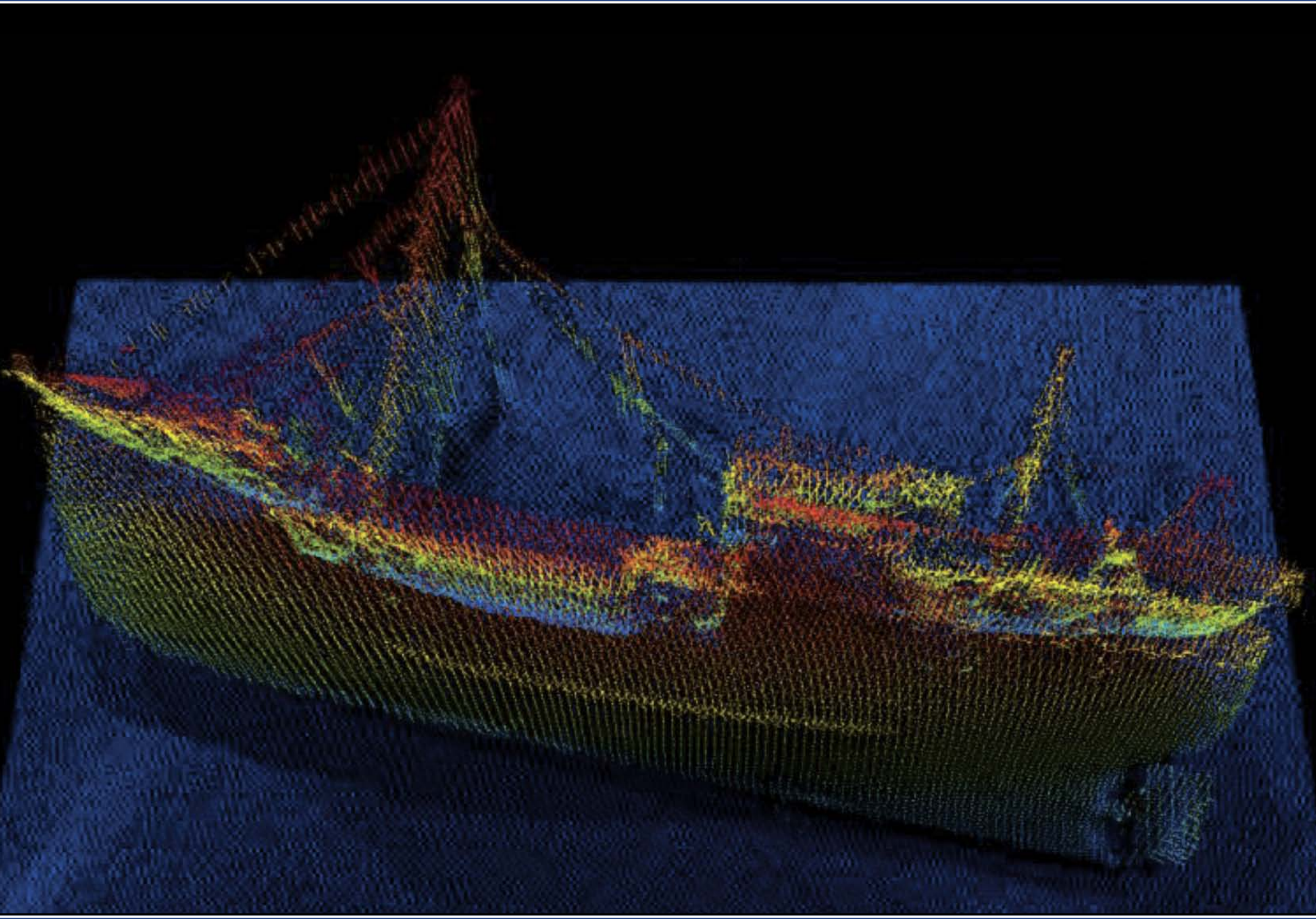
UNH/NOAA Joint Hydrographic Center

Performance and Progress Report



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

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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).

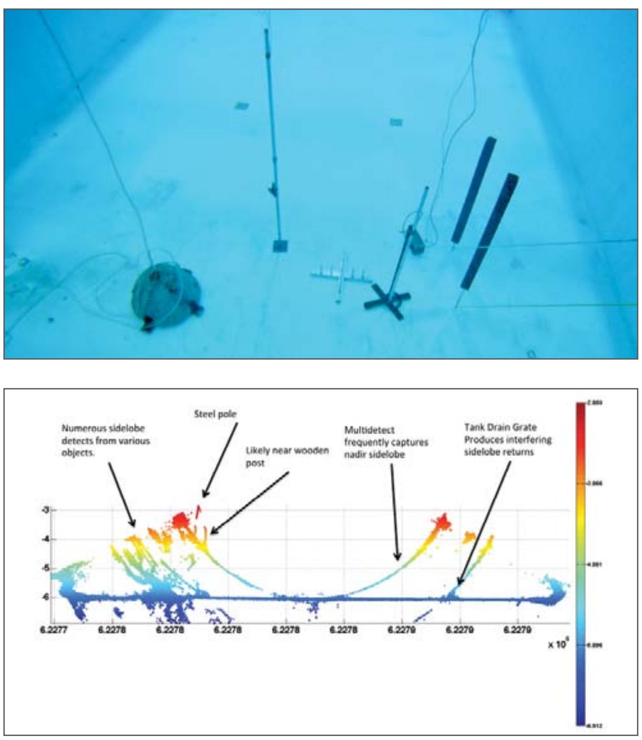


Figure ES-2. Various targets placed in the Center's acoustic test tank to test their detectability with a RESON T20-P MBES. The sonar was operated from right to left in the image (top), on the far side of the targets such that they appear in the port side of the swath. The full data set across all targets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

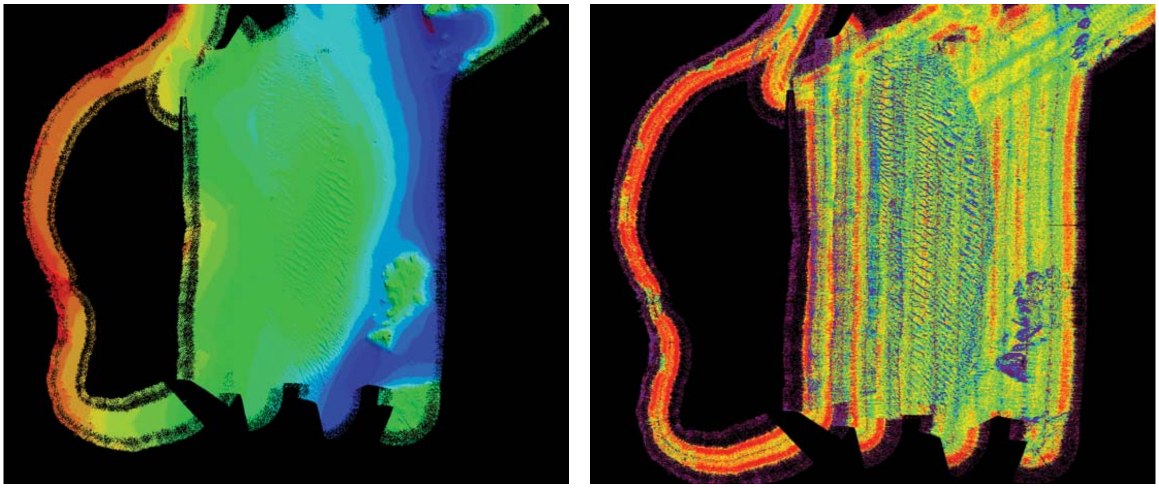


Figure ES-4. On the left, Edgetech 6205 data is shown, collected over the Portsmouth Harbor sand wave field and gridded at 0.5 m. Depths range from 1m (red) to ~28m (purple). On the right, uncertainty for this surface, 0 (red) to 0.15 m (purple), measured as the standard deviation of soundings contributing 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).

