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2012 UNH/NOAA Joint Hydrographic Center Performance and Progress Report

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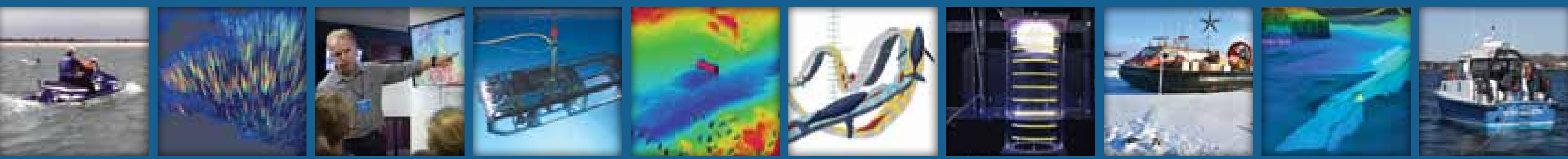
NOAA-UNH Joint Hydrographic Center (JHC/CCOM)

UNH/NOAA Joint Hydrographic Center

Performance and Progress Report



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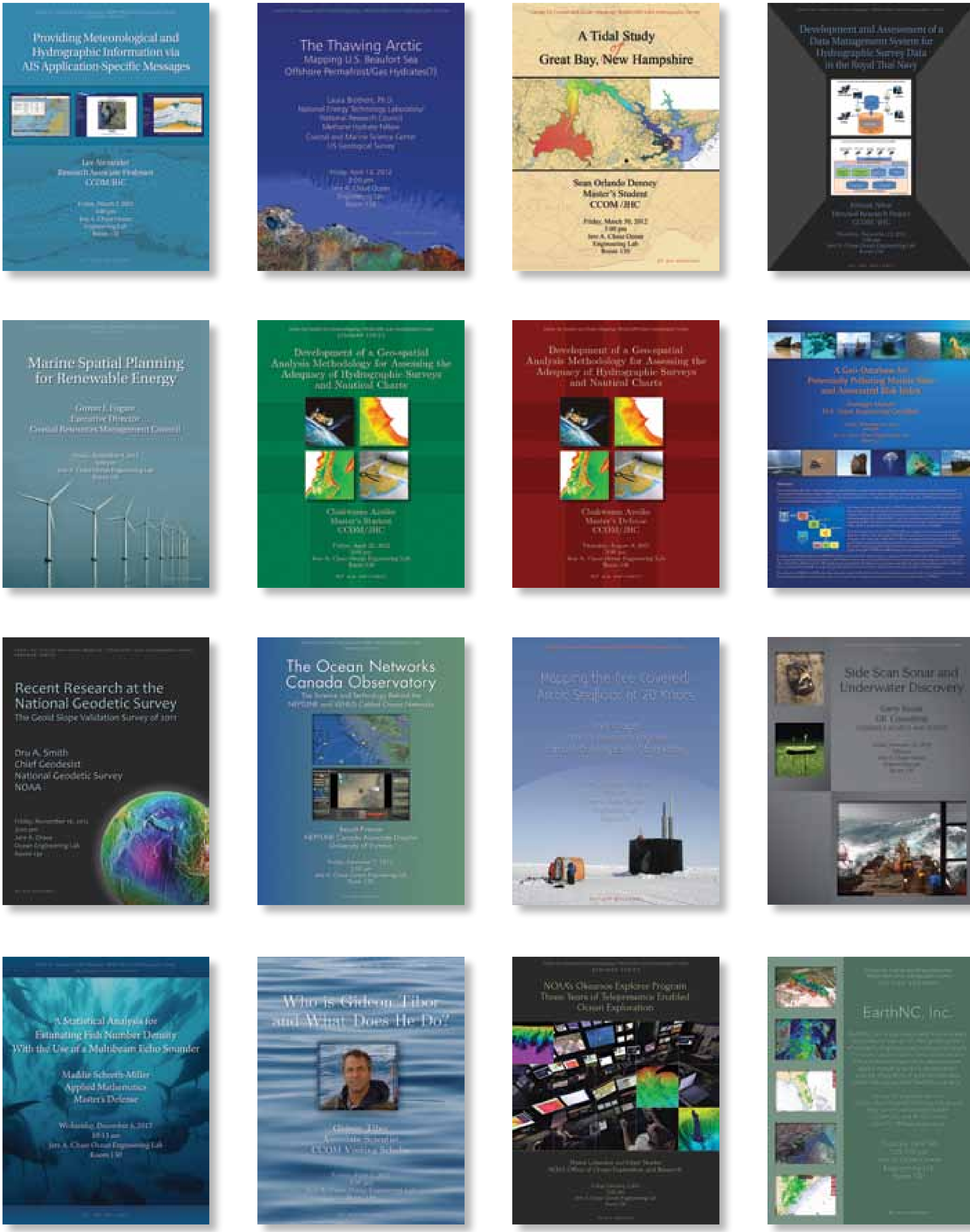


Flyers from the 2012 JHC/CCOM Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded thirteen 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 echo sounders, and to promote the development of new ocean mapping technologies. Over the years, the focus of research at the Center has expanded, now encompassing a broad range of ocean mapping applications. Since its inception, the Center has been funded through Cooperative Agreements with NOAA. The most recent of these, the result of a national competition, funds the Center for the period of 1 July 2010 until December 2015. 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. Over the years, 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 opportunity 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, fisheries management, and national security). Our approach to extracting "value added" from data collected in support of safe navigation has become 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 epitomized 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 over 90 employees and 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, 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 do 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). We sadly note the death of Capt. Parsons in 2011—a tragic loss to the hydrographic and ocean mapping communities.

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 has been opportunistically processed for seabed characterization in support of essential fish habitat (EFH) and also in support of safety of navigation, including submission for charts and identification of a Danger to Navigation. In 2012, seafloor mapping data from the ME70 was used by fisheries scientists to identify optimal sites for fish-traps during a red snapper survey. Scientists on board ship said that the seafloor data provided by Center software was, "invaluable in helping accomplish our trapping objectives on this trip."

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 many of the tools we have developed together 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 scientist 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.

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 the sanctuary, Craig MacDonald, superintendant said:

> *"… JHC/CCOM has been instrumental in creating novel tools to provide sound scientific understanding and information central to NOAA's ability to make informed spatial decisions that support ecosystem-based management in the sanctuary. As the National Marine Sanctuaries Act requires decisions to be made in an inclusive and transparent manner, the ability of JHC/CCOM to provide complex information in a form that can be readily understood by stakeholders (e.g., 3D swim paths of whales combined with multi-beam data on seafloor topography and sediment type) improves NOAA's ability to leverage stakeholder support for controversial decisions. In addition, our collaboration with CCOM has allowed us to monitor and evaluate the efficacy of our decisions, a key EBM requirement that is often neglected. These contributions have allowed NOAA and the sanctuary to occupy a lead position in CMSP and EBM, as identified by our Traffic Separation Scheme initiative being chosen as the single example illustrating the potential benefits of CMSP in the White House Council on Environmental Quality's Interim Framework for Effective Coastal and Marine Spatial Planning."*

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 2012 Program

Our efforts in 2012 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 (Sensors, Processing, Habitat and Water Column Mapping, IOCM, Visualization, Chart of the Future, and Law of the Sea). As our research progresses and evolves, the clear boundaries between these themes have become more diffuse. For example, from an initial focus on sonar sensors we have expanded our efforts to include lidar. 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. While the boundaries between the themes are often diffuse and 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. Among the highlights of this year's efforts are the calibration of a Reson 7125 multibeam echo sounder (MBES) from the NOAA ship *Fairweather* and the return of that sonar 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.

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 software that have already been introduced into the NOAA fleet.

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 for capturing the true variability of the water column. Too few profiles can lead to poor data quality and too many can lead to degradation and possibly loss of the instrument. To address this problem, graduate student and NOAA Physical Scientist Matt Wilson and Center researcher Jonathan Beaudoin have developed the "CastTime" algorithm that determines the optimal spacing for MVP casts and automatically controls the profiler. CastTime was tested in the field on the NOAA Ship *Ferdinand R. Hassler* in September with excellent results leading to greatly reduced utilization of the system but the assurance of high quality data. The software will be installed on a small subset of NOAA field units during the 2013 field season with the goal of a fleet-wide deployment in 2014. This example epitomizes the role that the Center can play in support of NOAA. A NOAA student arrives at the Center with specific NOAA problem. She or he works with our faculty and staff to come up with a solution to the problem and returns to the fleet with a solution and implementation.

The efficiency of multibeam sonar mapping decreases as the water depths get shallower, yet the risks to navigation are typically magnified in the shoalest of waters. To address this issue, NOAA and others have looked to airborne lidar techniques as a possible means of providing rapid mapping in very shallow waters. Thus, in concert with our efforts to understand the behavior

Figure ES-1. The Coastal Bathymetry Survey System (CBASS).

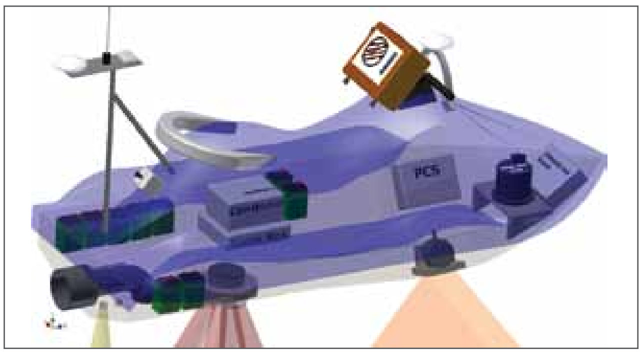


Figure ES-2. Scaled CAD drawing showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS.

of sonar sensors, we are also undertaking a number of projects aimed at understanding the characteristics, behavior and limitations of lidar sensors. Shachak Pe'eri, working closely with NOAA's Chris Parish, has been developing a lidar simulator in the lab that will supplement theoretical studies to determine the behavior of the lidar pulse once it enters the water column. Among the issues being examined (both empirically and theoretically) are the impact of sea state on the resolution of the lidar pulse and the influence of substrate on the lidar return. This year, a new suite of in situ instruments (The Optical Collection Suite) has been developed that enable researchers to collect underwater imagery while measuring the spectral response, performing radiometric calibrations and quantifying the clarity of the water using simple and relatively inexpensive instruments that can be hand-deployed from a small vessel.

Many questions (resolution, target detection and limitations due to water clarity) remain about the ultimate viability of airborne lidar as a hydrographic tool. We are thus also exploring other means to make high-resolution bathymetric measurements in very shallow, rugged coastal areas. One of our approaches is the Coastal Bathymetry Survey System (CBASS), a highly maneuverable personal watercraft equipped with a very high-end motion sensor (POS-MV), kinematic GPS positioning, and a multibeam echosounder. This year, CBASS was deployed in New River Inlet, NC and produced bathymetric maps with 10-20 cm vertical resolution in water depths ranging from less than 1 m to 12 m (Figure ES-1).

Through collaboration with Prof. Art Trembanis at the University of Delaware, we are also exploring the viability of using Autonomous Underwater Vehicles (AUVs) as a platform for hydrographic measurements. This year, the Gavia AUV was equipped with a magnetometer module that allowed us to explore the positional drift of the AUV while surveying. To our very pleasant surprise, calibration surveys with the magnetometer revealed positional errors of 0.15 m in Easting and 0.88 m in Northing with standard deviations of 0.43 m and 0.54 m, respectively, for a typical 55 minute mission, much better than we had envisioned. The Gavia was also used to survey an artificial reef site off Delaware Bay a few days before and a few days after Hurricane Sandy in conjunction with a hull-mounted Reson 7125 (Figure ES-4). The results of these surveys will greatly enhance our understanding of the impact of the storm offshore as well as provide a direct comparison of data collected from a hull-mounted multibeam sonar with those collected by an AUV deployed phase-measuring bathymetric sonar.

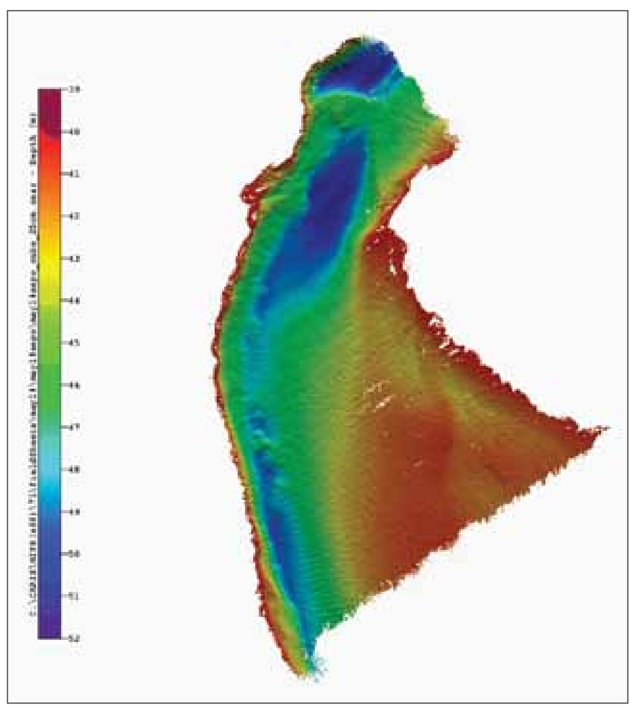


Figure ES-3. Bathymetry produced from CBASS (right). Color scale is meters relative to ellipsoid—depths were consistently measured in water less than 1 m deep.

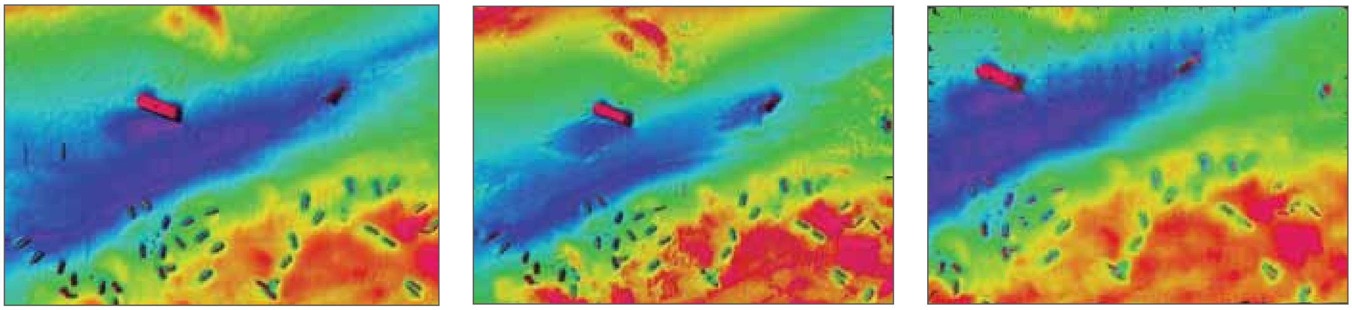


Figure ES-4. Seafloor surveys of "Redbird Reef" from before Hurricane Sandy (left) and after (middle) with the R/V *Sharp's* Reson 7125. The large object is a barge, smaller objects are New York City subway cars. The horizontal extent of the seafloor shown is approximately 425 m with depths ranging from 27.8 to 30.1 m with the exception of the sunken barge and tug. Some subway cars may have moved as much as 10 m during the storm while others appear to have collapsed. Pre-hurricane bathymetry produced by Gavia AUV with GeoSwath phase measuring bathymetric sonar processed with Center-derived software (right).

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. As CUBE becomes more and more accepted as the standard approach to processing hydrographic data, Brian Calder, developer of the algorithm, has continued to work with software vendors and NOAA to ensure appropriate implementation of the code.

This year's efforts have focused on the CHRT (CUBE with Hierarchical Resolution Techniques) algorithm. CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of the estimates of depth. As part of this year's effort, Calder has improved the accuracy of the resolution prediction, improved the stability and accuracy of the algorithm, implemented a parallelized version of the core algorithm, and is implementing a distributed (multi-computer) version for blade-server deployment.

Another exciting achievement in 2012 was Calder's work with the new multibeam sonar data collected by Andy Armstrong and Jim Gardner in support of our Law of the Sea efforts (see below) in the Mariana Trench region, applying robust statistical methods to determine the deepest depth in the world's oceans (10984±25m (95%) on 9 d.f.). Although developed for the specific purpose of finding the deepest depth in this data set, the technique may have important ramifications for several other hydrographic applications.

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.

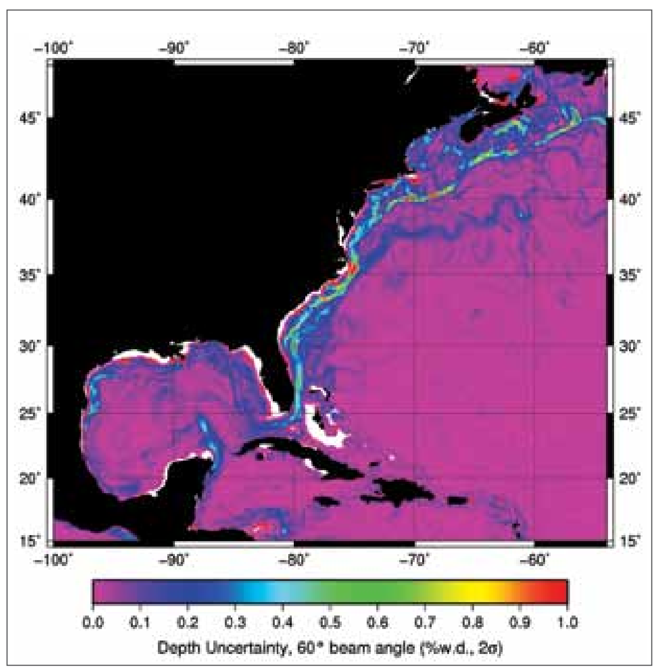


Figure ES-5. High-resolution SVP "Weather Map" of the Gulf Stream region, based on ray tracing analysis of NOAA's Real-Time Ocean Forecast System nowcast for February 17th, 2012.

This year, Schmidt has combined his techniques with an approach developed by Center visiting scholar, Xavier Lurton, to determining uncertainty in PMBS and has used the combined tools to robustly process data collected with a PMBS system deployed on the Gavia AUV (see Figure ES-4).

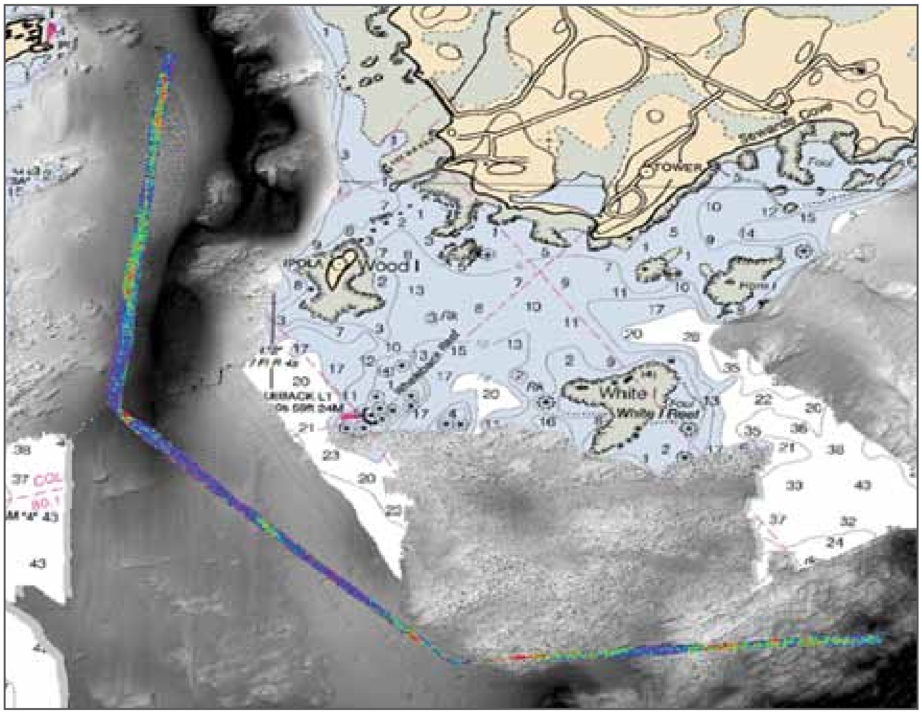


Figure ES-6. Backscatter repeatability measured with 10 passes of a standard line. The color represents the range within which 75% of the data fall over the 10 passes, with blue representing 2 dB or lower variation and red representing 5 dB variation or higher. High backscatter variability seem to be associated with shallow bedrock outcroppings (cause unknown but possibly related to macroalgae), moving bedforms such as sand waves, and boundaries between different types of seabed substrate.

