



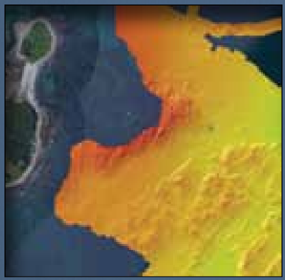

UNH/NOAA Joint Hydrographic Center
Performance and Progress Report

Project Title: Joint Hydrographic Center
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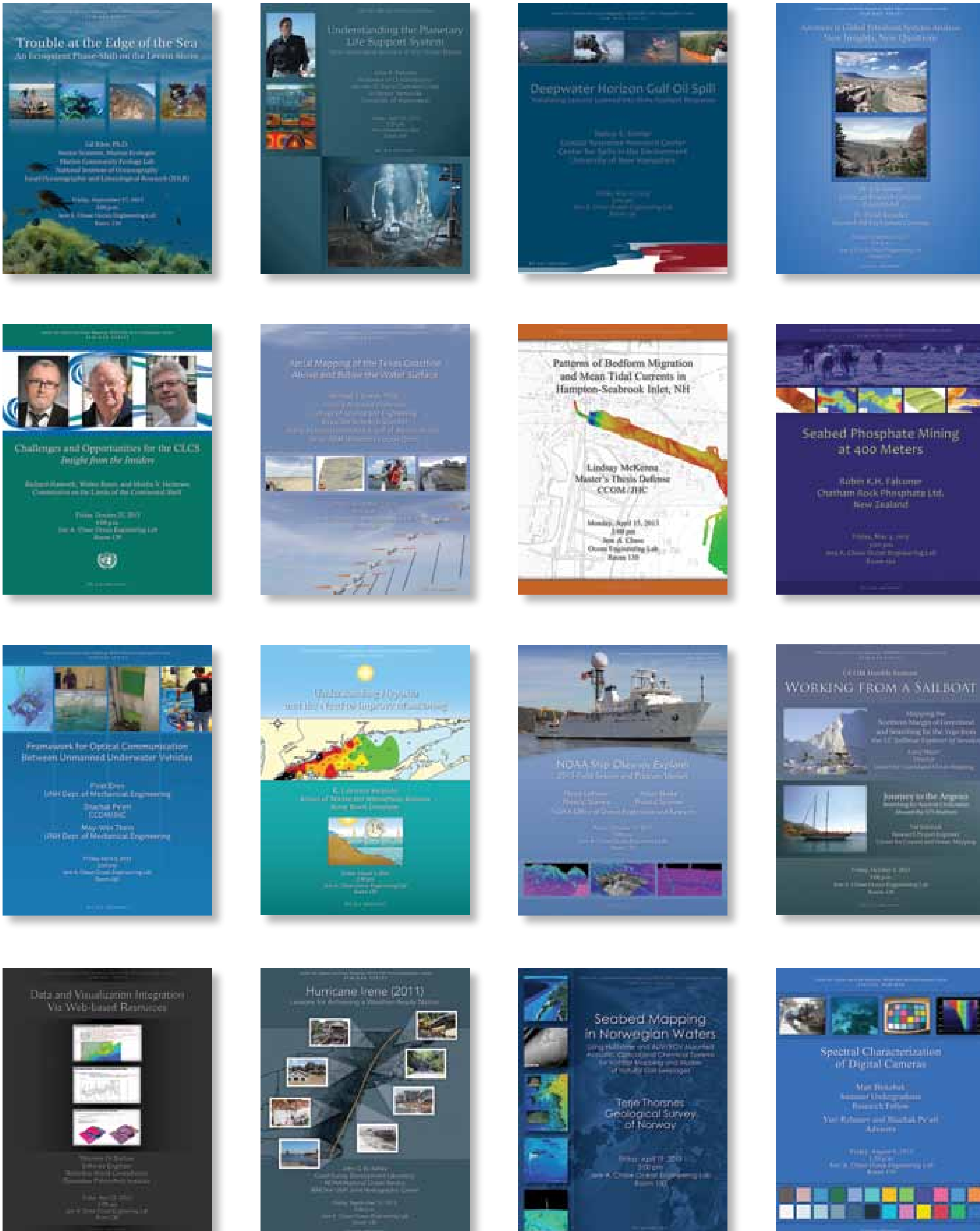


Flyers from the 2012 JHC/CCOM Seminar Series.

Cover photo of the FERDINAND R. HASSLER by Mike Ross, UNH Photo Services.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded fourteen years ago with the objective of developing tools and offering training that would help NOAA and others 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 echosounders 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, the result of a national competition, funded the Center for the period of 1 July 2010 until December 2015.

Over the years, the focus of research at the Center has expanded, and now encompasses a broad range of ocean mapping applications. An initial goal of the Center was to find ways to process the massive amounts of data coming from 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 could be collected. We have made great progress 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, 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 relatively short period of 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, i.e., The Navigation Surface, were, after careful verification and evaluation, accepted by NOAA, the Naval Oceanographic Office and other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has, or is, incorporating these approaches into their products. It is not an overstatement to say that these techniques are revolutionizing the way NOAA and others in the ocean mapping community are doing hydrography. These 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: "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 being 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 developing a simple-to-use tool (GeoCoder) for generating a sidescan-sonar or backscatter "mosaic"—a critical first step in analyzing the 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 we developed for producing bathymetry and other products from fisheries sonars are being installed on NOAA fisheries vessels and operators are being trained for their regular use. All of these (CUBE, GeoCoder, and our fisheries sonar tools) are tangible examples of our (and NOAA's) goal of bringing our research efforts to operational practice.

As technology evolves, the tools needed to process the data and the range of applications that the data can address will also change. We are beginning to explore the use of Autonomous Underwater Vehicles (AUVs) as platforms for hydrographic and other mapping surveys and are looking closely at the capabilities and limitations of Airborne Laser Bathymetry (lidar) 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 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) with 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 effort to the Deepwater Horizon oil spill and continue to be a focus of national and international interest as a means to help quantify the flux of methane into the ocean and atmosphere.

Figure ES-1. NOAA Ship FERDINAND R. HASSLER (S-250) at the pier in New Castle, NH. Photo by Mike Ross, UNH Photo Services.

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 2013 Program

Our efforts in 2013 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). Given severe budget cuts in 2013, efforts on several initiatives (Habitat Mapping, Chart of the Future and, particularly, Law of the Sea) had to be reduced relative to previous years, but progress was still made in each of the themes. Additionally in 2013, some of our efforts were diverted to research and data processing associated with a response to Hurricane Sandy. These efforts, while drawing on research conducted under this grant, are funded by a separate grant.

As our research progresses and evolves, the initially clear boundaries between the research 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 is a natural (and desirable) evolution that slowly changes the nature of the programs and the thrust of our efforts. Although the boundaries between the themes are 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.

One of the highlights of 2013 was the arrival of the newest addition to the NOAA hydrographic survey vessel fleet, the NOAA Ship *Ferdinand R. Hassler* (S-250), to its new homeport at the UNH pier facilities in New Castle, New Hampshire. The *Hassler* is a coastal mapping vessel utilizing the Small Waterplane Area Twin Hull (SWATH) design. The homeporting of the *Hassler* in proximity to the Center will enable researchers at the Center to work much more closely with the NOAA team on the *Hassler*, greatly increasing our ability to understand the survey challenges facing NOAA hydrographers and the efficiency with which we can turn our research into real-world solutions. Additionally, the proximity of the NOAA crew to the lab will allow ongoing interactions, including the easy participation of the *Hassler* crew in workshops, seminars and classes at the University. In celebration of the arrival of the *Hassler*, the University hosted a well-attended welcoming ceremony with State, Federal and University officials as well as many members of the local community (Figure ES-1).

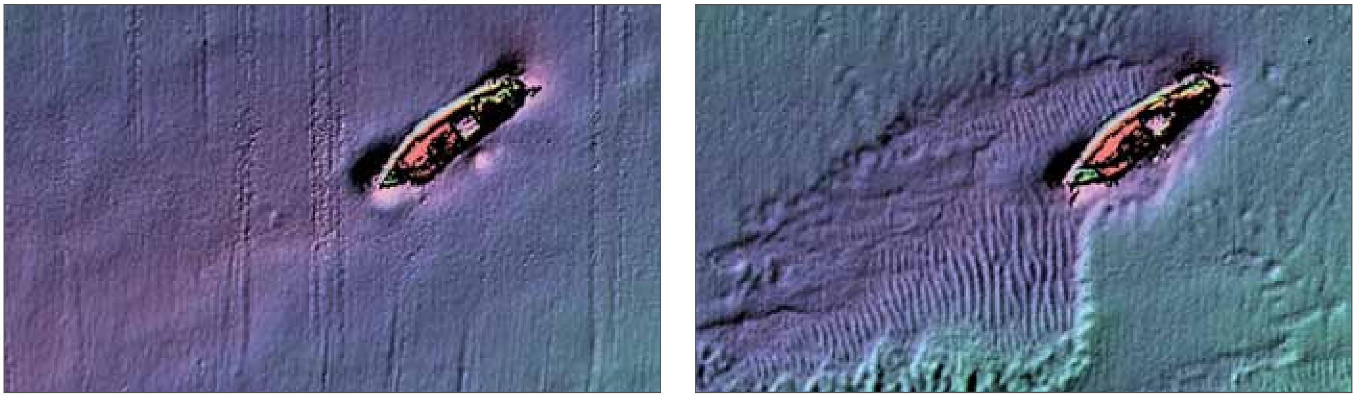


Figure ES-2. Bathymetry before (*left*) and after (*right*) Superstorm Sandy on the seafloor of the Redbird Reef site off Delaware.