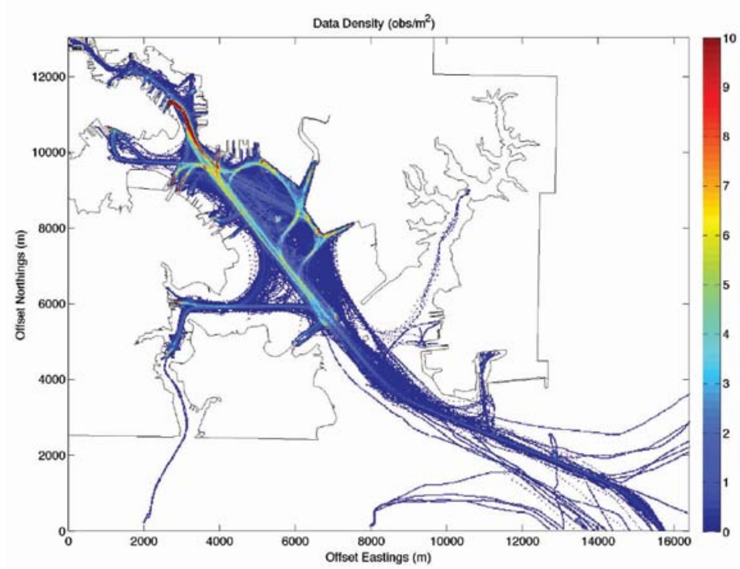


Figure ES-5.Observation density (observations per square meter) in Baltimore Harbor from ARGUS systems.

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-

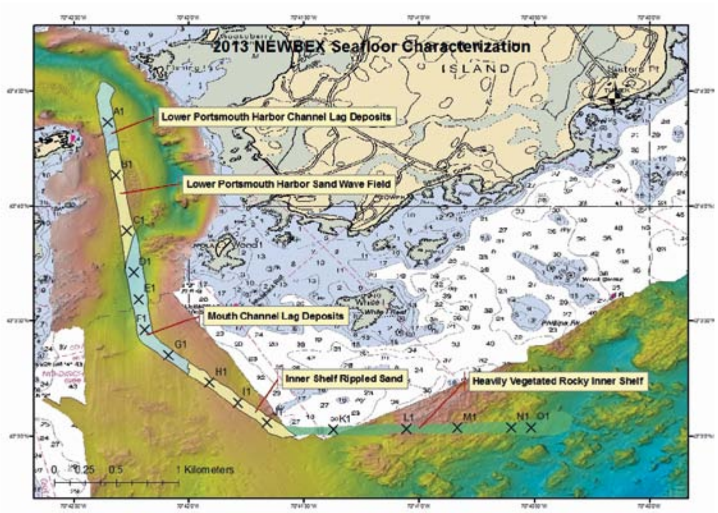


Figure ES-6. Location map of the NEWBEX transect, the 2013 sampling stations (targets), and an initial division of seafloor types.

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

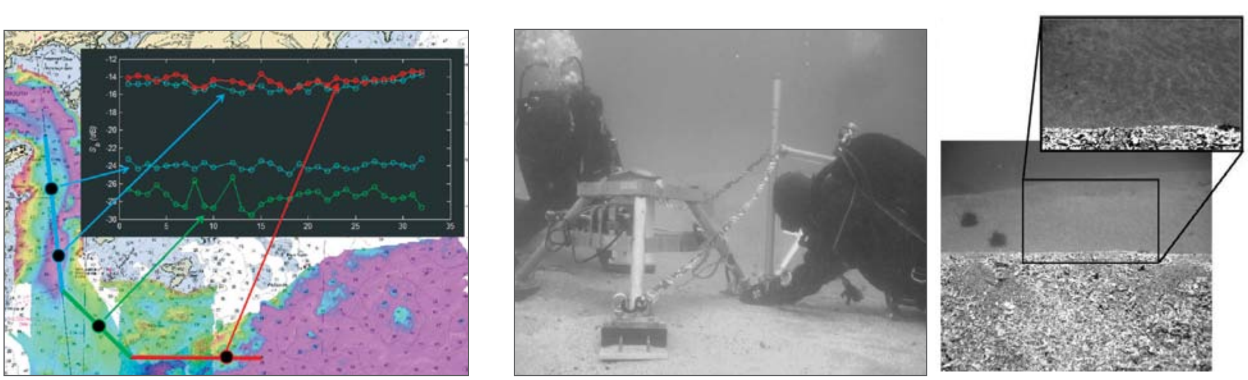


Figure ES-7. Time series of seafloor backscatter from select locations along the NEWBEX line (left) Deployment of ground-truthing system at sandwave site. Note the contrasting orientation of the sandwaves and the ripples.

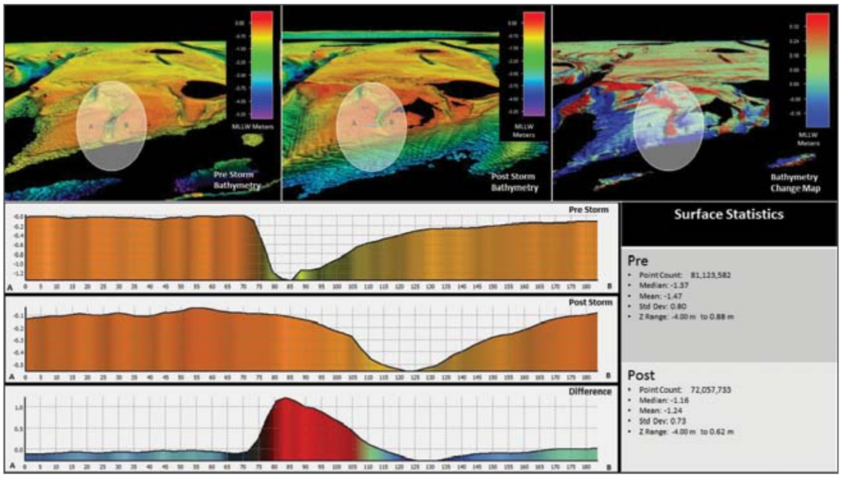


Figure ES-8. A transect across a channel in Barnegat Bay shows the creation of a new shoal, significant shift of the channel, and a change in morphology due to the effects of the storm.

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).

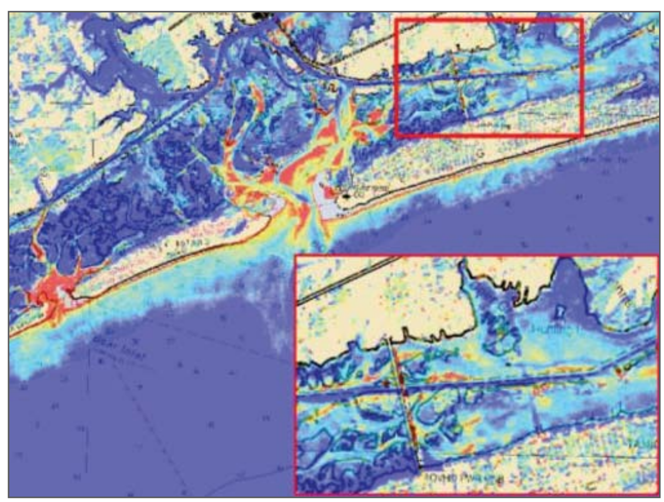


Figure ES-9. Satellite-derived bathymetry (Landsat 8) over Bouge Inlet, South Carolina superimposed on the NOAA chart. In some locations along the channel, a horizontal shift is noticeable between the charted channel and the bathymetry derived from satellite imagery.