As discussed earlier, it is becoming increasing 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 also looking at the use of historical or model data to help in those areas where sufficient 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 addition of points for vertical extrapolation.

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 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 which 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 then 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 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.

Carrying the approach of using oceanographic models in aid of seafloor mapping one step further, Beaudoin is working 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 (Figure ES-5). The approach has proven invaluable for planning cruises and in avoiding times or areas of high oceanographic variability.

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 was previously ignored 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 to understand the uncertainty associated with the measurement of acoustic backscatter from the seafloor. The fundamental question is: when we see a difference in the backscatter displayed in a sonar mosaic, does this difference truly represent a change in seafloor characteristics or can 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 New Castle 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 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. Epitomizing this effort is the development by Glen Rice and Tom Weber (building on the work of Sam Greenaway) of a backscatter "saturation monitor," a software tool that helps field teams ensure they collect backscatter data that remains within calibration parameters. This tool has successfully been deployed in the fleet and is already improving the quality of data collected. This past year the NEWBEX project began a series of field experiments aimed at understanding the consistency (and sources of inconsistency) in backscatter data through the establishment of "reference surface" for data collection. The results of these experiments have already provided important insights into backscatter behavior (Figure ES-6).

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 multibeam 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

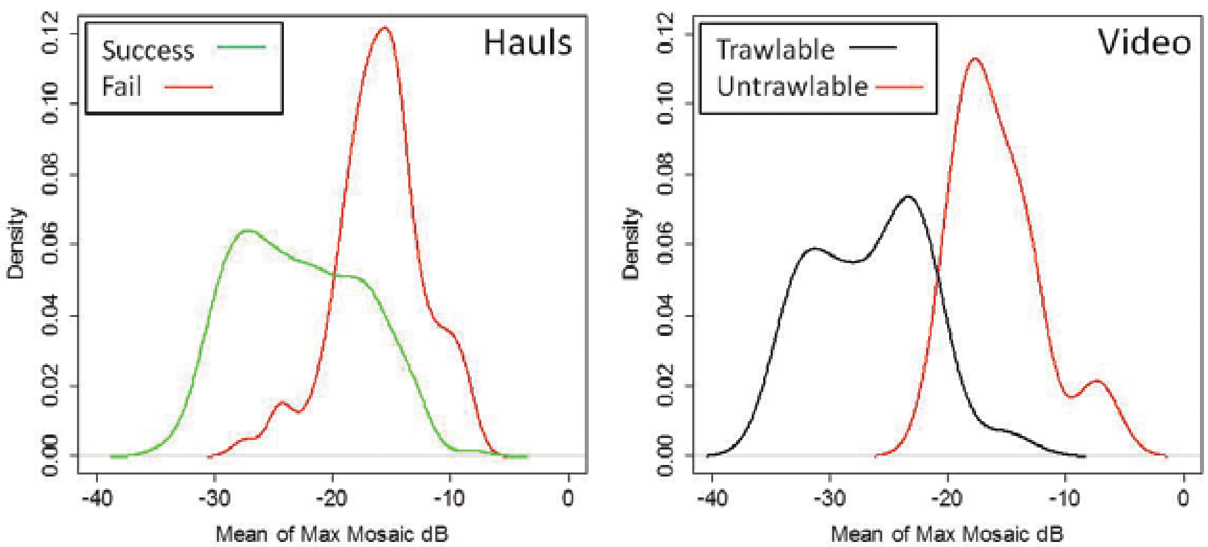


Figure ES-7. Histograms describing the distribution of seafloor backscatter strength (Ss) (mosaic values normalized to oblique incidence angles of 30-50°) at locations in the GOA previously sampled (1996-2011) by the AFSC bottom trawl survey and classified by performance as successful (success) or marginally successful and failed due to gear damage (fail) (left) and at camera stations characterized as trawlable or untrawlable based on video (right).

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. While GeoCoder has been implemented by many of our Industrial Associates, 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, led by Yuri Rzhanov, have focused on automating techniques for segmenting backscatter data into regions of common character and in sensitivity studies to better understand the relative importance of various components of the inversion model and the corrections being made. We have also begun to restructure the GeoCoder processing pipeline into software modules; these modules honor the algorithms implemented in the original GeoCoder framework but with clear boundaries being 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 also exploring means of extracting multiple data sets from a single sonar survey/system. To this end, Jodie Pirtle and Tom Weber are collaborating 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. Last year, a clear relationship was demonstrated between the angular dependence of backscatter and the trawlability of the seafloor. This year, a simpler parameter, the maximum backscatter between 30-50°, was shown to be a good predictor of trawlability; a similar pattern was observed for trawlable and untrawlable camera stations (Figure ES-7).

This information will ultimately improve efforts to determine habitat-specific groundfish biomass and 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. And all this from a sonar that was not purchased to map the seafloor.

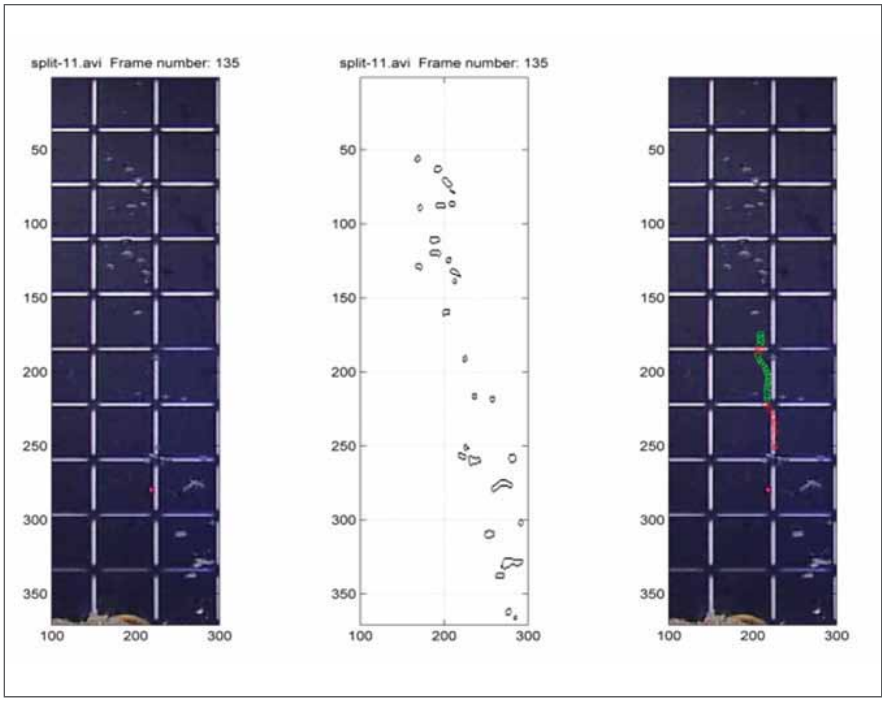


Figure ES-8. A calibrated grid for measurement of bubble size and rise rate (right).

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, including work with NOAA's biogeography group focused on mapping coral habitat in the U.S. Virgin Islands.

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

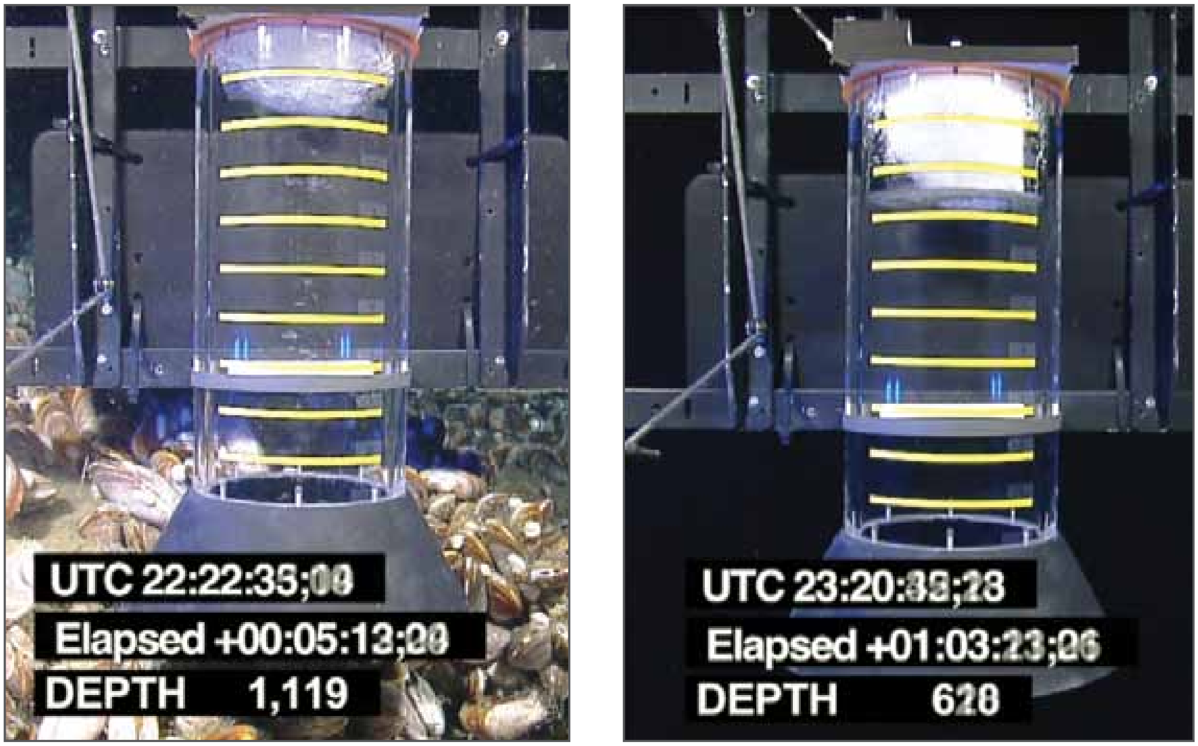


Figure ES-9. A methane capture device used to assess methane flux from a seep in the Gulf of Mexico. Note the hydrates forming in the top of the cylinder, which dissociate to form gas and water as the ROV rises to shallower depths and warmer waters.

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 (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 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 and we used fisheries sonars instead.

In August and September of 2011, we finally had the opportunity to bring the EM302 multibeam echo sounder onboard the NOAA Ship *Okeanos Explorer* to the Gulf of Mexico in order to 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 making 573 seep observations. The results from this cruise demonstrate a new mid-water mapping technology for the *Okeanos Explorer*, and also suggest 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.

In 2012, we followed up these studies with another program on the *Okeanos Explorer* aimed again at making acoustic measurements but also using an ROV to estimate gas flux rates to compare to the acoustic data. For this effort, we took advantage of our telepresence capability and guided the science from shore including EM302 and EK60 seep mapping as well as the deployment from the Little Herc ROV of gas sampling apparatus and a calibrated bubble grid aimed at measuring bubble sizes and rise rate (Figures ES-8 and ES-9). These studies set the framework for using surface-ship acoustic backscatter mapping to determine methane flux rates over large areas of the Gulf of Mexico and elsewhere.

IOCM—Integrated Ocean and Coastal Mapping

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

Representing the Office of Coast Survey at the Center, LTJG Glen Rice has partnered 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 on 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 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.

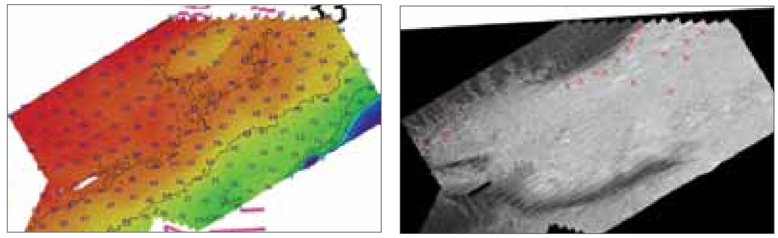


Figure ES-9. Bathymetry (left) and backscatter mosaic (right) used to determine areas of hard-bottom for optimal trap locations. Red Xs mark actual spots of trap drops.

This past year we had a similar example of the power of the IOCM approach when graduate student (and NOAA physical scientist) Matt Wilson, along with Jonathan Beaudoin and Glen Rice, installed Center-developed bottom mapping algorithms into the workflow of the NOAA Fisheries Vessel *Pisces*' Simrad ME70 producing both multibeam bathymetry and backscatter from this fisheries sonar in near real-time (Figure ES-9). Using these products, NOAA fisheries scientists were able to quickly and accurately identify areas of red snapper habitat suitable for setting their traps. In their words, these data were "invaluable in helping accomplish our trapping objectives on this trip."

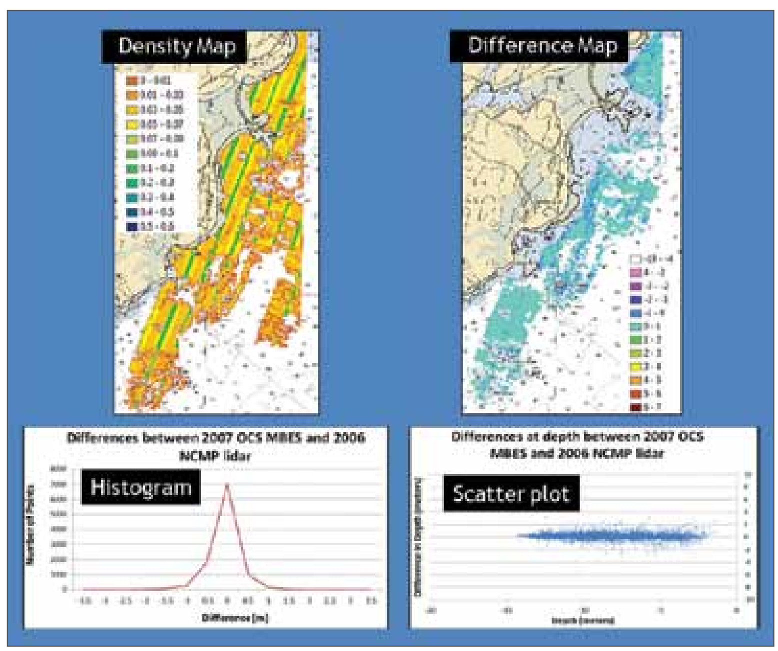


Figure ES-10. Statistical comparison of ACOE ALB data to NOAA MBES data from Kittery, ME. (Top left) Density map of laser measurement in laser measurements per square meter. (Top right) Difference map between ACOE lidar survey and NOAA OCS multibeam survey. (Bottom left) Histogram plot of the depth difference values between the NCMP and OCS datasets. (Bottom right) Scatter plot of the depth difference values between the ACOE and OCS datasets as a function of depth.

We are indeed mapping once and using many times. We are now formalizing the sounding extraction portion of the workflow with the goal of making this process standard aboard NOAA vessels with ME70s 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 (see Sensor theme), 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 (Figure ES-10).

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, Ware and Tom Butkiewicz have continued the development of a new interactive visualization environment for 3D/4D ocean data. The current focus is on multi-depth flow models, but the techniques are general enough to incorporate many other types of data. This project is unique in that it is an effort to bring together a number of different visualization/interaction technologies and techniques and combine them to support a cohesive visual analysis system that will empower users with the ability to explore and analyze complex time-dependent 3D ocean models. The system being developed employs a combination of stereoscopic rendering, to best reveal and illustrate 3D structures and patterns, and multi-touch interaction, to allow for natural and efficient navigation and manipulation within the 3D environment. Exploratory visual analysis is facilitated through the use of a highly-interactive toolset leverages the use of a smart particle system (a system that allows the particles to have independent properties).

Example of analyses that can be performed within the system include simulating pollutant releases by releasing particles configured with specialized behaviors such as vertical movements induced by density differences (modeling, e.g., oil spills or radioactive fluid leaks) and decay over time. Habitat mapping can be supported by modeling larval transport, etc. Survey mission planning for autonomous underwater vehicles can be enhanced by adding information on forecasted flow conditions. Imported or multi-touch plotted path-lines can be automatically evaluated against the surrounding flow patterns, resulting in energy efficiency scores along the proposed vehicle track.

In February 2012, Colin Ware visited Hendrik Tolman, the Branch Chief of Marine Modeling and Analysis NCEP in Camp Springs. The result is an agreement to collaborate on adapting the 3D environment so that it can display the global RTOFS model (a very high-resolution ocean flow model) and in this context show Argos float and glider data. A new analytical feature is the ability to evaluate the predictions within the Global RTOFS forecast model through comparison with collected observational data. This is accomplished by loading the newest profiles and positional data from Argo's global network of 3000 autonomous floats. Each Argo float drifts underwater for nine days, and

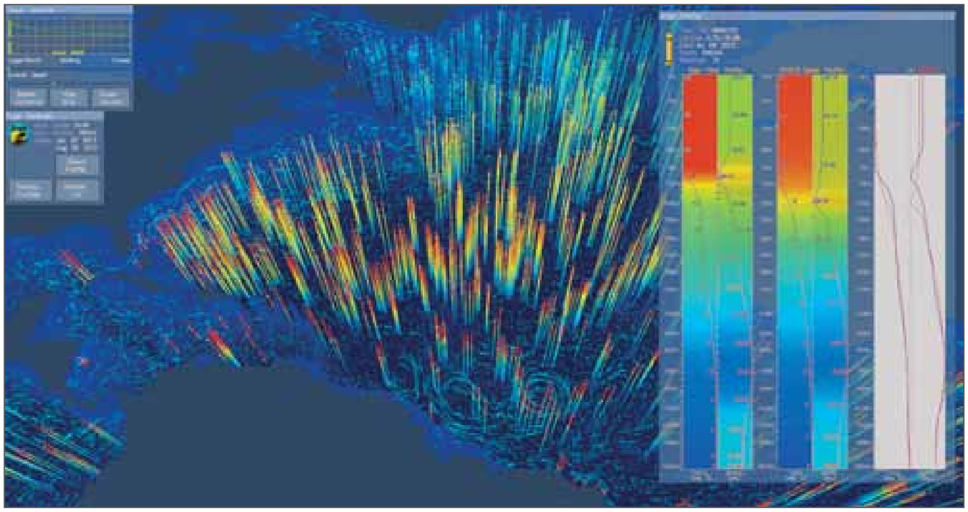


Figure ES-11. Profile explorer window showing the observed and predicted temperature and salinity profiles from an Argo float and the RTOFS model. The rightmost graph plots them against each other to highlight deviations.

