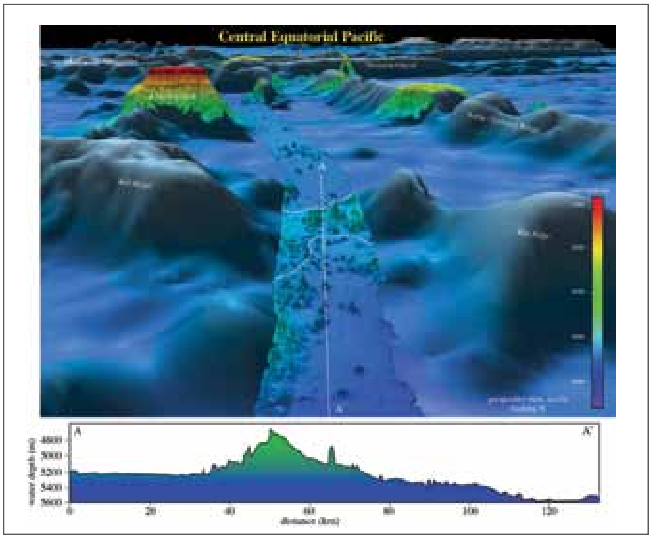


Figure 9-5. Perspective view of Keli Ridge gap with profile A-A' (lower panel) that shows the raised platform (dashed white line on upper panel) ~400 m above abyssal depths. Vertical exaggeration is 5x, looking north.

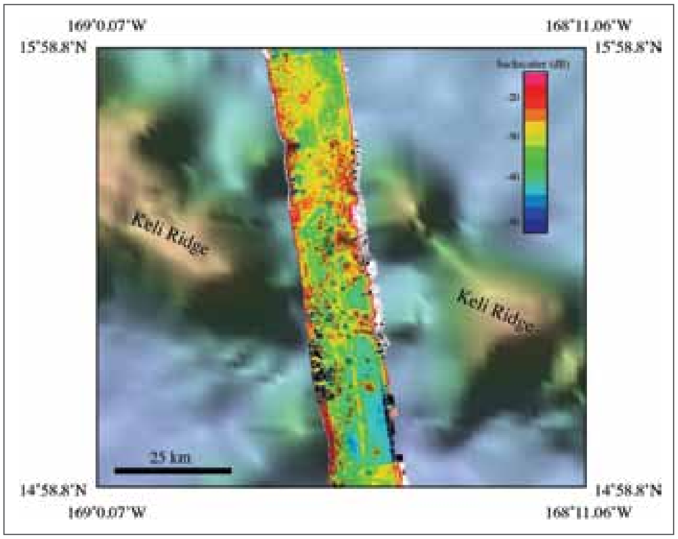


Figure 9-6. Map view of backscatter of Keli Ridge gap. Backscatter of bare rock of the volcanic features (-30 to -25 dB) contrasts with that of the sediment cover (-48 to -32 dB) that comprises the seafloor of the gap.

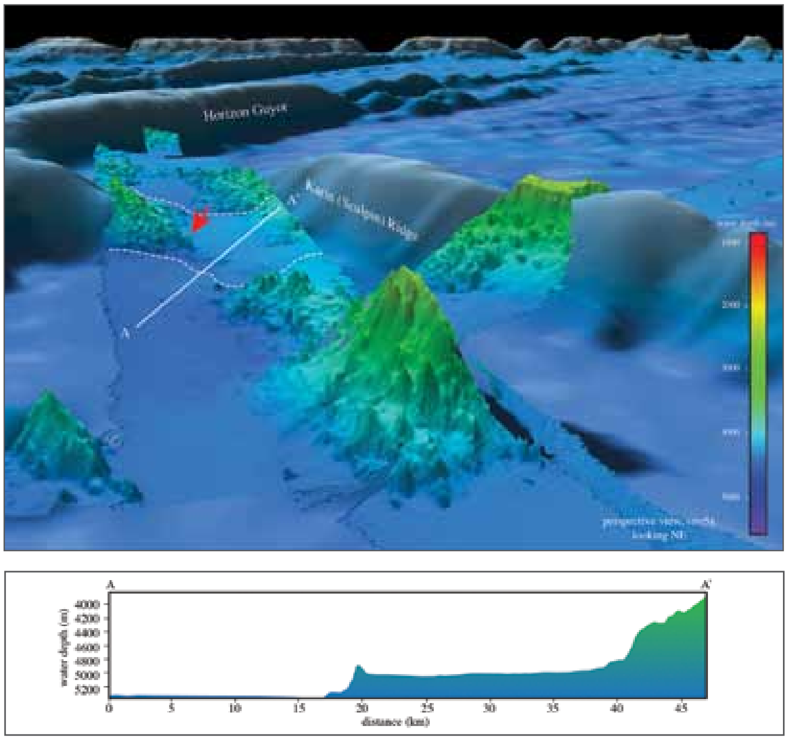


Figure 9-7. Perspective view of bathymetry of Karin Ridge gap. Profile A-A' shows the elevated nature of the seafloor within the gap area.

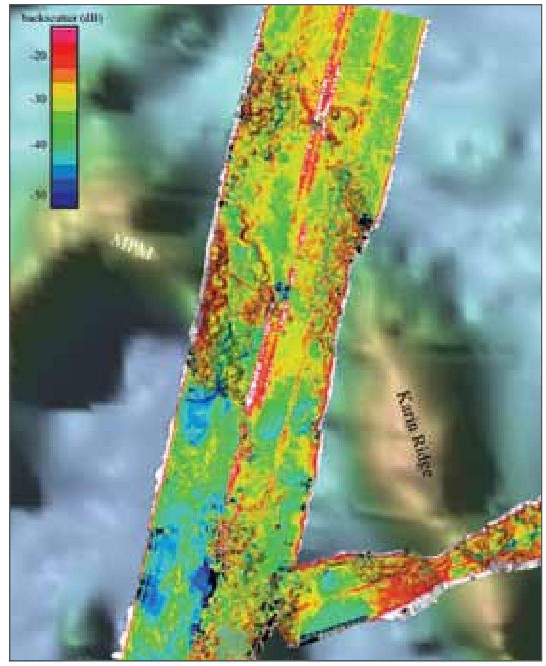


Figure 9-8. Map view of backscatter of Karin Ridge gap. Backscatter of bare rock of the volcanic features (-30 to -25 dB) contrasts with that of the sediment cover (-48 to -32 dB) that comprise the seafloor of the gap. MPM is Mid-Pacific Mountains.

on October 11. A total area of 93,086 km^2 (7939 line kilometers) of multibeam sonar data was collected in the Mendocino region over a period of 19.5 days (with four days of transit). These data have been combined with the 2009 data to form a single data set that represents a coverage of 107,222 km^2 (Figure 9-9) and most likely represents all the data that will be needed in the region to address ECS issues. Metadata was generated for each of the 200 lines of 2014 multibeam and subbottom data and these data have been archived into the Center's Law of the Sea database as well as the NOAA/National Geophysical Data Center and the Columbia University Lamont Doherty Earth Observatory's GeoMap App public database. The merged dataset provides a high-resolution comprehensive bathymetry DTM of the entire 1,000 km of the easternmost Mendocino Ridge (Figure 9-10).

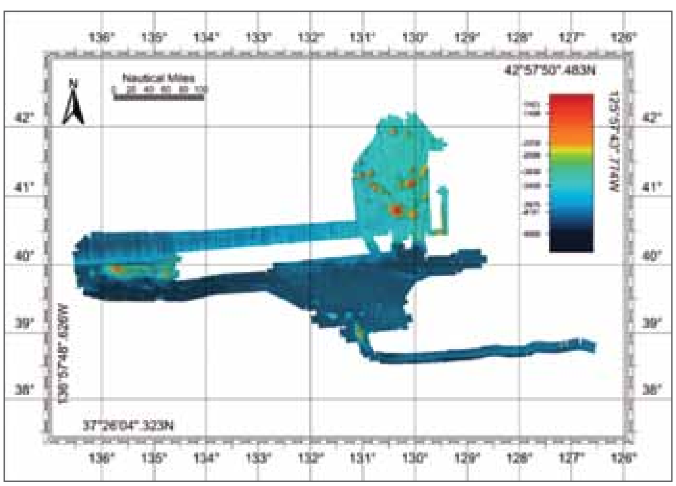


Figure 9-9. 2014 mapping in the vicinity of Mendocino Ridge.

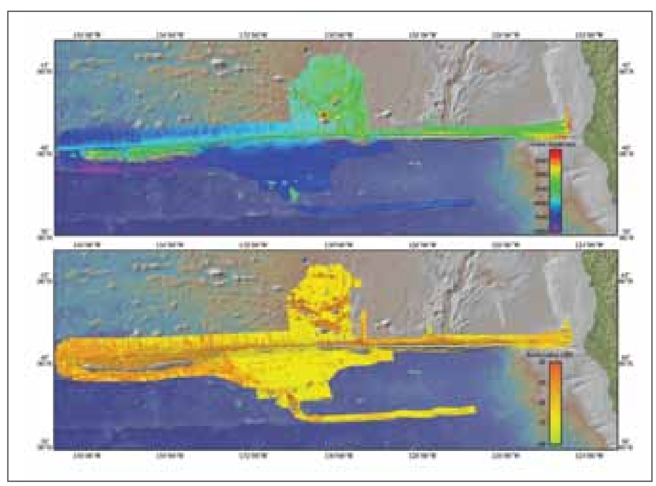


Figure 9-10. Upper panel shows merged 2009 and 2014 Mendocino Ridge bathymetry; lower panel shows merged backscatter.

Other ECS Activities

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 late spring of 2014 Paul began the process of conducting a full review of the Law of the Sea data collected in the Arctic Ocean from 2003 to 2012. As part of this examination, all existing processed data were evaluated for completeness, any quality data that had been previously excluded from final data products were now marked for inclusion, and all processed files were assimilated into a single bathymetric grid, instead of being subdivided into separate grids from each survey program.

This process yielded a new all-inclusive Law of the Sea Arctic Ocean bathymetry synthesis. During the steps defined above, certain cruises were identified as requiring further processing and this processing was begun.

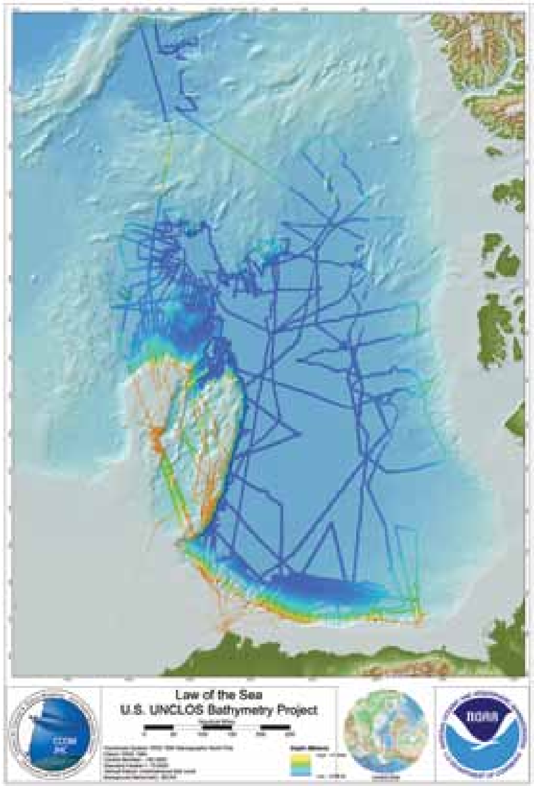


Figure 9-11. Preliminary Arctic bathymetry synthesis map. The map is generated from a single gridded dataset instead of a combined multi-year map product.

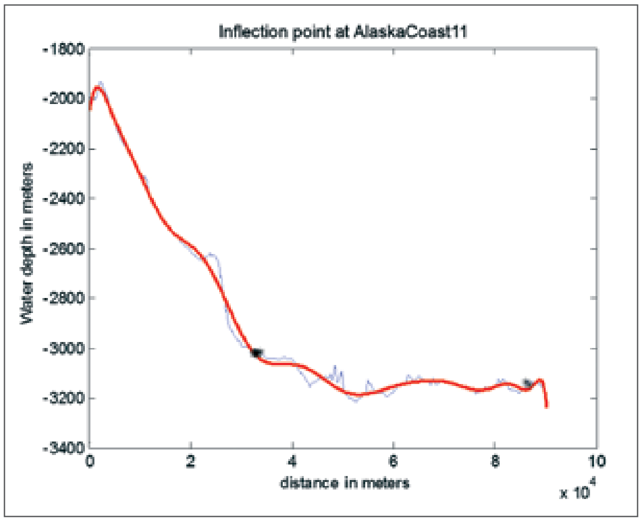


Figure 9-12. Automatic pick of foot of slope using "FoL learning algorithm."

A preliminary version of the Arctic Ocean bathymetry synthesis grid and an updated map, including the newly processed data were released at the end of July (Figure 9-11).