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 for ocean mapping. Many of these take advantage of our unique acoustic test tank, the largest of its kind in New England and now equipped with state-of-the-art test and calibration facilities. Among the highlights of this year's efforts are the calibration of two Reson 7125 multibeam echosounders (MBES) from the NOAA Ship *Fairweather* and the return of those sonars to the fleet so that we can begin to inter-calibrate the many 7125s that NOAA uses and better understand the backscatter collected with these systems. Understanding that it will be impossible to bring all of NOAA's sonars into the calibration facility, we are developing a procedure for calibrating these sonars in the field. Additionally, we calibrated and explored the capabilities of several other sonars of potential interest to NOAA and others including Teledyne's MB-1, ENL's WASSP, Simrad's EK-60 and EK-80 WideBand Transceiver, and Klein's Hydrochart 5000 Phase Measuring Bathymetric Sonar.

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 in the establishment (through funding from the National Science Foundation) 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-practice documentation and quality assurance and performance prediction software that have already been introduced into the NOAA fleet. In 2013, the MAC team assisted in sonar installation and acceptance trials on the Schmidt Ocean Institute's R/V *Falkor* and the Ocean Exploration Trust's E/V *Nautilus*. They also visited the UNOLS vessels *Melville* and *Kilo Moana*, assessing and reporting on the performance of their sonar systems. Center staff also made visits to, or consulted with staff on the NOAA vessels *Rainier*, *Ron Brown*, and *Thomas Jefferson* to help troubleshoot problems associated with the sonar systems on these vessels.

Our concern about sensors extends to the instruments that collect the critical ancillary data needed for producing accurate bathymetric data. Unquestionably, one of the greatest sources of uncertainty in our bathymetric data is our inability to capture the spatial and temporal changes of the sound-speed structure of the water column (needed to convert the echosounder measurements to accurate depths). To address this issue, NOAA has adopted "Moving Vessel Profilers" (MVPs) that allow closely-spaced sound-speed profiles to be collected rapidly while the vessel is underway. One of the key questions facing those using these systems is the profiling interval needed to capture the true variability of the water column. Too few profiles can lead to poor data quality whereas too many can lead to degradation and possibly the loss of the instrument. To address this problem, graduate student and NOAA Physical Scientist Matt Wilson and Center researcher Jonathan Beaudoin developed the "CastTime" algorithm that determines the optimal spacing for MVP casts and automatically controls the profiler. In 2013, plans were developed to implement CastTime as an operational tool in the NOAA fleet and test implementations took place on the NOAA Ships *Thomas Jefferson* and *Rainier*. This example epitomizes the role that the Center can play in support of NOAA. A NOAA student arrives at the Center with a specific NOAA problem. She or he works with our faculty and staff to come up with a solution to the problem and then returns to the fleet with a solution and implementation.

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, we have continued to take advantage of an ONR-funded "Bedforms" project where numerous repeat deployments of the Gavia AUV have allowed us to explore the hydrographic and positional accuracy of AUV-collected data as well as directly address the question of the impact of Superstorm Sandy. The focus of the work is the "Redbird Reef" site off Delaware where hundreds of subway cars and other man-made objects have been submerged to form an artificial reef. Six bathymetric surveys using a Geoswath phase-measuring bathymetric sonar deployed from the AUV and a surface ship-mounted Reson 7125 MBES were completed over the site (three in 2012, three in 2013), including one survey three days before and one survey seven days after Superstorm Sandy (Figure ES-2). The combination of both surface ship and AUV-navigated surveys afforded an opportunity to compare survey quality and to consider alternative methods for the processing of AUV collected data. Comparisons between AUV-based and surface ship-based bathymetric surveys revealed that, in 27 m of water, it may be possible to meet the IHO Special Order 2-sigma depth uncertainty requirement with the AUV if it's carefully positioned and the data is very carefully processed.

Processing

In concert with our efforts focused on understanding the behavior and limitations of the sensors we use, we are developing a suite of processing tools aimed at improving the efficiency of producing the end products we desire but, just as importantly, are also 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—CHRT (CUBE with Hierarchical Resolution Techniques) algorithm.

CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of the estimates of depth. This year's efforts have focused on four areas: a fully-distributed version of the algorithm; transition to practice of the serial and single-processor parallel versions of the algorithm in conjunction with NOAA and Center Industrial Partners; improvements to the core algorithm to support interactive data analysis in implementation; and extensions to the algorithm to allow first-order slope correction based on preliminary robust estimates of surface parameters. 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 (Figure ES-3).

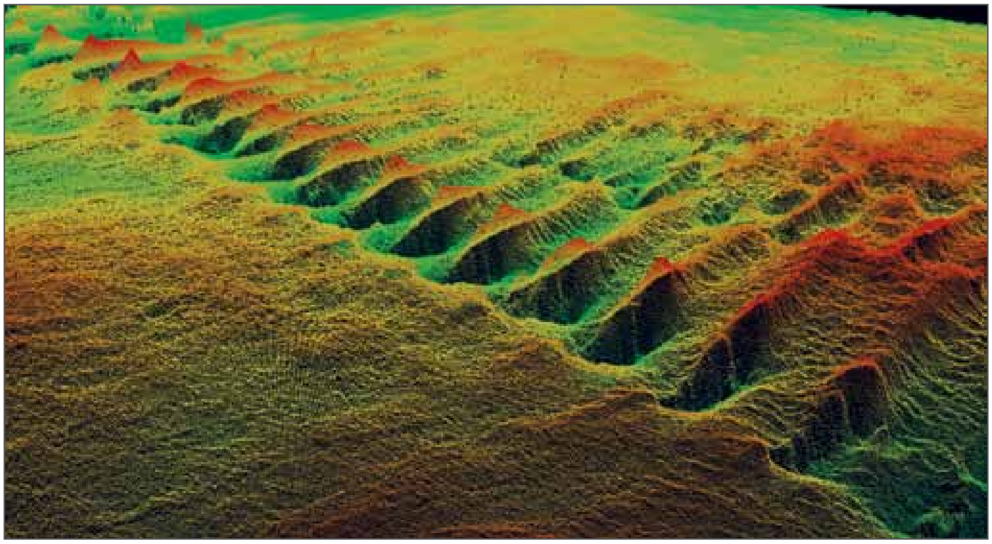


Figure ES-3. Visualization of an early CHRT hierarchical surface in CARIS software (in this case of bridge supports). The co-development model encourages early adoption of software and synergies between developers and testers that can benefit the whole community and ensure correct transmission of algorithms from research to operations. (Data courtesy of Bill Lamey, CARIS, and Jack Riley, NOAA.)

Our efforts to understand uncertainty and improve data-processing flow have also expanded to an alternative type of swath-mapping sonar—one that uses 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, comparisons of PMBS systems at the Redbird Reef site (see above) and field trials with a Klein Hydrochart 5000 PMBS have provided important new insights into the hydrographic capabilities of PMBS.

As discussed earlier, it is becoming increasingly apparent that the largest contributor to uncertainty in our collection of seafloor mapping data is our inability to fully capture the spatial and temporal variability of the speed of sound in the water masses in which we work. In addition to the CastTime approach to optimizing moving vessel profiler casts, Jonathan Beaudoin is looking at the use of historical or model data to help in those areas where sufficient real-time data does not exist and to streamline the process of entering sound-speed data into our sonar systems. As part of these efforts, Beaudoin has developed an "SVP Editor" that allows for the rapid and automated input of sound-speed profiles into MBES systems as well as interactive graphical data editing for removal of outliers and/or the addition of points for vertical extrapolation. In 2013, the SVP Editor was integrated with the software used on NOAA vessels (QINYSy, Hypack, Caris HIPS, and PDS2000) and the SVP Editor was installed on NOAA Ship *Rainier* along with CastTime as an additional tool to improve real-time refraction corrections with *Rainier's* EM710.