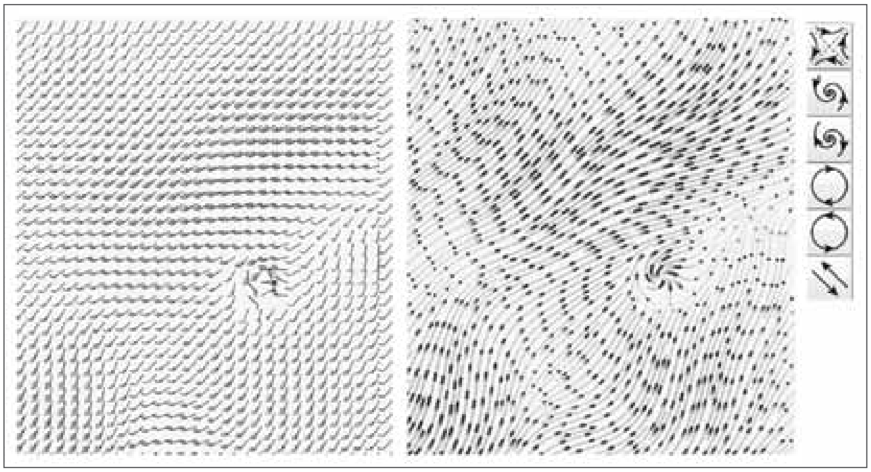


Figure ES-12. A wind pattern shown using the traditional method and using our new method (Pilar and Ware, in press). This is part of a study of pattern perception using different portrayal methods.

then ascends to the surface while collecting a temperature and salinity profile, which it transmits along with its current location before diving again. Analysts can select Argo profiles in the 3D view, which spawns profile explorer windows (Figure ES-11) that present the Argo profile data, along with corresponding profiles automatically extracted from the RTOFS model at the same location. By comparing the observed temperature and salinity values to those in the forecast model, simulation designers can gain critical insight regarding where and how their model succeeds or fails in its predictions. Furthermore, the accuracy of the model's flow forecasts can also be evaluated by comparing the float's observed positional data to predicted trajectories generated using the model's forecasted flow vectors. The Argo float analysis is just one example; we envision that this new visualization environment will become a powerful analytic tool for the exploration and evaluation of many types of complex 3- and 4D oceanographic data sets.

Adding to our visualization research, are efforts to establish new ways to display wind and wave patterns using newly developed wind "glyphs." Research into flow visualization has suggested that streamlines better represent flow patterns but these methods lack a key property—unlike the wind barb they do not accurately convey the wind speed. With the goal of improving the perception of wind patterns, and at least equaling the quantitative quality of wind barbs, graduate student David Pilar and Ware developed variations on the wind barb and designed a new quantitative glyph (Figure ES-12). Testing of the results has shown that the new design is superior to the classic, but also that the classic barb can be redesigned and substantially improved. They are currently investigating ways of using the new glyphs to show wave patterns from the WaveWatch III model and current patterns and will be integrating these innovations into NOAA's NowCoast Portal.

The visualization team also continues to develop tools to better understand the underwater behavior of humpback whales and the applications of this work in support of both basic science and policy decisions (humpback whales are an endangered species whose decline is attributed to ship collisions and fishing-gear entanglement). NOAA and Woods Hole Oceanographic Institution scientists have developed suction-cup-mounted tags that are attached to a whale that record depth, pitch, roll and sound for as long as the tag remains on the whale. Our visualization team has taken these data and created fully georeferenced 4D displays of the whale's diving and swimming behavior in the context of the bathymetry, other vessels and ambient sounds. Numerous papers on, and demonstrations of, this technology have been presented at both scientific and policy meetings. Ware has extended this work with the development of TrackPlot, an application designed to help visualize and analyze data from tagged marine mammals. It has evolved over the past eight years in close collaboration with marine mammal scientists and has become a significant research tool resulting in a number of journal papers detailing the kinematic behaviors of various species. Development of TrackPlot is ongoing and the user base of TrackPlot continues to expand. It has at least 14 users from different groups and it has been applied to 11 different species.

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 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, has developed an iPad application that allows display on the iPad, iPhone, and other hand-held devices; we are now exploring using this model to transmit other information (e.g., tides) to vessels (Figure ES-13). In support of the growing need to support navigation in an ice-diminished Arctic, we have worked with Lysondros Tsoulos of the National Technical University of Athens to establish optimal map projections for Arctic navigation charts.

The revolutionary track for the Chart of the Future involves three-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 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 could, in real-time on the vessel or before entering a harbor, 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 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-14). The Local Notice to Mariner project has matured to the point where project lead, Briana Sullivan, has made several presentations to NOAA and USGC personnel involved in the creation and distribution of Local Notice to Mariners. These presentations have been well-received and further collaboration is being explored.

Figure ES-13: WhaleALERT iPad display as seen by a mariner approaching Boston Harbor. Credit: NOAA.

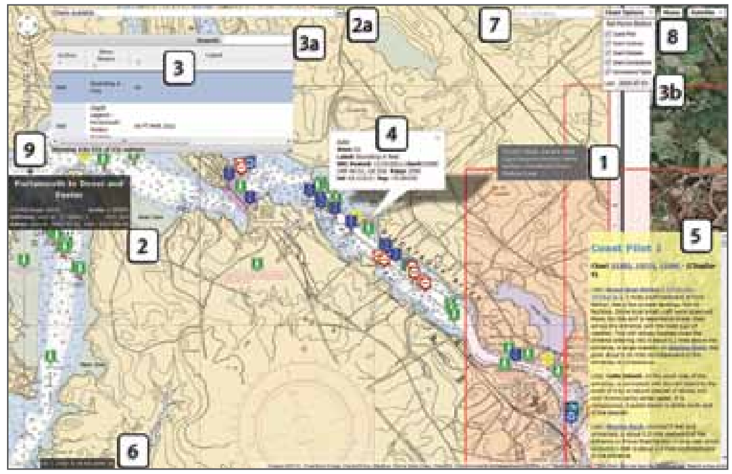


Figure ES-14. GeoCoastPilot (left) and Local Notice to Mariner Google Maps Mashup (right).

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 (**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 2,070,000 km2 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.

In 2012, the Center organized and ran two Law of the Sea cruises—one in the Atlantic to continue mapping the location of the foot of the slope and the second in the high Arctic around the northern extension of the Chukchi Cap. The Atlantic margin survey work is a continuation of mapping started in 2004 and continued in 2005 and 2008 (see Progress Reports for those years or cruise reports at **ccom.unh.edu/theme/law-sea/cruise-reports**). These earlier cruises identified multiple possibilities for the location of the foot of the slope, a critical component for establishing an extended continental shelf, and additional mapping work was deemed necessary. A 30-day ECS cruise was planned using the NOAA Ship *Ronald Brown* but repeated generator failures led to a curtailed cruise of 17 days with Andy Armstrong, Brian Calder, and Shep Smith serving as co-chief scientists. The shortened cruise concentrated on the depositional lobe downstream of Hatteras Transverse Canyon and mapped 65,000 km^2 of seafloor with

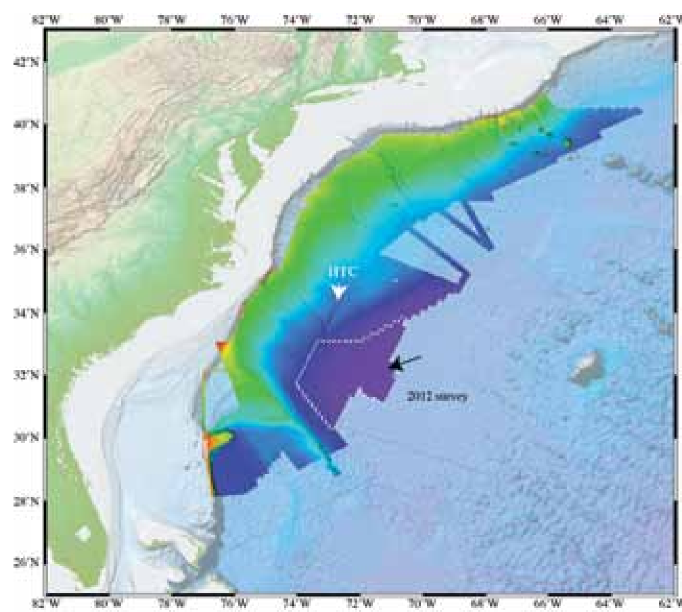


Figure ES-15. Location of the 2012 survey and Hatteras Transverse Canyon (HTC) and depositional lobe.

multibeam sonar bathymetry and backscatter (Figure ES-15). The data clearly show two large-scale mass failures (Cape Fear and Cape Lookout Slides) as well as the depositional lobe of Hatteras Transverse Canyon and will help define the foot of the slope in this region. Additional surveying will be required to the north.

The seaward termination of Blake Ridge had never been mapped before this cruise. Although the area where any relief from Blake Ridge disappears was not mapped, almost all of the eastern-most section of the ridge was mapped and shows a bifurcation of the ridge crest. The ridge extends as a single-crested feature for 450 km before the pronounced split (yellow arrow head in Figure ES-16). The bifurcation must be related to the interaction of the ridge sediments to the dynamics of the Western Boundary Current as it maneuvers around the bathymetric feature.

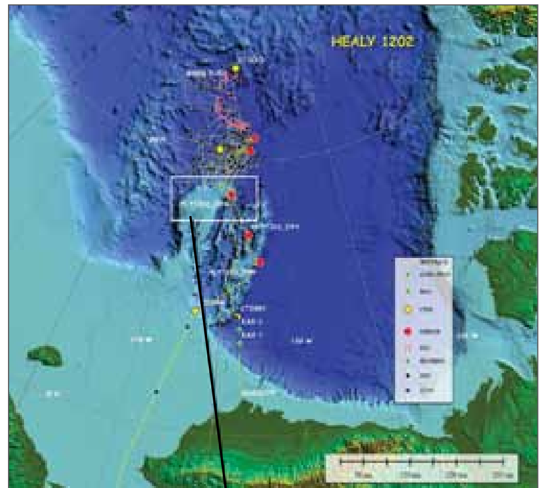


Figure ES-17. HEALY 1202 shiptrack, XBT, XCTD, CTD, buoy, and dredge locations.

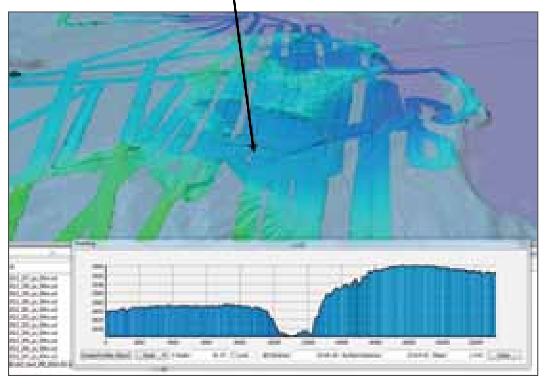


Figure ES-18. Submarine channel north of Chukchi Cap—overall length is approximately 160 km. Cross-section shown in figure is 23 km long.

This year's Arctic cruise (HEALY-1202) was the first ECS mapping program since 2008 that did not include participation of a Canadian icebreaker. The primary objective of this leg was to collect high-resolution multibeam sonar data in the region north of Chukchi Cap leading into Nautilus Basin in order to unambiguously locate the position of the "foot of the slope" as defined by Article 76 and to better understand the morphology of the northward extension of Chukchi Cap into Nautilus Basin. Secondary objectives included the collection of high-resolution chirp sub-bottom profiles to help in the determination of the location of the foot of the slope, the collection of dredge samples to better understand the geologic nature of Chukchi Cap and its northern extension, and the collection of underway gravity data. Ancillary projects were also carried out including oceanographic, wildlife and ice studies. Record breaking minimal ice conditions in 2012 allowed all scientific objectives to be met and much more seafloor was mapped than originally planned. Total track covered on HEALY 1202 was 11,965 km with 10,030 km of MBES collected in support of ECS purposes (Figure ES-17). These data were collected in average ice conditions of 6/10 ice cover and at an average speed of 7 knots in the ice, covering an area of approximately 68,600 km2 and adding approximately 25% to the U.S. Arctic MBES data holdings. Among the highlights of this cruise was the discovery of a spectacular submarine channel north of Chukchi Cap that drains from west to east over a distance of at least 160 km with an average gradient of about 0.18 degrees. The channel does not significantly meander but is complex with numerous small tributaries and several bifurcations. The maximum depth of the channel is approximately 80 m (Figure ES-18).

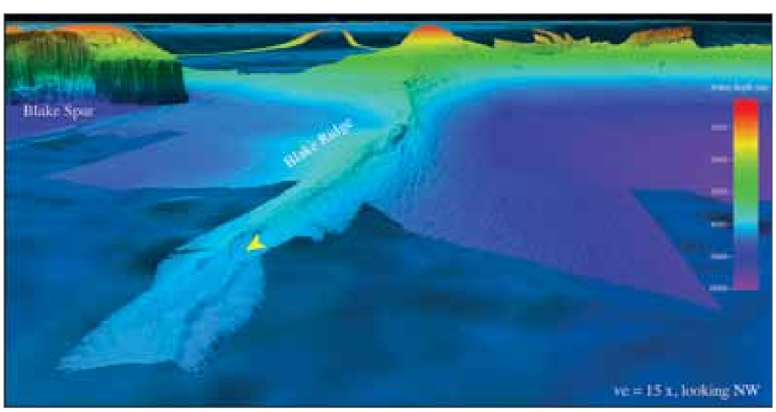


Figure ES-16. Perspective view of Blake Ridge showing a bifurcation in the ridge crest (yellow arrowhead).

Five dredge sites were occupied recovering a wide suite of rock types ranging from basalts to metamorphic rocks. At 78 degrees north, a sample of coral was recovered—most likely the farthest north a coral sample has ever been discovered. Analyses are currently underway on samples. Finally, as part of USGS studies of ocean acidification, four CTD stations, 625 discrete underway samples for pH, 614 discrete underway samples for alkalinity and 4000 continuous measurements of pH, pCO_2, and TCO_2 were taken.

Outreach

In addition to our research efforts, we also recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those who ultimately bear the cost our work. One of the primary methods of this communication is our website which underwent a substantial redesign and upgrade this year. Visits to the site (28,882) represent a 19% increase over last year with the visit duration increasing by 35%.

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 photostream, Vimeo site, and Facebook. Our Flickr stream currently has 1,547 photos (with over 5500 views) and our videos have been viewed 1902 times. Our seminar series is widely advertized and webcast, allowing NOAA employees and our Industrial Associates around the world to listen to 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). Tara has hosted tours of the Center for hundreds of school children and community groups. Several large and specialized events were organized by the Center outreach team, including several SeaPerch ROV events and the annual UNH "Know the Coast" event. The SeaPerch ROV events have been coordinated with the Portsmouth Naval Shipyard (PNS). Students build ROVs and then bring them to the Center to test them in our deep tank (and also tour the Center and the Engineering facilities on campus). The interest in these ROVs was so great that PNS and the Center decided to hold our first competition between schools, the UNH SeaPerch Competition (Figure ES-19).

Further outreach is coordinated through Bob Ballard's E/V *Nautilus* and its "Educators At Sea" program. Here, we use the Telepresence Console to communicate with students across the country (many at Boys and Girls Clubs), researchers on the *Nautilus*, and visitors to the Mystic Aquarium's Nautilus Live Theater and the Nautilus Live website.

Center activities have been featured in many international, national, and local media outlets including *Science*, the BBC, *Sea Technology*, *The Telegraph* (U.K.), *Geographical Magazine*, *Science Now*, and *The Boston Globe*. Our work on the *Healy* was featured on National Geographic's Alien Deep series with more than 6 million viewers. The episode we were in won the Blue Ocean 2012 Film Festival Award for Best Exploration and Adventure Film.

The highlights presented here represent only a fraction of the activities of the Joint Hydrographic Center in 2012; more detailed discussions of these and other activities of the Center can found in the full progress report.

Figure ES-19. Middle school children building and testing small ROVs as part of the SeaPerch program (left) and learning about the activities of the Center at Know the Coast Day (center, right).

Introduction

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

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

This report is the seventeenth in a series of what were, until December 2002, bi-annual progress reports. Since December 2002, the reports have been produced annually; this report provides an overview of the activities of the Joint Hydrographic Center, highlighting the period between 1 January and 31 December 2012. As such, it represents the third progress report for the current grant (NA10NOS4000073). Copies of previous reports and more detailed information about the Center can be found on the Center's website (**http://www.ccom.unh.edu**). More detailed descriptions of the research efforts can be found in the individual progress reports of Center researchers that are posted on our internal wiki; these are available on request.

Infrastructure

Personnel

Over the past 12 years, the Center has grown from an original complement of 18 people to more than 80 faculty, staff and students. Our faculty and staff have been remarkably stable over the years but as with any large organization, inevitably, there are changes. In 2012, Kurt Schwehr joined Google in California where he will work on Google Ocean. Kurt will retain an adjunct position with the Center that will hopefully lead to very close ties between the Center and Google. We had two new hires in 2012. Jenn Dijkstra joined the staff as a habitat specialist. Jenn has a Ph.D. in zoology with a specialty in biogeography and habitat structure; she will be adding strength to our growing interest in habitat mapping. Rochelle Wigley, a former GEBCO student has joined the GEBCO program to lead an Indian Ocean compilation project and to assist Dave Monahan with the overall supervision of the GEBCO program. Over the course of the year we had three visiting scholars: Xavier Lurton from IFREMER finished up his visit in February (and returned for another visit in October/November), Gideon Tibor from Israel Oceanographic & Limnological Research Institute and the Leon H.Charney School of Marine Sciences in the University of Haifa, and Seojeong Lee from Korea Maritime University. While at the Center, Gideon worked on the development and application of high-resolution marine geophysics and remote sensing techniques for the study of phenomena that influence the marine environment. Seojeong is working on software quality assessment of e-navigation and development of e-navigation portrayal guidelines. Finally, in 2012, Jonathan Beaudoin and Tom Butkiewicz were promoted to Assistant Research Professors and Tom Weber was appointed as a tenure-track Assistant Professor with a joint appointment in Mechanical Engineering and CCOM.

Faculty

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

Jonathan Beaudoin has a Ph.D. (2010) in Geodesy and Geomatics Engineering from the University of New Brunswick and Bachelor's degrees in Geodesy and Geomatics Engineering (2002) and Computer Science (2002), also from UNB. Having arrived at JHC/CCOM in the Spring of 2010, he has carried on in the field of his Ph.D. research estimating sounding uncertainty from measurements of water mass variability. His research includes an examination of oceanographic resources such as the World Ocean Atlas, the World Ocean Database and real-time oceanographic predictive models to see how the data contained in these comprehensive collections can be turned into information that is meaningful to a hydrographic surveyor. Other research involves assessing how to best acquire, visualize, process, and analyze data from high-resolution underway sound speed sampling systems, again, in terms that are meaningful to a hydrographic surveyor. Jonathan has also become involved with the seafloor characterization projects, adding his experience in processing and normalization of backscatter measurements from a variety of multibeam echosounder systems to the team skill set.

Thomas Butkiewicz received a Bachelor of Science degree in Computer Science from Ithaca College in 2005, where he focused on computer graphics and virtual reality research. During his graduate studies at The University of North Carolina at Charlotte, he designed and developed new interactive geospatial visualization techniques, receiving a Master's in Computer Science in 2007 and a Ph.D. in Computer Science in 2010. After a year as a research scientist at The Charlotte Visualization Center, he joined JHC/CCOM as a post-doctoral research fellow in 2011. In 2012, he joined the faculty as a research assistant professor. Dr. Butkiewicz specializes in creating highly interactive visualizations, that allow users to perform complex visual analysis on geospatial datasets through unique, intuitive exploratory techniques. His research interests also include multi-touch and natural interfaces, virtual reality, stereoscopic displays, and image processing/computer vision. His current research projects include visual analysis of 4D dynamic ocean simulations, using Microsoft's Kinect device to enhance multi-touch screens and provide new interaction methods, multi-touch gesture research, and developing new interface approaches for sonar data cleaning.