Gardner, Mayer and Andy Armstrong have also spent much time analyzing ECS data, participating in the ECS Task Force, Working Group, Integrated Regional Teams and other Law of the Sea-related meetings including a two-day workshop in Boulder focused on the Arctic. Throughout the year, various Extended Continental Shelf (ECS) conference calls, GoToMeetings and specific IRT calls occurred. Monthly ECS Working Group conference calls were scheduled to review overall ECS progress as well as unscheduled calls and GoToMeeting sessions that occurred to discuss specific IRT details. Additionally, the Center hosted a week-long training course in the use of the Geocap Law of the Sea software package.

Additionally, graduate student Onni Irish and Research Scientist Tianhang Hou have been looking at the U.S. ECS data collected in the Arctic and are developing approaches for automatically choosing the location of the foot of the slope (FoS). Hou has developed a "FoS learning algorithm" that determines the polynomial order and window size of a piece-wise fitting that is optimal to obtain a FOS result for a given profile and the maximum curvature computation rules defined by LOS Article 76 (Figure 9-12). The parameters produced are then used to automatically select FoS points for profiles with similar patterns; the output is then brought directly into ArcMap.

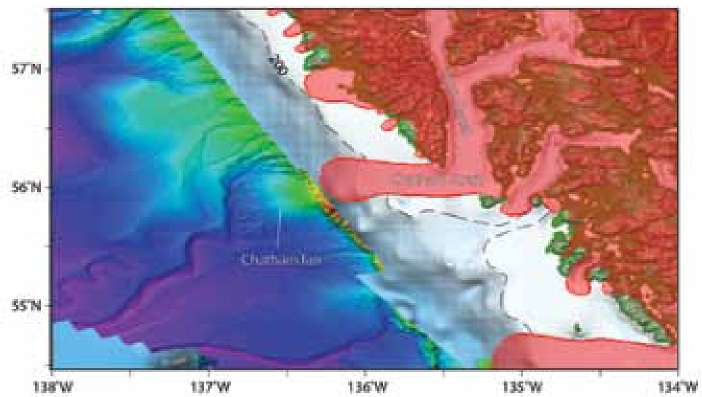


Figure 9-13. Map view of a section of the U.S. Gulf of Alaska and adjacent land showing the extent of glacial tongues that extended out onto and across the continental shelf. Chatham Fan is located directly in line with the glacial tongue that extended out of Chatham Strait (after Manley and Kauffman, 2002).

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 Law of the Sea team have been involved in writing peer-reviewed journal articles.

During 2014, three invited manuscripts based on Law of the Sea data were peer-reviewed, revised and are now accepted for publication in the *Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient* to be published in Geological Society, London, Memoirs. The first paper by Gardner and Mayer, "Chatham Fan and Adjacent Upper Baranof Fan Channels and Levee, U.S. Gulf of Alaska Margin," is based on Law of the Sea data collected in the Gulf of Alaska and describes the newly discovered Chatham Fan (Figure 9-13) and its formation during maximum glacial conditions by a glacial tongue that extended out of Chatham Strait and bulldozed a terminal moraine across the continental shelf and over the shelf edge to deposit the sediments on the lower slope as a submarine fan.

The second paper, by Mayer and Gardner, "Cascades and Plunge Pools in the Gulf of Alaska," also based on Law of the Sea data collected in the Gulf of Alaska, describes a sequence of plunge pools and cascades that were formed by hyperpycnal flows out of Yakutak Valley that moved down the relatively smooth upper slope and encountered bedrock outcrops that created the hydraulic jumps to generate the cascade structure. The orientation of the headwalls of the cascades are similar to those of the ridge-like structures seen to the east and west of the region of smooth upper slope. Evidence that the flow continued down slope is found in the backscatter but not the bathymetry, indicating a non-erosive flow below the depth of the cascade (Figure 9-14).

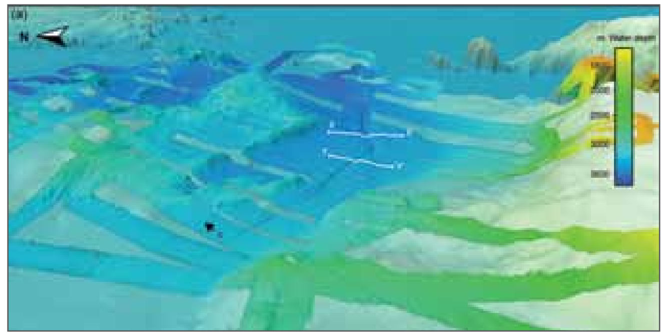


Figure 9-15. Perspective view of Weather Channel as it trends across the pull-apart basin north of Chukchi Cap.

The third paper, by Mayer, Gardner and Armstrong, "An Ultrahigh Latitude Submarine Channel: Northern Chukchi Rise," based on Law of the Sea data collected in the Arctic on the *Healy* describes a newly discovered channel that trends across a pull-apart basin that separates Chukchi Cap from Chukchi Rise in the Arctic Ocean. The channel, informally called the Weather Channel, runs orthogonal to the proximal steep relief to the north and south of it and transits at least 160 km over a gradient of less than 0.18˚ (Figure 9-15). Several tributary channels occur that come from the south but no connection was found to the bathymetric highs of Chukchi Cap. Mayer, Gardner, and Armstrong propose that small turbidity currents have flowed off bathymetric highs on both the north and the south of channel flow towards the center of the basin and then are bathymetrically constrained, particularly by the large sediment lobe at the base of Chukchi Cap. They speculated that the large asymmetry seen in the channel is not so much the result of levee building but rather is indicative of a bathymetric feature that constrained the flows. Recent evidence of wide-spread grounded ice to the south on Chukchi Rise indicates the delivery of large amounts of sediment to the margin and are a potential source for glacio-turbidites (Dove et al., 2014).

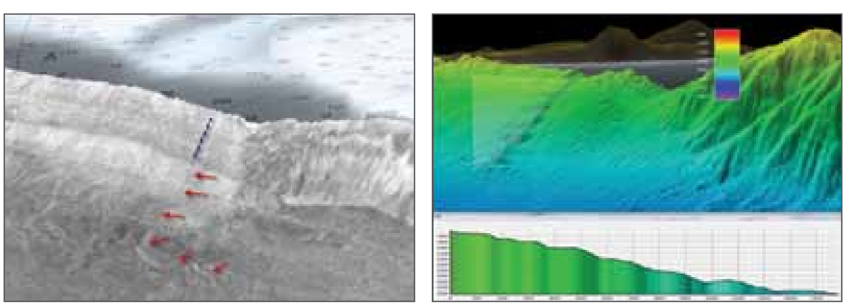


Figure 9-14. Perspective view of backscatter (left) and bathymetry (right) of cascades and plunge pools on the U.S. Gulf of Alaska margin.

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 entering 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 CCOM activities is provided below:

Feb. 12, 2014	Wildcats in Washington	*Campus Journal*
Feb. 19, 2014	Beyond the charts: geological highlights from NOAA's 2013 hydrographic field season in Alaska	*Hydro International*
Feb. 20, 2014	Research Profile: Colin Ware: Visualizing Patterns in the Data	*Campus Journal*
Feb. 28, 2014	UNH science discussions on tap at Brewery	*Seacoast Online*
Mar. 2, 2014	Spring Cafe series offers science in pub atmosphere	*Foster's Daily Democrat*
Mar. 12, 2014	Research Professor Receives Maritime Services Award	*Campus Journal*
Mar. 29, 2014	Missing Plane Searchers Checking Latest Objects for Link to Malaysia	*Huffington Post*
Mar. 29, 2014	No debris recovered in new search area for missing Malaysian jet	*Japan Times*
Mar. 29, 2014	Objects in new search area for missing jet need to be checked, Australia says	Boston Globe
Mar. 29, 2014	Searchers Checking Latest Objects for Link to Jet	NPR
Apr. 17, 2014	Flight 370 Search: Submersible Adjusted to Go Deeper	*ABC News*
May 5, 2014	As Research Gets More Expensive, Universities Will Be Pushed to Justify Costs	NPR
May 19, 2014	BOEM and New Hampshire sign agreement to identify sand resources	*Dredging News Online*
June 3, 2014	UNH scientist's research gets quick shot in new 'Godzilla' flick	*Foster's Daily Democrat*
June 4, 2014	Geologists Help 'Godzilla' Hide Out in World's Deepest Ocean Trench	*livescience.com*
June 18, 2014	How sea squirts are threatening the North Atlantic	WCSH6 Portland
June 19, 2014	Need help counting bubbles? Now you can use sound!	*Oceanbites*
July 23, 2014	Hydroid, NOAA Sponsor 2014 AUV Hydrographic Bootcamp	*OE Digital*
Aug. 20, 2014	New Seamount Discovered During ECS Mapping	*oceanexplorer.noaa.gov*
Aug. 25, 2014	New Seamount Discovered During ECS Mapping	*Hydro International*
Aug. 27, 2014	Scientific advice: Crisis counsellors	*Nature*
Sept. 2, 2014	UNH Ocean Mappers Discover Seamount in Pacific Ocean	*newswise.com*

Sept. 3, 2014	Massive Extinct Volcano Discovered Beneath Pacific Ocean	*livescience.com*
Sept. 4, 2014	Scientists Discover New 1100-Meter Seamount Rising from the Ocean Floor	*ScienceWorldReport*
Sept. 4, 2014	Scientists discover seamount in Pacific Ocean	*physorg.com*
Sept. 5, 2014	Scientists discover seamount under the ocean, possibly the remains of an underwater volcano	*Tech Times*
Sept. 5, 2014	Seamount Discovered Over 13,000 Feet Below Pacific Ocean	*Headlines & Global News*
Sept. 7, 2014	Massive Extinct Volcano Discovered Beneath Pacific Ocean	*Economic Times*
Sept. 9, 2014	New Hampshire Scientists Discover 100-year-old Giant Mountain in Pacific Ocean	*University Herald*
Sept. 11, 2014	Whale Alert App to Protect Marine Life	*Edhat Santa Barbara*
Sept. 11, 2014	Updated “Whale Alert” iPad, iPhone app invites public to contribute to protection of West Coast whales	*The Commerce Blog*
Sept. 15, 2014	Updated "Whale Alert" iPad, iPhone App	*The Maritime Executive*
Sept. 18, 2014	Dive into Marine Science at Free UNH Ocean Discovery Day	*Foster's Daily Democrat*
Sept. 23, 2014	Live: Explore Deep-Sea Canyons Never Before Seen by Humans	*Discover Magazine D-brief*
Oct. 3, 2014	Scientists Have Discovered Thousands of New Mountains—on the Ocean Floor	*Vox*
Nov. 12, 2014	Tracking Atlantic Bluefin Tuna	*Marine Technology News*

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. The Center hosted a number of local schools and community groups in 2014 that included Women in Science clubs, 120 students from Hampstead Middle School, 120 students from Barrington Middle School, 180 students from Oyster River Middle School, 120 students from Henniker Community School, 20 Somersworth High School students, 40 Manchester area students from ACCESS Academy, a group of 20 learning disabled adults from Friends in Action, and the Dover Navy Junior ROTC.

We have also worked hard to attract top-notch students to the program by making the activities of the Center known at appropriate venues including the American Geophysical Union Fall Meeting in San Francisco (attended by more than 24,000 people this year) where both a UNH booth in the academic showcase of the exhibitors hall (Figure 10-1) and an alumni event were organized and well attended.

Figure 10-1. UNH booth at the 2014 AGU Meeting.