The SVP Editor also offers the user the ability to run the software in "Server" mode whereby a synthetic sound-speed profile is delivered to the echosounder over the network based on oceanographic models such as the World Ocean Atlas (WOA) or the Real-Time Ocean Forecast System (RTOFS). The SVP Editor uses position information from the sonar to establish the date and position of the vessel that are then used to form a query for the oceanographic model of choice and to establish estimates of the temperature and salinity profiles for the desired location. A sound-speed profile is constructed from these and is delivered to the MBES. This can be done continuously while in transit, enabling opportunistic underway mapping such that echo-sounding data gathered in the absence of the directly observed sound-speed data has at least a rudimentary refraction correction applied with no operator intervention required. In both use-case scenarios, an important additional functionality of the SVP Editor is to provide the hydrographer with the ability to preview the effects

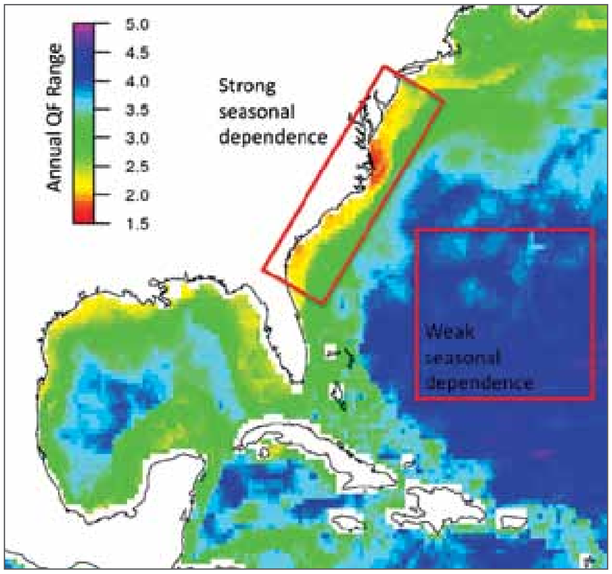


Figure ES-4. Annual range of Quality Factor (QF) based on WOA2001 (1/4°) ray tracing monthly analyses. Areas with strong seasonal effects exhibit a large difference between the highest and lowest QF over the course of the year, e.g., the inner shelf along the eastern seaboard. The WOA predicts weak seasonal dependence in the open ocean.

of applying the new sound-speed profile to data in real-time prior to delivery to the sounder in order to see the effect of the new profile. This allows for an important verification step in which the operator can correct or adjust the profile to minimize refraction residuals in real-time. In 2013, variations on this approach were implemented to allow fisheries sonar data from the NOAA Ship *Pisces* and single-beam sonar data from the USCG vessel *Hickory* to be used to update the charts in areas of very sparse data.

Carrying the approach of using oceanographic models in aid of seafloor mapping one step further, Beaudoin continues to work on developing tools to help better understand the "underwater weather" that can severely limit the achievable accuracies of echo sounding data, particularly with wide swath MBES. The result of this effort is something akin to a weather map for hydrographers—the basic idea is that oceanographic models of temperature and salinity can provide us with an estimate of where spatial variability in the water column can be problematic. With high-resolution models like RTOFS, it is now possible to compute forecasts with high spatial resolution and fidelity. The approach has proven invaluable for planning cruises and in avoiding times or areas of high oceanographic variability. In 2013, efforts were focused on incorporating well-established sonar quality factors into the model so that the output is presented in a hydrographically recognized metric representing the quality of the bathymetric data collected (Figure ES-4).

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 bathymetric data but have traditionally not been used by hydrographic agencies. These 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. Essential to this effort is understanding the uncertainty associated with the measurement of acoustic backscatter from the seafloor. The fundamental question is: when we see a difference in the backscatter displayed in a sonar mosaic, does this difference truly represent a change in seafloor characteristics or can it be the result of changes in instrument behavior or the ocean environment? The focus of our effort in addressing this difficult question is a new project we call the Newcastle Backscatter Experiment (NEBEX). This project, which involves close collaboration with NOAA's Glen Rice and NOAA graduate student Briana Welton, 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; Sam Greenaway's and Glen Rice's efforts toward field procedures for proper backscatter data collection; backscatter mosaicing (GeoCoder); backscatter inversion; and backscatter ground truth (e.g., optical imagery, bottom sampling, 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. Tools and protocols that were developed as part of this effort (e.g., a backscatter "saturation monitor" developed by Glen Rice) and designed to ensure that high-quality backscatter data are collected have already been implemented in the NOAA hydrographic fleet.

Fundamental to the NEWBEX experiment is a field campaign designed to establish a "standard backscatter line" conveniently located near the UNH pier in Newcastle, NH with known seafloor backscatter (at 200 kHz), where "known" equates to an empirically derived absolute seabed backscattering cross section with an associated uncertainty. Throughout 2013, data along the standard line was (and still is being) collected with a calibrated split-beam echosounder at a launch angle of 45° on a weekly basis. The standard line, chosen in consultation with NOAA OCS in anticipation of the arrival of the *Ferdinand R. Hassler*, begins in a gravel area on the north end, traverses a large sand wave field, and ends in an area of clean gravel. At regularly spaced intervals along the line, the data have been averaged to provide an estimate of the mean backscatter level. The variability in the mean backscatter level over an initial ten-week period of the study was remarkably small, with a total spread that is typically less than 2 dB (Figure ES-5). This coming year, we will be analyzing the backscatter trends over the entire time frame, and will also attempt to observe any changes resulting from

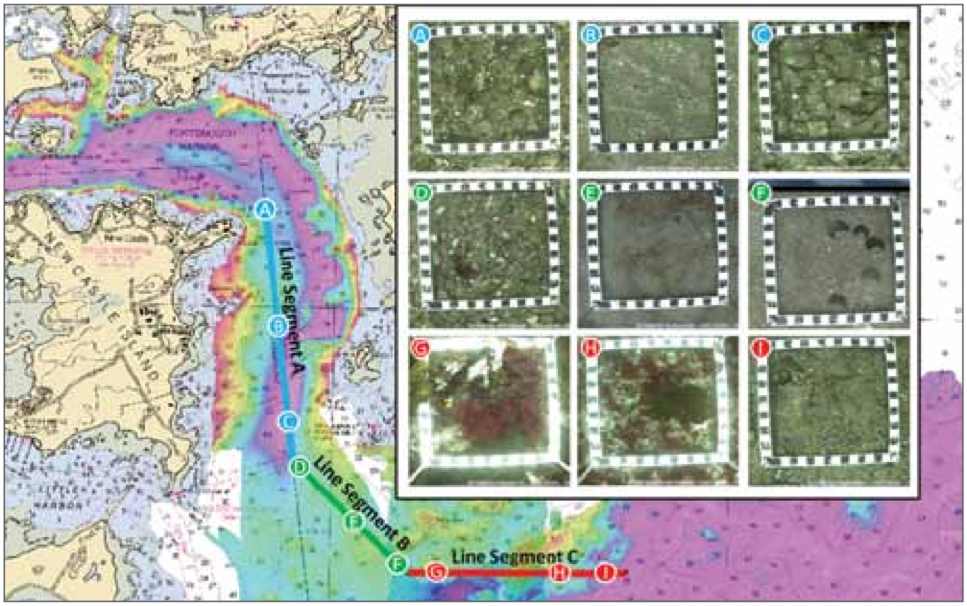


Figure ES-5a. The NEWBEX standard line and field campaign locations. Images from a subset of groundtruth sites are shown.

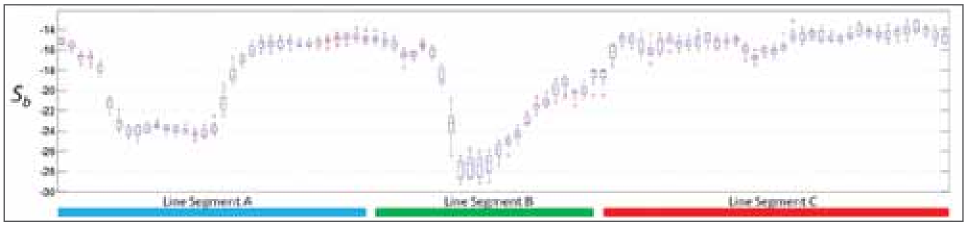


Figure ES-5b. A boxplot describing the distribution of average seabed backscatter, Sb, collected weekly over ten weeks. The boxes describe the boundaries of the 25th and 75th percentiles, the central mark is the median, and the whiskers extend to the most extreme data points not considered to be outliers.

large storm events including a storm event that took place at the end of December.

Our processing efforts have extended beyond acoustic systems to also look at developing better ways to extract information about bathymetry, navigation and shorelines from lidar, photogrammetry and satellite imagery. Included amongst these efforts is our collaboration with scientists from the National Geodetic Service (NGS) looking at the uncertainty associated with photogrammetric- and lidar-based shoreline estimates. This work, led by Chris Parrish, has produced an "EO TPU Tool" and a set of standard operating procedures (SOP) for production use of directly-georeferenced aerial imagery in NGS's Coastal Mapping Program (CMP). In tests of this approach in a complex region of "Downeast" Maine in 2013, the estimated shoreline TPU was found to be well within the IHO S-44 standards for uncertainty in positioning the coastline using both tide-coordinated and non-tide-coordinated imagery. It is anticipated that this work will assist NGS in generating accuracy metadata for photogrammetrically-mapped shorelines, as well as in project planning and decision making. An important characteristic of the TPU model developed in this work is that it is general enough to be extended to other coastal regions and settings.

Figure ES-6. Pre- and Post-Hurricane Sandy shoreline (referenced to MHW) along 5 km of Long Beach Island, NJ (*left*). Areas of erosion and deposition in Barnegat Bay caused by Hurricane Sandy (*right*).

Shoreline estimation techniques developed at the Center have also been used as part of the Center's effort to support post-Hurricane Sandy relief activities. Lindsay McKenna, working with Chris Parrish, Brian Calder and others, has developed a work flow for establishing pre- and post-storm shoreline and erosion maps along the New Jersey coast using EARRL-B topo-bathy lidar collected by the USGS (Figure ES-6).

Finally, a new and exciting start this year has been our evaluation of the potential for using satellite imagery as a means to extract shallow water bathymetric information in regions where vessel access is limited. Shachak Pe'eri has led a Center effort to develop approaches for deriving bathymetry from imagery and for assessing the value of these data for change analysis, habitat mapping, and hydrographic survey planning. Initial efforts focused on data from tropical regions with relatively clear waters (e.g., Belize). The most appropriate algorithms were chosen and the accuracy of the results modeled using a Monte Carlo simulation and validated against reference datasets.