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

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

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

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

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

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

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

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

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

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

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

Colin Ware is a leading scientific authority on the creative invention, and the scientifically sound, correct use of visual expressions for information visualization. Ware's research is focused on applying an understanding of human perception to interaction and information display. He is author of *Visual Thinking for Design* (2008) which discusses the science of visualization and has published more than 120 research articles on this subject and his other book, *Information Visualization: Perception for Design* (2004) has become the standard reference in the field (New Edition to appear 2012). He also designs, builds and experiments with visualization applications. One of his main current interests is interpreting the space-time trajectories of tagged foraging humpback whales and to support this he has developed TrackPlot an interactive 3D software tool for interpreting both acoustic and kinematic data from tagged marine mammals. Trackplot shows interactive 3D tracks of whales with whale behavioral properties visually encoded on the tracks. This has resulted in a number of scientific discoveries, including a new classification of bubble-net feeding by humpbacks. Fledermaus, a visualization package initially developed by him and his students is now the leading 3D visualization package used in ocean mapping applications. GeoZui4D is an experimental package developed by his team in an initiative to explore techniques for interacting with time-varying geospatial data. It is the basis for the CCOM Chart of the Future project and work on real-time visualization of undersea sonar data. In recent work with BBN, he invented a patented technique for using motion cues in the exploration of large social networks, and later used at Ft. Meade. He has worked on the problem of visualizing uncertainty for sonar target detection. Ware is a Professor of Computer Science and Director of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping, University of New Hampshire. He has advanced degrees in both computer science (M.Math, University of Waterloo) and psychology (Ph.D., University of Toronto).

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

Research Scientists and Staff

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

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

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

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

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

Tianhang Hou was a Research Associate with the University of New Brunswick Ocean Mapping for six years before coming to UNH. He has significant experience with the UNB/OMG multibeam processing tools and has taken part in several offshore surveys. In addition to his work as a research scientist, Mr. Hou has also begun a Ph.D in which he is looking at the application of wavelets for artifact removal and seafloor classification in multibeam sonar records. He is also exploring several approaches for automated cleaning of multibeam sonar data as well as developing algorithms for determining the "foot of the slope" for Law of the Sea issues.

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

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

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

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

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

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

Lester Peabody has a B.Sc. in Computer Science from the University of New Hampshire (2011). The responsibilities Les is charged with include, but are not limited to, desktop support for the Center's workstations and internal development projects. He is currently engaged in developing the Center's intranet, which will serve as a central access point for the major administrative functions performed at the Center.

Jodi Pirtle has a Ph.D. in Fisheries from the University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, which she completed in 2010. Jodi joined JHC/CCOM in 2011 as a postdoctoral research associate to apply seafloor mapping techniques to study fish habitat and to improve fishery resource and habitat assessment. Jodi's research focuses on the habitat ecology of marine species, in particular, harvested crustaceans and groundfish, including early life stages and adults, and deep-water coral and sponge communities. Jodi seeks to understand marine community structure and the ecological mechanisms underlying habitat associations and species distributions. Jodi approaches these topics through laboratory and field experiments, seafloor characterization, habitat mapping, multivariate analysis, and predictive modeling. Jodi's research incorporates the use of underwater acoustics, oceanographic sampling, fishery resource assessment, optical imagery, geographic information systems, remotely operated vehicles, occupied submersibles, and SCUBA.

Matt Plumlee became a Research Scientist with the Center after completing his Ph.D. at UNH under Dr. Colin Ware. Matt is continuing his work on data visualization and human-computer interaction on a part-time basis. He is focusing his efforts on the Chart of the Future project and in particular the Digital Coast Pilot.

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

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

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

Emily Terry joined JHC/CCOM as Relief Captain in 2009. She focuses her efforts on operating and maintaining the Research Vessel *Cocheco*. She came to JHC/CCOM from the NOAA Ship *Fairweather* where she worked for three years as a member of the deck department, separating from the ship as a Seaman Surveyor. Prior to working for NOAA, she spent five years working aboard traditional sailing vessels. Emily holds a USCG 100 ton near coastal license.

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

In addition to the academic, research and technical staff, our administrative assistants, Linda Prescott, Maureen Claussen and Dan Trefethen ensure the smooth running of the organization.

NOAA Employees

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

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

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

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

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

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

Mashkoor Malik who received his M.S. degree from the University of New Hampshire in 2005 has been hired by NOAA (through ERT) as a physical scientist assigned to the new NOAA vessel of exploration *Okeanos Explorer*. In this capacity, Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the *Okeanos Explorer*. While not serving on the vessel, Mashkoor works at NOAA HQ in Silver Springs. Mashkoor also continues to be a Ph.D. student at the Center, his research focusing on understanding the uncertainty associated with backscatter measurements.

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

Glen Rice is a Lieutenant (Junior Grade) in the NOAA CORPS, and has been stationed with the Joint Hydrographic Center as Team Lead of the Integrated Ocean and Coastal Mapping Center. He previously served aboard the NOAA Hydrographic Ships *Rude* and *Fairweather* along the coasts of Virginia and Alaska after receiving a master's of science in Ocean Engineering at the University of New Hampshire.of New Hampshire in 2006 with an M.S. in Ocean Engineering and in 1999 with a B.S. in Physics.

Adam Skarke is a Physical Scientist with the NOAA Office of Ocean Exploration and Research. He is responsible for coordinating expeditions and conducting seafloor mapping in support of the ocean exploration mission of the NOAA ship *Okeanos Explorer*. Adam is a Ph.D candidate at the University of Delaware, and holds a M.S. in geology from the University of Delaware as well as a B.A. in geology from Colgate University. His graduate research was focused on acoustic seafloor sediment characterization, parameterization of bedform morphology from sonar imagery, and sediment transport processes at the estuary-shelf interface.

Other Affiliated Faculty

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

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

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

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

Visiting Scholars

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

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

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

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

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

John Hall (August 2003-October 2004) also spent his sabbatical from the Geological Survey of Israel at JHC/CCOM. John has been a major player in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black, and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

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

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

Lysandros Tsoulos (January-August 2007) is an Associate Professor of Cartography at the National Technical University of Athens. Lysandros is internationally known for his work in digital mapping, geoinformatics, expert systems in cartography, and the theory of error in cartographic databases. At the Center, Lysandros worked with NOAA student Nick Forfinski exploring new approaches to the generalization of dense bathymetric data sets.

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

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

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

Xavier Lurton (August 2010–March 2012) graduated in Physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in Applied Acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems today—Thales Underwater Systems) as a R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989 he joined IFREMER (the French government agency for Oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (data transmission, fisheries sonar, ocean tomography…). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (both in physical modeling and in sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson). In this context he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote An Introduction to Underwater Acoustics (Springer) widely based on his own experience as a teacher. He manages the IFREMER team specialized in underwater acoustics, and has been the Ph.D. advisor of about 15 students. He spent six months as a visiting scholar at UNH in 2012, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

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

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

Facilities, IT and Equipment

Office and Teaching Space

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

Figure 1-1. Aerial view of Chase Ocean Engineering Lab and the NOAA/UNH Joint Hydrographic Center. Photo courtesy of Rob Roseen, UNH Stormwater Center.

Of this 18,000 square feet of space, approximately 4,000 square feet are dedicated to teaching purposes and 11,000 square feet to research and outreach, including office space. Our teaching classroom can seat 45 students and has two high-resolution LCD projectors capable of widescreen display. There are 33 faculty or staff offices, four of which are dedicated to NOAA personnel including the NOAA co-director. The new IOCM Data Processing Center has space for an additional nine NOAA personnel, bringing the total space for NOAA personnel to 13, though two of these are currently occupied by NOAA students. The Center has 27 student cubicles (seven of which are for GEBCO students) and we typically have two or three NOAA students. Two additional NOAA cubicles are available for NOAA Marine Operations Center employees at the pier support facility in New Castle (see below).

Laboratory Facilities

Laboratory facilities within the Center include a map room with light tables, map-storage units and two 60-inch large-format color plotters. Users have the ability to scan documents and charts up to 54 inches using a wide-format, continuous-feed, high-resolution scanner. There are 13 printers positioned throughout the Center including a Canon Pixma Pro 9000 professional photo printer; all computers and peripherals are fully integrated into the Center's network and are interoperable regardless of their host operating system. A computer training classroom consists of fifteen small-form-factor computer systems that were upgraded in 2011, and a ceiling-mounted NEC high-resolution projector. The Center's presentation room is the home of a Telepresence Console, which is used for real-time communications with the NOAA Ship *Okeanos Explorer,* the E/V *Nautilus* or other vessels equipped with a satellite link (Figure 1-2), as well as a GeoWall high-resolution display system (Figure 1-3); these will be described further in the IT section below. Our visualization lab includes an ASL eye-tracking system, an ultra-high-resolution stereoscopic setup with 3840 x 2400 pixel displays, a 4-projector 180 degree display for immersive human factors' research, a custom multi-touch stereoscopic viewing environment for visualizing oceanographic flow model output, force-feedback and six-degree-of-freedom tracking devices, and a Minolta LS-100 luminance meter. We have also built a lidar simulator lab, providing a secure and safe environment in which to perform experiments with our newly constructed lidar simulator (this will be described in more detail in the Research Activities section). The Center also maintains a full suite of survey, testing, electronic, and positioning equipment.

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

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 foot long, 12 foot wide and 8 foot deep. It provides a 90 foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that

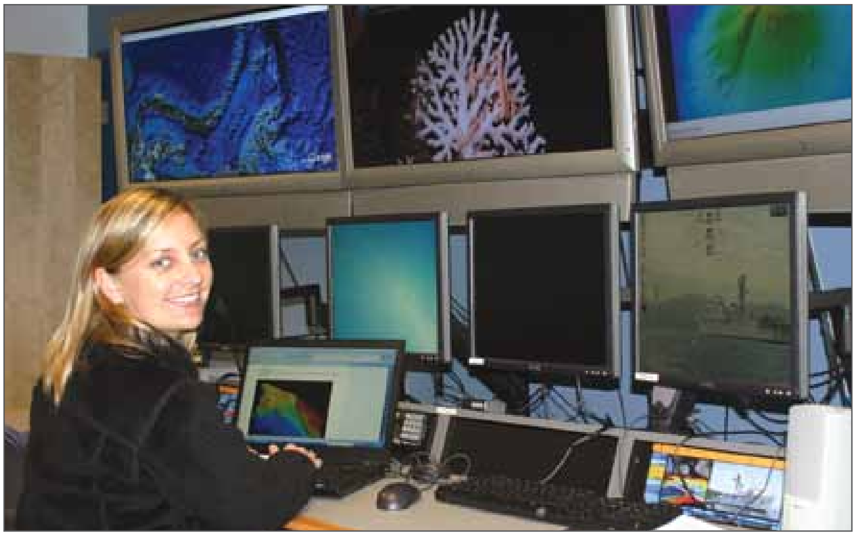


Figure 1-2. NOAA Physical Scientist Meme Lobecker mans the Telepresence Console.

can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geo-textile construction that has an average 92% efficiency in the specified frequency range. The wave-maker software allows tank users to develop regular or random seas using a variety of spectra. A user interface, written in LabView, resides on the main control station PC and a wireless LAN network allows for communication between instrumentation and data acquisition systems.

The engineering tank is a freshwater test tank 60' long by 40'wide with a nominal depth of 20'. The 380,000 gallons that fill the tank are filtered through a 10-micron sand filter twice per day providing an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH scuba course, many of the OE classes in acoustics and buoy dynamics as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20' span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmitting voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1 degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2012, the engineering tank saw 218 days of use and modification to the rail system to allow safer deployment of large equipment in the tank.

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

Figure 1-3. Global circulation model displayed on the JHC/CCOM GeoWall.

Pier Facilities

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

Information Technology

The IT Department currently consists of four full-time staff members, two part-time help desk staff and a part-time web developer. Jordan Chadwick fills the role of Systems Manager and deals primarily with the day-to-day administration of the JHC/CCOM network and server infrastructure. He is also responsible for leading the development of the Information Technology strategy for the Center. The Systems Administrator, William Fessenden, is responsible for the administration of all JHC/CCOM workstations and backup systems. In addition, William serves as Jordan's backup in all network and server administration tasks and contributes to the planning and implementation of new technologies at the Center. Paul Johnson, JHC/CCOM's Data Manager is responsible for organizing and cataloging the Center's vast data stores. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and Federal standards. Lester Peabody is the Web Application Developer. Lester leads the development of the Center's Intranet project and is the primary developer and administrator of the JHC/CCOM public website. He assists with workstation, network, and server administration on an as-needed basis in addition to these duties.

In March of 2012, after over a year of development, the Center launched the next iteration of the JHC/CCOM website—**http://www.ccom.unh.edu**. The new website utilizes the Drupal content management system as its framework. It allows for content providers within the Center to make changes and updates without the assistance of a web developer. The flexibility of the new framework also allowed for the creation of a data content portal, which can dynamically serve any dataset hosted through JHC's ArcGIS Server. Additionally, the new website offers a more robust platform of multimedia and other rich content, as well as a polished look and feel.

In addition to the launch of the new website, work continues on the development of Center-wide Intranet services. Previous versions of the Intranet were developed on a Ruby on Rails/Apache/MySQL platform. However, with the introduction of the Drupal content management system at the Center, the decision was made to migrate the existing Intranet applications to Drupal. Enhanced security, community support, and the desire to consolidate web services to a single platform were all driving factors in the IT Group's decision. The Intranet provides a centralized framework for a variety of new network services and information silos, including the Center's wiki, inventory system, purchase tracking system, library services, and most recently, Progress Reporting. In December of 2012, the IT Group launched a progress reporting module, which assists users in providing feedback to management regarding their research and performance. Additionally, development continues on the Center's ArcGIS server, and as this evolves, more Intranet services will be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services.

As the Center continues its development and implementation of server virtualization, it is now hosting the JHC/CCOM website, Intranet, and many other servers within virtual server environments. Virtualized servers allow both for decreased administrative overhead and increased cost-efficiency, and allow for the same level of security that separate physical computers benefit from. In the event of a virtual server being compromised, the damage is isolated to a single virtual server instance and can be contained.

VMware vSphere serves as the primary virtualization technology at JHC/CCOM. Previously, OpenVZ/ Red Hat was also used for Linux server virtualization; however the IT Group migrated the last of its OpenVZ servers to the VMWare environment in the spring of 2012, consolidating all server virtualization on a single platform. The VMware vSphere infrastructure, in addition to the previously mentioned servers, hosts the JHC/CCOM email server, Vislab web server, Certification Authority server, several Apache web servers, a Windows 2008 R2 domain controller, version control server, Helpdesk server, two JIRA project management servers, FTP server, and IPS management server. VMware vSphere allows for centralized management, cross-platform capabilities (hosting Linux and Windows virtual servers on the same physical server), and the ability to create or remove virtual servers on demand. The virtualization infrastructure consists of two Dell servers capable of hosting dozens of virtual machines. vSphere provides for the ability to snapshot these machines for rapid failover in the event of a physical system failure. In addition, vSphere provides the capability to provision virtual machines with storage on an as-needed basis, maximizing physical disk utilization. JHC/CCOM IT Staff plan to improve the VMware vSphere infrastructure in the first quarter of 2013 with the installation of three new, clustered VMware ESXi hosts. The clustered VMware servers will provide for virtual server high-availability and better performance management. The new servers will also allow the IT staff to better utilize Storage Area Network (SAN) storage resources to improve performance and storage efficiency.

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

In the third quarter of 2012, JHC/CCOM began utilizing Bitbucket to facilitate software collaboration between its own members as well as industrial partners and other academic colleagues. Bitbucket is a world-class source control management solution that hosts Mercurial and Git software repositories. Atlassian, the company behind Bitbucket, states that Bitbucket is SAS70 Type II compliant and is also compliant with the Safe Harbor Privacy Policy put forth by the US Department of Commerce.

JHC/CCOM IT implemented internal and external JIRA project management and issue tracking servers in 2012. The internal server is used for in-house development projects, whereas the external server is used for projects requiring outside collaboration and is integrated with Bitbucket.

The Helpdesk system, Request Tracker by Best Practical, previously used exclusively by the IT Group, has been expanded to include several other groups that need to closely follow the resolution status of requests and to reduce the duplication of effort among the staff. JHC/CCOM staff, students, and faculty have submitted over 4300 Request Tracker tickets since its inception in mid-2009. In 2012, the IT Staff was able to resolve 90% of tickets within three days.

With the rollout of new services and hardware on the JHC/CCOM network, information security remains a top priority for the IT Group. Members of the JHC/CCOM staff have been working closely with NOAA's Office of Coast Survey IT personnel to develop and maintain a comprehensive security program for both NOAA and JHC/CCOM systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. Recent measures taken to enhance security include an upgrade of the Center’s Intrusion Prevention System (IPS), which allows the IT Group to monitor and respond to malicious network traffic more efficiently. JHC/CCOM utilizes Avira Antivir antivirus software to provide virus and malware protection on individual servers and workstations. Avira server software allows for centralized monitoring and management of all Windows and Linux systems on the JHC/CCOM network, including the Center’s email server. Microsoft Windows Server Update Services (WSUS) is used to provide a central location for JHC/CCOM workstations and servers to download Microsoft updates. WSUS allows the IT staff to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems.

In an effort to tie many of these security measures together, the IT Group runs a server that utilizes Nagios for general network monitoring and service monitoring. Nagios not only provides for enhanced availability of services for internal JHC/CCOM systems, but has been a boon for external systems that are critical pieces of several research projects, including AIS ship tracking for the U.S. Coast Guard. The same server that hosts Nagios also runs Syslog-ng as a central repository for system logs, and utilizes custom-built modules for event identification and report generation to meet a variety of additional logging needs. The installation of a biometric door access system, which provides 24/7 monitoring and alerting of external doors and sensitive areas within the facility, has begun and is intended to greatly improve the physical security of Chase Ocean Engineering Lab in general, and sensitive IT areas in particular. This system should be fully in operation by the middle of 2013.

These security measures, as well as others, were independently assessed for the third year in a row by UNH's Research Computing Center in April. The assessment report, along with other documentation, was included in a Assessment and Accreditation package submitted to NOAA's Office of Coast Survey and is currently pending review. This package demonstrates JHC/CCOM's compliance with the Department of Commerce's Information Technology Security Program Policy (ITSPP).

In addition to the security measures previously mentioned, the JHC/CCOM network is protected by a Cisco Adaptive Security Appliance (ASA). This device provides enhanced security for the network at Chase Lab, as it serves as an internal firewall that protects the most sensitive networks from both internal and external threats. The ASA also offers a host of secure remote access options, including IPSec and SSL VPN tunnels. Remote access was previously accomplished through secure shell (SSH) to the Center. Although this is a secure and workable solution, it requires end-user configuration, a dedicated computer on the JHC/CCOM network, and is not ideal in many situations. The IT Group has supplemented SSH with the aforementioned remote access VPN technologies. Users are able to join their local computer to the JHC/CCOM network from anywhere in the world, allowing them to use many of JHC/CCOM's network-specific resources on their local computer.

JHC/CCOM also maintains a network at the Pier Support Building at UNH's Coastal Marine Lab facility in New Castle, NH where the *Ferdinand R. Hassler* will be home-ported. The JHC/CCOM network is extended through the use of another Cisco ASA VPN device. This allows for a permanent, secure network connection over public networks between the support building and Center's main facility at Chase Lab on the UNH campus. The VPN connection allows the IT Group to easily manage JHC/CCOM systems at the facility using remote management and conversely, systems at the Marine Lab facility have access to resources at Chase Lab. Both of the JHC/CCOM research vessels are located at the pier adjacent to the Pier Support Building. The IT Group maintains computer systems and local network on both the R/V *Coastal Surveyor* and the R/V *Cocheco*.