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 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.

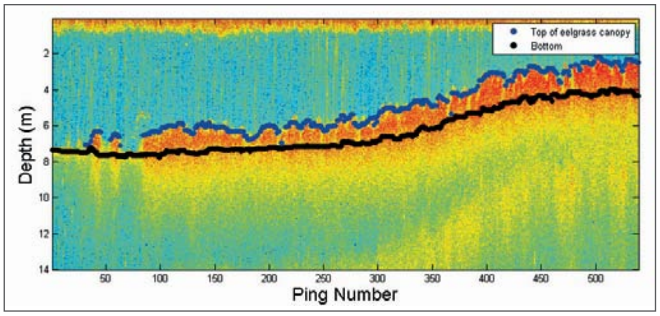


Figure ES-10. Acoustic response of eelgrass.

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

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

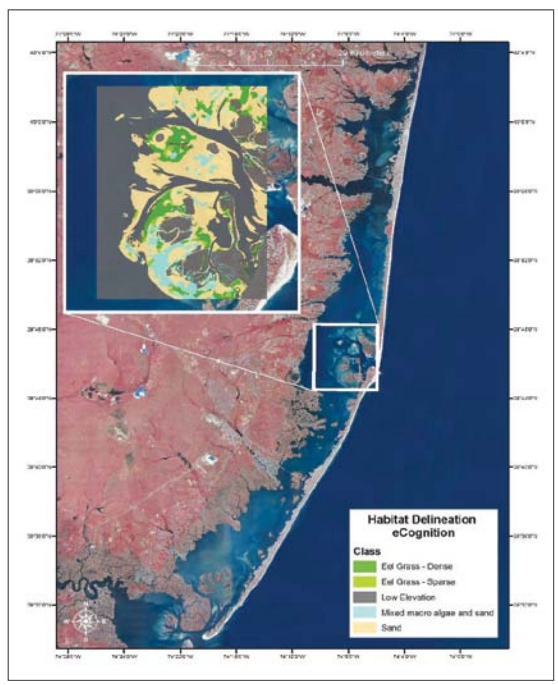


Figure ES-12. 2012 infrared image of Barnegat Bay, NJ. Inset: Map of four separate habitat types generated in eCognition by combining aerial images, waveform features, and bathymetry derived from the NOAA Riegl VQ-820-G topographic-bathymetric lidar system.

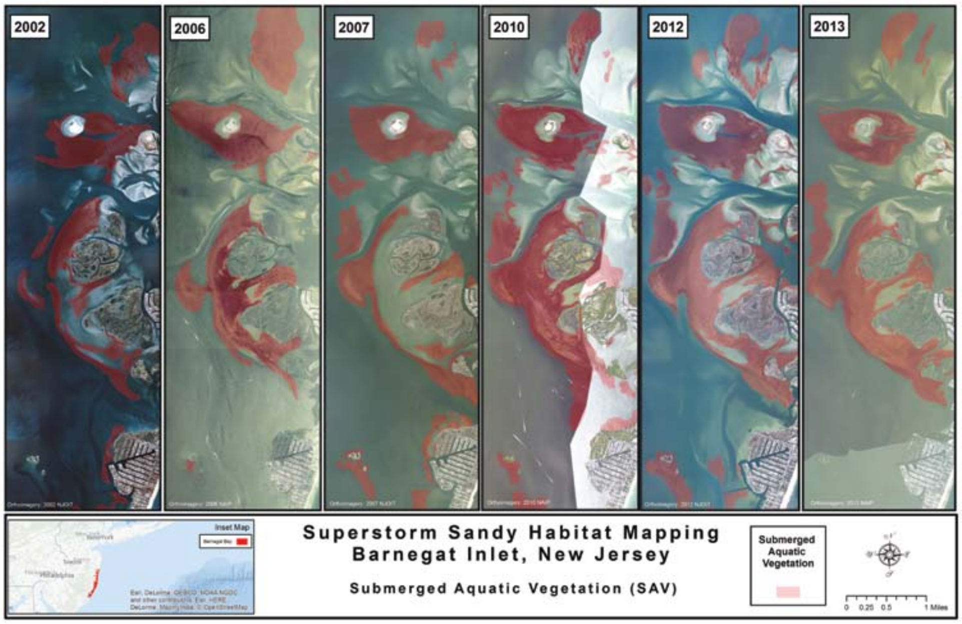


Figure ES-13. Digitized aerial imagery depicting areas of submerged aquatic vegetation in Barnegat Bay Inlet for 2002, 2006-2007, 2010, and 2012-2013.

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.

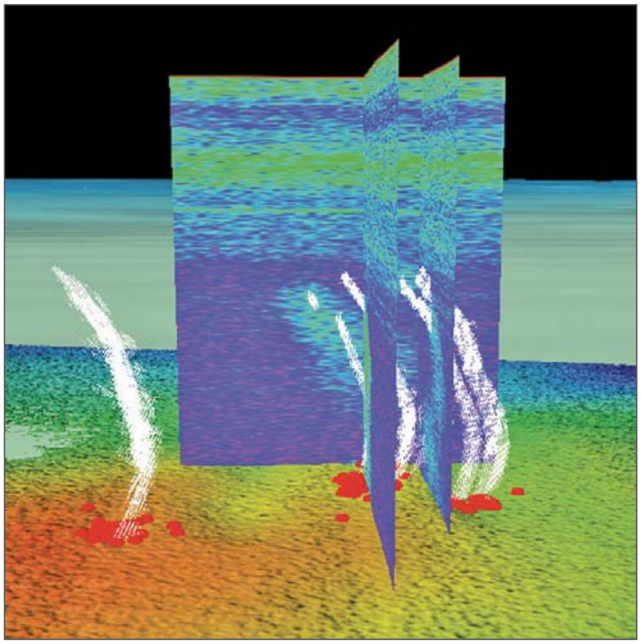


Figure ES-14. Methane seeps (vertical plumes) observed by the *Okeanos Explorer* on the western Atlantic Margin overlaid on bathymetry (ETOP02).

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.