In 2013, these techniques were applied to two regions, Haiti and offshore of the North Slope of Alaska, where bathymetric data is very sparse. In response to the Haiti Earthquake disaster, NOAA and other hydrographic offices around the world have provided support to SHOH (Service Hydrographique et Océanographique de Haiti) by training SHOH personnel, surveying key areas around Haiti, and updating the charts. As part of the 2013 NOAA effort to support SHOH, the satellite-derived bathymetry (SDB) was used and proved useful in identifying shoal features not surveyed in 2010. A more challenging application was the attempt to extract bathymetry in remote regions where seasonal runoff can create very turbid waters (Figure ES-7). To accommodate this, the SDB procedure was further developed to compile multiple satellite images and use only the areas that were identified "clear" by comparison (i.e., minimum water clarity change between two satellite images). This work, done in collaboration with NOAA's Marine Charting Division, is now being evaluated by NOAA's Hydrographic Survey Division (HSD) as a potential aid for survey planning. Along with estimates of satellite-derived depth, Chris Parrish has developed a total propagated uncertainty (TPU) model for satellite-derived bathymetry grids, an essential component for understanding the usefulness of these data for future applications.

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 producing products that not only support safe navigation but that can also provide information critical to fisheries management and other environmental and engineering problems. These efforts have focused on understanding and interpreting the backscatter (both from the seafloor and more recently with the advent of a new generation of multi-beam sonars, in the water column) and generating tools to use this information to provide key information useful to marine managers. Our efforts in acoustic seafloor characterization have focused around the GeoCoder software package (designed to make fully corrected backscatter mosaics and calculate a number of backscatter statistics) and 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 many of our Industrial Partners, many questions remain about the calibration of the sonars (e.g., the work described in the Sensor and Processing sections) and the inherent nature of the approaches used to segment and characterize seafloor properties. This year's efforts focused on rebuilding and restructuring the GeoCoder processing pipeline into software modules. These modules honor the algorithms implemented in the original GeoCoder framework but clear boundaries are set between the various data-flow and processing stages so that researchers can investigate and potentially improve upon a single module without the overhead of maintaining the overall software framework or rebuilding (compiling) the entire application. Several "plug-in" modules have already been created that are enhancing the capabilities for specific sonars or applications.

As part of our IOCM activities (see IOCM theme), we are exploring means of extracting multiple data sets from a single sonar survey/system. To this end, Jodi Pirtle and Tom Weber collaborated with the NOAA Alaska Fisheries Science Center (AFSC) to map groundfish habitat in the Gulf of Alaska (GOA) using the Simrad ME70 multibeam echosounder (ME70) with the primary goal of distinguishing between trawlable and untrawlable areas of the seafloor. Several parameters (angular dependence and maximum average backscatter between 30-50°) have been shown to be good predictors of trawlability. This information will ultimately improve efforts to determine habitat-specific groundfish biomass and to identify regions likely to contain deep-water coral and sponge communities that may be considered Habitat Areas of Particular Concern (HAPCs). This research supports NOAA's efforts to identify and describe Essential Fish Habitat (EFH) for harvested species, and to improve fisheries stock assessment methods for locations and seafloor types that are not easily accessible.

We are also exploring approaches to identify bottom type from single-beam echo-sounder data in very shallow water environments. Initial studies in Great Bay have revealed a promising relationship between maximum and total backscatter intensity, depth and fine-grained components of the sediment (Figure ES-8).

Along with our work using 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, we initiated a research project with Steve Rohmann of the NOAA Office of National Marine Sanctuaries (ONMS) to develop tools and workflows that will enable

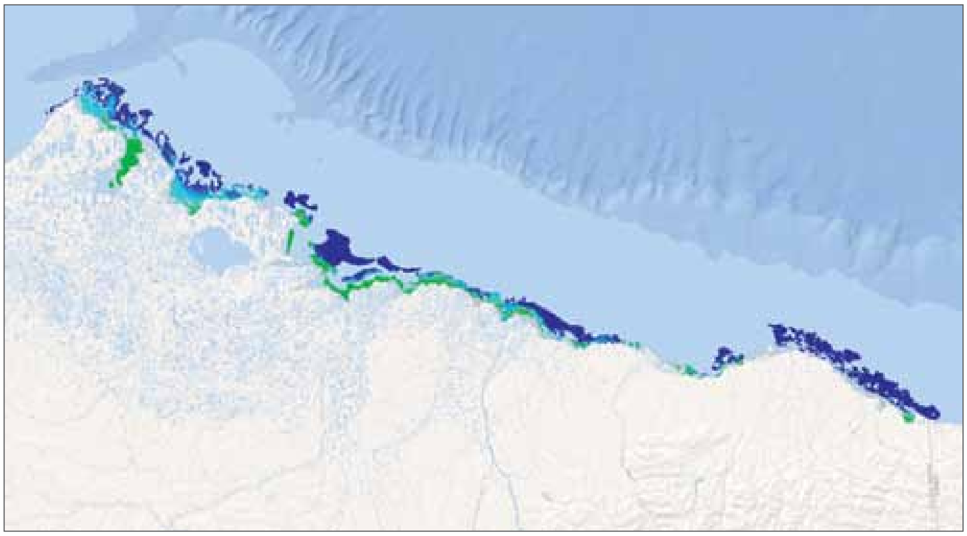


Figure ES-7. Shallow-water bathymetry derived offshore of the North Slope of Alaska using Landsat 7 (1999-2003) and Landsat 8 (2013) imagery.

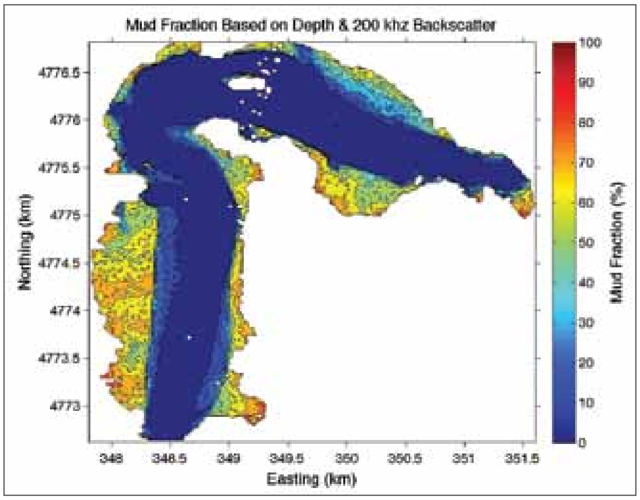


Figure ES-8. Distribution of mud fraction based on an average logarithmic model that includes depth, Itot, and Imax and all sediment samples of Great Bay. These data provide a gross, first order approximation of the mud fraction in the surficial sediment of the Bay.

wide-scale use of remotely-sensed data for producing the required decision-making products without the need for expensive, specialized software and training or additional resources. The primary goal of this work is to build upon existing benthic habitat mapping procedures developed by the NOAA National Centers for Coastal Ocean Science (NCCOS) and overcome the challenges listed above. Initial efforts have focused on a ~1600 km² area in the Marquesas Keys, a chain of mangrove islands in the National Wildlife Refuge ~40 km west of Key West, Florida. Progress to date on this project has included developing and documenting a new method for classification of geographic zones and the demonstration of the ability to remove seamline artifacts from lidar relative-reflectance data through processing applied in the Fourier domain using commercially-available image processing software (Figure ES-9).

As part of our lidar-based habitat mapping effort, we have also been looking at the behavior of the returned lidar waveform as an indicator of substrate type. An important finding of this work is that simple estimates of return pulse width alone were able to explain nearly 60% of vertical uncertainty variation in three salt marshes on Cape Cod, Massachusetts (Figure ES-10). This variation in elevation uncertainty throughout a marsh is important to scientists and managers, since elevation differences of just a few centimeters can affect marsh migration and loss in response to sea level rise.

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. Combining 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 developing tools to capture, analyze and visualize water-column data. 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 (DWH) 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 wellhead, 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 wellhead for leaks. At the time of the spill, such a system was not available so we used fisheries sonars instead. In August and September of 2011, we finally had the opportunity to bring the EM302 multibeam echosounder onboard the NOAA Ship *Okeanos Explorer* to the Gulf of Mexico and test the water-column mapping capability for detecting and characterizing methane gas seeps. During this relatively short cruise (less than two weeks of active mapping), we mapped 17,477 km² of the northern Gulf of Mexico

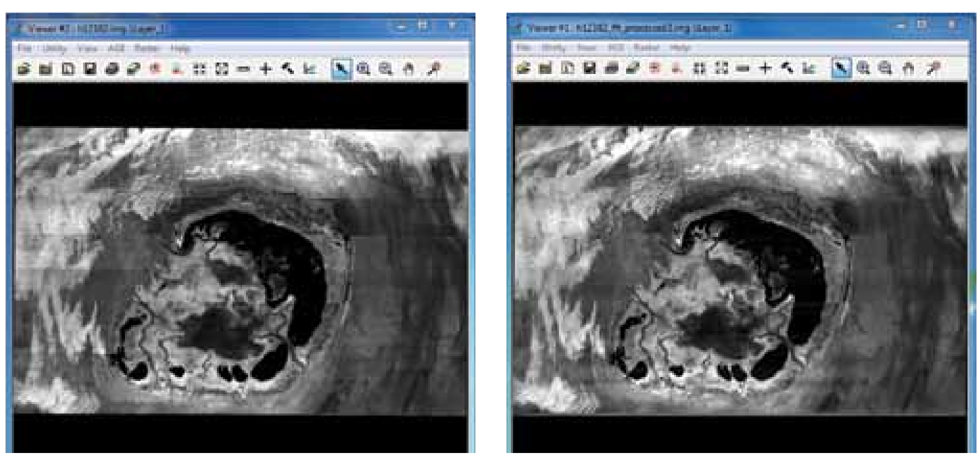


Figure ES-9. Results of the procedure to remove seamline artifacts in lidar relative reflectance data to facilitate coral reef habitat mapping. *Left*: input to Fourier-domain seamline removal procedure; *right*: output. It can be seen in the output image that many of the seamlines between adjacent flightlines (oriented east-west in the original image) have been greatly reduced or even eliminated.

making 573 seep observations. The results from this cruise demonstrated a new mid-water mapping technology for the *Okeanos Explorer,* and 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.