At the heart of the JHC/CCOM's infrastructure lies its robust networking equipment. In early 2012, the IT Group replaced one of the Center's Foundry BigIron RX-8 192-port enterprise-level switches with a Dell/Force10 C300 switch. In addition to hosting 192 gigabit Ethernet ports of its own, the Dell C300 also boasts built-in Power over Ethernet (PoE), as well as 24 x 10-gigabit Ethernet ports. 10-gigabit ports will provide much faster interface to network storage, as well as a larger network pipe to the Center's compute cluster. In early 2013, the IT Group plans to replace the other RX-8 with a Brocade ICX 6610 switch stack, which provides 192 1-Gigabit Ethernet copper ports for workstation connectivity and 32 10-Gigabit Ethernet fiber ports, to be used for access to the network backbone as well as for certain workstations needing high-speed access to storage resources. In addition to the two enterprise switches, one 3Com 4924 24-port Gigabit Ethernet switch, one Dell PowerConnect 2924 switch, four Brocade 7131N wireless access points, one Brocade IronPoint 250, and one QLogic SANBox 5800 Fibre Channel switch round out the rest of the JHC/CCOM network infrastructure. The RX-8 and C300 are currently handling the bulk of CCOM's network traffic and are responsible for all internal routing. The PowerConnect and 3Com switches handle edge applications such as the center's Electronics Laboratory, GeoWall, and Telepresence Console. The SANBox 5800 provides Fibre Channel connectivity to the Storage Area Network for backups and reliable server access to storage resources. The C300 PoE ports power the wireless access points as well as the various Axis network cameras used to monitor physical security in the Lab. The Brocade wireless access points provide wireless network connectivity for both employees and guests with the same equipment. Internal wireless is secured through the use of Extensible Authentication Protocol (EAP), simplifying the management of encryption keys for all internal wireless networks.

In addition to the new network hardware, this year the Center upgraded its network storage with the purchase of a new Storage Area Network (SAN). A clustered Netapp FAS3240 SAN was purchased in early 2012 and represents the next generation of NetApp SAN storage at the Center. The new system currently hosts almost 70TB of raw storage and is capable of expanding to nearly 2 petabytes. The FAS3240 also supports clustered operation for failover in the event of system failure, better disk performance for faster access, block-level de-duplication to augment efficiency of disk usage, and support for a number of data transfer protocols, including iSCSI, Fibre Channel, NFS, CIFS, and NDMP. Migration of data from the old FAS960c storage system to the new FAS3240 was completed in December of 2012. In addition to the FAS3240, the purchase also included a FAS3140 SAN filer provided as a charitable donation by NetApp for the Center's storage purchase. IT Staff chose to implement Microsoft's Distributed File System (DFS) to organize all SAN data shares logically by type. In addition to DFS, a custom metadata cataloging web application was developed to make discovering and searching for data easier for both IT Staff and the Center as a whole.

Increased storage needs have created a greater demand on JHC/CCOM's backup system. To meet these demands, the IT Group upgraded the Center's backup hardware and software in late 2011/early 2012 with the addition of a new backup server, tape library, and backup software suite. Over the last several years, the Center has utilized EMC Networker for server, workstation, and SAN backups. Workstations and servers were backed up by a Quantum M1500 LTO3 tape library, while the FAS960c SANs were backed up by a Quantum Scalar 50 LTO4 tape library. The new CommVault Simpana backup solution provides all the features of the EMC system at a lower price, and introduces a number of new features. With the replacement of the JHC/CCOM backup server, de-duplicated disk-to-disk backup is now being utilized in addition to tape backup, providing another layer of data security and allowing for more rapid backup and restore capabilities. In addition, the purchase of a Quantum i40 LTO5 tape library, capable of backing up 120TB of data without changing tapes, combined with Simpana's NDMP backup capabilities, allow the IT Group to back up data on the newly acquired FAS 3240 SAN directly over Fibre Channel. The Fibre Channel interface allows for backup data rates more than twice as fast as the old libraries and SANs, while reducing network utilization significantly. Simpana also provides easier, more powerful management and reporting.

Simpana, like Networker, performs a daily backup for all computers at the Center. Recent backups are kept on disk, and then cloned to tapes that are held in a fire-proof safe. Older backups and archived datasets are sent offsite to an Iron Mountain data protection facility where they are stored in an environmentally controlled vault. In addition, a full suite of peripherals (DLT, LTO, CD-R, DVD±R, Blu-Ray, flash, HDD) are available so that data can re-distributed on a range of media types.

With the addition of larger, faster storage and network equipment, JHC/CCOM employs a Dell computer cluster for resource-intensive data processing. The cluster utilizes seven Dell blade servers running Microsoft Windows HPC Server 2008. This allows the Center to harness the computing power of 56 CPU cores and over 50GB of RAM as one logical system, greatly reducing the amount of time it takes to process datasets. This also frees up scientists' workstations while the data is processed, allowing them to make more efficient use of their time. JHC/CCOM evaluated and purchased MATLAB Distributed Computing Server in 2011 for HPC, and is in the process of developing a next-generation, parallel-processing software system with consortium partners.

Currently, all CCOM servers are consolidated into seven full height cabinets with one or more Uninterruptible Power Supply (UPS) per cabinet. At present, there are a total of 41 servers, including 21 virtual servers, three SANs, two with two clustered filers each, and one with a single filer, and a total of 14 disk arrays, and the compute cluster consisting of seven nodes. A NitroSecurity Intrusion Prevention Systems (IPS), an IPS Management Console and a Cisco ASA 5520 firewall provide boundary protection for our Gigabit Local Area Network (LAN). JHC/CCOM also hosts five dedicated servers for NOAA's nowCOAST Web Mapping Portal, which mirror the primary nowCOAST web and database servers, currently hosted in Silver Spring, MD.

The IT facilities consist of two server rooms, a laboratory, the Presentation Room, Computer Classroom, and several staff offices. The server room in the south wing of the building is four times larger than its counterpart in the north wing, and has the capacity to house 14 server racks, giving CCOM's data center the capacity to house 20 full-height server racks. Both server rooms are equipped with redundant air conditioning, temperature/humidity monitoring and FE-227 fire suppression systems, helping to ensure that JHC/CCOM network services have as little downtime as possible. Additionally, the larger server room employs a security camera, as well as a natural gas-powered generator to provide electrical power in the event of a major outage. The IT lab provides ample workspace for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

The JHC/CCOM Presentation Room houses the Telepresence Console that was initially purchased for the 2005 Lost City Expedition, as well as the Geowall high-resolution display system. The hardware for the Telepresence console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video using VLC, three 37" Westinghouse LCD displays through which the streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints. A multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Console are connected to an Eaton Powerware UPS to protect against power surges and outages. A generator provides backup power in the event of electrical and UPS failure. In 2012, JHC/CCOM participated in research with the NOAA vessel *Okeanos Explorer* and URI's vessel *Nautilus* on their respective cruises. Both vessels had successful field seasons in

2010, 2011, and 2012 utilizing the Telepresence technology to process data and collaborate with scientists and educators ashore.

The IT Group collaborates with the JHC/CCOM seminar organizers to provide both live webinar versions of the JHC/CCOM Seminar Series, as well as video and audio archives available through the web after each event. Building on the success of the seminar series in 2011 and 2012, the IT Group plans to make improvements to both the quality and accessibility of these seminars throughout the 2012-2013 Seminar Series through better video and audio hardware, as well as distribution of the finished product through the new website.

The Center has continued to upgrade end user's primary workstations, as both computing power requirements, and the number of employees and students have increased. The total of faculty/staff/student workstations is 220 high-end Windows 7/XP and Linux desktops/laptops, as well as 18 Apple Mac OS X computers. In 2012, the IT Group continued to deploy Microsoft Windows 7 to old and new workstations, and as of December, phased Windows XP out of the primary working environment. Additionally, Mac OSX users are also being upgraded to OSX 10.8, the latest version of that operating system. Deploying the 64-bit version of these operating systems allows faculty, staff and students to take advantage of new, enhanced versions of scientific and productivity software, while maintaining interoperability with older applications.

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

Research Vessels

The Center operates two dedicated research vessels (Figs. 1-4 and 1-5), the 40-foot R/V *Coastal Surveyor* (JHC/CCOM owned and operated) and the 34-foot R/V *Cocheco* (NOAA owned and JHC/CCOM maintained and operated). In 2012, the *Coastal Surveyor* operated for ten months (March through November) with much of its operation focused on collecting data in support of the Summer Hydrography Field Course and the NEWBEX experiment (see below). The *Coastal Surveyor* is also often used by our Industrial Associates to test their sonar systems over the well-known Portsmouth Harbor Shallow Survey Common Data Set field area. The *Cocheco* operated for eight months, focusing on over the side operations such as deploying buoys and bottom mounted instruments, bottom sampling, and towing instruments. This will be the fourth year that both vessels will be left in the water over the winter at the UNH pier facility in New Castle. Winter mooring has reduced the winter costs and added the advantage that vessels are at the ready through the entire year. The vessels are operated primarily in the area of Portsmouth, NH, but are capable of transiting and operating from Maine to Massachusetts. Neither vessel is designed for offshore operations; they are ideally suited to near-shore and shallow water (in as little as four meters depth).

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

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

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


Figure 1-4. R/V *Coastal Surveyor* with bow ram.

The *Coastal Surveyor* (Figure 1-4) was built by C&C Technologies (Lafayette, LA) approximately twenty years ago on a fiberglass hull that had been a U.S. Navy launch. She was built specifically for the purpose of collecting multi-beam sonar data, and has a bow ram for mounting sonar transducers without hauling the vessel. C&C operated the *Coastal Surveyor* for a decade and a half, and then made a gift of her to JHC/CCOM in 2001. She has become a core tool for JHC/CCOM's operations in New Hampshire. The *Coastal Surveyor* continues to be invaluable to the Center. Thanks to the improved hydraulic stabilizers (in 2005), the high precision of boat offset surveys and the remarkably stable transducer mount, she remains one of the finest shallow-water survey vessels in the world. A marine survey was completed in 2008, acknowledging that the vessel is sound but beginning to show her age. The main engine, a 200 BHP Caterpillar diesel with over five thousand hours, although running reliably, does not run efficiently. Minor electrical and plumbing issues were identified in the survey and were addressed. In 2010, the ship's AIS transponder and a new Simrad AP28 autopilot was installed and the HVAC seawater pump and manifold and engine room bilge pump were also replaced. In 2011, the Isuzu-powered 20 kilowatt generator termially failed and was replaced with a 12 kilowatt Northern Lights generator. Additionally, the degraded engine room soundproofing was replaced along with the hydraulic steering piston and several hydraulic hoses. In 2012, leaking hatches, caulking and gaskets were replaced.

R/V *Coastal Surveyor* Scheduled Research and Educational Operations for 2012

Month	Days	User
March	2	Other (Maintenance)
April	3	L3-Klein
April	2	Other
May	3	Other
June	14	Summer Hydro 2012
June	5	Kongsberg 2040
June	2	Other
July	2	L3-Klein
August	1	Other
September	1	Other
October	1	Jenn Dijkstra
October	1	Sontek
October	2	NEWBEX
October	1	Other
November	8	NEWBEX
December	1	L3-Klein
December	3	Other


Figure 1-5. R/V *Coastal Surveyor* with ram mount lowered.

R/V *Cocheco*

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

R/V *Cocheco* (Figure 1-6) is designed for fast transits and for over-the-stern operations from her A-Frame. Several years ago, a hydraulic system and winch equipped with a multiconductor cable were installed making the vessel suitable for deploying or towing a wide variety of samplers or sensors. Upgrades to the UPS-power system, wiring for 220 VAC, and instrument bench wiring for both 24 VDC and 12 VDC were also completed. In 2009, AIS was permanently installed on *Cocheco*, her flux-gate compass was replaced, and improvements made to her autopilot system. In addition, *Cocheco's* 12 VDC power system, hydraulic system wiring and communications wiring were updated. In 2010, a second VHF radio and antenna was installed and several battery banks were replaced and upgraded. This past year, routine preventative maintenance was carried out (e.g., replacing fluids and filters, cleaning the bilge, etc.).

Figure 1-6. R/V *Cocheco*.

R/V *Cocheco* Scheduled Research and Educational Operations for 2011

Month	Days	User
May	1	Klein
May	1	Seamanship Course - buoy operations
June	28	Summer Hydrographic Field Course & Matt Wilson's Research
July	1	Semme Dijkstra, Larry Ward - underwater camera work
July	2	Val Schmidt - AUV ops
August	1	Val Schmidt, Jen Dijkstra - AUV ops
October	1	Know the Coast Day - outreach

Figure 1-7. Lab space on the R/V *Cocheco.*

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

Figure 1-9. R/H *Sabvabaa* listening for earthquakes on the Gakel Ridge.

R/H *Sabvabaa*

Dr. John K. Hall, visiting scholar at the Center in 2003 and 2004 funded the construction of a hovercraft designed to support mapping and other research in the most inaccessible regions of the high Arctic. The construction of the hovercraft, a 13 m Griffon 2000T called the R/H *Sabvabaa* (Figure 1-9), was underwritten by the Blodgett Foundation. The vessel has been operated out of UNIS, a University Centre in Longyearbyen, Svalbard, since June 2008 under the supervision of Professor Yngve Kristoffersen of the University of Bergen. Through donations from the Blodgett Foundation, the Center for Coastal and Ocean Mapping provided a Knudsen 12-kHz echosounder, a four-element Knudsen CHIRP sub-bottom profiler and a six-channel streamer for the *Sabvabaa*. Using a 20 to 40 in^3 airgun sound source, the craft is capable of profiling the shallow and deep layers over the most interesting areas of the Alpha Rise, a critical component to understanding the origin and history of the Arctic Ocean.

Figure 1-19. Hovercraft *Sabvabaa* during a rendezvous with the Swedish Icebreaker ODEN during the 2012 expedition

Last summer, the *Sabvabaa* spent 10 weeks on the ice conducting the Norwegian FRAM-2012 expedition. The two part trip was to consist of two weeks over the spreading Gakkel Mid-Ocean Ridge to acoustically monitor earthquakes, and then to the Lomonosov Ridge past the North Pole, refueled by the Swedish icebreaker *Oden*'s LOMROG III cruise. Unfortunately, summer 2012 was the year that the ice cover shrank to a new minimum, and a severe Arctic storm put the thinner pack into compression, producing vast fields of rubble ice and pressure ridges, with fog and white-out conditions for up to 22 hours a day. Unable to make its way farther north after the first refueling some 500 km into the ice pack, the *Sabvabaa* spent more than

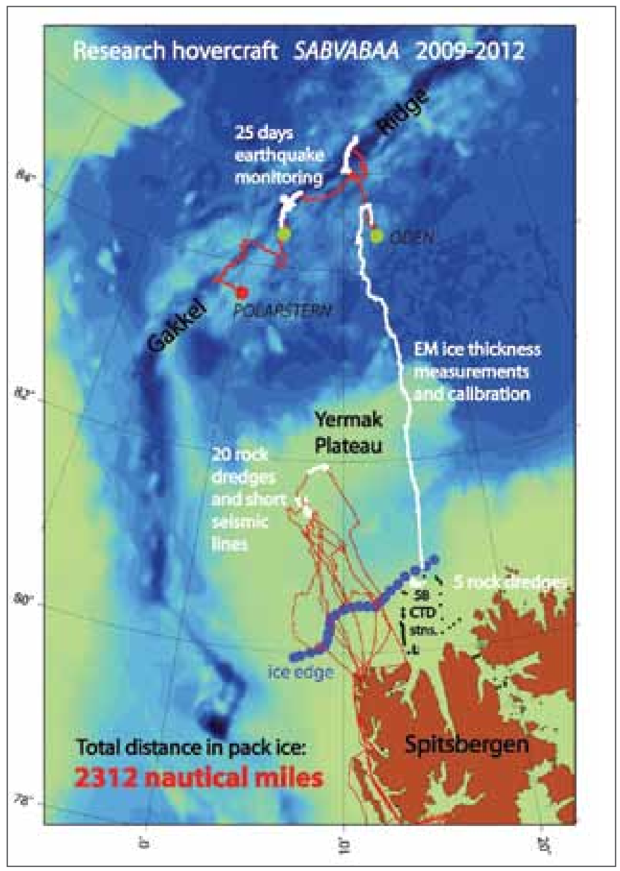


Figure 1-11. Total operations of R/H *Sabvabaa* including 2012 expedition

five weeks monitoring some 300 earthquakes with triangular arrays of WiFi-linked hydrophones that were relocated whenever the drift took the ice away from the seismically active rift valley 5 km below. As ODEN returned, *Sabvabaa* was refueled and left to proceed south with Yngve Kristoffersen aboard alone. Further bad weather pushed the ice west and prevented further progress south, so that the craft had a lift of opportunity from the German icebreaker *Polarstern*, returning safely to Svalbard in early October.

NOAA ROV

The new NOAA cooperative agreement includes a much closer and more formalized collaboration with the NOAA's Office of Ocean Exploration and Research (OER). As part of this collaboration, the OER program has chosen to use the facilities of the Center as the staging area for the development of their new deep-water Remotely Operated Vehicle (ROV). In support of this effort, the Center has constructed a large, secure work area in proximity to our deep acoustic test tank so that, as development is underway, components or the entire system can be tested in the tank (Figure 1-12).

Figure 1-12. New room constructed in the high bay for ROV storage.

The NOAA ROV system comprises two vehicle systems—an ROV (Figure 1-13) and a Camera Sled (Figure 1-14). The ROV, which is currently being upgraded by OER here at the Center, is connected to a camera sled by a flexible electro-optical tether which, in turn, is connected to the support vessel via a standard oceanographic 0.68" armored electro-optical-mechanical cable. Each vehicle carries separate subsea computers, high-definition (HD) cameras and Hydrargyrum Medium-Arc Iodide (HMI) lighting. Both are controlled independently of the other in the topside control system.

The ROV operates in a traditional manner, employing lights, cameras, manipulators, thrusters and other science equipment to explore its surroundings. The camera sled serves three primary purposes: to decouple the ROV from any ship movement, provide an alternative point of observation for ROV operations and to add substantial back-lighting for the ROV imaging. Both systems are rated for operations down to 6000 m. In 2011, the camera sled, christened *Seirios*, was constructed and deployed.

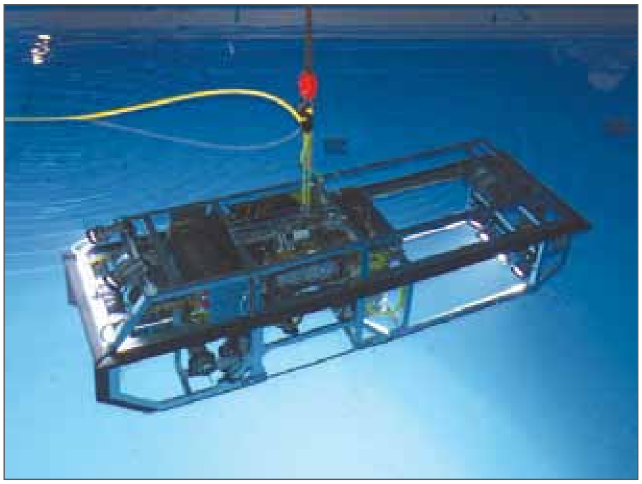


Figure 1-13. Camera sled for ROV being developed by OER at the Center.