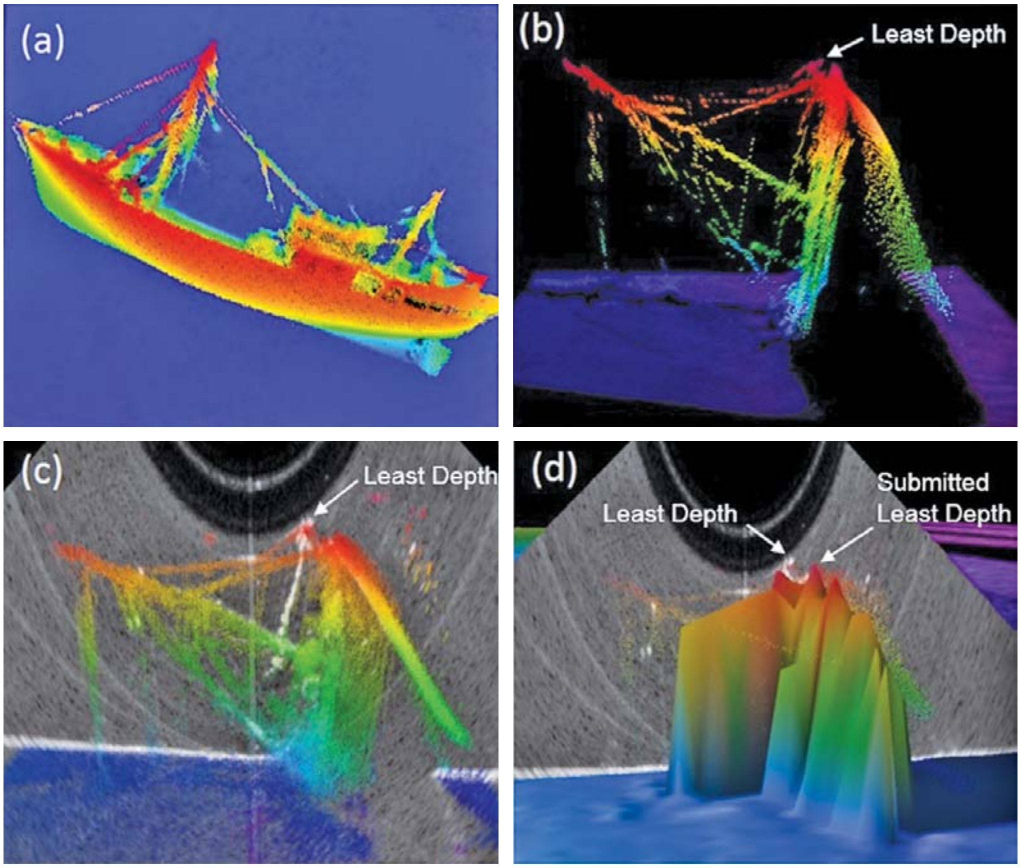


Figure ES-15. (a) Bathymetry lines collected over Women's Bay wreck. (b) Analyzed bathymetry line of wreck with least depth position indicated. (c) Water column exported point cloud of wreck with the fan at the timestamp of the least depth. (d) Verified 1m bathymetry surface with water column point cloud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

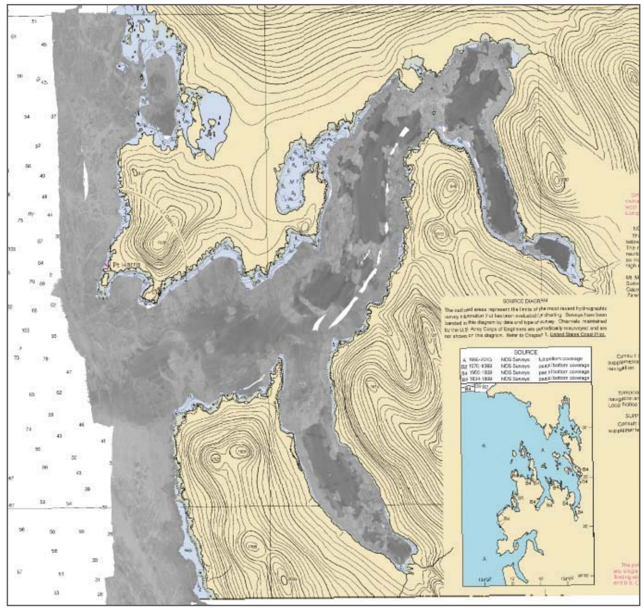


Figure ES-16. Processed backscatter mosaic from survey H11818, collected by the NOAA Ship *Fairweather* in 2010.

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.

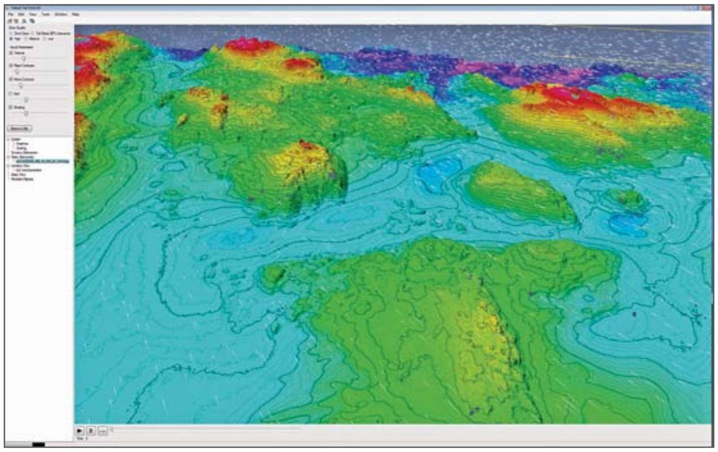


Figure ES-17. Screenshot of the VTT4D interface showing bathymetry (Isles of Shoals) and flow data.

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

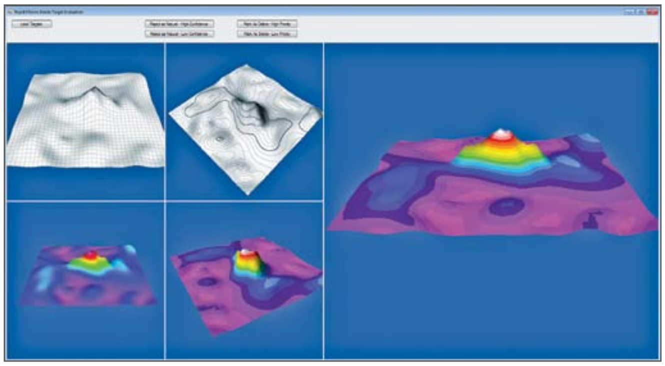


Figure ES-18. Multi-view Marine Debris Decision Tool.

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.

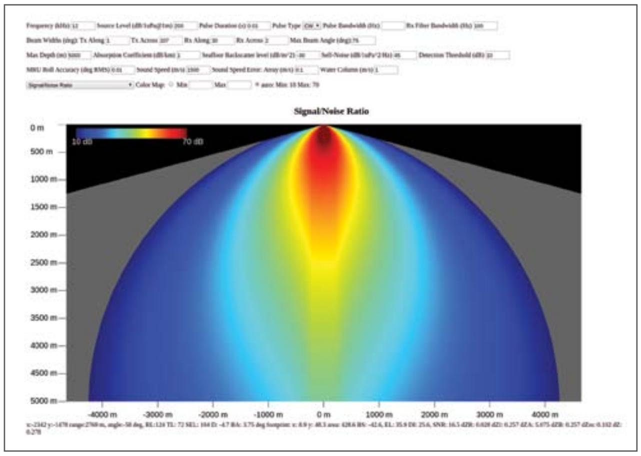


Figure ES-20. Web-based implementation of Lurton's sonar-equation based multibeam sonar performance tool.

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).

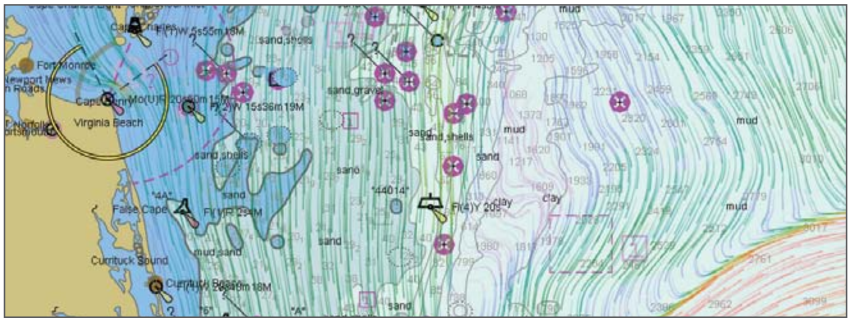


Figure ES-21. Representation of ocean currents. When animated, the flow visualization minimally interferes with other chart data.