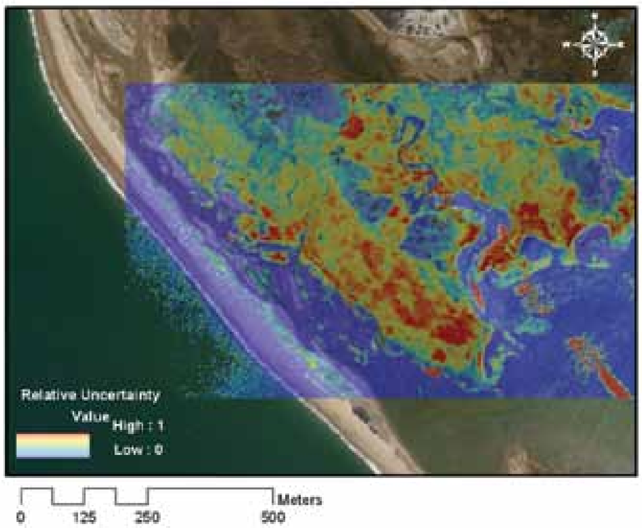


Figure ES-10. Relative uncertainty surface (arbitrary scale of 0-1 "relative uncertainty units") for Moors marsh on Cape Cod, Massachusetts. If these types of surfaces can be provided as a standard output of future NOAA lidar projects, they may enable coastal managers to better understand the relative quality of elevation information across a marsh and assist in decision-making.

In 2013, we continued to analyze acoustic and ROV data collected with the *Okeanos Explorer* in our attempts to further our capabilities to detect, localize, and quantify gas seeps using split-beam and multibeam echosounders. We exploit MBES data collected on the *Okeanos Explorer* for its wide field of view and accurate positioning capability in order to examine the locations, morphologies, and rise heights of the plumes, and we exploit the split-beam echosounder data to provide calibrated measurements of seep target strength (Figure ES-11) that we can relate to gas flux if we know the bubble size distribution. A comparison of gas flux estimates made from acoustic and ROV direct capture methods has shown a remarkably close agreement (within 20%) from a seep on the Pascagoula Dome in the Gulf of Mexico, an encouraging result. These efforts have garnered great interest from the international community, particularly for their potential to help quantify the fate of methane in the ocean and the atmosphere.

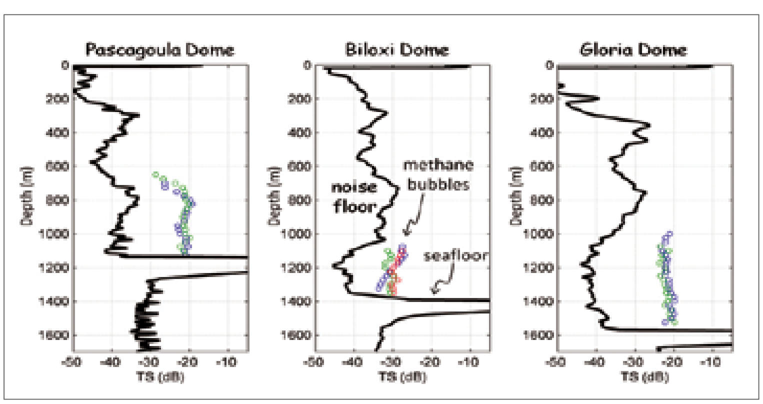


Figure ES-11. Split-beam echosounder measurements of gas plume target strength (colored circles) and background noise floor (black line) from seeps observed in the Gulf of Mexico.

IOCM—Integrated Ocean and Coastal Mapping

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

Representing the Office of Coast Survey at the Center, Glen Rice has been partnering with a number of Center members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. In addition, Glen provides a direct link when specific operational difficulties arise in the field, allowing Center personnel to take part in designing an appropriate solution.

Epitomizing the IOCM concept have been our efforts aboard the NOAA fisheries vessel *Oscar Dyson*. 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 from 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 this from a sonar that was not purchased to map the seafloor.

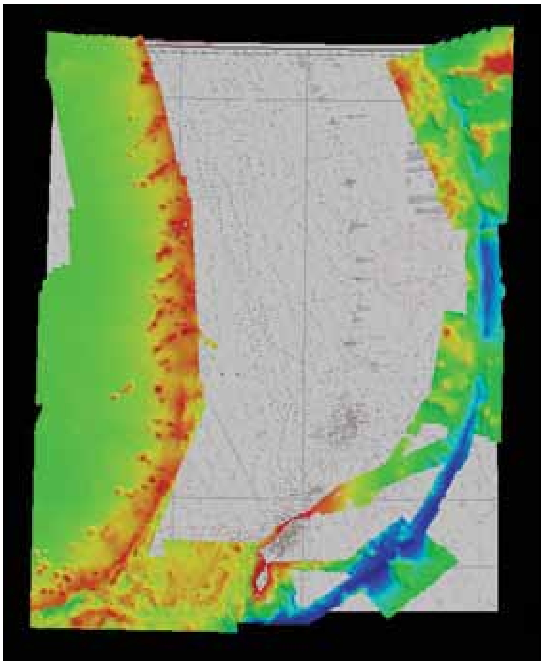


Figure ES-12. Data derived from UNH Extended Continental Shelf surveys being used to update W00270 NOAA Chart 81004.

This year, many of the IOCM-relevant tools and protocols developed at the Center are being put into practice in the fleet. Briana Welton and Glen Rice are developing and implementing calibration techniques and protocols to assure that the backscatter collected by NOAA hydrographic launches is comparable between launches and between surveys. Sarah Wolfskehl is using tools developed at the Center to produce qualified bathymetry and backscatter from fisheries sonars (ME70s) on NOAA Fisheries Service Vessels and efforts are underway to incorporate Center-developed techniques into the software packages in use by the fleet. Wolfskehl has also taken data collected for Law of the Sea purposes in the Marinas region and been able to use these data to update the chart (Figure ES-12).

We are indeed mapping once and using many times, and 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 and to compare the quality of the data collected by these systems as well as their standards and operations, to NOAA MBES data and to NOAA and international hydrographic survey standards.

Visualization

We continue 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. This year, Thomas Butkiewicz and Colin Ware continued 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.

Virtual Test Tank 4D (VTT4D) is a new 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. It replicates many of the analytic abilities and model support found

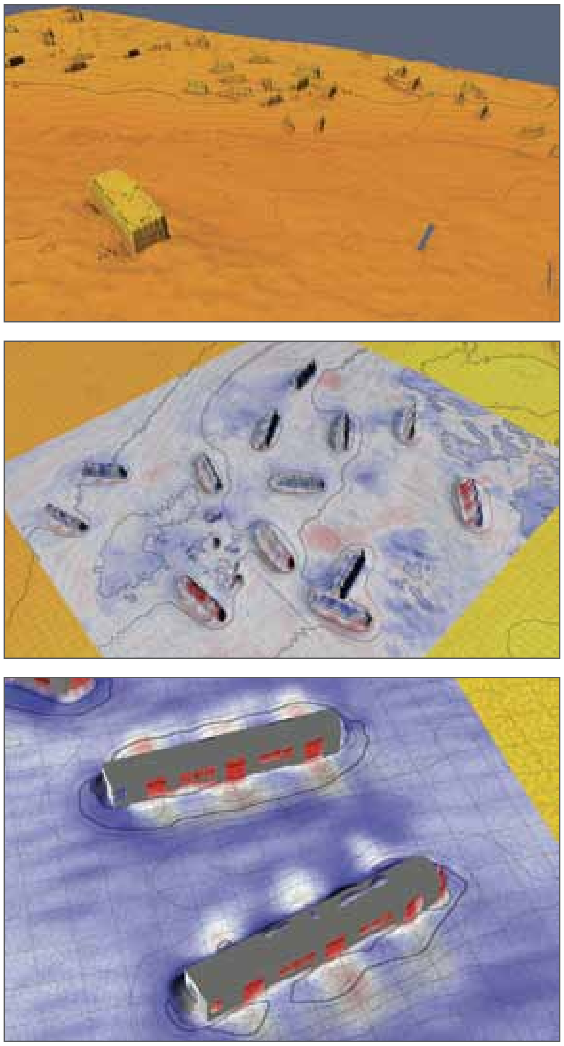


Figure ES-13. *Top*: static bathymetry of the Redbird artificial reef site as displayed in VTT4D. Rectangular objects are the bathymetric rendering of subway cars sunk to serve as artificial reefs. *Middle*: animated dynamic bathymetry at the Redbird reef site generated within VTT4D from five overlapping survey missions. Red areas experienced erosion, blue areas, deposition. *Bottom*: erosion (red surrounded by white) can be seen on either side of the subway cars in a pattern that is easily correlated to the locations of the doors as seen in the high resolution models of the cars. As the water flows through these openings it becomes turbulent and scours the seafloor.

in the previous flow visualization projects, but does so within an updated code base in an easy to distribute application. Its increased flexibility allows users outside the Center to utilize these 4D visualizations with their own data, without the need for custom programming on our end. It also implements many new features to support analysis and to aid presentation. An example is its use to visualize the dynamic seafloor changes after Superstorm Sandy in the Red Bird Reef site discussed previously (Figure ES-13). Such visualizations may have important applications in determining the impact of events like Superstorm Sandy and the need for new survey work for chart updates. To support our visualization efforts and human-factor studies, the lab has also built a new immersive large-format display (Figure ES-14).