The Center directly supported the NOAA team in the construction of the camera sled through machining of parts, assembly of the sled and supporting testing in the Engineering Tank (see letter from Dave Lovalvo below). The *Seirios* was fully tested in the lab and deployed on the NOAA Ship *Okeanos Explorer* where it has worked successfully for the entire season.

While we hope that access to the Center's facilities will be helpful to OER in their development of the ROV, we know that having this development take place on campus will be a tremendous advantage to our students and staff. Students and staff will be able to participate in this development and will be exposed to the state-of-the-art in deep-sea vehicle technology. Already, several students have become involved with the project.

Figure 1-14. New 6000 m ROV being developed by OER at the Center.

Educational Program

Curriculum Development

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

The FIG/IHO Certification for the Center was up for renewal in 2011 and in light of the need for a new submission to the FIG/IHO, the extraordinary growth of the Center (and expansion of faculty expertise), and the recognition that certain aspects of our curriculum were leading to unrealistic demands on our students, the Center, under the leadership of Semme Dijkstra, redesigned the entire ocean mapping curriculum.

The goals of the new curriculum were to:

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

This curriculum was presented to the FIG/IHO/ICA education board by Semme Dijkstra and Capt. Armstrong and accepted (the board lauded the UNH submission as "outstanding"). Thus the Center maintains an IHO Category A Certification until at least 2021 and continues to be one of only two Category A programs available in North America. The new curriculum (Appendix A) has since been accepted by the College of Engineering and Physical Sciences curriculum committee, approved by the graduate school and presented for the first time in 2012. Although well-received by the students, adjustments will be made after a first-year review.

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

Figure 2-1. 2012 incoming students.

This year we have begun a re-vamp of the Tools for Ocean Mapping Course. The core of the course is now a 21-step practical assignment. In the course of this assignment, the students combine data for various data sources including bathymetry, DTM's, video, etc., into a single GIS database and learn to process and manipulate the data (e.g., changing datums) using a variety of software tools.

We have 28 full-time students currently enrolled in the Ocean Mapping program (see page 49), including six GEBCO students, two NOAA Corps officers and a NOAA physical scientist. We have produced five PhDs: Luciano Fonseca (2001); Anthony Hewitt (2002); Matt Plumlee (2004); Randy Cutter (2005); and Dan Pineo (2010). This past year we graduated six new Masters students and six Certificate students, bringing the total number of Masters of Science degrees completed at the Center to 43 and the total number of Certificates in Ocean Mapping to 46.

Hydrographic Field Course

The 2012 Summer Hydrographic Field Course brought the R/V *Coastal Surveyor*, R/V *Cocheco*, 13 JHC/CCOM students, and several technical staff under the supervision of Semme Dijkstra to the waters offshore of Gerrish Island, ME. The primary objective was to extend eastwards the survey area covered by the same course in 2006. A secondary objective was to resurvey an area previously survey by the NOAA ship R/V *Rude* in 1997 with the objective of obtaining higher resolution bathymetry data in an area containing an aeromagnetic anomaly for Dr. Wallace Bothner of the UNH Earth Science Dept., to investigate whether it may be caused by a small Mesozoic intrusive complex. The survey revealed an unexpected dune-like feature that will be further investigated in order to explain its origins.

Data were collected and processed using HYPAC, CARIS and QPS software.

A comparison with Chart 13282 was performed and the observed depths generally matched the charted depths, but close to Cutts Island some significantly shoaler depths were observed resulting in the submission of 20 DTONS (affecting 8 charts). The charted contours align well in places with the automatically generated contours from the dense MBES data.

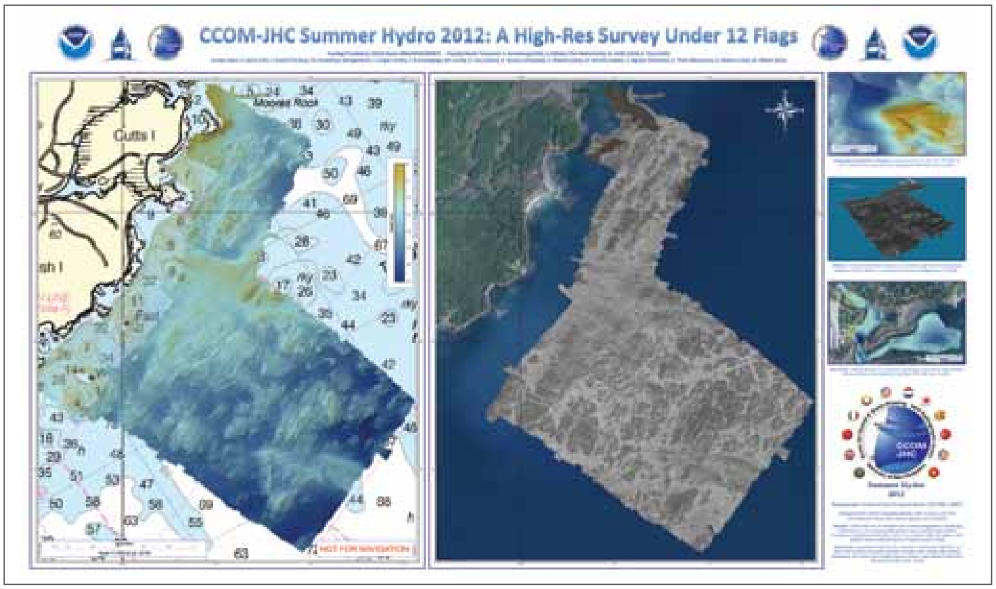


Figure 2-2. Product of the 2012 Hydrographic Field Course off Gerrish Island NH.

JHC – Originated Courses

COURSES	INSTRUCTORS
Fundamentals of Ocean Mapping	Armstrong, Dijkstra, Mayer, and others
Ocean Mapping Tools	Schwehr, Monahan, and others
Hydrographic Field Course	Dijkstra and Armstrong
Marine Geology and Geophysics	Mayer and Gardner
Acoustics	Weber
Data Structures	Ware
Data Visualization	Ware
Seafloor Characterization	Mayer, Calder, Rzhanov
Geodesy and Positioning for OM	Dijkstra and Wells
Special Topics: Law of the Sea	Monahan
Special Topics: Bathy-Spatial Analysis	Monahan
Special Topics: Ocean. Data Analysis	Weber
Mathematics: For Geospatial Studies	Math Dept.
Time Series Analysis	Lippmann
Seamanship	Armstrong, Keley
Underwater Acoustics	Weber
Nearshore Processes	Ward
Seminars in Ocean Mapping	All

Modules

Recognizing the need for advanced training for NOAA personnel as well as the need to develop modules for our new "Fundamentals of Ocean Mapping" course. Tom Weber, Andrew Armstrong, Larry Mayer and Semme Dijkstra developed a module teaching the fundamentals of vertical beam echo sounding and associated acoustic principles. This module was delivered remotely from the Center (with a Center representative on site) to students in Newport, Oregon in association with the NOAA hydrographic training.

GEBCO Certificate Program

In 2004, the Center was selected through an international competition (that included most of the leading hydrographic education centers in the world) to host the Nippon Foundation/GEBCO Bathymetric Training Program. UNH was awarded $1.6 M from the Nippon Foundation to create and host a one-year training program for seven international students (initial funding was for three years). Fifty-seven students from 32 nations applied and in just 4 months (through the tremendous cooperation of the UNH Graduate School and the Foreign Students Office) seven students were selected, admitted, received visas and began their studies. This first class of seven students graduated (receiving a "Certificate in Ocean Mapping") in 2005, the second class of 5 graduated in 2006, the third class of six students graduated in 2007. The Nippon Foundation extended the program for another three years and the fourth class graduated six in 2008, another five graduated in 2009; and six more students graduated in 2010. The Nippon Foundation continued to fund the program beyond 2010 and we graduated another six students in the 2011 academic year and have another six enrolled for academic year of 2012 (see listing below).

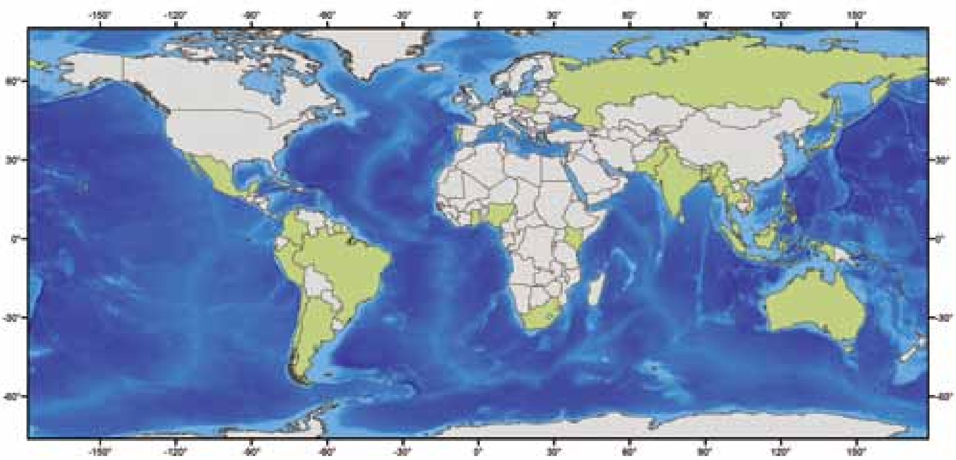


Figure 2-2. Nippon Foundation/GEBCO scholars home countries (including the 2013 students).

The Nippon Foundation/GEBCO students have added a tremendous dynamic to the Center both academically and culturally. Funding from the Nippon Foundation has allowed us to add Dave Monahan to our faculty in the position of program director for the GEBCO bathymetric training program and this year the addition of Rochelle Wigley to assist Dave. Dave brings years of valuable hydrographic, bathymetric and UNCLOS experience to our group and, in the context of the GEBCO training program, has added several new courses to our curriculum.

The Nippon Foundation continues to provide funds to GEBCO to develop and deliver projects in which the graduates from the first eight years will be trained to take leadership roles, and this funding was used to launch a project to produce an international bathymetric compilation map and grid of the Indian Ocean. The aim of this multi-nation project is to assemble all acoustic bathymetric data from the different research cruises and hydrographic surveys undertaken in the Indian Ocean, combine them with satellite altimetry where necessary, and to publish a regional bathymetric map and grids that will stand alone and will also be integrated into the next world ocean map and grid by GEBCO. Twenty graduates of the UNH program in eleven nations bordering on the "Indian Ocean" were invited to participate and it is expected that other Scholars from adjacent areas will play a role. GEBCO has contracted with CCOM to host the project and in response, Dr Rochelle Wigley, a former CCOM student and GEBCO scholar, was recruited to direct the project.

Extended Training

With our fundamental educations programs in place, we are expanding our efforts to design programs that can serve undergraduates, as well as government and industry employees. We have begun a formal summer undergraduate intern program we call SURF (Summer Undergraduate Research Fellowship - see below), and continue to offer the Center as a venue for industry and government training courses and meetings (e.g., CARIS, Triton-Elics, SAIC, Geoacoustics, Reson, R2Sonics, IVS, ESRI, GEBCO, HYPACK, Chesapeake Technologies, ATLIS, IBCAO, SAIC, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, NPS, ECS Workshops, USGS, Deepwater Horizon Subsurface Monitoring Unit, and others). This has proven very useful because our students can attend these meetings and are thus exposed to a range of state-of-the-art systems and important issues. A particular highlight this year was a very successful "AUV Boot Camp" organized by Val Schmidt (see below). Particularly important have been visits to the Center by a number of members of NOAA's Coast Survey Development Lab and National Geodetic Service in order to explore research paths of mutual interest and the visits of many NOAA scientists to discuss NOAA priorities for multibeam-sonar systems and surveys as part of a series of NOAA Multibeam Workshops and the developing Intergovernmental Working Group for Integrated Ocean and Coastal Mapping (IWG-IOCM).

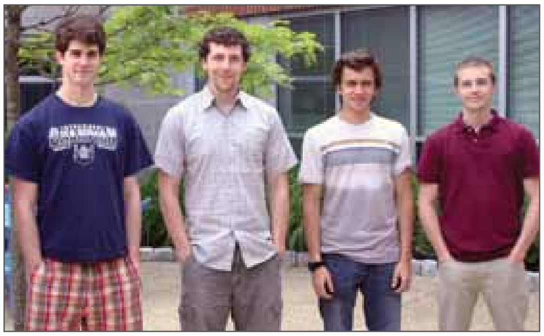


Figure 2-3. Charter members of the SURF program (from left): Eric Escobar, John Heaton, David Baryudin, Kurt Murphy.

SURF Program

The Summer Undergraduate Research Fellowship (SURF) program successfully concluded its inaugural year and we have begun to advertise the program for next summer. The SURF program is designed to create research experiences for undergraduate students who are interested in pursuing graduate work. SURF is aimed primarily at students who are working toward a degree in science, engineering, or math and are completing their junior year. Students accepted into the program spend up to 10 intensive weeks (normally early-June to mid-August) working under the guidance of a faculty member. They conduct research related to acoustics, bathymetric mapping, habitat mapping, lidar, marine geology and geophysics, optical imaging, sonar signal processing, or data visualization. Research activities include lab-oratory experiments, field work, a research cruise, data analysis, model development, or instrument development. The research conducted by the fellows is presented to Center faculty and staff at the end of the summer, and summarized in a written report.

2012 SURF Fellows and Projects

Fellow: Eric Escobar - UNH
Advisor: Shachak Pe'eri
Project: Contribution of Water on Airborne Lidar Bathymetry (ALB) Measurements

Fellow: John Heaton - University of Hartford
Advisor: Tom Weber
Project: Acoustic Characterization of an Extended Calibration Target

Fellow: Kurt Murphy - UNH
Advisor: Dr. Larry Ward
Project: Morphologic Change Analysis of Hampton-Seabrook Harbor Area

Fellow: David Baryudin - McGill University
Advisor: Tom Weber
Project: Tracking Bubbles from ROV-Video of Natural Gas Seeps in Gulf of Mexico

AUV Bootcamp

In August, the Center hosted AUV Hydrographic Bootcamp 2012. AUV Bootcamp is a focused pressure-cooker type event in which new methods of Autonomous Underwater Vehicle (AUV) operations, data collection, processing and display are developed and made operational. It is an event for AUV operators, commercial software developers, engineers, researchers and graduate students to directly interact, in a small group environment, both in the field and ashore. AUV Bootcamp provides a means to try new things, make mistakes in a controlled manner, and learn how to operate and process data from an AUV.

The mission of AUV Bootcamp 2012 was focused on the operational methods of AUVs to collect bathymetric data for the purposes of nautical charting and the data processing techniques required to create hydrographic quality survey products.

Among the areas under consideration were:

- Operational methods optimized for hydrographic surveys, including survey efficiency and cross-checks.
- Minimization and quantification of navigation uncertainty. Items for consideration include developing a workflow for Real-Time Kinematic or Post Processed Kinematic GPS solutions to constrain surface navigation of an AUV, use of seafloor or buoy-based relative or absolute navigation aids imaged in sonar or camera or other sensors, and use of seafloor bathymetry itself for relative survey corrections.
- Assessment of the impact of surface swell on a shallow water survey and methods to mitigate the effect on the bathymetry.
- Generation of an uncertainty model for bathymetric data collected from an AUV.
- Complete workup of bathymetric data suitable for submission to NOAA for charting applications.
- Explore other methods of processing Geoswath sonar data by the Center's MPAA algorithm or by CARIS, OIC, FM, MB-System or other tools.

This year's AUV bootcamp event was made possible by a sizable donation by Teledyne-Gavia (Kopavor, Iceland). The Center's corporate partner, Substructure, Inc. (Portsmouth, NH) donated five days of boat time and surface ship multibeam surveys. Addition donations were provided by Kearfott, CARIS, NCS Survey, Ocean Imaging Consultants, and UTEC Survey.

Figure 2-4. Bootcamp participants crowd around Cory Collins (CARIS) as he demonstrates preliminary results of his data processing. (Photo courtesy of Vince Capone, Black Laser Learning Inc.)

AUV Bootcamp 2012 was a terrific success with participants from NOAA, the Naval Oceanographic Office, the University of Delaware, the Monterey Bay Aquarium Research Institute, Lamont Doherty Earth Institute of Columbia University, Teledyne-Gavia, Kearfott, CARIS, QPS/FM, Ocean Imaging Consultants, NCS Survey, UTEC Survey, and the hydrographic offices of Japan and Nigeria. The six-day event began with an introduction to what is required by NOAA to produce a fully documented, hydrographic quality seafloor survey suitable for use in charting for safety of navigation. Successive days included break-out sessions for the discussion of both vertical and horizontal uncertainty in AUV surveys, methods of correcting surveys for navigation and vertical positioning errors and processing methods for phase-differencing sidescan sonar systems. The group designed surveys to be run by a dedicated operations team each day and analyzed the previous day's surveys to discern what could be learned (Figure 2-4).

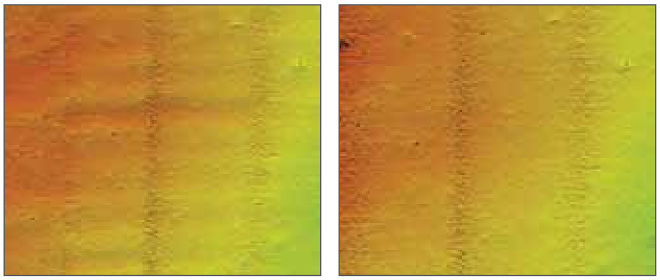


Figure 2-5. A small portion of a bathymetric survey collected from the Gavia AUV. On the left, the survey is processed using the AUV's onboard pressure sensor as the AUV's vertical reference. On the right, the data has been reprocessed using a complementary-filter vertical positioning estimate incorporating both the pressure sensor and the inertial navigation system depth estimate. Undulations resulting from 1 m (peak to peak) surface waves are successfully removed with the new method.

Along with the training aspects and sharing of information, the Bootcamp provided an opportunity for users and manufacturers to get together and solve real-world problems. AUV surveys have long been known to suffer from the effects of surface waves on the vehicle when operating in relatively shallow water. When the waves are small in length compared to the size of the vehicle, they can impart a fluctuation on the AUV's pressure sensor with no actual vertical movement of the vehicle. When the waves are large compared to the size of the vehicle the entire water column moves taking the AUV with it but without a commensurate variation in the pressure sensor signal. Either effect results in an apparent heave-like artifact in any bathymetry measured by the AUV.

For the Gavia AUV and the Kearfott INS, one has the option of utilizing either the onboard pressure sensor for vertical reference or the INS depth estimate, which incorporates both the input signal from the pressure sensor and also the double integration of vertical accelerations measured by the inertial unit. Unfortunately, the INS depth estimate tends to drift away from the pressure sensor depth measurement over time resulting in a slowly growing bias to any bathymetric survey. This AUV Bootcamp afforded the opportunity to test a technique to blend the pressure sensor and INS depth estimates into a new depth estimate using a complementary filter. As shown in Figure 2-5, the method allowed us to successfully remove surface wave artifacts and maintain a self-consistent long-term seafloor trend to the data.