Several large and specialized events were organized by the Center outreach team, including SeaPerch ROV events, the annual UNH "Ocean Discovery Days" event, and several workshops for educators. Throughout the

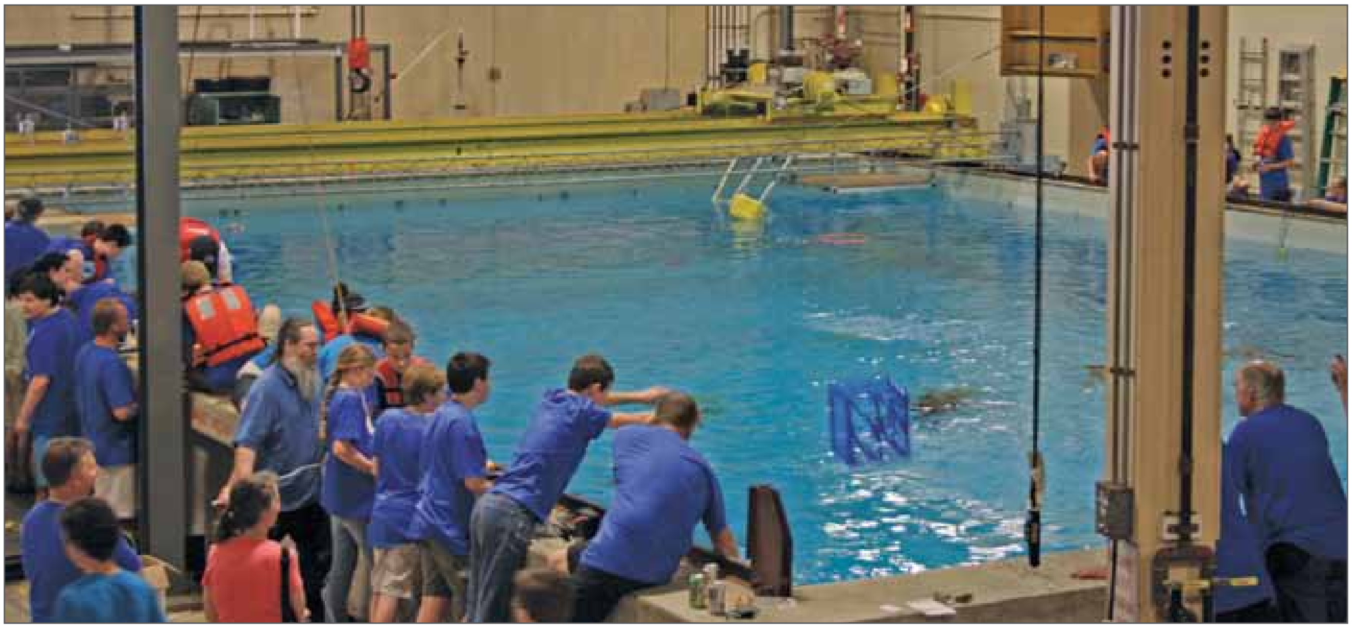


Figure 10-2. 2014 SeaPerch Competition.

year, the Center has been working with the Portsmouth Naval Shipyard (PNS) and UNH Cooperative Extension to host participating schools and community groups that have built SeaPerch ROVs and wish to test them in our facilities. The interest in these ROVs has been so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012.

Figure 10-3. 2014 SeaPerch Competition.

The third annual UNH Seacoast SeaPerch Competition was held Saturday, June 7, 2014 on the UNH campus. Twenty-four teams from New Hampshire schools, after-school programs, and community groups competed in this ROV (Remotely Operated Vehicle) challenge, using ROVs that they built themselves (Figures 10-2 and 10-3). A SeaPerch is an underwater Remotely Operated Vehicle made from simple materials like PVC pipe, electric motors and simple switches. Although there is a basic SeaPerch ROV design, the participants have the freedom to innovate and create new designs that might be better suited for a specific challenge. The 2014 competition included challenges such as an obstacle course where pilots had to navigate their ROVs through five submerged hoops, a salvage course called "The Heist" where pilots had to maneuver their ROVs to open a door and pass through to retrieve four submerged boxes on the bottom of the pool, and a poster session where they presented posters and explained their building process to a panel of judges. There was also a non-competitive challenge where teams had to work together to modify their ROVs to collect debris that had been scattered by a hurricane. By having the students tackle an engineering challenge like documenting and removing marine debris, it brought some real world relevance to the day. "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."

SeaPerch Educator Workshop

Twice in 2014 (January and November), the Seacoast SeaPerch program held educator ROV workshops at the

Figure 10-4. SeaPerch Educator Workshop.

Center. Both informal and formal educators were in attendance from all over the state, including representatives from 4H Clubs, UNH Cooperative Extension, Boys and Girls Club of Nashua, the Dover Housing Authority, homeschool educators, and teachers from 19 different schools in New Hampshire, Maine and Massachusetts (Figure 10-4). The training 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.

NOAA Educators Workshop: How Do We Explore?

On March 8, 2014, the Center hosted a NOAA-sponsored professional development workshop focused on ocean exploration (Figure 10-5) in collaboration with the NOAA Office of Ocean Exploration and Research. The NOAA Ship of Exploration *Okeanos Explorer* was used as the focal point as educators from New Hampshire, Massachusetts and Maine were guided through lessons that involved innovative, modern ocean-exploration strategies, and the sophisticated instrumentation and equipment used to explore our largely unknown oceans. Lesson topics included how targets are selected for exploration, mapping techniques, water-column exploration, remotely operated vehicles and the telepresence technology that enables access to real-time ocean exploration. Participants learned how to use lessons to assist in meeting performance expectations of the Next Generation Science Standards. The participants toured the Center during the workshop and were able to communicate with the *Okeanos Explorer* at sea via the telepresence console.

Ocean Discovery Days

Ocean Discovery Days is a joint outreach event run through the Center, the UNH School of Marine Science and Ocean Engineering, and the New Hampshire Sea Grant office that relies on faculty, staff and student volunteers from UNH and volunteers from the UNH Marine Docent program. The annual two-day event is held at the Chase Ocean Engineering Lab on campus and at the Judd Gregg Marine Research Facility in New Castle, NH. The 2014 Ocean Discovery Days were held on Friday and Saturday, October 3 and 4. On Friday, more than 1,000 students from school groups and homeschool associations from all over New Hampshire came to visit our facilities to learn about the exciting research happening here at the Center. The New Castle Marine Facility was also open to the public on Saturday, October 4 (Figure 10-6). Activities and demonstrations for all ages highlighted research on acoustics, ocean mapping, ROVs, lidar and ocean visualization. Students and the public were able to tour our engineering test tanks, see high-definition video from the deep sea in our Telepresence room, and try their hand at mapping the ocean floor. They could sit on the jetski that we use to map shallow coastal areas, 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 10-5. Brochure advertising the NOAA Educator's Workshop on Ocean Exploration.

Figure 10-6. Images from Ocean Discovery Day 2014.

Website Upgrades and Other Activities

Website

The website is the public face of the Center. Colleen Mitchell and Les Peabody took the lead in 2011 on a complete redesign of the Center website. The graphic design, navigation and overall feel have been changed to reflect a more modern design and are implemented using Drupal (an extensible content management system). The redesign of the Center's website culminated in the public launch of the new site in late March 2012. With the departure of Lester Peabody, who was responsible for coding the site in Drupal, Colleen still leads the development and we have contracted with UNH's Office of Research Computing and Instrumentation (RCI) for technical support.

The website contains new publications, seminar announcements, news items, and people pages and allows for the dynamic display of data. The home page is continually updated with newly featured images and videos, slides, publications, and news. The website is dynamic with new content continually being added. In particular, the publications, seminars and events, and news articles are updated frequently (Figure 10-7). Twenty-two front page slides were featured in 2014, highlighting cruise reports, television interviews, news articles, and outreach events.

Figure 10-7. The homepage of the Center's website.

In 2014, the website received 42,991 visits from 27,266 unique visitors; 62% of the visits were first time visitors. The average visit lasted 2 minutes and 31 seconds. Of the 42,991 visits, 86% were from desktop computers, 9% from mobile devices and 5% from tablets. One thousand nine hundred and eighty three visits were referred from social media sites with 56% of those coming from Facebook. Sixty-five percent of visits originated in the U.S. whereas the other 35% is spread all over the world. The most popular landing page is the home page, followed by an article that Giuseppe Masetti wrote about the Pacific seamount discovery, the People main page, and the Indian Ocean Project page.

While the average number of visits is about 160 on weekdays and 50 on weekends, there was a spike of 695 visits on Saturday, September 6, which occurred when several news articles were published about the discovery of an unmapped seamount in the Pacific during an ECS mapping cruise aboard the R/V *Kilo Moana* (Figure 10-8). Although seamounts are numerous and ocean mappers may be somewhat jaded by their discovery, this shows that the public has a fascination with such findings.

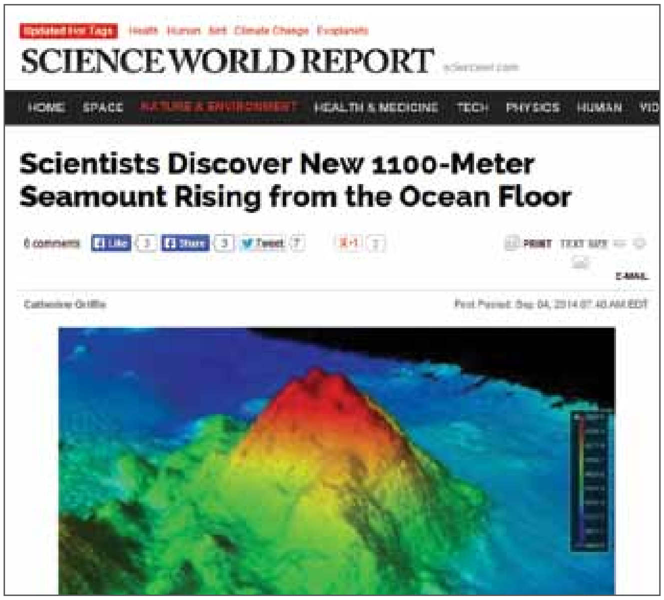


Figure 10-8. One of several news articles about the discovery of a new seamount in the Pacific.

Pinterest

The Center's Pinterest page (**www.pinterest.com/ccomjhc**) has a board for faculty members that serves as a kind of look book. A board dedicated to the Center and a board for research vessels has also been created (Figure 10-9). Pinterest serves as another social-media outlet to enhance the Center's digital presence, particularly in reference to attracting graduate students.

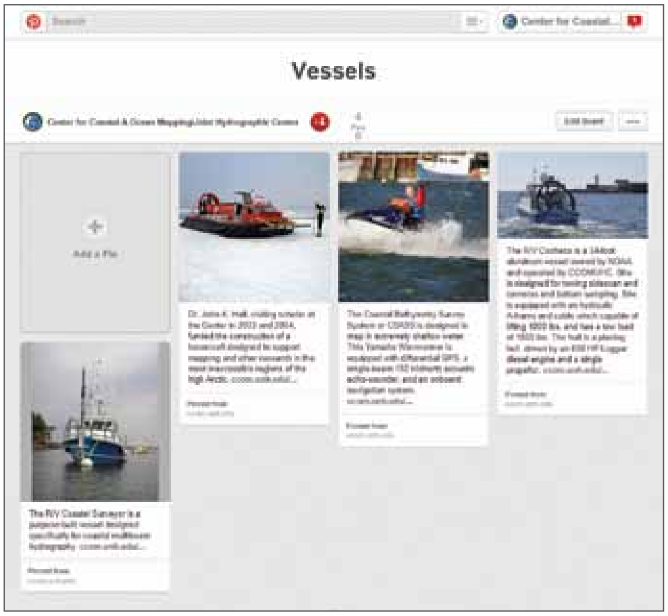


Figure 10-9. The Vessels board on the Center's Pinterest page.

Vimeo

The Center's videos are hosted by Vimeo (**http://vimeo.com/ccomjhc**). There are currently 72 videos in the Center's catalog (Figure 10-10). Some of these videos are short clips, such as a sampling of the Wind-Vis Weather Display or a quick underwater tour of the SeaPerch competition's salvage operation course. Other videos are full-length recordings of our seminar series. In addition to broadcasting the seminars as webinars, the talks are recorded as long as the speaker is amenable. Will Fessenden and Colleen Mitchell edit the videos and upload them to the Vimeo site.

In 2014, the Center's videos were played more than 17,599 times. Although the U.S. is the origin of most plays (more than 10,000), Center videos have been viewed all over the world, including such far-flung places as Mongolia, Pakistan, and the Isle of Man. The most popular video continues to be, "Mariana Trench Fly Through," which was created by Research Professor Jim Gardner and has been a featured video on the website.

Flickr

There are currently 1,988 images in the Center's Flickr photostream (**www.flickr.com/photos/ccom_jhc**). Since August 2009, when the account was created, these images have received a total of 162,594 views (Figure 10-11).

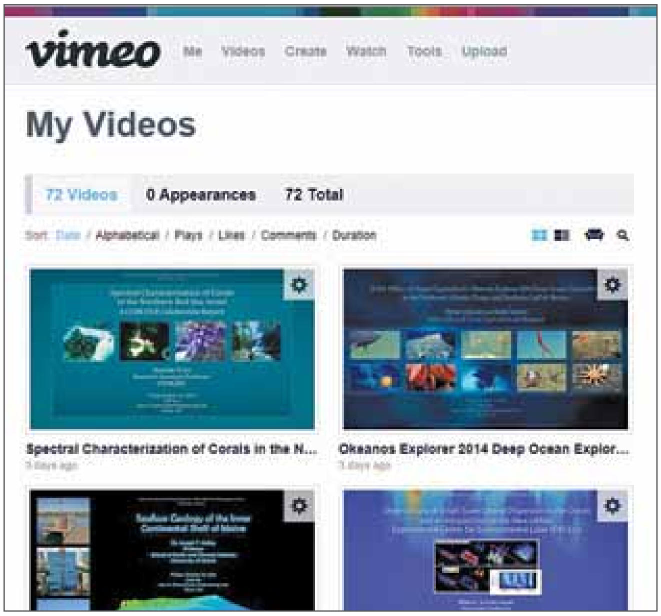


Figure 10-10. A sampling of the videos available in the Center's Vimeo catalog.