Closely related to our Chart of the Future Theme (see below), our visualization group is working with the International Hydrographic Organization to develop an S-100- (hydrographic data standard) compliant specification for the portrayal of tides and currents. Survey results of mariners overwhelmingly support the streamline-type portrayal developed by the Center (Figure ES-15). We are also looking at optimal ways to display 3D flow patterns using 3D tubes following streamlines with multiple cross sections or profiles.

Our visualization team has also been working with NOAA fisheries scientists to create visualizations to help interpret fisheries food web interactions and to interactively explore ecosystem based models of interactions between the key commercial species in the region (Figure ES-16). These tools can be used by NOAA fisheries and fishery management councils to make better-informed decisions relating to tasks such as setting fishing quotas. It will allow for long-term impacts (as modeled) of changes in policy to be easily seen and understood, and to be 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 enabling better estimates of energy expenditure during various phases of foraging.

Figure ES-14. The Center's new semi-immersive display in use. Its large format allows multiple users to examine and analyze data collaboratively in the same space.

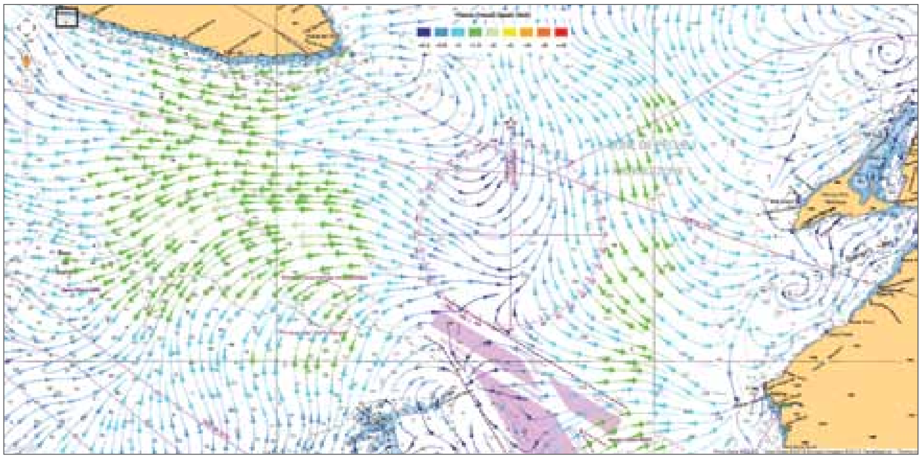


Figure ES-15. Proposed flow-pattern scheme for the Gulf of St. Lawrence rendered over a chart background in a browser using Google Maps.

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 that 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 the "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. Kurt Schwehr, in collaboration with EarthNC, developed an iOS application

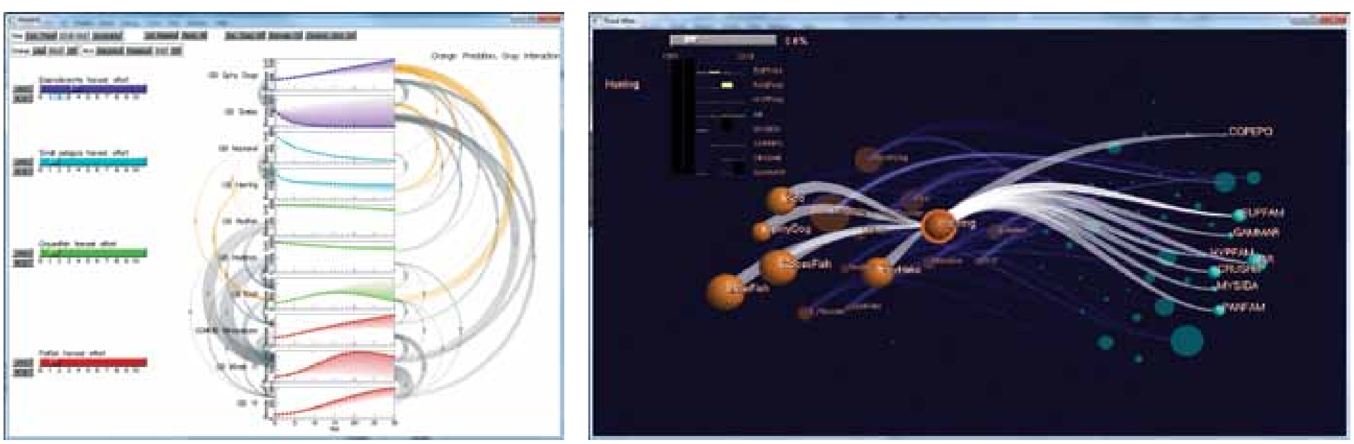


Figure ES-16. *Left*: Interactive visualization of the forecast for ten Gulf of Maine species based on the NOAA KRAKEN model. The effects of increasing the catch of Elasmobranchs is visualized. The arcs show causal links in the model, with predation in yellow and species competition in grey. *Right*: Food web visualization based on NE Fisheries data. Herring has been selected; herring predator species are shown to the left, herring prey species are shown to the right. Other species can be interactively selected to reveal their major predators and prey species. The layout adjusts automatically.

that allows display on an iPad, iPhone, and other hand-held devices. This year, Roland Arsenault extended the capability to a web-based application that serves as a cross-platform alternative to the iPad WhaleALERT app and has the ability to generate KML files so that WhaleALERT data can be viewed dynamically in GoogleEarth (Figure ES-17).

Figure ES-17. *Left*: WhaleALERT iPad app. Credit: NOAA. *Right*: Web-based WhaleALERT data as a dynamically updating KML layer in Google Earth (right).

The revolutionary track for the Chart of the Future involves 3D displays and much more interactivity. In the last few years, the focus of this effort has been the development of "GeoCoast-Pilot," a research software application built to explore techniques for simplifying access to the navigation information a mariner needs prior to entering or leaving a 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, the mariner, in real-time, on the vessel or before entering a harbor, could explore, through 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 linkages 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 further developing automated techniques for incorporating Local Notice to Mariners into the digital products and perhaps the GeoCoastPilot (Figure ES-18). The project called Chart Update Mashup (CHuM) led by Briana Sullivan, 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 (Figure ES-18). An outgrowth of this effort is 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-18. GeoCoastPilot (*left*) and ChuM prototype (*right*).

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.

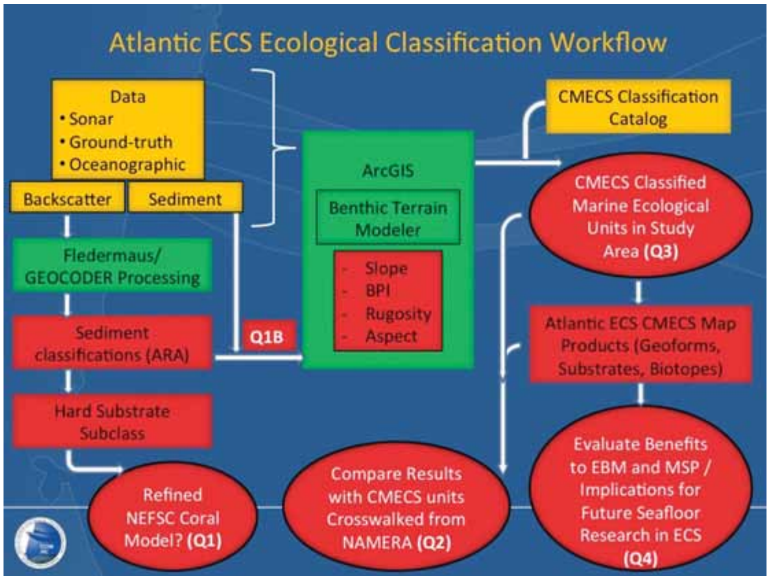


Figure ES-19a. Approach to using ECS multibeam sonar data (and ancilliary data sets) to generate habitat relevant maps of the Atlantic Margin.

Since 2003, Center staff have lead 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 2,070,000 km^2 of multimbeam 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.