Academic Year 2011-2012 Graduate Students

STUDENT	PROGRAM	ADVISOR
Chukwuma Azuiki	MS OE Mapping (Rec'd 2012)	Armstrong/Pe'eri
Anna Berry	Certificate OE (Rec'd 2012)	Armstrong
Sean Denney	MS OE Mapping (Rec'd 2012)	Armstrong
Christopher Englert	MS ESci Ocean Mapping	Mayer
Olumide Fadahunsi	Cert OE Mapping (Rec'd 2012)	Armstrong
Christina Fandel	MS ESci Ocean Mapping	Lippmann
Ashton Flinders	MS OE Mapping	Mayer
Xiao Guo	MS OE Mapping	Parrish
John Heaton	MS Mechanical Engineering	Weber
Han Hu	MS OE Mapping	Rzhanov
Joshua Humbertston	MS ESci Ocean Mapping	Lippmann
Kevin Jerram	MS OE Mapping	Weber
Christina Lacerda	MS. ESci Ocean Mapping	Monahan
Giuseppe Masetti	MS OE Mapping	Calder
Lindsay McKenna	MS Esci Ocean Mapping	Lippmann/Ward
Dandan Miao	MS OE Mapping	Calder
Garrett Mitchell	MS Esci Ocean Mapping	Gardner
Kittisak Nilrat	MS Esci (Rec'd 2012)	Armstrong
Ashley Norton	Ph.D. NRESS	Dijkstra
David Pilar	MS CS (Rec'd 2012)	Ware
Glen Rice (NOAA)	Ph.D. OE	Armstrong/Calder
Maddie Schroth-Miller	MS Math (Rec'd 2012)	Weber
Derek Sowers	Ph.D. NRESS	Mayer
Michael Sutherland	MS OE Mapping	Weber
Rohit Venugopal	MS CS	Calder
Briana Welton (NOAA)	MS ESci Ocean Mapping	Armstrong/Weber
Matt Wilson (NOAA)	MS ESci Ocean Mapping (Rec'd 2012)	Armstrong/Beaudoin
Monica Wolfson	Ph.D. NRESS	Boettcher
Fang Yao	MS Esci Ocean Mapping	Parrish
Qian Yin	MS OE Mapping	Rzhanov

GEBCO Students: (2012-2013)

STUDENT	INSTITUTION	COUNTRY
Karolina Chorzewska	Polish Navy	Poland
Hashimoto Takafumi	Japan Coast Guard	Japan
Htike Htike	Myanmar Maritime Univeristy	Myanmar
Xinh Sy Le	Vietnam Maritime University	Vietnam
Siong Hui Lim	Royal Malaysian Navy	Malaysia
Eunice Nuerki Tetteh	Ghana National Oceanographic Data and Information Center	Ghana

Status of Research: January–December 2012

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

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

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

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

As our research progressed and evolved, the clear boundaries between these themes became more diffuse. For example, from an initial focus on sonar sensors we expanded our efforts to include lidar. Our data-processing efforts are evolving into our data-fusion and Chart of the Future efforts. The data-fusion and visualization projects are also blending with our seafloor characterization 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.

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

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

These new thematic headings do not represent a significant departure from our previous research endeavors but, inasmuch as our 2012 efforts were conducted under these new thematic headings our current research efforts will be described in the context of these seven themes. As with the earlier themes, the many of the projects areas overlap several themes. This is particularly true for habitat, IOCM, and processing efforts. In this context, distribution of projects among the themes is sometimes quite "fuzzy."

Theme 1 :: Sensors

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

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

Sonars

Sonar Calibration Facility

Developing Approaches to Calibrate MBES in the Field

We continue to make progress in the upgrades to the Center's sonar calibration facility (originally funded in part by NSF), which is now one of the best of its kind in New England. The facility is equipped with a rigid (x,y)-positioning system, computer controlled transducer rotor (with resolution of 0.025 degree) and custom-built data-acquisition system. Measurements that can now be completed include transducer impedance (magnitude and phase) as a function of frequency, beam patterns (transmit and receive), open circuit voltage response (receive sensitivity), and transmit voltage response (transmit sensitivity). In addition, the A/D channel inputs have been optimized as a function of beam angle and the cross-correlation and r.m.s. levels of the transmitted and received channels can be computed in real-time.

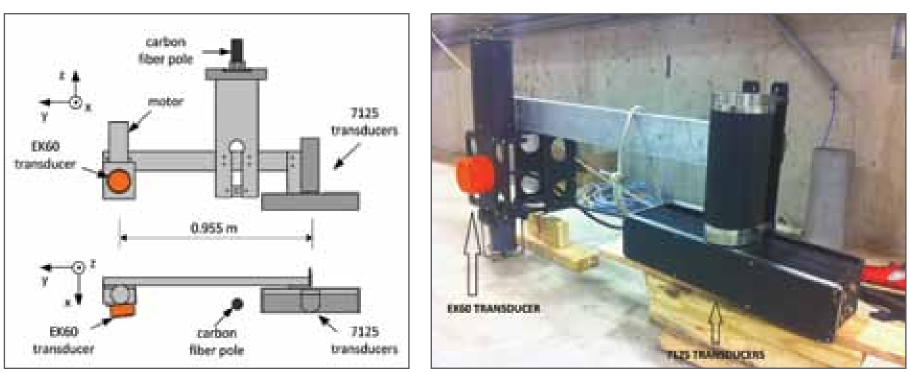


Figure 3-1. Mount for the transducers used in the field calibration methodology tests.

Carlo Lanzoni, now working as a research engineer, and Tom Weber were the prime users of the calibration facility in 2012, continuing the work started as part of Lanzoni's M.Sc. thesis aimed at developing field-calibration procedures for multibeam echosounders (MBES) using a Simrad EK-60 split-beam echosounder and a target calibration sphere. The idea of this approach is that the split—beam echosounder provides precise information about the target sphere position allowing beam pattern and other calibration measurements to be made on the MBES in the field while it is mounted on the vessel. This procedure can reduce the time necessary for a MBES calibration compared to the standard indoor tank methods and allow systems to be calibrated as installed on the vessel on which they will be used.

The original design for field calibration had the split beam system fixed, which allowed the determination of the target position inside a limited range of beams of the MBES. This year, the calibration methodology was adapted to incorporate a high-resolution rotation mechanism to the split-beam system mount to provide coverage of the whole range of beams of the MBES under calibration. The split-beam rotation system built for this purpose also has other potential calibration applications in the tank.

The rotation mechanism for the Simrad EK60 split-beam transducer was built utilizing a high-resolution stepper motor that allows the positioning of the split-beam transducer with an angular resolution of 0.1o. The mechanical parts of the mount were designed, manufactured, and assembled by Paul Lavoie, including the waterproof motor case (Figure 3-1). The split-beam rotation system

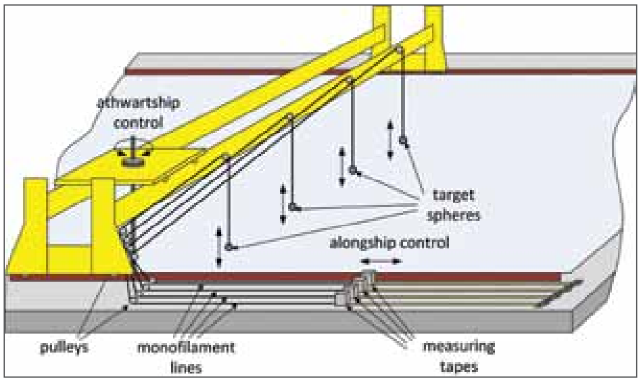


Figure 3-2. Positioning system for the target spheres.

was first tested outside of water to verify its accuracy and repeatability of the angular position provided by the stepper motor and also to verify its rigidity. The system performed well during the tests, although a backlash of 0.05o was verified (this is the backlash from the manufacturer specifications).

Beam pattern calibrations were conducted on a Reson 7125 MBES in the Chase acoustic test tank using two different methods. The first method employed standard target spheres suspended in the water column by monofilament line and the high accuracy rotation mechanism installed in the tank. The second method employed the field calibration methodology of multibeam echo sounders using a standard target and a split-beam system. Figure 3-1 shows the mount for the transducers used in the tests. Figure 3-2 depicts the setup to control the position of the target spheres relative to the MBES and Figure 3-3 shows the overview of the field calibration methodology.

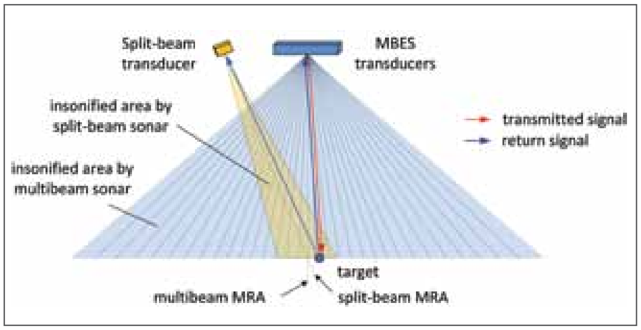


Figure 3-3. Field calibration of multibeam echo sounder methodology.

These tests have demonstrated that the field calibration procedure achieved results similar (though a bit less accurate) to the tank calibration results. This suggests that the multibeam field calibration methodology offers the possibility of field calibration for vessel mounted systems without the need to remove the sonar system from a vessel. This results in significantly reduced operational time when compared to conventional tank calibrations although having to accept a potential reduction in accuracy. The results of this work were presented at the 2012 ECUA conference in Edinburgh, Scotland.

A positioning system for the target sphere has been designed for use the R/V *Coastal Surveyor* (Figure 3-4) and will be used for field calibrations in 2013.

Calibration of Other Sonar Systems

Along with supporting our own research projects, the center acoustic calibration facility is also available to NOAA, our Industrial Associates, and others for use in quantifying the behavior of new or existing sonar systems. In 2012, we worked with Kongsberg Maritime

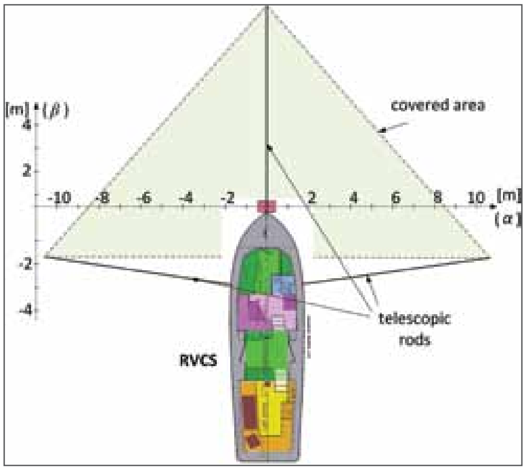


Figure 3-4. Overview of target positioning system on R/V *Coastal Surveyor.*

and calibrated a new broadband echosounder they will be introducing to the market as well as a 38kHz EK60 fisheries sonar. Additionally, in support of our NEWBEX backscatter experiment (see below) and in general support of the NOAA fleet, we calibrated two Reson 7125 multibeam sonars from the NOAA vessel *Fairweather* returning one to the fleet so that we will have at least one calibrated sonar in the field to compare to other systems. The backscatter collected from the calibrated 7125 that has been returned to the *Fairweather* is being used by NOAA Corps Officer Briana Welton to better understand commercial backscatter processing software as part of her studies at the Center.

Very Shallow Water Surveying – CBASS

Tom Lippmann has focused on mapping bathymetry around shallow harbor entrances and inlets, a region of particular interest to mariners because it is often characterized by rapidly shifting sands, bedforms, and submerged shallow-water hazards. It is also a region of high scientific interest because sediment fluxes through inlets are often high, playing a role in contaminant transport and in determining the rate of organic carbon transmitted to the continental shelf by rivers. Difficulties working in shallow hazardous waters often preclude accurate measurement of water depth both within the river channel where high flows rapidly change the location of channels, ebb tide shoals, and sand bars, and around rocky shore where submerged outcrops are poorly mapped or uncharted. To address these issues, Tom has developed the Coastal Bathymetry Survey System (CBASS; Figure 3-5), and expanded its capabilities to include multibeam echosounding for fine-scale bathymetric measurement and acoustic Doppler current profiling for measurement of mean currents in shallow marine environments.

The CBASS has been used extensively in challenging marine environments such as the surf zone where breaking waves are present, in very shallow freshwater bodies around the Great Lakes, and inland rivers near bridge piles. Estimated accuracies of the 192 kHz single-beam echosounder (SBES) are 0.07 to 0.10 m in the vertical, and on the order of 0.1 to 1.0 m horizontally, depending on the water depth and bottom slope. The high maneuverability of the personal watercraft makes very shallow-water bathymetric surveys possible, particularly in regions where airborne remote-sensing systems fail because of water-clarity issues or where repeated high-resolution surveys are required (e.g., where an erodible bottom is rapidly evolving). It is particularly useful where shallow hazards prevent the use of vessels with larger drafts.

This year, numerous improvements have been made to the CBASS. The first notable improvement is the development of full waveform capabilities in the 192 kHz SBES. This SBES, designed and built by Bill Boyd of Scripps Institution of Oceanography, allows for the examination of spatial variation in bathymetry coincident with textural classification of seafloor properties in shallow water depths in the range of 1 to 25 m. The system is presently being used in a joint effort with the NH Department of Environmental Services (DES) to survey the Little Bay estuary that connects the Piscataqua River to the Great Bay Estuary. This region is of particular interest because of the important benthic habitat that significantly impacts the estuary ecosystem. Coincident with observation of the water depths are maps of the backscatter intensity at the seafloor that define the spatial properties of the acoustic reflection at the seabed, largely a function of the seafloor characteristics and benthic communities.

Figure 3-5. Photograph of the CBASS in operation at the RIVET field experiment at New River Inlet, NC.

The second improvement is the integration and field use of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) for observation of the vertical structure of mean currents in shallow water, particularly around inlets and river mouths where the flows are substantial, can cause navigational difficulties for recreational boaters and commercial shipping, and can rapidly change the configuration of the seabed bathymetry potentially creating submerged navigational hazards. This work was in collaboration with the UNH Ocean Engineering program (Dr. Jim Irish and Dr. Ken Baldwin). The combination of coincident, repeated observation of both fine-scale bathymetry and mean flow properties over large nearshore areas will allow for models on seafloor evolution to be tested.

The third, more substantial improvement is the integration of the 240 kHz Imagenex Delta-T multibeam echosounder (MBES) with a state-of-the-art inertial measurement unit (IMU). Figure 3-6 shows a CAD drawing (to scale) of the CBASS and its various components. The new multibeam capabilities allow for detailed examination of seafloor bathymetric evolution in very shallow water with typical water depths of 1-25 m. In the CBASS, the POS/MV is installed in the forward cabin of the CBASS, and integrated directly with both the SBES and the Delta-T, flush mounted on the starboard hull tilted at a 20 deg angle. The system was tested over a four week period in May 2012 at New River Inlet, NC, as part of the Office of Naval Research (ONR) sponsored Inlet and River Mouth Dynamics Experiment (RIVET). Because this was the first time (to our knowledge) that an IMU and MBES have been integrated into a watercraft of this size and utilized in field settings, considerable time was spent determining the appropriate method-

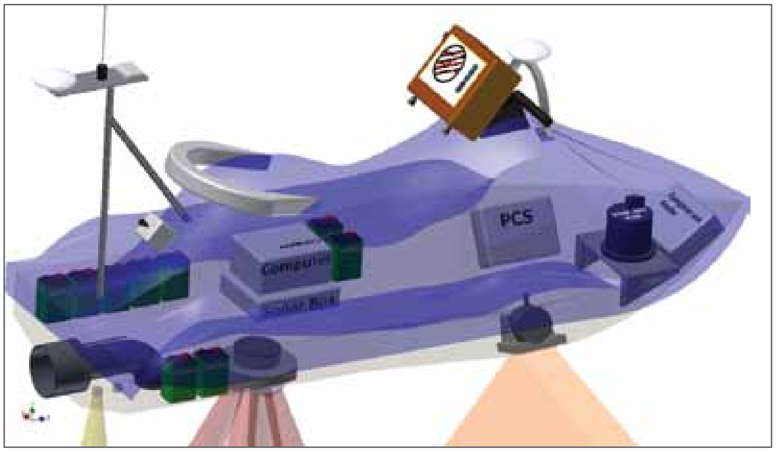


Figure 3-6. Scaled CAD drawing showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery packs, GPS and RTK antennae,and navigational display monitor.

ologies for operating in waves and currents in shallow water, and in determining the accuracies and limitations of the system. During RIVET, bathymetric maps were produced at 10-20 cm resolution from multiple overlapping transects in water depths ranging from 1 to 12 m within the inlet (Figure 3-7). The noise floor for the attitude sensors was 0.03 to 0.06 deg, within the specifications of the POS/MV IMU. Ultimately, the noise floor of bathymetric maps obtained with the CBASS (after incorporating CUBE uncertainty analysis) was found to be between 2.5 and 5 cm, with the ability to resolve bedforms with wavelengths greater than 30 cm, typical of large ripples and megaripples.

Because the IMU and MBES are located in proximity to the CBASS engine, one important question that needed to be resolved was impacts from vibrational noise. The RIVET survey data revealed vibrational noise between 20 to 100 Hz in all attitude and elevation signals, but that the noise is orders of magnitude below typical roll, pitch, heading, and elevation values associated with boat dynamics in the presences of strong currents and steep wave motions. This vibrational noise amounts to an error in vertical resolution of less than 1 mm/m over a range of beam angles out to 60 degrees. The result is that the vibrational noise does not limit survey capabilities in the CBASS. We compared the vibrational noise from the CBASS to that observed with a POS/MV 320 V4 on the R/V *Coastal Surveyor* operating in quieter conditions. Although, the *Coastal Surveyor* was found to have better vibrational qualities, the CBASS system is not limited by the vibration.

During RIVET, the CBASS was operated under a range of conditions with strong currents (3 knots) and steep high frequency (near breaking) waves with 1 m amplitudes and 3 to 7 second periods. The system works well under these conditions provided the CBASS speed is less than about 5 knots.

The efficacy of using the Delta-T for repeated surveys was examined using data obtained as part of both the RIVET (2012) and Hampton Inlet (2011) field experiments. In particular, the combination of mean flows and fine-scale bathymetry are used to examine the behavior of seafloor bedform evolution in the presence of strong tidal currents that vary significantly over fortnightly time periods. This work is part of thesis research by graduate student Lindsay McKenna under Lippmann's supervision, and was presented at the 2012 Ocean Sciences and AGU meetings held in Salt Lake City, UT, and San Francisco, CA. For example, at Hampton, the inlet navigation channel is approximately 1 km in length and 300 m in width, with bottom sediments consisting of medium to coarse-grained quartz sand. Seafloor topography was measured nine times over a four-week period with the Delta-T (Figure 3-8). Coincident observation of mean current profiles spanning the inlet were conducted with the CBASS. The inlet channel topography is dominated by a field of migrating sand waves, on the order of 1 m in amplitude and 10 to 30 m in wavelength and with crests oriented across the channel. Superimposed on

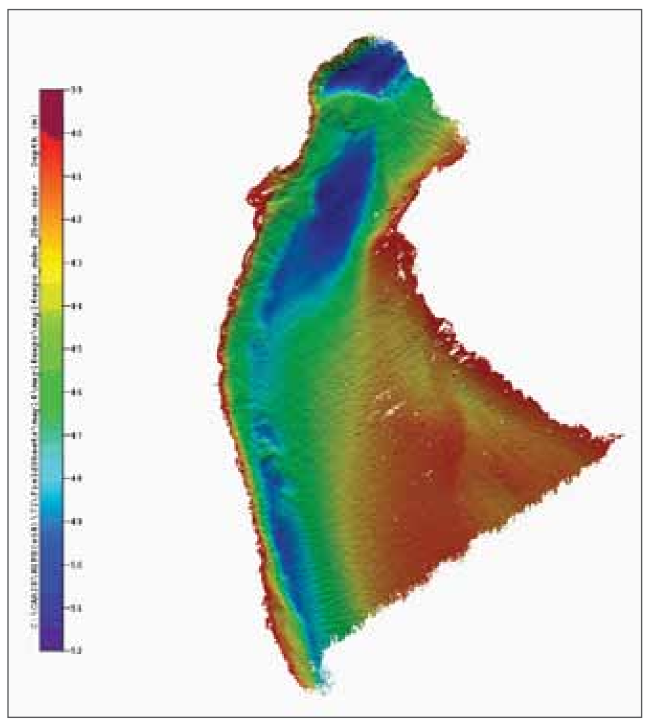


Figure 3-7. Fine scale bathymetry of New River Inlet observed from the CBASS on 14 May 2012. Elevations are in meters relative to the ellipsoid. Actual water depths range 0.5–12 m below mean sea level.

the larger-scale features are smaller scale megaripples with 25-50 cm amplitudes and 1-6 m wavelengths. The megaripples were widespread throughout the inlet channel, and grew in amplitude during a rising spring tide, and diminished in amplitude during periods of neap tide. Mean flows were strong, exceeding 2 m/s during spring tides, and varied greatly across the short width of the inlet. Observations show that the large sand waves migrated up the inlet (inshore) during the weaker neap tide periods, and out the inlet channel (seaward) during the stronger spring tidal periods. The net movement of the sand waves was seaward over the four week period indicating that the spring tidal flows dominated the bedform migration. The flow structure along the channel length was strongly influenced by the seafloor bathymetry. Calculations of the shear velocity, indicative of sediment transport magnitude and direction, were consistent with the overall behavior of the bedform migration.