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.

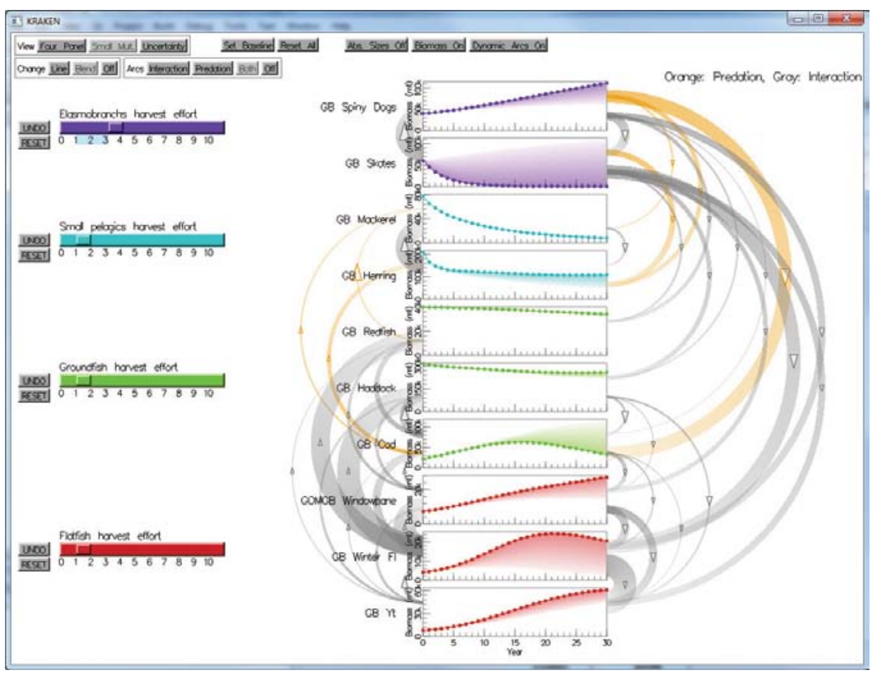


Figure ES-22. Interactive visualization of the forecast for ten Gulf of Maine species based on the NOAA KRAKEN model. The effects of increasing the catch of Elasmobranchs is visualized. The arcs show causal links in the model, with predation in yellow and species competition in grey.

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

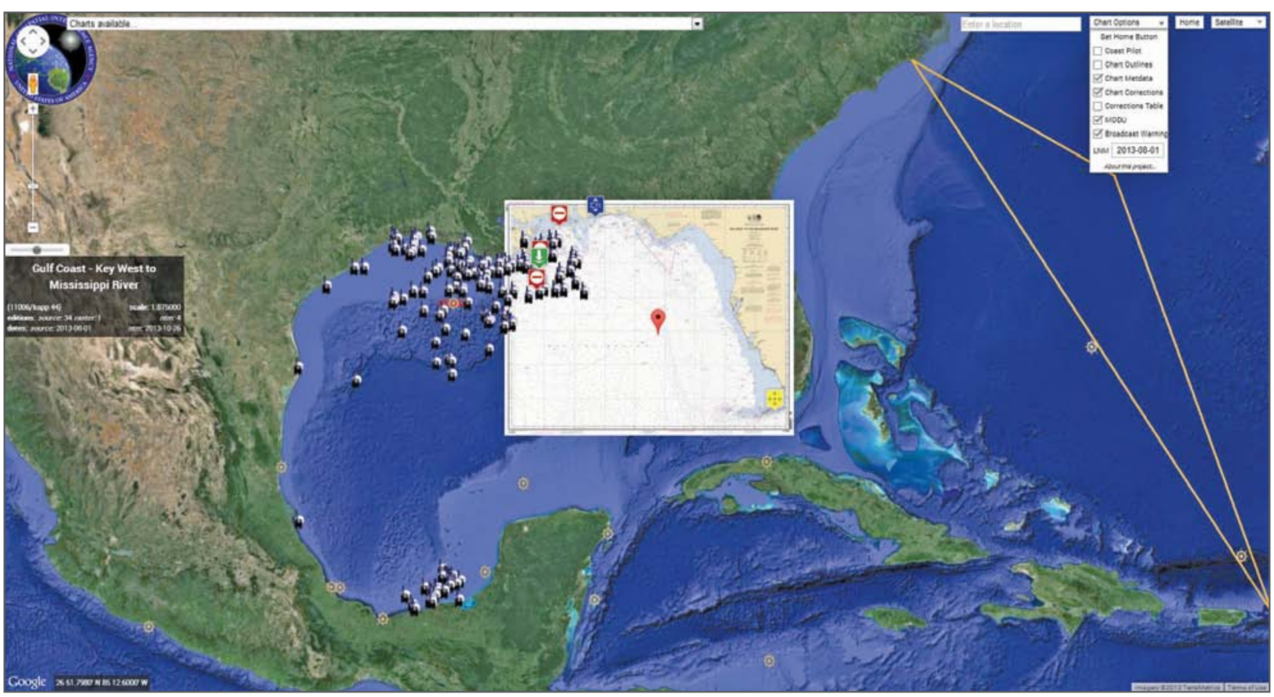


Figure ES-23. Navy version of CHuM with MODUs and Broadcast Notices.

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).

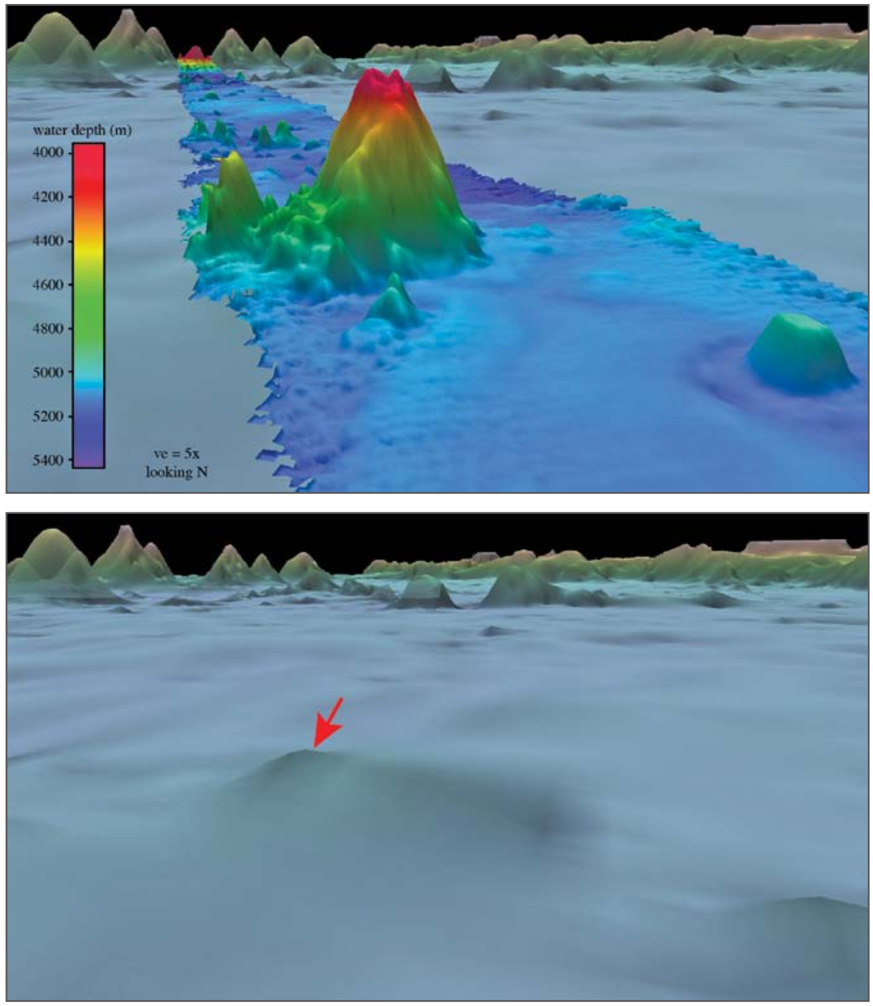


Figure ES-24. Perspective view of newly discovered seamount. Bottom panel shows the seamount from Smith and Sandwell (1997) v. 17.1 predicted bathymetry (red arrow). Top panel shows seamount in new multibeam bathymetry.