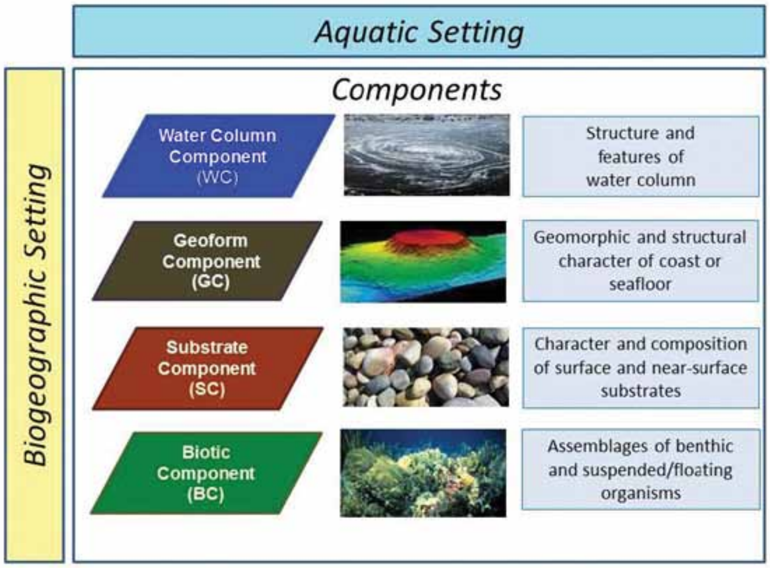


Figure ES-19b. Components of the CMECS Classification Standard—from NOAA.

Budget reductions resulted in no U.S. Law of the Sea cruises in 2013, but Center staff have continued to play an active and important role in managing and archiving the Law of the Sea data as well participating in a range of Law of the Sea Task Force activities. Jim Gardner, Larry Mayer and Andy Armstrong are heavily involved in analyzing ECS data and participating in ECS Task Force, Working Group, Integrated Regional Team and other Law of the Sea-related meetings including a three-day U.S. State Department-led workshop held in Washington D.C. to critique a pilot submission for the U.S. Western Gulf of Mexico.

Demonstrating the value of the ECS multibeam sonar data beyond the establishment of an extended continental shelf, Jim Gardner spent much of 2013 involved in writing peer-reviewed journal articles and a USGS Open-File Report all using ECS data. Additionally, graduate student Derek Sowers, under the supervision of Larry Mayer, has been investigating the potential of using the data collected in support of ECS studies for broad-scale habitat mapping. This effort will attempt to use the multibeam bathymetry and backscatter data collected on ECS (and other cruises) along with the ancillary data sets to see if the Atlantic Margin can be characterized using NOAA's Coastal and Marine Ecological Classification Standard (CMECS) (Figure ES-19).

Outreach

In addition to our research efforts, we recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those who ultimately bear the cost of our work. One of the primary methods of this communication is our website (**www.ccom.unh.edu**) that underwent a substantial redesign and upgrade in 2011. Visits to the site in 2013 (41,329) represent a nearly 50% increase over last year with the visit duration also increasing substantially.

We also recognize the importance of engaging young people in our activities so as to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have upgraded other aspects of our web presence including a Flickr stream, Vimeo site, and a Facebook page. Our Flickr stream currently has 1,735 photos with over 91,452 views since 2009, and our videos were viewed 2391 times in 2013. 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 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 and bring them to the Center to test them in our deep tank (and also tour the Center and the Engineering facilities on campus). In this year's annual SeaPerch Competition, 17 teams from Maine and New Hampshire schools competed in several events. In a timed obstacle course, the teams had to maneuver their ROV through a series of underwater hoops, and then trace their steps back. A salvage operation challenged the students to remove weighted buckets from the bottom of the pool using their ROVs. In the afternoon challenge event, the students had to modify their ROVs using materials found around the lab in order to scoop up ping pong balls representing an oil spill from an exploded rig (Figure ES-20).

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

Further outreach is coordinated through the use of the Telepresence Console to communicate with Bob Ballard's E/V *Nautilus* and its "Educators at Sea" program, and the researchers and technicians aboard the NOAA Ship *Okeanos Explorer*. Students visiting the Center have been able to chat live with ROV pilots, technicians, researchers and graduate students while they participate in research cruises.

Center activities have been featured in many international, national, and local media outlets including, this year, *The Los Angeles Times*, *The Wall Street Journal*, *National Geographic*, *The Washington Post*, and *The Boston Globe*.

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

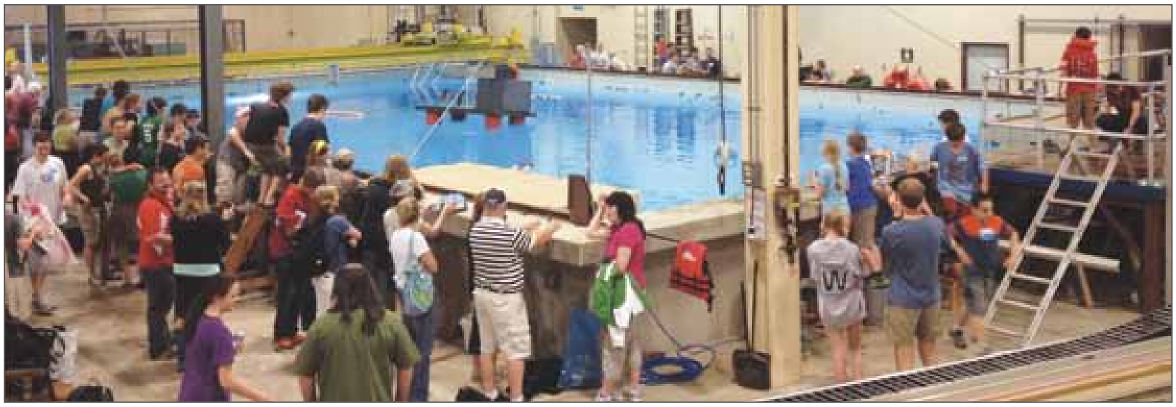


Figure ES-20. Teams prepare for the collapse of an "oil rig" and subsequent spill that they will be charged to clean up with the ROVs they have built.

NOAA/UNH Joint Hydrographic Center 2013 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 we briefly outline in this report those aspects of our 2013 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 2013 Annual Performance and Progress Report at **www.ccom.unh.edu/reports**.

Sensor Research Theme

- ***Update from 2012.*** In support of the thesis work of NOAA Corps officer and graduate student Briana Welton, two Reson 7125 multibeam echo sounders (on loan from the NOAA Ship *Fairweather*) were calibrated in our acoustic tank over the past two years. These calibrations have enabled Welton (working with Jonathan Beaudoin, Tom Weber and Carlo Lanzoni) to develop field procedures and data-reduction and analysis tools for the relative calibration of the Reson 7125 MBES used on NOAA launches. The goal is to develop a general approach to improve the consistency of backscatter measurements made from multiple MBES systems and specifically to improve the quality and utility of backscatter mosaics created from Reson 7125 systems, the most common shallow-water system currently being used by NOAA hydrographic field units. The approach was applied to three NOAA launches operated by the NOAA Ship *Fairweather* in Newport, Oregon during September 2013, and is currently being evaluated. Upon completion of the evaluation in mid-2014, the technique and procedures will be offered to NOAA for their test and evaluation and operational implementation.

- ***Update from 2012.*** The CastTime Algorithm was developed by Jonathan Beaudoin, and implemented by NOAA Physical Scientist Matt Wilson during his tenure as a graduate student at the Center. The algorithm automatically optimizes the sampling interval of a Moving Vessel Profiler in reaction to changing oceanographic conditions assuring that sampling is neither too sparse (degrading bathymetry) or too dense (inefficient, costly, and potentially risky to the equipment). In conjunction with Rolls Royce, an interface has been developed that allows algorithms like CastTime to automatically trigger their moving vessel profiler and, in collaboration with NOAA HSTP, a testing and implementation plan was developed to add CastTime as an operational tool in the NOAA hydrographic survey fleet. The algorithm was tested on the NOAA Ships *Thomas Jefferson* (MVP100) and *Rainier* (MVP200) during the 2013 field season. Initial impressions from the ships are that CastTime works well in the areas where *Thomas Jefferson* operates, i.e., on the Atlantic coast where seafloor depths (and thus casting depth) are relatively consistent, but the algorithm logic needs further refinement to adequately treat the wide range of depths encountered on a cast-by-cast basis during work done by *Rainier* in Alaska.

Processing Research Theme

- ***Update from 2012.*** 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 is available for license to industrial partners. IFREMER, CARIS, SAIC (Leidos), Alidade Hydrographic, and QPS are the first five licensees. The source code has also been made available to NOAA/HSTP to allow them to test the code and provide feedback on observed difficulties and desired functionality. Co-developers have also submitted documentation on best practices, which have been incorporated into the project's wiki, and methods to build the test suite for the code are under investigation.

- ***Update from 2012.*** Jonathan Beaudoin has developed the "SVP Editor"—an application that provides pre-processing tools to help bridge the gap between sound-speed/CTD profiling instrumentation and multibeam echosounder acquisition systems. The main goal of the software is to standardize and streamline the processing of oceanographic information that is collected in support of multibeam echosounder refraction corrections. The operational software, including the source code, is now publicly available online and has been installed on R/V *Kilo Moana*, R/V *Marcus G. Langseth*, R/V *Hugh R. Sharp*, NOAA Ship *Okeanos Explorer*, R/V *Falkor*, NOAA Ship *Ronald H. Brown* (Armstrong, Calder), NOAA Ship *Pisces* (Weber, Beaudoin, Rice, Wilson), R/V *Atlantis* (Welton), and NOAA Ship *Rainier* (Beaudoin and Wilson).