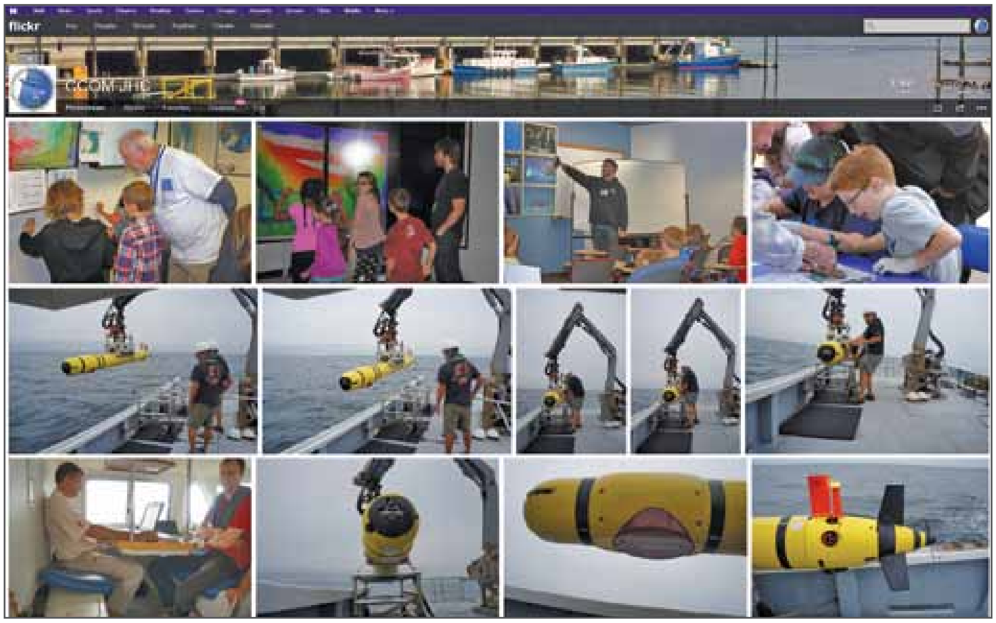


Figure 10-11. The Center's Flickr photostream.

Seminar Series

Thirty-four seminars comprised the 2014 seminar series. Five of these seminars were master's thesis defenses, two were presentations of directed research projects, and the remainder were by Center researchers or experts from industry and academia.

Graduate students Ashley Norton and Josh Humberston served as seminar coordinators for the 2013/2014 academic year and did an exemplary job of populating the schedule and interfacing with the speakers. At the beginning of the fall semester, Kelly Nifong and Scott Loranger took over as student coordinators. We have learned that communication is the key to making sure that all facets of the seminar procedure are attended to. Kelly and Scott have not only embraced this but also initiated early planning meetings. Will Fessenden continues to contribute his IT prowess in helping the speakers set up their presentations, making sure that the webinars ran smoothly, and recording the presentations' video and audio. Colleen Mitchell advertises the seminars with customized flyers 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 10-12).

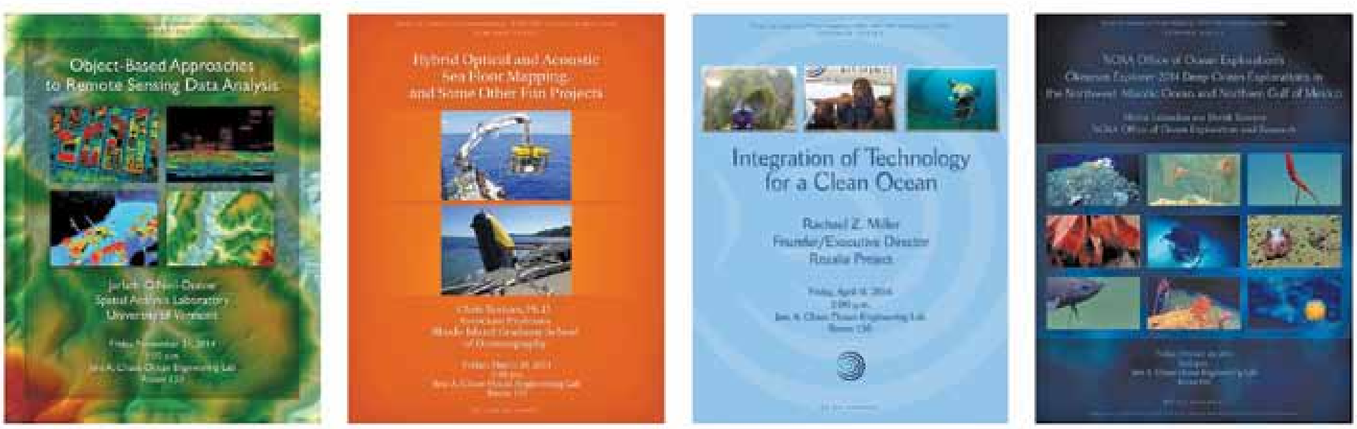


Figure 10-12. Some of the 34 flyers produced for the 2014 Seminar Series.

Figure 10-13. The Center's Facebook page.

Facebook

The Center's Facebook page (**http://www.facebook.com/CCOMJHC**) mirrors the website and provides a less-formal venue for posting Center news, announcements, videos, and photos (Figure 10-13). The page currently has 420 followers. Colleen Mitchell administers the page and creates posts that are interesting and informative, as well as carefully monitors 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, which exponentially increases exposure. Like the website, the Center's Facebook page is vibrant and content-rich and works in tandem with the website to increase the Center's on-line presence. The Facebook page also provides an easy way for alumni to stay involved with the Center.

The most popular post this year was on July 11 when we said goodbye to the 2013/2014 GEBCO class. That post reached 830 people. An October 8 post about the discovery of an undersea volcano off the coast of San Francisco reached 662 people (Figure 10-14). Not surprisingly, every time there is a GEBCO-related post, it is not only popular but usually results in new followers.

Facebook's privacy guidelines do not allow divulging individual page followers, although a notification is made when a follower first joins the page. Because the page administrator, Colleen Mitchell, has viewed these notifications since the page was created in September 2011 and is aware that our Facebook audience mostly comprises researchers and scientists from around the world with a large representation of NOAA people and former GEBCO fellows. The decisions about what content to share and how to write the post are made with this in mind.

Figure 10-14. Two of the posts with the most exposure in 2014.

Field Season Reporting

Two thousand fourteen was the first year that the Center's summer cruise calendar was made public. It was published on both the website and Facebook (Figure 10-15). As administrator of those two sites, Colleen Mitchell reached out to Center staff who planned to participate on these cruises to send back reports from the field. Nearly everyone she contacted did so. The responses ranged from simple photos with a one sentence caption to more formal reports such as Giuseppe Masetti's articles on the discovery of the Pacific seamount and the underwater volcano and the detailed journal that Kevin Jerram kept while he participated in the SWERUS-C3 Expedition to the Arctic aboard the icebreaker *Oden*.

Figure 10-15. The 2014 Summer Cruise Calendar.

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 the 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.

- Airborne Hydrography AB
- Alidade Hydrographic
- AML Oceanographic
- Bluefin Robotics
- C&C Technologies Inc.
- CARIS, Inc.
- Chesapeake Technologies
- Clearwater Seafoods
- EarthNC
- EdgeTech
- Environmental Systems Research Institute, Inc. (ESRI)
- Fugro LADS Inc.
- Geocap
- HYPACK, Inc.
- IFREMER
- IIC Technologies
- Instituto Hidrografico (IH)
- Kongsberg Underwater Technology, Inc. (KUTI)
- L-3 Communications Klein Associates
- Leidos
- Novatel
- Ocean High Technology Institute
- Ocean Imaging Consultants, Inc.
- Ocean Science
- Odom Hydrographic Systems, Inc. (Odom)
- Optech
- Quality Positioning Services B.V. (QPS)
- Quester Tangent
- Rolls Royce
- Science Applications International Corporation (SAIC)
- Seismic Micro Technology
- SevenCs
- SMT Kingdom
- Substructure
- Survice Engineering Company
- Teledyne Benthos, Inc.
- Teledyne Reson
- Triton Elics International, Inc.
- Tycom LTD
- YSI, Inc.

In addition, grants are in place with:

- 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
- U.S. Geological Survey

The Center also received support from other sources of approximately $2.498 M for 2014 (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. M.S. degree requirements are described below.

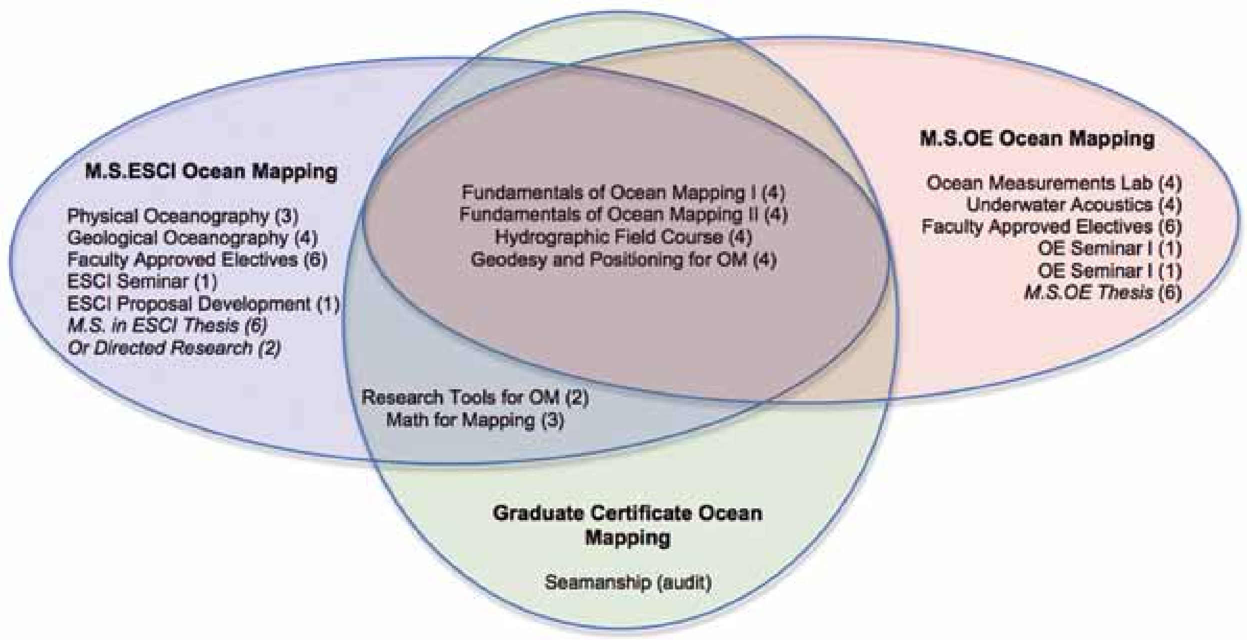


Figure 10-16. Curricula for master's degrees and certificates in Ocean Mapping at UNH JHC/CCOM.