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 (Fig. 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.

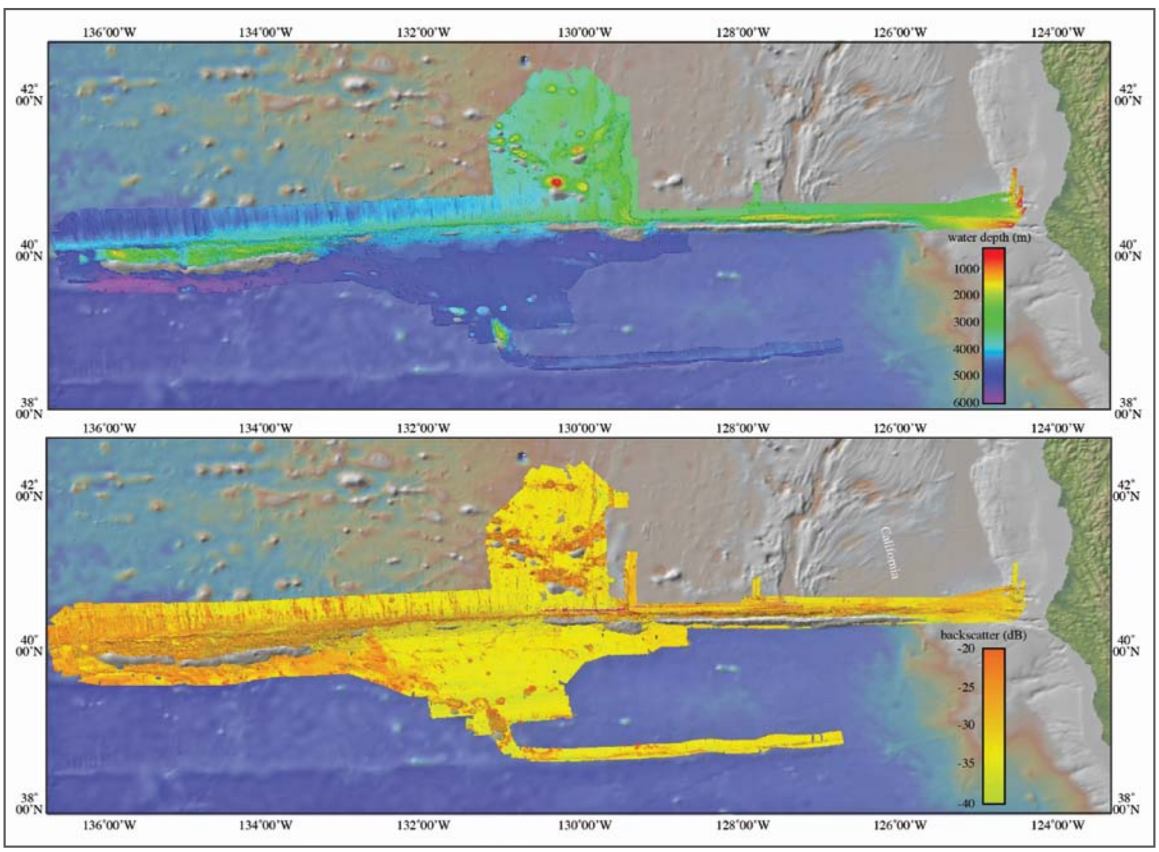


Figure ES-25. Upper panel shows merged 2009 and 2014 Mendocino Ridge bathymetry; lower panel shows merged backscatter.

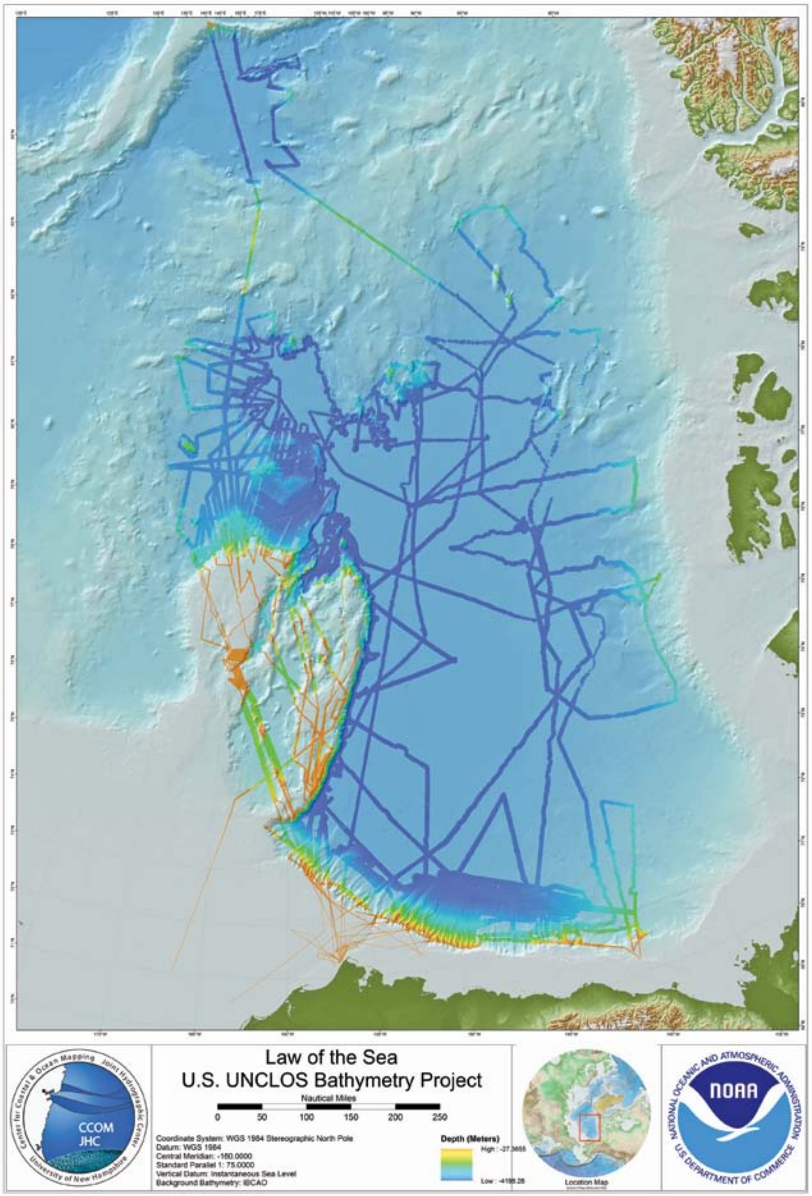


Figure ES-26. Preliminary Arctic bathymetry synthesis map. The map is generated from a single gridded dataset instead of a combined multi-year map product.