- ***New item.*** A software tool developed by Chris Parrish that allows for the determination of uncertainties in ground coordinates of mapped points determined through photogrammetry has been put into operational use by NOAA/NGS's Coastal Mapping Program. This tool allows shorelines for some coastal projects to be determined from directly geo-referenced imagery without aerotriangulation and has saved many person-hours per year. Additionally, Center lidar researchers are working with the American Society for Photogrammetry and Remote Sensing to make the storage and retrieval of information extracted from topo-bathy lidar waveforms available to all.

- ***New item.*** A real-time multibeam performance prediction model developed by Jonathan Beaudoin, Xavier Lurton, and Roland Arsenault that uses sonar run-time parameters (e.g., source level, beam patterns, pulse widths), and environmental data to drive a sonar equation-based range performance prediction model has been developed. The tool enables MBES operators to quickly determine whether their system is underperforming by comparing the achieved coverage to that predicted by a continually updated performance prediction model. This is particularly useful during sea acceptance trials to help explain discrepancies between expected and achievable coverage that can result from unrealistic expectations that are often driven by experience with other systems in other environmental conditions. The tool is available through the web and has been used aboard both UNOLS and NOAA vessels.

- ***New item.*** 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 2013, in conjunction with NOAA, these techniques were applied to two regions where bathymetric data is sparse (Haiti and off the North Slope of Alaska) in order to better understand their viability as tools for producing useful hydrographic data. (The results from Alaska identified a possible uncharted shoal that will be shown as a danger on the charts of the area, and is slated for investigation by a survey ship in 2015.) Procedures for operational use of the SDB technique have been promulgated in the publically available GEBCO Cookbook (an international guidebook for ocean mapping techniques).

IOCM Research Theme

- ***Update from 2012.*** 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. Although 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. Additionally, Sarah Wolfskehl, building on the work of Jonathan Beaudoin to correct backscatter problems on the NOAA Ship *Fairweather*, has been processing backscatter data from the *Fairweather* and submitting these data to the National Geophysical Data Center (NGDC) for archiving.

- ***Update from 2012.*** 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. In an effort to transfer this capability to "off-the-shelf" software, Glen Rice and Sarah Wolfskehl have been working with industrial partner HYPACK, Inc., to test HYPACK's integration of Weber's ME70 bottom detection code with their hydrographic acquisition and processing software. Incorporating Weber's code into HYPACK would enable ship personnel to produce bathymetry and visualize ME70 data in real-time. This capability within HYPACK would offer an inexpensive option for other fisheries survey vessels to generate bathymetry data and produce an output file in a format that is easily accepted into the Office of Coast Survey hydrographic pipeline. Initial testing of Weber's code in HYPACK was conducted aboard *Bigelow* in 2013 and will continue in 2014.

- ***New item.*** The bathymetric data collected on NOAA Fisheries Survey Vessels do not always meet the standards set by the NOAA Office of Coast Survey for hydrographic charting. Specifically, sound-speed casts do not always meet the four-hour time period recommended in the Field Procedures Manual and the uncertainty values recommended for that time period. Wolfskehl, under the supervision of Rice, has been tasked with processing and preparing an IOCM data set from NOAA Ship *Pisces* and, as part of this task, has been charged with computing total propagated uncertainty (TPU) estimates for the ME70 soundings. Techniques developed by Beaudoin have been adopted to calculate TPU for these data and a new procedure and workflow is emerging that will be brought to HSTP for implementation in standard NOAA SVP processing tools such as Velocipy.

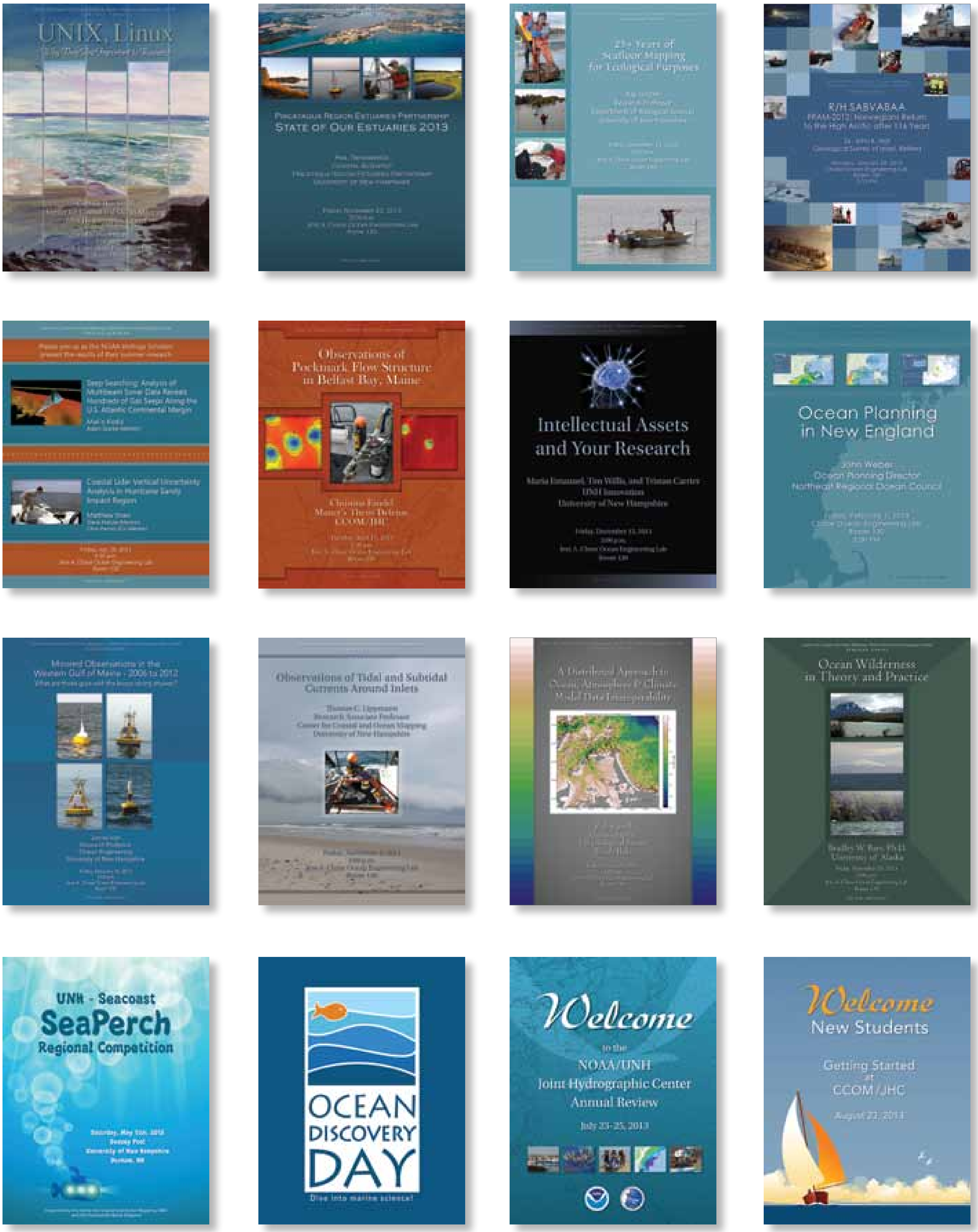
- ***New item.*** Single-beam sonar data has been collected by USCGC *Hickory* in the Arctic in regions of interest to NOAA but without the sound-speed data needed to produce hydrographic-quality depths. HSTP has worked with Beaudoin to generate synthetic water-column models for the entire survey. A total of 441 sound-speed profiles were generated and then resampled to 1-m depth resolution through linear interpolation and were then converted into a single Caris HIPS SVP file for use in post-processing. This allowed NOAA to evaluate the value of this approach for the recovery of data in remote regions where real-time sound speed information was not collected.

- ***New item.*** Epitomizing the multipurpose use of data collected by Center scientists is the reprocessing to NOAA Hydrographic Standards of MBES data collected in support of establishing the limits of a potential extended continental shelf under article 76 of the Convention on the Law of the Sea around the Mariana Islands. These data have now been submitted to the Office of Coast Survey as W00270 to update the chart.

Electronic Chart of the Future Research Theme

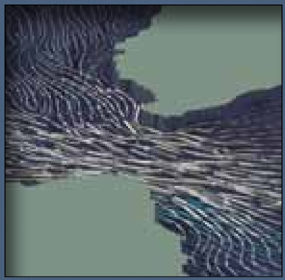
- ***Update from 2012.*** The Center continues to lead efforts to standardize formats for the distribution of full-density bathymetric data to be included in ENCs through the Open Navigation Surface Working Group. Brian Calder serves as the Chair of the Open Navigation Surface Working Group and as a member of its Architecture Review Board. In 2013, Version 1.5.2 was put out as an interim release. This version primarily addresses the stability of the build system, resource versioning, and the use of external libraries.

- ***Update from 2012.*** 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. Last year, an iOS 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. In 2013, a web-based WhaleALERT was developed to serve as a cross-platform alternative to the iOS WhaleALERT app and provide the ability to generate KML files so that WhaleAlert data can be viewed dynamically in GoogleEarth.



Welcome signs and flyers from the 2013 JHC/CCOM Seminar Series.





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