Figure 10-17. 2014 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		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

Little Bay Surveys, January 1–June 17, R/V *Galen J*. Conduct acoustic single-beam survey in the Little Bay, NH. Sample and analyze bottom sediments for grain size distribution, bulk density, water content, and porosity in support of Joshua Humberston's thesis projects. (Jon Hunt, Joshua Humberston, Tom Lippmann)

CBASS Current Surveys, January 1–June 17, *CBASS*, Conducted current surveys in support of Eric Bajor's thesis as part of the NEWBEX field program. (Jon Hunt, Tom Weber, Eric Bajor, Tom Lippmann)

RA1401 Pre-shipyard EM710 Performance Evaluation, January 13–14, NOAA Ship *Rainier*. This was a short transit for the NOAA Ship *Rainier* from Newport, Oregon to the Lake Union Dry Dock in Seattle, Washington. Glen Rice planned and gathered pre-shipyard EM710 echosounder data to compare to post-shipyard performance. Part of the shipyard work included swapping the EM710 transducers for ice hardened transducers. The new titanium covered receiver and transmitter have not been widely tested on other vessels, so there was interest in their field performance in comparison to the standard units. (Glen Rice)

FK140204 R/V Multibeam Echo Sounder Review, February 3–7, R/V *Falkor*. EM710 and EM302 annual multibeam checkup. (Paul Johnson)

EX1402 Leg 1 Gulf of Mexico Mapping, February 24–March 15, NOAA Ship *Okeanos Explorer*. Lead Watch Stander, Expedition Coordinator training. (Derek Sowers, Meme Lobecker, Lindsay McKenna)

EX1402 Leg 2 NW Gulf of Mexico Mapping, March 19–April 4, NOAA Ship *Okeanos Explorer*. Expedition Coordinator, Mapping Team Lead. (Lindsay McKenna)

RA1403 Post-shipyard EM710 pPerformance Evaluation, March 21–June 24, NOAA Ship *Rainier*. The EM710 was updated to new ice-hardened transducers during the first few months of 2014. Sea acceptance trials were conducted immediately following the shipyard period with representatives from both NOAA and Kongsberg aboard. (Glen Rice)

Edgetech 6205 Field Trial, April 28–May 2, R/V *Coastal Surveyor*. Conducted a field trial of an Edgetech 6205 bathymetric sidescan sonar system. Val Schmidt facilitated this event along with help from Kevin Jerram. Evan Gray (graduate student) also participated. Damon Wolfe and Garry Kozak of Edgetech were on hand to provide technical support. (Kevin Jerram, Val E. Schmidt)

NovAtel Field Trial, April 28–May 7, R/V *Coastal Surveyor.* Conducted a field trial of the NovAtel LN200 and ProPac6 inertially aided navigation system. Val Schmidt facilitated this trial, along with assistance from Kevin Jerram and Brian Calder. The trial was conducted, in part, in conjunction of a field demo of an Edgetech 6205 sonar system. (Brian Calder, Kevin Jerram, Val E. Schmidt)

1 Edgetech Bathy Sonar Cruise, May 1, R/V *Coastal Surveyor.* Took class out with Garryz Kozak from Edgetech to demo the 6205 PDES. (Val E. Schmidt, Semme J. Dijkstra)

Multibeam Trials and Training NA040, May 4–10, E/V *Nautilus*. NA040 included calibration for angular offsets (patch testing) and acoustic extinction testing of the Kongsberg EM302 multibeam echosounder. The operational area was the continental shelf break in the Gulf of Mexico off St. Petersburg, FL. Ancillary activities included training for multibeam mapping watchstanders and assistance with additional shipboard acoustic testing. (Paul Johnson, Kevin Jerram)

NEWBEX, May 14, R/V *Coastal Surveyor*. NEWBEX-related cruises. (John Heaton, Eric Bajor, Glen Rice, Carlo Lanzoni)

Great Bay Lines Surveys, May 15–June 30, *Galen J.* and WHOI's *Limulus*. Obtain acoustic single-beam full-waveform surveys along four lines within the Great Bay. Also obtain bottom sediment samples for grain size analysis and carbon content. Obtain video surveys of the bottom seafloor characteristics. (Jon Hunt, Joshua Humberston, Tom Lippmann)

Achziv2014 Ground Truth Survey 2014, May 26–27, R/V *Etziona*. In order to ground truth spectral imagery collected using an airborne CASI systems and Landsat satellite imagery, we collected UW imagery, UW spectral measurements, grab samples and side scan sonar (Klein 5100) imagery. (Shachak Peeri)

Summer Hydro 2014, June 6–July 4, R/V *Coastal Surveyor* and R/V *Cocheco*. This is the field part of the Summer Hydro course taught by Semme Dijkstra. Students plan a survey, mobilize vessels, execute the survey, process the data, create a sampling program based on the data, collect samples, write a comprehensive descriptive report and create an ENC cell from the data. (Ben Smith, Emily Terry, Semme J. Dijkstra)

CO140609 ADCP deployment, June 9, R/V *Cocheco*. This cruise deployed equipment for the Newbex project and supported Eric Bajor's master's research. (Eric Bajor, Liam Pillsbury, Jon Hunt, Glen Rice)

Great Bahama Bank, Exploration/ROV, June 11–December 19, E/V *Nautilus*. Fort Lauderdale to Gulfport FL, Exploration/ROV. (Larry Mayer)

NBP1405 EM122 MBES Sea Trials, June 14–19, I/B *Nathaniel B. Palmer.* NBP1405 involved sea trials of the vessel's multibeam echosounder after an upgrade of its transceiver from a Kongsberg EM120 to an EM122. Paul and Kevin reviewed the system geometry and software configuration and performed a patch test calibration and deepwater accuracy assessment. (Paul Johnson, Kevin Jerram)

ASIS Leg 1 NPS Habitat Mapping Project, June 14–25, R/V *Lookdown* and R/V *Daiber*. This is an AUV and surface vessel mapping project conducted by Art Trembanis (Univ. Delaware, CCOM Affiliate Associate Professor) for the National Park Service. Schmidt and intern Loker Xu provided AUV operational support and technical support related to sonar and navigation system operation and data processing. (Val E. Schmidt)

Humpback Tagging: Stellwagen, June 16–26, R/V *Auk*. This study focused on foraging behaviors of humpback whales on Stellwagen Bank. (Colin Ware)

Eilat2014 Spectral Characterization of Stylophora Corals in Eilat, June 16. Using UW light sources (tungsten and UW blue, green and red laser), we measured the spectral response of coral. (Shachak Peeri)

Eelgrass Backscatter Experiment, June 23–July 2. This was a 12-day field experiment during which the eelgrass canopy adjacent to the UNH/NOAA pier at New Castle was examined over a number of tidal cycles from six different angles of ensonification by a single-beam transducer. A high-resolution current profiler and video camera were also deployed to observe the movement of the canopy under currents in the field. This experiment was the first part of Ashley's dissertation research, and she oversaw the construction of the experiment apparatus and implementation of the experiment. Semme J. Dijkstra supervised and assisted in the deployment and implementation of this experiment; Jennifer Dijkstra assisted in diving logistics throughout the experiment; and Andy McLeod assisted with the construction and transportation of the experimental apparatus. (Semme J. Dijkstra, Jenn Dijkstra, Andy McLeod, Ashley Norton)

Scallop Incident Mortality, July 8–20, M/V *Christian and Alexa*. The Scallop Incident Mortality research initiative is a program awarded to Art Trembanis (Univ. Delaware, CCOM Affiliate Associate Professor), through the NOAA Fisheries "Reserve Set-Aside" program. The grant was awarded to study the health of scallops not captured in routine fishing operations through seafloor photography and sonar mapping. Through the Center's ongoing collaboration with Dr. Trembanis, Schmidt was the lead AUV engineer for this effort. (Val E. Schmidt)

FL 01 Flathead Lake Circulation, July 14–November 15, R/V *Jessie B*. Deployed four upward-looking ADCPs in Flathead Lake, MT for four months. Also conducted surface survey transects for currents across the lake. The goal was to examine circulation and mixing in the lake with forward looking to effects on bathymetric evolution and ecological response. (Jon Hunt, Tom Lippmann)

Multi-beam Eelgrass Survey, July 15–19, *Orion*. An Odom MB1 was mounted on the survey vessel *Orion*, owned and operated by Substructure, Inc. Eelgrass beds at three locations in the Great Bay estuary were surveyed. These data are an important part of Ashley Norton's dissertation and she led the data collection and processing effort in the field. Semme J. Dijkstra supervised and assisted in obtaining the sonar, coordinating with Substructure, and in data collection. (Semme J. Dijkstra, Ashley Norton)

AUV Hydrographic Bootcamp, August 3–8, R/V *Muriel B.* and R/V *Resolution*. AUV Hydrographic Bootcamp is a workshop hosted by the Center to forward the state of the art of hydrographic surveys from AUVs. As part of this workshop several days of field operations and data collection are undertaken by workshop members. Field operations were facilitated by the R/V *Muriel B.* operated by Hydroid Inc. and the use of NOAA's REMUS 600 AUV with EM3002 multi beam sonar. Participants: Vince Capone (Black Laser Learning), Burns Foster, Bill Lamey (Caris), Val Schmidt, Evan Gray, Jon Hunt (CCOM), Taylor Brown (DOF), Steve Brodet, Kevin Brown, Rick Morton, Maureen Kelly, Richard 'Bungy' Williams, Julie Ferland, John Duchesney (Hydroid), John Hesse, (Hydroid Boat Capt.), Joseph Adamski, Harold Orlinsky (Hypack), Oyvind Hegrenaes (Kongsberg Horten), Dale Chayes (LDEO), Jenny Paduan (MBARI), Dave Small (NAVO), Lawrence Haynes Haselmaier, Casey Taylor (NAVOCEANO), James Miller, NOAA OCS, Lindsay McKenna, NOAA OE, Janice Eisenberg, NOAA/HSTP, Rob Downs, NOAA/HSTP, Mike Annis, Glen Rice (NOAA/HSTP), Vitad Pradith (NOAA/NRT), Robert Schleck (Portsmouth Naval Shipyard), Erin Heffron (QPS), Shannon Byrne (SAIC/Leidos), Trevor Metz, Kenny Haulsee, Hunter Brown, Carter Duval, Art Trembanis (UDEL), PO Michael Hughes, CPO Jason Dumbleton (UK MoD), Ian Vaughn (URI), Megan Thomas (USNA), Patrick Scalli (Navis Group, LLC), Damian Manda, NOAA. (Glen Rice, Lindsay McKenna, Damian Manda, Jon Hunt, Val E. Schmidt)

KM14-17 ECS Cruise to Johnston Atoll Area, August 9–22, R/V *Kilo Moana*. Jim Gardner planned and was the Chief Scientist on this cruise and processed all the data collected from departure at Papeete, Tahiti to Honolulu, HI. The cruise mapped two bathymetric gaps—one that occurs along Keli Ridge and the other that spans a region between the northern nose of Karin Ridge and a bank of the Mid Pacific Mountains. The gaps were mapped to determine whether they descended to adjacent "abyssal depths" or not. Evan Robertson, NOAA/NGDC, participated on this cruise as one of the watch standers and Andrew Armstrong participated as a co-Chief Scientist. (Andrew Armstrong, Brian Calder, Kelly Nifong, Giuseppe Masetti, Jim Gardner)

SKQ201400L3 MBES Shipboard Acceptance Tests, August 9–18, R/V *Sikuliaq*. Planned and led the shipboard acceptance tests (SAT) for a new EM302 and EM710 multibeam echosounder system. This included reviewing all installation documentation, conducting patch tests for static offset calibrations, assessing swath performance and accuracy testing, self-noise testing, backscatter equalization data collection, and water column verification. Lieutenant Commander Samuel Greenaway from NOAA's Office of Coast Survey observed and participated in this field program in order to document how the Multibeam Advisory Committee conducts MBES SATs. (Paul Johnson)

EM2040 Evaluation, August 11–15, *Bay Hydrographer II*. Evaluate the EM2040. This consisted of applying the new Coast Survey Sonar acceptance procedures for the first time. (Mashkoor A. Malik, Glen Rice)

SWERUS-C3 Leg 2 Swedish-Russian-US Arctic Ocean Investigation of Climate-Cryosphere-Carbon Interactions, August 17–October 6, I/B *Oden*. The SWERUS-C3 expedition included two extended cruises aboard the Swedish icebreaker *Oden* to detect and characterize methane pathways from the seabed to the atmosphere in the East Siberian Arctic Ocean. Larry, Tom, and Kevin participated in Leg 2 of the expedition (Larry and Kevin on board receiving technical support from Tom on shore), using a Kongsberg SBP120 sub-bottom profiler, Kongsberg EM122 multibeam echosounder, and Simrad EK80 wideband split-beam echosounder simultaneously for seabed, seafloor, and water column mapping of methane sources and bubble plumes. (Larry Mayer, Kevin Jerram, Tom Weber)

Megapex, September 1–October 31, various small boats. Conducted field experiments as part of the international MEGAPEX experiment held in The Netherlands at their "sand engine" site. Field observations include small-scale bedform evolution and fine-scale currents inside the surf zone in collaboration with Dutch colleagues. Efforts here in collaboration with Diane Foster and her doctoral student, Meagan Wengrove. (Jon Hunt, Tom Lippmann)

Barnaget Bay 2014, September 6–7. Field work to characterize submerged aquatic vegetation (SAV) in a storm impacted area around Barnegat Bay, NJ. (Shachak Peeri)

Scallop Incident Mortality, September 8–16, F/V *Christian and Alexa*. This was the second of two field programs for the Scallop Incident Mortality research initiative. This is a program awarded to Art Trembanis (Univ. Delaware, CCOM Affiliate Associate Professor) through the NOAA Fisheries "Reserve Set-Aside" program. The grant was awarded to study the health of scallops not captured in routine fishing operations through seafloor photography and sonar mapping. Through the Center's ongoing collaboration with Dr. Trembanis, Schmidt was the lead AUV engineer for this effort. (Val E. Schmidt)

Ground Truth 2014, Ocean Mapping class 2014, September 13, R/V *Gulf Challenger.* Ground truth cruise for Ocean Mapping class. (Jim Gardner, Larry Ward, Shachak Peeri)

FK140922 Multibeam Echosounder System Calibration and Review, September 22–24, R/V *Falkor*. Planned and led the calibration and quick review of the EM302 and EM710 multibeam echosounder system. This included conducting patch tests for static offset calibrations as the ship had just installed a new Seapath and a new POS MV position systems, assessing swath performance, and evaluating self-noise. (Paul Johnson)