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. We have had 38 students enrolled in the Ocean Mapping program in 2014, including six GEBCO students, three NOAA Corps officers and four NOAA physical scientists (three in 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.

NOAA/UNH Joint Hydrographic Center 2014 Research to Operations Initiatives

Since its inception, the NOAA/UNH Joint Hydrographic Center has taken pride in its efforts to turn the research projects undertaken by the Center into practical operational tools that serve NOAA and the nation. Examples of past successes are the CUBE and GEOCODER algorithms, both of which are now in widespread use by NOAA and other U.S. agencies, by hydrographic agencies worldwide, and by academics and the private sector. The concept of turning research into practical operational tools has now been formalized within NOAA under the label of "Research to Operations" (R2O), and in this report we briefly outline those aspects of our 2014 research endeavors that we believe qualify as successful examples of R20. A more detailed description of these research endeavors can be found in the JHC 2014 Annual Performance and Progress Report at **www.ccom.unh.edu/reports**.

Sensor Research Theme

- ***New item: geoCamera.*** Over the past few years, in support of our Arctic mapping work, a ship-borne system was developed that combined low-cost, off-the-shelf cameras and custom software to capture imagery from a platform equipped with a motion sensor and produce georeferenced maps of the ice surface surrounding the vessel (up to a kilometer range depending on the elevation of the cameras). The success of these research prototypes has led to the installation, in 2014, of permanent systems on the icebreaker *Healy* and the new UNOLS ice-strengthened vessel R/V *Sikuliaq*.

Processing Research Theme

- ***Update from 2013.*** Brian Calder is developing a second generation of the CUBE algorithm—CUBE with Hierarchical Resolution Techniques (CHRT) that allows for variable resolution of data representation and is data adaptive, meaning that the density of data collected is reflected in the resolution of estimates of depth generated. A co-development model that has the software vendors who are implementing CHRT assisting in the development of a test suite has now been implemented, and the software is available for license to industrial partners. IFREMER, CARIS, SAIC (Leidos), Alidade Hydrographic, and QPS are the first five licensees, with CARIS providing a version to NOAA/HSTP and the CHS for testing and feedback. Co-developers have also submitted documentation on best practices, which have been included in the project's wiki, and methods to build the test suite for the code are under investigation.

- ***Update from 2013.*** Real-time multibeam performance prediction models and other system performance tools (e.g., BIST test analysis tool) have been developed as part of our Multibeam Advisory Committee Activities. These tools are available via the web and have been used on both UNOLS and NOAA vessels during sea trials (SATs) to help explain discrepancies between expected and achievable coverage and evaluate a range of performance parameters.

- ***Update from 2013.*** A Center team, led by Shachak Pe'eri, has been 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. In 2014, in conjunction with NOAA, we derived bathymetry from Landsat 8 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.

- ***New item.*** 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. Val Schmidt 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. In 2014, Val Schmidt worked with the Klein Hydrochart bathymetric system identifying processing and conceptual errors in the handling of Klein's uncertainty data by third-party commercial software packages and the Edgetech 6205 bathymetric sonar, discovering issues with third-party commercial bathymetric data-processing packages that led to interpretation problems and other errors. This led to modifications in the software and important improvements in the quality and usefulness of data products produced by PMBS.

- ***New item: HUDDL.*** To facilitate the processing and exchange of hydrographic data collected by different systems and processed with different software, Calder and Massetti have developed the Hydrographic Universal Data Description Language—HUDDL. The intent of HUDDL is to provide a simple means to document 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 and/or write the file, and human-readable documentation of the file format. This simplifies 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. HUDDL is now being evaluated by hardware and software manufacturers.

Water Column Mapping and Habitat Theme

- ***New item.*** Techniques for mapping, locating, and visualizing gas seeps developed by Center researchers, led by Tom Weber, have now been put into application both through the direct use of Weber's research software and through the use of commercial versions of this software implemented by our industrial partners. As an example, the *Okeanos Explorer* mapped 17,477 km^2 of the northern Gulf of Mexico, observing 573 seeps and discovering many new seeps on the Atlantic margin. The results from these cruises have demonstrated a new mid-water mapping technology for the *Okeanos Explorer* and suggests that wide-scale mapping of seeps in the deep Gulf of Mexico and elsewhere is viable and important for both scientific and industry studies.

- ***New item.*** NOAA Physical Scientist and graduate student Katrina Wyllie developed processing and work-flow approaches for using MBES-derived water column data for determining least depths on wrecks. As a result of this study, NOAA hydrographic vessels will have an additional tool to support NOAA's mission to provide accurate navigation products that ensure mariner safety.

IOCM Research Theme

- ***Update from 2013.*** The collection of quality backscatter data from Office of Coast Survey hydrographic MBESs is a primary focus for the NOAA Integrated Ocean and Coastal Mapping effort. This includes both the acquisition of useful backscatter data with all the information needed for post-processing, as well as a streamlined workflow to quality-check the acquired data. In support of this goal, Glen Rice, in collaboration with Center scientists, has developed a NOAA OCS backscatter workflow, applying tools and principles developed at the Center to NOAA hydrographic launches working in the field. An effective workflow for quality-checking backscatter has now been established. While improvements to this backscatter workflow continue to be implemented, a procedure and introductory training has now been passed on to the NOAA Hydrographic Processing Branches for implementation. The Branches continue to use the workflow provided with IOCM Center support in accommodating the many changes in the processing software. Building on earlier Center work to correct backscatter problems on the NOAA vessel *Fairweather*, 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. She also updated the Backscatter Processing Standard Operating Procedure (SOP) used by the OCS processing branches and worked with industrial partner QPS to improve processing software in order to streamline the processing of backscatter data and gain efficiency at the branches.

- ***Update from 2013.*** Just as the IOCM project seeks to extract useful backscatter data from hydrographic surveys, it also seeks to extract useful hydrographic data from fisheries surveys, particularly those conducted with the ME70 fisheries MBES. The collection of bathymetric data from the ME70 fisheries sonars has depended on research code developed by Tom Weber at the Center. 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 commercial Hypack acquisition software that is standardly used on these vessels. In June, implementation and testing began aboard the NOAA Ship *Pisces*. Work on the *Pisces* this summer by NOAA Physical Scientist and former Center graduate student Matt Wilson clearly demonstrated the value of this software when bathymetry and backscatter data produced by the ME70 provided invaluable near real-time information that allowed Southeast Fisheries Independent Survey scientists to accurately locate their fish-traps on well-constrained bathymetric targets. The surveys also located several shoals that were not accurately depicted on the charts.

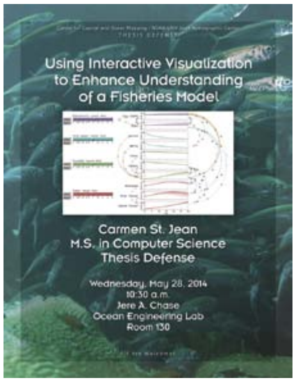
Electronic Chart of the Future Research Theme

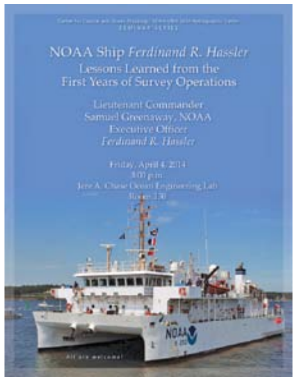
- ***Update from 2013.*** The Center continues to lead efforts to standardize formats for the distribution of full-density bathymetric data to be included in ENCs through the Open Navigation Surface Working Group. Brian Calder serves as the Chair of the Open Navigation Surface (ONS) Working Group. The 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 in June of 2014.