AT26-21 ECS 2014 Cruise to the Mendocino Ridge, September 23–October 11, R/V *Atlantis*. Andrew Armstrong was the Chief Scientist on this cruise that collected data from departure at Astoria, OR to San Francisco, CA. The cruise, part of U.S. Extended Continental Shelf effort, completed a high resolution mapping of the Mendocino Ridge off the California coast junctioning with bathymetry acquired on *Okeanos Explorer* Cruises EX 0903-0905 in 2009. Margot Bohan (NOAA), Jennifer Jencks (NOAA-CIRES), Elliot Lim (NOAA-CIRES), Meredith Westington (NOAA), and Daishi Horiuchi (GEBCO fellow) participated on this cruise as watch standers. Giuseppe Masetti participated as a co-Chief Scientist (Andy Armstrong, Giuseppe Masetti)

GB 01 Stark Penetrometer, September 27–28, *Eastern*. Conducted field sampling in the Great Bay with sediment penetrometer developed by Dr. Nina Stark. Analysis underway for comparison with bulk density and acoustic backscatter. (Tom Lippmann)

Barnegat Bay Field Sampling, October 2–5. Field sampling involved traveling to multiple sites in Barnegat Bay and identify shallow water vegetation. This information will be used as ground truth for our lidar and satellite remote sensing portion of the Super Storm Sandy grant. (Shachak Peeri, Jenn Dijkstra)

Edgetech 4600 - QPS Field Trials, October 13–17, R/V *Coastal Surveyor.* This week-long field trial was a collaborative event between Edgetech and QPS-QINSy to integrate an Edgetech 4600 PMBS sonar (on long-term loan from Edgetech) with various data acquisition and processing packages (SonarWiz, Hypack, and QINSy). Participants: LCDR Sam Greenaway (NOAA), Lisa Brisson (Edgetech), Daman Wolfe (Edgetech), Evan Martzial (QPS). (Kevin Jerram, Paul Johnson, Kelly Nifong, Val E. Schmidt)

Bluefin Robotics Hydro Field Trial, October 27–31, R/V *Resolution*. This was a collaborative effort with Bluefin Robotics to begin a close inspection of their systems and operations with regard to hydrographic survey. Their Bluefin 9" AUV was operated from their vessel the R/V *Resolution* which was brought to Portsmouth for the event. Bluefin Participants included Jim Glynn (former UNH graduate), Will O'Halleran (Director of Operations) and Scott Biddlestone (Lead Systems Engineer) from Bluefin, as well as John Gann and Dave Finlaysen from Chesapeake Technology. (Val E. Schmidt)

Sonar and Navigation System Integration, December 1–4, R/V *Daiber*. This event was an engineering integration and field trial of an Edgetech 6205 and Coda F190 navigation system. The event was part of our ongoing close collaboration with Dr. Art Trembanis, (Univ. Delaware, CCOM Affiliate Associate Professor). (Val E. Schmidt)

2014 Velodyne laser scanner, December 1, R/V *Coastal Surveyor*. We are integrating a velodyne 2D scanner to a survey vessel. The goal is to see how well the scanner performs to identify piles, piers and other hazard-to-navigation targets. (Shachak Peeri)

PNS 01 Portsmouth Naval Shipyard, December 15–18, *CBASS*. Conduct MBES and ADCP surveys near the Portsmouth Naval Shipyard in New Hampshire’s Piscataqua River. (Jon Hunt, Tom Lippmann)

Appendix C: Other Funding

Name of Project	PI	Grantor	FY Award	Total Award	Length
GeoCamera Software Installation on the USCGC *Healy*	Arsenault, R.	University of California, San Diego	6,679	6,679	9 months
IT Support for NOAA Employees	Calder, B.	NOAA	51,575	51,575	1 year
IOCM Research in Support of Super Storm Sandy Disaster Relief	Calder, B. Mayer, L.	NOAA	-	999,984	2 years
Optimizing Multibeam Data Acquisition, Operations, and Quality for U.S. Academic Research Fleet	Johnson, P.	National Science Foundation	-	420,527	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	600,000	600,000	1 year
UNH/CCOM Technical Services	Mayer, L.	University of Alaska, Fairbanks/ National Science Foundation	42,405	42,405	2 months
Seafloor Methane Deposits	Mayer, L.	Columbia University/Sloan Foundation	46,250	46,250	1 year
Petermann Gletscher, Greenland	Mayer, L.	National Science Foundation	249,278	249,278	3 years
Support for R/V *Falkor* Mapping Support	Mayer, L.	Ocean Exploration Trust	-	19,260	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
Mapping and Quantifying Methane Seeps on the Eastern Siberian Shelf and Slope—A Component of the Swedish Russian U.S. Climate-Cryosphere-Carbon Interactions (SWERUS-C3) Program	Mayer, L. Weber, T.	National Science Foundation	290,667	290,667	2 years
Seafloor Video Mosaic Research	Rzhanov, Y.	U.S. Geological Survey	10,000	50,000	4 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	15,858	1 year
Aerial Imagery of Bluefin Tuna	Rzhanov, Y.	U. Mass Amherst/NOAA National Marine Fisheries Services	-	14,603	2 years
AUV Boot Camp 2014	Schmidt, V.	Hydroid, Inc.	20,000	20,000	-
Assessment for Offshore Sources	Ward, L.	Bureau of Ocean Energy	199,997	199,997	2 years
TrackPlot	Ware, C.	Office of Naval Research	43,661	78,179	1.5 years
Visualization of Human Systemns	Ware, C.	Systems & Technology	101,515	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
Enhancements Currents, Sea State, and Weather Information to Submarine Navigator	Ware, C. Calder, R.	Office of Naval Research	30,000	30,000	8 months
Development of a Broadband Acoustic System for Quantifying the Flux of Free Gas in Methane Seeps	Weber, T.	National Science Foundation	353,222	690,785	5 years
Modeling Statistics of Fish Patchiness and Predicting Associated Influence on Statistics of Acoustic Echoes	Weber, T.	Office of Naval Research	39,349	180,720	3 years
Fate of Methane	Weber, T.	Massachusetts Institute of Technology	160,945	245,788	3 years
TOTAL			2,498,359	10,673,561	

Appendix D: Publications

Journal Articles

Fadahunsi, O., Pe'eri, S., and Armstrong, A.A., Characterization of the Nigerian Shoreline Using Publicly-Available Satellite Imagery, *Hydro International*, vol. 18(1). pp. 22–25.

Flinders, A.F., Mayer, L.A., Calder, B.R., and Armstrong, A.A., Evaluation of Arctic Multibeam Sonar Data Using Nadir Crossover Analysis and Compilation of a Full-Resolution Data Product, *Computers and Geosciences*, vol. 66. Elsevier, pp. 228–236.

Gardner, J.V., Armstrong, A.A., Calder, B.R., and Beaudoin, J., So, how deep is the Mariana Trench?, *Geology*, DOI:10.1080/01490419.2013.837849. Geological Society of America, Boulder, CO.

Jakobsson, M., Andreassen, K., Bjarndottir, L. R., Dove, D., Dowdeswell, J., England, J. H., Funder, S., Hogan, K., Ingolfsson, O., Jennings, A., Larson, N.K., Kirchner, N., Landvik, J.Y., Mayer, L.A., Mikkelsen, N., Moller, P., Niessen, F., Nilsson, J., O'Regan, M.A., Polyak, L., Norgaard-Pedersen, N., and Stein, R., Arctic Ocean Glacial History, *Quaternary Science Reviews*, vol. 92. pp. 42–67.

Lee, S. and Alexander, L., Software Quality Assurance in e-Navigation: Developing Standards to Harmonize Ship and Shore e-Navigation, *Sea Technology*, vol. 55, no. 1. pp. 46–48.

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*, DOI: 10.11109/JOE.2013.2294291. IEEE, pp. 1–13.

Masetti, G. and Calder, B.R., A Risk Index Methodology for Potentially Polluting Marine Sites (PPMS), Environment Systems and Decisions, Springer, p. 14.

Mayer, L.A., Ocean Mapping, *Journal of Ocean Technology*, vol. 9. no. 2. Fisheries and Marine Institute of Memorial University of Newfoundland, St. John's, Newfoundland, Canada, pp. 13–18.

Parrish, C.E., Rogers, J., and Calder, B.R., Assessment of Waveform Shape Features for Lidar Uncertainty Modeling in a Coastal Salt Marsh Environment, *Geoscience and Remote Sensing Letters*, vol. 11, no. 2. IEEE, pp. 569–573.

Tetteh, E., Pe'eri, S., and Marks, K., Updating the Landsat Satellite-Derived Bathymetry Procedure, Hydro International, vol. 18, no. 2. pp. 18–21.

Ware, C. Improving the Display of Wind Patterns and Ocean Currents, *Bulletin of the American Meterorological Society*, vol. 95. American Meteorological Society, Boston, MA, pp. 1–9.

Ware, C., Wiley, D.N., Friedlaender, A.S., Weinrich, M.T., Abernathy, K., Hazen, E., Bocconcelli, A., Stimpert, A.K., and Thompson, M.A., Bottom-Roll Feeding by Humpback Whales (Megaptera Novaeangliae) in the Southern Gulf of Maine, *Marine Mammal Science*, vol. 30, issue 2. pp. 495–511.

Weber, T.C. , Mayer, L.A., Jerram, K., Beaudoin, J., Rzhanov, Y., and Lavalvo, D., Acoustic Estimates of Methane Gas Flux from the Seabed in a 6000 km2 Region of the Northern Gulf of Mexico, *Geochemistry, Geophysics, Geosystems*, vol. 15, no. 5. AGU, pp. 1911–1925.

Wolfson-Schwehr, M.L., Boettcher, M.S., McGuire, J.J., and Collins, J.A., The Relationship Between Seismicity and Fault Structure on the Discovery Transform Fault, East Pacific Rise, *Geochemistry, Geophysics, Geosystems*, vol. 15. pp. 3698–3712.

Conference Abstracts

Aslaksen, M. and Parrish, C.E., New Topographic-Bathymetric Lidar Technology for Post-Sandy Mapping, Canadian Hydrographic Conference, St. John's, Newfoundland, Canada, April 14–17.

Bortoluzzi, G., Spagnoli, F., Aliani, S., Romeo, T., Canese, S., Esposito, V., Grassi, M., Masetti, G., Dialti, L., Cocchi, L., Muccini, F., Lacono, V., Yakimov, M., La Spada, G., Ligi, M., Giordano, P., Franchi, F., Ferrante, V., Borgognoni, L., Tudino, T., Guideri, M., Ivaldi, R., Pratellesi, M., Marziani, F., Niccolini, F., Barbieri, E., Capaccioni, B., and Andaloro, F., New Geological, Geophysical and Biological Insights on the Hydrothermal System of the Panarea – Basiluzzo Volcanic Complex (Aeolian Islands, Tyrrhenian Sea), SGI-SIMP 2014, Milan, Italy, September 10–12.

Carman, M.R., Colarusso, P.D., Grunden, D.W., Wong, M.C., McKenzie, C., Matheson, K., Davidson, J., Heinig, C., Fox, S., Neckles, H., Schott, S., Pickerell, C., and Dijkstra, J.A., Distribution and Diversity of Invasive Tunicates on Eelgrass in Eastern North America: A Latitudinal Study Between N 40° and N 50°, New Jersey to Newfoundland, EPA, Eelgrass Conference, Boston, MA, March 18.

Chase, A.L., Dijkstra, J.A., and Harris, L.G., The Influence of Substrate Identity on Ascidian Larval Settlement Preference and Fouling Community Development, International Invasive Sea-Squirt Conference, Woods Hole, MA, October 29–31.

Chase, A.L., Dijkstra, J.A., and Harris, L.G., The Influence of Substrate Identity on Ascidian Larval Settlement Preference and Fouling Community Development, International Invasive Sea-Squirt Conference, Woods Hole, MA, October 29–31.

Colarusso, P.D., Carman, M.R., Nelson, E.P., Chintala, M.M., Grunden, D.W., Wong, M.C., McKenzie, C., Matheson, K., Davidson, J., Heinig, C., Fox, S., Neckles, H., Schott, S., Pickerell, C., and Dijkstra, J.A., Casual Observations, Random Musings and Wild Extrapolations Based on Some Actual Data on the Impact of Invasive Tunicates to Eelgrass, New England Estuarine Research Society, Salem, MA, May 1–3.

Dijkstra, J.A. and Litvaitis, M., Evolutionary Response of Colonial Invertebrates to Temperature in the Gulf of Maine, International Invasive Sea-Squirt Conference, Woods Hole, MA, October 29–31.

Dijkstra, J.A. and Simkanin, C., Phenotypic and Reproductive Trade-Offs of Colonial Invertebrates to Salinity, International Invasive Sea-Squirt Conference, Woods Hole, MA, October 29–31.

Eren, F., Pe'eri, S., Rzhanov, Y., Thein, M.W., and Celikkol, B., Pose Detection and Control of Multiple Unmanned Underwater Vehicles Using Optical Feedback, Oceans '14 MTS/IEEE, Taipei, Taiwan, April 7–10.

Eren, F., Pe'eri, S., Thein, M.W., Rzhanov, Y., Celikkol, B., and Swift, R., Evaluation of Detector Array Designs for Optical Communication Between Unmanned Underwater Vehicle, SPIE 2014, August 19–21.

German, C.R., Boetius, A., Whitcomb, L.L., Jakuba, M., Bailey, J., Judge, C., McFarland, C., Suman, S., Elliott, S., Katlein, C., Arndt, S., Bowen, A., Yoerger, D., Kinsey, J., Mayer, L.A., Nicolaus, M., Laney, S., Hu, H., Rzhanov, Y., and Boyen, T., Euclidean Reconstruction of Natural Underwater Scenes, American Society for Photogrammetry and Remote Sensing (ASPRS) 2014, March 23–27.

Johnson, P., Beaudoin, J., and Ferrini, V. L., Multibeam Advisory Committee (MAC) – Three Years of Working towards the Consistent Acquisition of High Quality Multibeam Echosounder Data across the US Academic Fleet, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Masetti G. and Calder, B.R., Development of an Adaptive Fusion Algorithm for Marine Debris Recognition Within the Post-Sandy Restoration Framework, Canadian Hydrographic Conference 2014, St. John's, Newfoundland, Canada, April 14–17.

Masetti G. and Calder, B.R., Huddl for Description and Archive of Hydrographic Binary Data, Canadian Hydrographic Conference 2014, St. John's, Newfoundland, Canada, April 14–17.

Mayer L.A. and Gardner, J.V., What a Difference a Swath Makes!, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Mello, K.L., Litterer, A.S., Wells, C.D., and Dijkstra, J.A., Complexity Matters: The Effect of Non-Native Algal Species on Habitat Architecture, Biodiversity and Predator-Prey Interactions, The Regional Association for Research on the Gulf of Maine, Boston, MA, September 30.

Mosher, D.C., Jakobsson, M., Gebhardt, C., and Mayer, L.A., Mapping the Surficial Geology of the Arctic Ocean, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Parrish, C.E. and Dijkstra, J.A., Benthic Habitat Mapping in Barnegat Bay with Topographic-Bathymetric Lidar Waveform Features, European LiDAR Mapping Forum, Amsterdam, North Holland, The Netherlands, December 8–10.

Parrish, C.E, Dijkstra, J.A., and McKenna, L., Assessing Hurricane Sandy Impacts on Benthic Habitats in Barnegut Bay with New Topographic-Bathymetric LIDAR Technology, 2014 AGU Ocean Sciences Meeting, February 23–28.

Parrish, C.E., Rogers, J., Ward, L., and Dijkstra, J.A., Enhanced Coastal Mapping Using Lidar Waveform Features, 15th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, Mobile, AL, June 10–12.

Pe'eri, S., Tibor, G., Madore, B., Illin, V., Ben-Avraham, Z., Rilov, G., Ketter, T., and Dijkstra, J.A., Seafloor Characterization and Monitoring of the Inner Shelf in Northern Israel Using Remote Sensing, Ocean Optics XXII, Portland, ME, October 26–31.

Rzhanov, Y., Eren, F., Pe'eri, S., and Thein, M.W., An Image Processing Approach for Determining of Relative Pose of Unmanned Underwater Vehicles, Oceans '14 MTS/IEEE, Taipei, Taiwan, April 7–10.

Rzhanov, Y., Hu, H., and Boyen, T., Dense Reconstruction of Underwater Scenes from Monocular Sequences of Images, Oceans '14 MTS/IEEE, Taipei, Taiwan, April 7–10.

Singh, H., Maksym, T.L., and Team, P.S. 86 Scienti, First Scientific Dives of the Nereid Under Ice Hybrid ROV in the Arctic Ocean, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Vanderlaan, A.S.M., Jech, M., Weber, T.C., Rzhanov, Y., and Lutcavage, M. E., Direct Assessment of Juvenile Atlantic Bluefin Tuna: Integrating Sonar and Aerial Results in Support of Fishery-Incident Surveys, International Commission for the Conservation of Atlantic Tunas, Olhão, Portugal, September 1–5.

Ward, L.G. Depositional Environments of Jeffreys Ledge, Western Gulf of Maine: Impacts of Glaciation, Sea-level Fluctuations and Marine Processes Assessed Using High Resolution Multibeam Bathymetry, Subbottom Seismics, Videography, and Direct Sampling, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Ward, L.G. Morphologic Changes of a Heavily Developed and Modified Back-Barrier System: Hampton-Seabrook Harbor, NH, Geological Society of America Annual Meeting, Vancouver, British Columbia, Canada, October 12–15.

Conference Proceedings

Alexander, L., e-Navigation 101: What Is It, Why Important, and How Should It Work?, e-Navigation Underway 2014 - North America, California Maritime Academy, Vallejo, CA.

Alexander, L., e-Navigation: Some Core Technologies and Solutions, 8th Seoul International Maritime Forum, Seoul, South Korea.

Butkiewicz, T., Low-Cost Coastal Mapping Using Kinect v2 Time-of-Flight Cameras, MTS/IEEE OCEANS '14, St. John's, Newfoundland, Canada.

Di Stefano, M., Masetti, G., and Mayer, L.A., Use of Seafloor Stereo-Images to Validate Automatic Classification of Benthic Habitats, GeoHab 2014, Lorne, Victoria, Australia.

Pe'eri, S., Smith, S.M., Snyder, L.P., and Madore, B., Satellite-Derived Bathymetry Using Multiple Images: The Alaska North Slope Case Study, 2014 Canadian Hydrographic Conference, St. John's, Newfloundland, Canada.

Schmidt, V.E., A New Method for Generation of Soundings from Phase-Difference Measurements, 2014 Canadian Hydrographic Conference, St. John's, Newfloundland, Canada.

Conference Posters

Butkiewicz, T., Measuring Waves and Erosion in Underwater Oil Blobs and Monitoring Other Arbitrary Surfaces with a Kinect v2 Time-of-Flight Camera, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Freire, F.F., Gyllencreutz, R., Greenwood, S., Mayer, L.A., and Jakobsson, M., High-Resolution Mapping of Offshore and Onshore Glaciogenic Features in Melville Bay, Northwestern Greenland, 2014 Fall Meeting, American Geophysical Union (AGU) San Francisco, CA, December 15–19.

McKenna, L., Hunt, J., Lippmann, T., Observations of Seafloor Roughness in a Tidally Modulated Inlet, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA, December 15–19.

Whitcomb, L.L., Jakuba, M., German, C.R., Bowen, A., Yoerger, D., Kinsey, J., Mayer, L.A., McFarland, C., Suman, S., Bailey, J., Judge, C., Elliott, S., Gomez-Ibanez, D., Taylor, C., Machado, C., Howland, J., Kaiser, C.L., Heintz, M., Pont-briand, C., O'hara, L., McDonald, G., and Boetius, A., Preliminary Polar Sea Trials of Nereid-UI: A Remotely Operated Underwater Vehicle for Oceanographic Access Under Ice, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Wigley, R., Nippon Foundation / GEBCO Indian Ocean Bathymetric Compilation Project, 2014 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, December 15–19.

Wigley, R., Nippon Foundation/GEBCO Postgraduate Certificate Alumni Perspectives (Poster 1 & 2), Fifth Extraordinary International Hydrographic Conference, Monaco, October 6–10.

Wigley, R., Nippon Foundation/GEBCO Postgraduate Certificate in Ocean Bathymetry, Fifth Extraordinary International Hydrographic Conference, Monaco, October 6–10.

Wigley, R., Alumni of the First Ten Years of Nippon Foundation/GEBCO Postgraduate Certificate in Ocean Bathymetry Training Program, Fifth Extraordinary International Hydrographic Conference, Monaco, October 6–10.

Reports

Beaudoin, J., Johnson, P., and Flinders, A. F., R/V *Falkor* Multibeam Echosounder System Review, 82 pp.

Gardner, J.V. and Armstrong, A.A., U.S. Extended Continental Shelf Cruise to Map Gaps in Kela and Karin Ridges, Johnston Atoll, Equatorial Pacific Ocean, CCOM/JHC, Durham, NH, 67 pp.

Grassi, M., Masetti, G., Dialti, L., Bortoluzzi, G., Filippone, M., Ricci, E., Pratellesi, M., Spagnoli, F., Borgognoni, L., Tudino, T., Aliani, S., and Battaglia, P., Rapporto sulle attivita' oceanografiche, geochimiche, geologiche, geofisiche e di campionamento durante la crociera PANA13 con ITS Magnaghi: Panarea, I.Eolie, Tirreno S.Orientale, 2013-06-02-2013-06-08, RAPPORTI ISMAR, Roma, Italy, 22 pp.

Johnson, P., R/V *Falkor* Multibeam Echosounder System Calibration, 36 pp.

Johnson, P., Flinders, A. F., and Greenaway, S. F., R/V *Sikuliaq* EM302 & EM710 Multibeam Echosounder System Shipboard Acceptance Tests–SKQ201400L3, 172 pp.

Johnson, P. and Jerram, K., RVIB *Nathaniel B Palme*r EM122 Multibeam Sea Acceptance Trials–NBP1405, 23 pp.

Johnson, P. and Jerram, K., E/V *Nautilus* EM302 Multibeam Echosounder System Review, 18 pp.

Sullivan, B.M. ChUM: Chart Update Mashup, NOAA Office of Coast Survey, Silver Spring, MD, 12 pp.

Wells, C. D., Pappal, A. L., Cao, Y., Carlton, J. T., Currimjee, Z., Dijkstra, J.A., Edquist, S. K., and Gittenberger, A., Report on the 2013 Rapid Assessment Survey (RAS) of Marine Species at New England Bays and Harbors, Massachusetts Office of Coastal Management (CZM), Boston, MA, 32 pp.

Theses

Heaton, John, *Utilizing an Extended Target for High Frequency Multi-beam Sonar Intensity Calibration*, Master of Science in Mechanical Engineering, University of New Hampshire, Durham, NH.

Miao, Dandan, *Gradual Generalization of Nautical Chart Contours with a B-Spline Snake Method,* Master of Science in Ocean Engineering: Mapping Option. University of New Hampshire, Durham, NH.

Welton, Briana, *A Field Method for Backscatter Calibration Applied to NOAA's Reson 7125*, Master of Science in Earth Sciences: Ocean Mapping Option. University of New Hampshire, Durham, NH.

Yao, Fan, *Uncertainty Analysis on Photogrammetry-Derived National Shoreline*, Master of Science in Earth Sciences: Ocean Mapping Option, University of New Hampshire, Durham, NH.

Appendix E: Technical Presentations and Seminars

Carmen St. Jean, Contributed, January 24, Using Interactive Visualization to Enhance Understanding of MS-PROD, Northeast Fisheries Science Center, Georges Bank Prototype Analysis, Woods Hole, MA.

Larry Mayer, Andrew Armstrong, and Brian Calder, Invited, January 28, U.S. Mapping Activities in the Arctic, Arctic Hydrographic Commission Science Day, Durham, NH.

Larry Mayer, Invited, February 4, Testimony before the Subcommittee on Coast Guard and Maritime Transportation Committee on Transportation and Infrastructure U.S. House of Representatives, Washington, DC.

Glen Rice, Invited, February 10, Acoustic Backscatter and Ellipsoid Reference Survey, NOAA Office of Coast Survey (OCS), NOAA Basic Hydrographic Training, Yorktown, VA.

Tom Weber, Shachak Peeri, Invited, February 11, Satellite-Derived Bathymetry: A reconnaissance tool for hydrography, NOAA Office of Coast Survey (OCS), 41st Joint Meeting UJNR Sea Bottom Surveys Panel, Silver Spring, MD.

Larry Mayer, Invited, February 18, Exploring the Secrets of the Deep: New Tools for Ocean Mapping, Texas A&M University Institute for Nautical Archeology, College Station, TX.

Brian Calder, Invited, February 19, Telepresence presentation of Center Activities report for NOAA Board of Hydrographers, NOAA, Board of Hydrographers Meeting, Durham, NH.

Shachak Peeri, Invited, March 10, Assessing Chart Data Using Satellite Derived Bathymetric Data: Case Study in Haiti, NOAA/OCS, Hydrographic Delegation Visit from the Service Maritime et de Navigation d'Haiti (SEMANAH), Silver Spring, MD.

Shachak Peeri, Invited, March 12, Satellite-Derived Bathymetry: A Reconnaissance Tool for Hydrography, NOAA/NOS/OCS/MCD, NOAA's Carto Workshop, Silver Spring, MD.

Larry Mayer, Invited Plenary Lecture, March 20, Mapping to Establish the Extended Continental Shelf under Article 76, Intl Cable Protection Commission, Dubai, UAE.

Larry Mayer, Invited Plenary Lecture, March 20, Mapping in the High Arctic, Cable Protection Commission, Dubai, UAE.