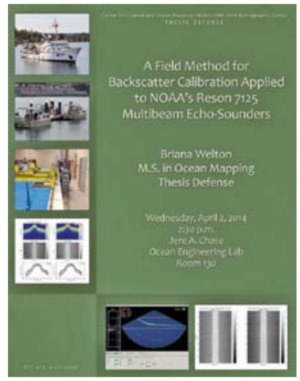
- ***Update from 2013.*** The Center has been a key player in the Right Whale AIS Project aimed at providing Liquid Natural Gas (LNG) carriers real-time input on the presence of right whales in their vicinity through a series of permanent, hydrophone-equipped buoys, a right whale vocalization system, 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 on board the vessel. In the past two years, an iPhone app—WhaleALERT—was developed to augment existing ship navigation tools informing mariners of the safest and most current information to reduce the risk of right whale collisions and a web-based WhaleALERT was developed to serve as a cross-platform alternative to the iPad WhaleALERT app and provide 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.

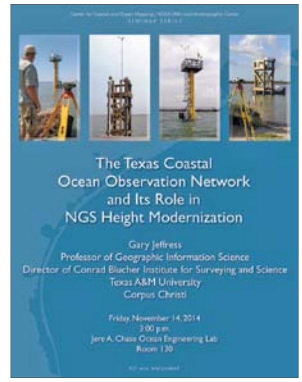
- ***New item.*** The Center's work, under the direction of Colin Ware, on the portrayal of meteorological data for the navigator, including currents from operational flow models, sea state from the Wavewatch III model, and weather from NOAA Mesoscale operational forecast models is being operationalized with the USN submarine fleet.

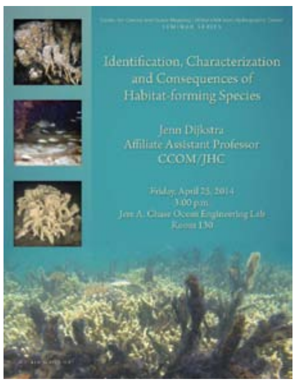
- ***New item.*** Based on earlier work of the Center in collaboration with the NowCoast project, the capability to display animated harbor and near-shore flows patterns from operational forecast models is now available even with low end laptop and desktop computers, tablets, and even some smart phones. The same technologies can be used to portray wind and wave forecasts.

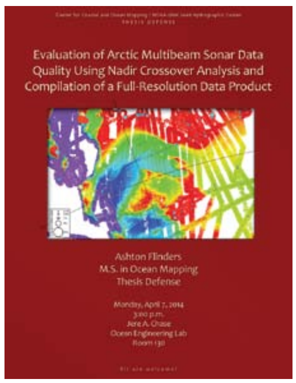


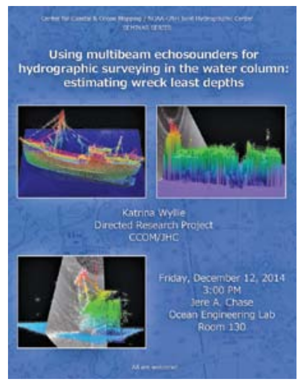


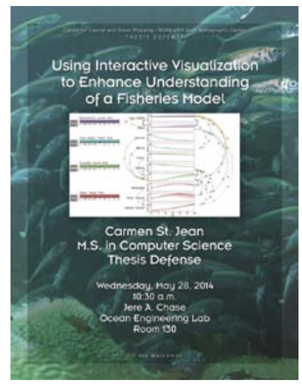


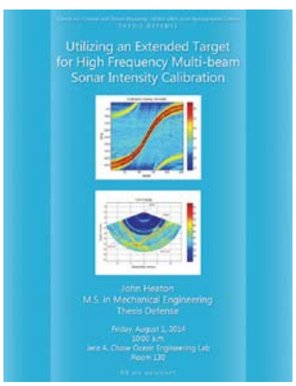


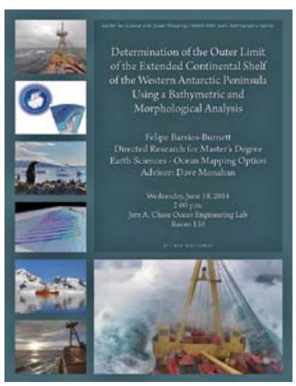


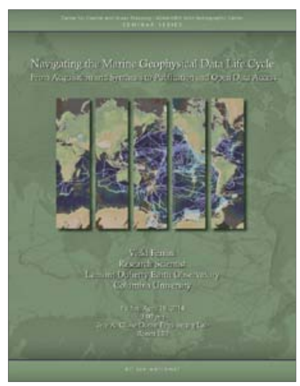


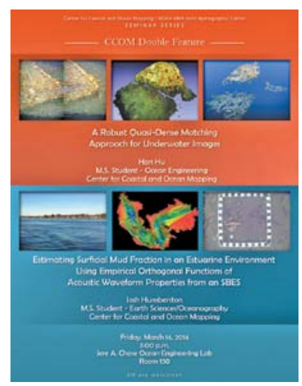


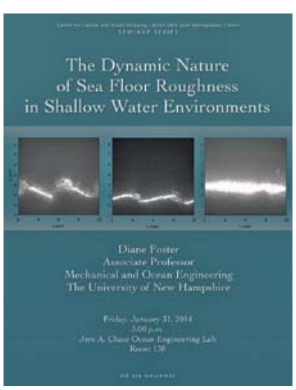


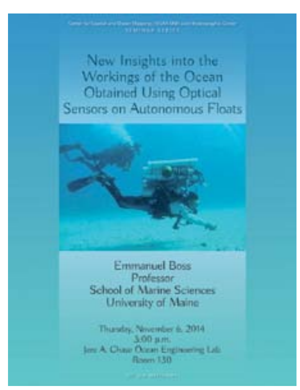


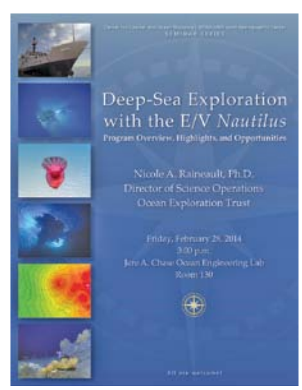




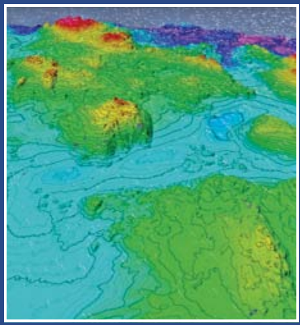


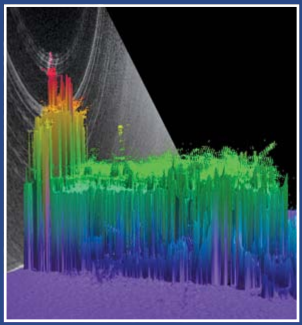


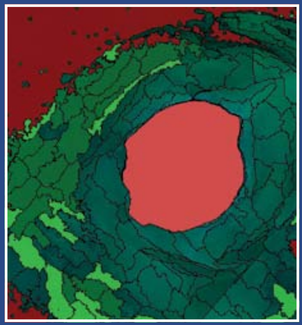




Flyers from the 2014 JHC/CCOM Seminar Series.







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