Larry Mayer, Invited, March 27, Mapping For Marine Policy, Marine Policy Seminar, Durham, NH.

Brian Calder, Giuseppe Masetti, Keynote, April 15, Development of an Adaptive Fusion Algorithm for Marine Debris Recognition Within the Post-Sandy Restoration Framework, Canadian Hydrographic Conference 2014, St. John's, Newfoundland, Canada.

Brian Calder, Giuseppe Masetti, Keynote, April 17, HUDDL for Description and Archive of Hydrographic Binary Data, Canadian Hydrographic Conference 2014, St. John's, Newfoundland, Canada.

Tom Weber, Val E. Schmidt, Contributed, April 17, A New Method of Generation of Soundings from Phase Difference Measurements, Canadian Hydrographic Conference 2014, St. John’s, Newfoundland, Canada.

Tom Lippmann, Invited, April 22, Observations of Subtidal Water Level Fluctuations Around Inlets, ONR Workshop for RIVET Analysis, Washington, DC.

Larry Mayer, Invited, April 30, Recent Changes in Arctic Ice Cover from First Hand Experience, European Geophysical Union GIFT Symposium, Vienna, Austria.

Tom Lippmann, Invited, May 2, Long Term Observations, Nearshore Scientific Community, The Past and Future of Nearshore Processes Research Workshop, Kitty Hawk, NC.

Tom Weber, Larry Ward, John Heaton, Carlo Lanzoni, Eric Bajor, Glen Rice, Contributed, May 5–9, Observed Variability in Seafloor Acoustic Backscatter During Repeat Surveys in Portsmouth Harbor, NH.

Giuseppe Masetti, Larry Mayer, Contributed, May 5–9, Use of Seafloor Stereo-images to Validate Automatic Classification of Benthic Habitats, GeoHab, Lorne, Victoria, Australia.

Thomas Butkiewicz, Larry Mayer, Invited, May 5, UNH CCOM Visualization Activities, U.S. Navy Technology Advancement for the Next Generation Workshop, Pearl Harbor, Hawaii.

Tom Weber, Glen Rice, John Heaton, Contributed, May 7, Utilizing an Extended Target for High Frequency Multi-beam Sonar Intensity Calibration, Acoustic Society of America's Spring 2014 Meeting, Providence, RI.

Shachak Peeri, Invited, May 29, Simulating Natural Daylight in Underwater Environment, Department of Geography, Tel Aviv University, Ramat Aviv, Israel.

Lee Alexander, Contributed, June 2–6, ECDIS Training Course for Masters/Mates, Maritime Institute for Training and Graduate Studies (MITAGS), Linthicum Heights, MD.

Shachak Peeri, Invited, June 5, Overview of JHC/CCOM and the Collaboration with IOLR, IOLR and the U.S. Embassy in Israel, IOLR, Haifa, Israel.

Larry Mayer, Invited, June 26, The Arctic Continental Shelf: The Evolving Morphologic Context, Challenges of the Changing Arctic Continental Shelf, Navigation, and Fisheries, Center for Oceans Law and Policy, Bergen, Norway.

Larry Mayer, Invited, October 14, Law of the Sea and Mapping the Extended Continental Shelf in the Arctic, Roger Williams School of Law, Bristol, RI.

Larry Mayer, Invited, October 14, Law of the Sea and Mapping in the Arctic (and elsewhere), Naval War College, Arctic Studies Group, Newport, RI.

Larry Ward, Contributed, October 15, Morphologic Changes of a Heavily Developed and Modified Back-Barrier System: Hampton-Seabrook Harbor, New Hampshire, Geological Society of America Annual Meeting, Vancouver, British Columbia, Canada.

Larry Mayer, Invited, October 22, Arctic Infrastructure and Operational Challenges: The Perspective of a U.S. Academic Researcher, Center for New American Security, Washington, DC.

Briana Sullivan, Colin Ware, Roland Arsenault, Brian Calder, Contributed, November 3, UNH METOC Activities, Office of Naval Research, MPA Technical Meeting, Arlington, VA.

Brian Calder, Contributed, November 3, Estimating Interval Bathymetry, Office of Naval Research, MPA Technical Meeting, Arlington, VA.

Paul Johnson, Invited, November 19, Multibeam Advisory Committee (MAC) – Three Years of Working Towards the Consistent Acquisition of High Quality Multibeam Echosounder Data Across the U.S. Academic Fleet, International Marine Technicians, 2014 R/VTEC/INMARTECH Symposium, Corvallis, OR.

Larry Mayer, Invited, November 25, Understanding Article 76 and the Challenges of Working in the Arctic, Centre for International Law, National University of Singapore, Singapore.

Larry Mayer, Keynote, December 3, Extended Continental Shelf Mapping in the Arctic, National Taiwan University, International Symposium on Frontier M Extended Continental Shelf Studies, Taipei, Taiwan.

Shachak Peeri, Invited, December 5, Satellite Activities in NOAA: Satellite-Derived Bathymetry (SDB), UKHO, Sam Harper Visit, Silver Spring, MD.

Larry Mayer, Contributed, December 15–19, First Scientific Dives of the Nereid Under Ice hybrid ROV in the Arctic Ocean, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA. Abs. #B23G-07

Larry Mayer, Contributed, December 15–19, What a Difference a Swath Makes!, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA. Abs. #OS34A-02

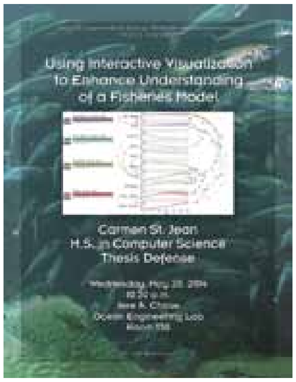
Larry Mayer, Contributed, December 15–19, Mapping the Surficial Geology of the Arctic Ocean, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA. Abs. #OS33D-07

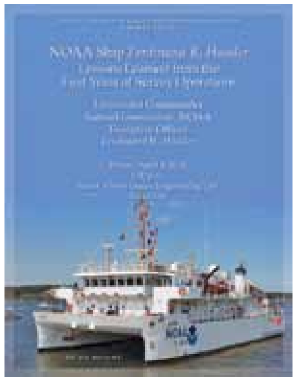
Larry Mayer, Contributed, December 15–19, High-resolution Mapping of Offshore and Onshore Glaciogenic Features in Melville Bay, Northwestern Greenland, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA. Abs. #OS31A-0973

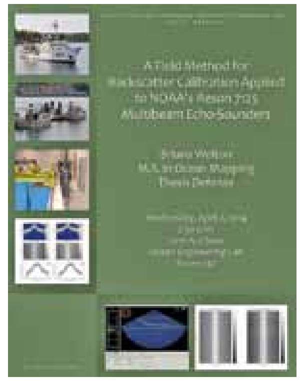
Larry Mayer, Contributed, December 15–19, Preliminary Polar Sea Trials of Nereid-UI: A Remotely Operated Underwater Vehicle for Oceanographic Access Under Ice, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA. Abs. #C31D-0343

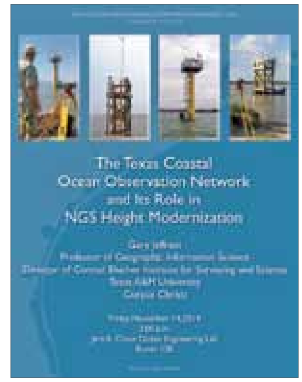
Paul Johnson, Mashkoor A. Malik, Larry Ward, Contributed, December 17, Depositional Environments of Jeffreys Ledge, Western Gulf of Maine: Impacts of Glaciation, Sea-level Fluctuations and Marine Processes Assessed Using High Resolution Multibeam Bathymetry, Subbottom Seismics, Videography, and Direct Sampling, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA.

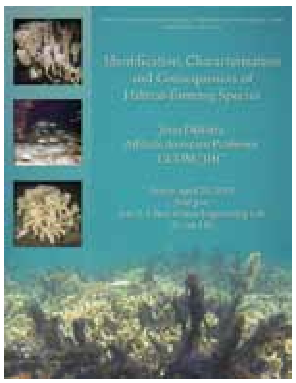
Jonathan Beaudoin, Paul Johnson, Contributed, December 17, Multibeam Advisory Committee (MAC) – Three Years of Working Towards the Consistent Acquisition of High Quality Multibeam Echosounder Data Across the US Academic Fleet, American Geophysical Union, 2014 Fall Meeting, San Francisco, CA.

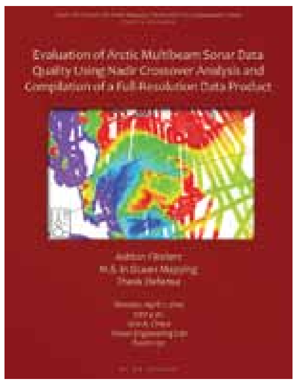


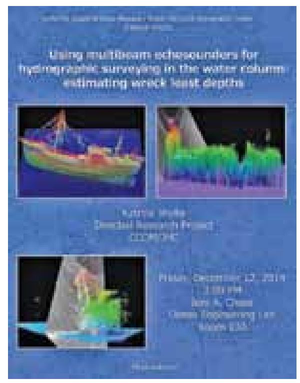


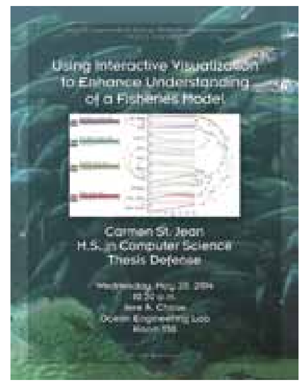


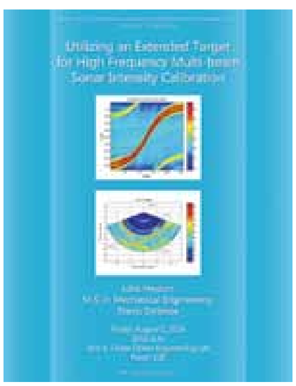


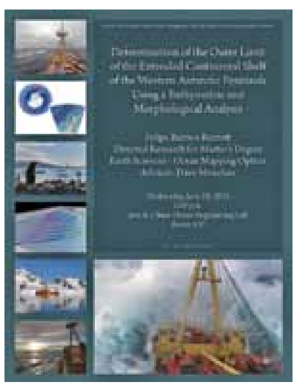


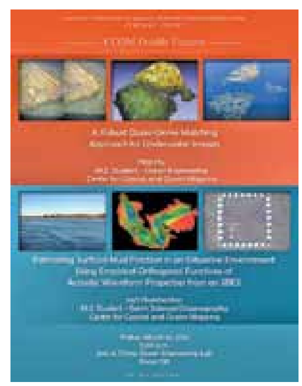


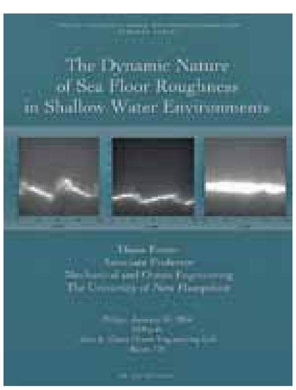


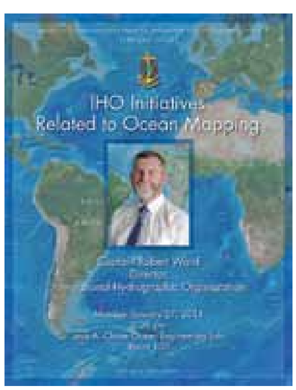


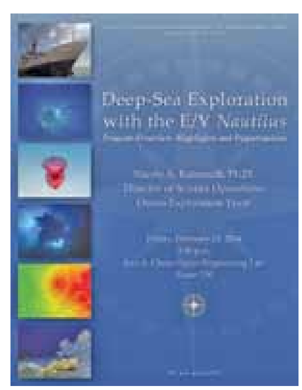




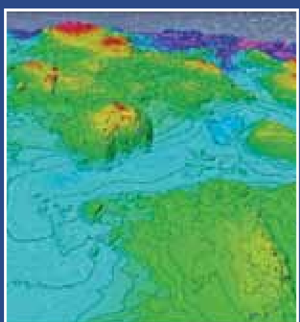


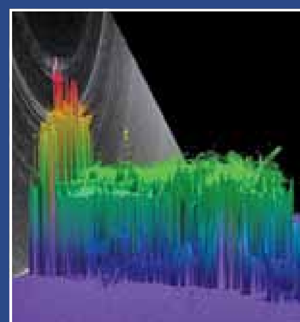


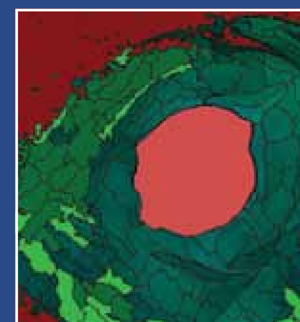




Flyers from the 2014 JHC/CCOM Seminar Series.







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