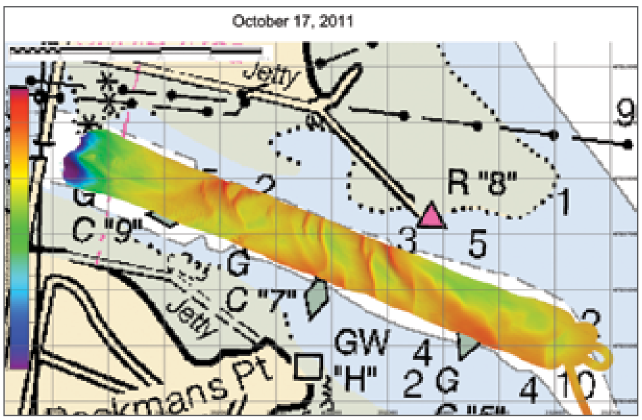


Figure 3-8. Fine scale bathymetry of the main inlet channel at Hampton Inlet, NH, showing the array of sand waves and megaripples observed on 17 October 2011.

Finally, continuous observation utilizing the 192 kHz SBES, 240 kHz MBES, and 1200 kHz ADCP on the CBASS showed no evidence of interference between the various acoustic systems, nor any significant degredation due to vibrational noise caused by the survey vessel itself. Our observations suggest a significant advancement to shallow water survey capabilities with the CBASS, allowing for examination of fine-scale seafloor evolution over the extent of typical inlet and other shallow water environments of interest to NOAA.

Sea Acceptance Trials – Multibeam Advisory Committee

For Information—funded by non-NOAA sources.

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

This process was formalized with the funding in 2011 of Center researchers Jonathan Beaudoin and Paul Johnson (along with Vicky Ferrini at LDEO) to establish a Multibeam Advisory Committee (MAC) with the goal of ensuring that consistently high-quality multibeam data are collected across the U.S. academic research fleet (UNOLS vessels). The strategy will be to create a community of stakeholders including representatives from operating institutions, funding agencies, and key outside experts from the user and technical/engineering communities that can assist in providing guidance on a broad array of multibeam issues.

A part of the MAC effort will be the development and dissemination of best-practice documentation and quality assurance software as well as collaboration on maintenance agreements and a spare parts pool. Institutions outside of the UNOLS fleet have already expressed interest in participation and the Center has already entered an agreement with the Schmidt Ocean Institute (SOI) in collaboration with colleagues from IFREMER in France, for assistance with the harbor and sea acceptance trials of all acoustic systems on their newly refitted vessel *Falkor* and is in discussion with SOI about long-term assistance in maintaining technician skill sets, monitoring of acoustic system health, etc. that are entirely consistent with the program being established under the MAC. CCOM has also been contracted by Dr. Robert Ballard's Ocean Exploration Trust to provide similar multibeam sonar installation guidance and long-term support for their vessel of exploration *Nautilus*.

MAC activities to date include ship visits by several of the team members. Acoustic noise profiling tests of R/V *Melville* (by Tim Gates, part of the MAC team) found that the *Melville* is a relatively quiet platform with the anti-roll tank transfer pumps being the only mechanical source of acoustic interference. In March 2012, Beaudoin and Johnson took part in R/V *Kilo Moana's* transit from Portland, OR to Honolulu, HI to document the EM710 and EM122 installations and to provide preliminary assessments of the sensors' performances. Additional activities included installation of, and training for Beaudoin's SVP Editor software (see below) and also establishment of automated data backup system and a system extinction program developed by Paul Johnson. This program can quickly plot swath width of a system(s) vs. depth (see Figure 3-9 and can be used to determine expected coverage as a function of depth. This will also allow operators to determine optimum switch over depths, to know when to switch mapping with a shallow water system to a deeper water system for vessels with multiple multibeams.

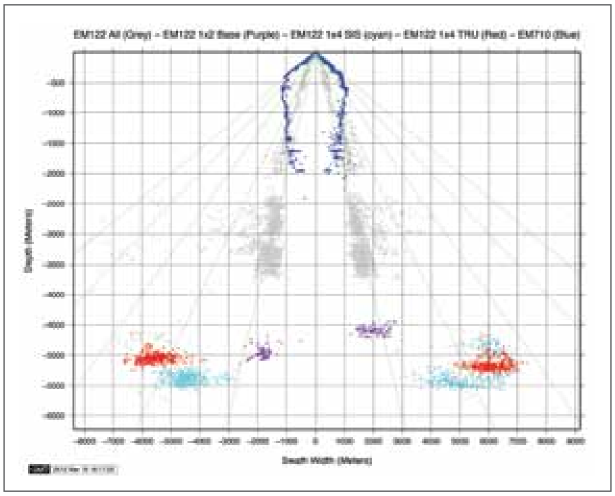


Figure 3-9. Swath extinction tool developed as part of the MAC tool suite.

During the *Kilo Moana* cruise, the MAC also established the conventions to be used for documenting the system status, acquisition parameters, and operational protocols for a properly functioning multibeam. As the MAC develops a database of best operating practices, documentation of system setups, and learns new ways of handling data this will be a benefit to all operators of multibeam systems since this knowledge will be shared through the MAC's website (**http://mac.unols.org/**).

Performance of the *Kilo Moana's* new EM122 receiver array was observed to be suboptimal during the transit with less than 1x water depth coverage achievable. Beaudoin and Johnson worked with the manufacturer during the transit through email correspondence to help establish the cause. Based on this work, it was eventually determined that the poor performance was due to factory misconfiguration of the EM122 system's receiver module.

Johnson and Ferrini participated in a short visit to R/V *Marcus G. Langseth* in July and assisted in a patch test and also installed Beaudoin's SVP Editor along with MAC cookbook documentation. Beaudoin visited R/V *Hugh R. Sharp* in October during the installation and calibration of their new Reson 7125 shallow water echosounder and a second time in November prior to a science cruise of which Beaudoin was a participant. On the *Hugh Sharp*, Beaudoin prepared system configuration documentation, installed the SVP Editor and assisted in training of shipboard technicians.

Lidar

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric lidar systems offer the possibility to rapidly collect bathymetric (and other) data in these very shallow regions but there still remains great uncertainty about the accuracy and resolution of these systems. Additionally lidar (both bathymetric and terrestrial) offer the opportunity to extract other critical information about the coastal zone including seafloor characterization and shoreline mapping data. We have thus invested heavily in lidar-based research (led by Drs. Shachak Pe'eri and Chris Parrish) and will report on this research later in the progress report. As with sonar sensors, our ability to properly and appropriately interpret the results depends heavily on our understanding of the behavior, capabilities and limitations of the lidar systems themselves and thus we have also invested in research focused on understanding and calibrating lidar sensors. This sensor-related research will be reported in this section.

The Impact of Sea State Condition on ALB Measurements

One of the key unknowns in establishing the uncertainty of Airborne Lidar Bathymetry (ALB) surveys is the impact of changing environmental conditions (particularly the sea) on the derived bathymetry. During the past year (May 2011-May 2012), theoretical and experimental work has focused on understanding the relationship between sea surface conditions and the accuracy of ALB measurements. Simulated environmental conditions were defined based on typical ALB survey conditions. The theoretical component of the work included simulations of the ray-path geometry of the laser beam as it propagates through the water column. The ALB simulator was then used in a wave-tank to compare to the theoretical results. A cross section of the laser beam was monitored underwater using a green laser with and without wind-driven waves (Figure 3-10). The results of the study show that capillary waves and small gravity waves distort the laser footprint. Because sea-state condition is related to wind to a first-order approximation, wind speed thresholds for various

Figure 3-10. An example of a laser beam pattern (cross section) collected underwater with a wind-driven surface (wind speed of 4 m/s).

ALB survey accuracy requirements can be established. Additionally these results provide a means to evaluate the accuracy of an ALB survey under various sea surface conditions. Another observation was of the sensitivity of the laser footprint size to the sea state. These results suggest that different analysis procedures may be necessary for narrow-beam ALB compared to broad-beam ALB systems. The sea-surface study is now being expanded to include the ray-path geometry underwater and the use of the lidar simulator as a laser source.

Instruments to Ground Truth ALB, Hyperspectral and other Remotely Sensed Data

Just as surface wave conditions can affect the nature of the lidar return, so can the nature of the water column and the seafloor substrate. In order to establish a broader understanding of the these factors, Pe'eri and colleagues have developed several instrument suites and collected a number of "ground-truth" data sets from areas where ALB data has been collected.

Optical Collection Suite (OCS and BUGS)

In order to better understand the environmental factors that influence optical remote sensing data and extend ground truth capabilities for NOAA platforms, the Center has been developing several ground-truthing sensor suites. The Optical Collection Suite (OCS) is a ground-truthing system that enables researchers to collect underwater imagery with real-time feedback, while measuring the spectral response and quantifying the clarity of the water with simple and relatively inexpensive instruments that can be hand-deployed from a small vessel. In 2012 the capability of performing a radiometric calibration underwater was added to the system. To perform this calibration an underwater white reference panel, which was calibrated against a Labsphere, Inc. certified reference standard, was added to facilitate acquisition of reference spectra (Figure 3-11). This panel is controlled by a pneumatic actuator with air lines run from a dive tank on the vessel such that the panel can be swung into or out of the spectrometer's field of view by simply flipping a switch. Using the pneumatic actuator-controlled underwater white reference panel, diffuse attenuation coefficient estimates can be obtained simultaneously with the seafloor reflectance spectra by also recording relative irradiance at multiple depths as the camera frame, with the white reference in the spectrometer's field of view, as it is lowered through the water column. Based on the success of the OCS, an autonomous system, the Benthic Underwater Groundtruthing System (BUGS) has been designed for deployment from AUV or ROV. The OCS system has been operational since 2009 and has been used in several ground-truth missions that supported airborne lidar bathymetry (ALB), hyperspectral imagery (HSI), and swath-sonar bathymetric surveys in the Gulf of Maine, southwest Alaska and the U.S. Virgin Islands.

The USVI data acquisition involved successful collaboration between the Center, NOAA NGS, NOAA NCCOS, USGS, and the National Park Service (NPS). The data acquired in this project included 36 seafloor reflectance spectra and corresponding video imagery for a variety of benthic habitat types, three Kd (diffuse attenuation coefficient) measurements, and extensive GPS ground truth in shallow-water shoreline transects (Figure 3-11).

Raman Scattering Response Due to Salinity and Temperature Changes in the Water Column

The response of laser Raman spectroscopy is directly related to the salinity and temperature of the water column and as a result, the potential exists to collect spatial measurements of sea surface temperature and sea surface salinity from airborne lidar observations. Research at the Center led by Shachak Pe'eri is focused on looking at the potential of using Raman scattering for *in situ* and aerial surveys using current ALB technology to provide regional-scale surface water temperature and salinity data. Experiments are being conducted using the lidar simulator to measure the Raman scattering under controlled and known conditions. In addition, Distributed Temperature Sensing (DTS) systems are also being investigated for marine applications. Future work will include field surveys that will be compared to both approaches.

Coastal Lidar Radiometric Performance Analysis and Calibration

Just as we seek to understand the performance of bathymetric lidars, we also seek to understand the performance and potential of terrestrial lidars that are used in the coastal zone. An emerging class of topographic-bathymetric ("topo-bathy") lidar systems appears very well suited for shoreline mapping in NOAA NGS, while simultaneously offering the potential to generate IOCM multi-use datasets. These new systems effectively span the middle ground between conventional bathymetric and topographic systems, employing narrow-beam, low energy, short-pulse green (532 nm) lasers and operating at extremely high sampling rates. Systems in this class are focused primarily on shallow waters and do not offer the depth penetration of some conventional bathymetric lidar systems. However, these lidars enable high-resolution, seamless coverage across the backshore, intertidal, and nearshore marine zones to depths of 5 to 25 m, depending on water clarity and other variables. In addition to mapping mean lower low water (MLLW) and mean high water (MHW) shorelines, envisioned uses of the data include filling in the data gap shoreward of the Navigable Area Limit Line (NALL), mapping benthic habitats, and supporting a range of coastal zone management applications and climate change studies.

Figure 3-11. Field data acquisition in the USVI. Clockwise from top left: deploying underwater spectrometer and video camera; GPS transects; underwater video imagery of a seagrass site; and GPS basestation. In the bottom right image, the underwater calibration panel for the spectrometer can be seen. This device enables efficient and reliable acquisition of seafloor reflectance spectra.

In collaboration with partners from NGS, JHC, OCS, NCCOS, USGS, JALBTCX and the private sector, Chris Parrish is leading two projects aimed at evaluating and enhancing new topo-bathy lidar technology for NOAA applications. The first project involves evaluation of commercial, topo-bathy lidar technology. In March, 2012, NOAA NGS flew a new commercial system, the Riegl VQ-820-G, aboard a NOAA Twin Otter aircraft (Figure 3-12). This narrow-beam, low-power system was designed to survey lakes, rivers, and nearshore coastal waters (up to ~1 Secchi depth) at very high spatial resolution, using a fixed 20o scan axis and a measurement rate of up to 195 kHz.

Parrish and colleagues are currently evaluating the data through comparison against reference data sets, which include NOAA multibeam data, JALBTCX CHARTS lidar data, and shallow-water GPS transects collected by NGS. Initial results for the Fort Lauderdale site indicate that the system reliably mapped bathymetry in depths of up to ~10 m, with sparser coverage in the 10 to 12 m depth range. Point densities on the seafloor were found to be quite high, approaching 2 points/m2 from a single flightline in many areas. After converting the test and reference data sets to a consistent vertical datum using VDatum and applying a further vertical bias correction, the RMS difference between Riegl VQ-820-G bathymetric data and the reference data was 19 cm. Continuing work is focusing on efficiently segmenting seafloor returns from the VQ-820-G data and on further evaluating the data for use in NOAA programs.

Parrish is also serving as PI on a collaborative project with the USGS Coastal and Marine Geology Program to evaluate and extend the capabilities of a new USGS topo-bathy lidar system. This new system, known as the Experimental Advanced Airborne Research Lidar –B (EAARL-B), became operational in late summer 2012. Built by USGS's Wayne Wright and his team in Salisbury, Maryland, the new system improves upon the capabilities of the previous EAARL-A. Key features of the new system include a more powerful laser, shorter pulses, optical segmentation of the outgoing pulse, and four receiver channels. These enhancements enable 6x greater data density, better water penetration, and improved discrimination of seafloor returns in shallow water.

In July, Parrish led a field campaign in the USVI to acquire ground truth for two phases of the EAARL-B collaborative research. The goal of the first phase is to assess the vertical uncertainty of both subaerial (land) and subaqueous (seafloor) EAARL-B data using GPS and NOAA MBES reference data. The second phase focuses on developing new tools and workflows for creating seafloor reflectance images from EAARL-B waveform data. Combined with the bathymetry, these calibrated reflectance images will enable NOAA NCCOS and ONMS to produce seafloor habitat maps to support ecosystem-based management.

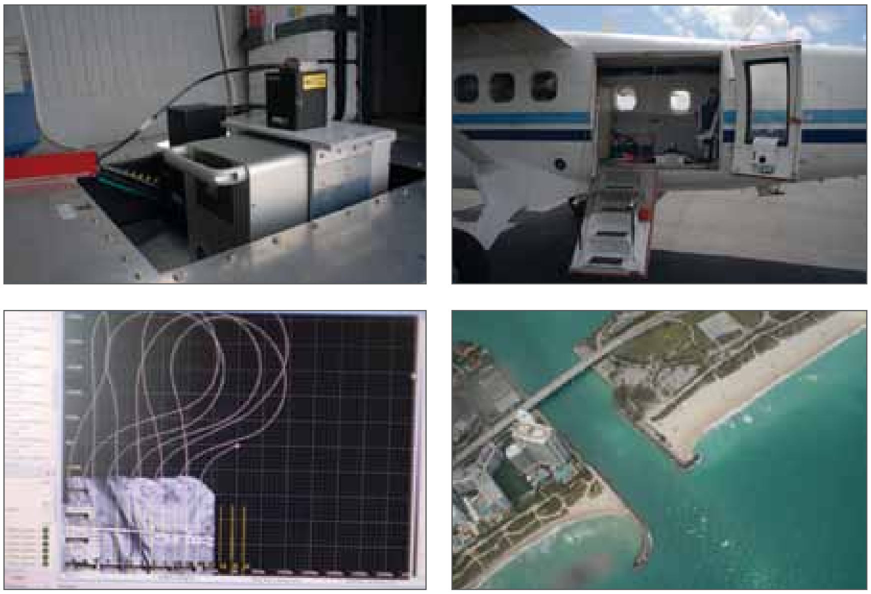


Figure 3-12. Riegl VQ-820-G evaluation flights aboard NOAA Twin Otter aircraft. Clockwise from top left: lidar sensor head; NOAA Twin Otter aircraft; Baker's Haulover Inlet, within the project site; flight management system, showing data coverage in real time.

Simulation of Natural Water Conditions in a Laboratory Environment

As part of our efforts to better understand the behavior of both optical and lidar-based measurements on the seafloor and in the water column, Shachak Pe'eri is participating in an ONR-funded study to simulate a natural marine environment (illumination and water clarity) in laboratory conditions and to create a well-controlled environment for testing systems underwater. During the summer of 2011 (May-September), experiments were conducted in an attempt to replicate the solar radiation expected at different latitudes with varying water clarity conditions up to 30 m in depth using a 2.5 m deep in the Center's engineering tank. The goals of the study were to configure an underwater light source to produce an irradiance spectrum similar to natural daylight with the sun at zenith and at 60° under clear atmospheric conditions (Figure 3-14); and to monitor water clarity as a function of depth (Figure 3-14). Irradiance was measured using a spectra-radiometer with a cosine receiver to analyze the output spectrum of submersed lamps as a function of distance.

In addition, an underwater reflection method was developed to measure the diffuse attenuation coefficient in real-time. Two water clarity types were characterized; clear waters representing deep, open-ocean conditions, and murky waters representing littoral environments. Results showed good correlation between the irradiance measured at 400 nm to 600 nm and the natural daylight spectrum at 3 m from the light source. This can be considered the water surface conditions reference. Using these methodologies in a controlled laboratory setting, it is possible to replicate illumination and water conditions to study the physical, chemical and biological processes on natural and man-made objects and/or systems in simulated, varied geographic locations and environments. The experimental setup within this long tank can be used for other marine applications. For example, the light field requirements are different for underwater photography and marine exploration. Results from this study were also used in the design of the BUGS system and the UUV optical communication project.

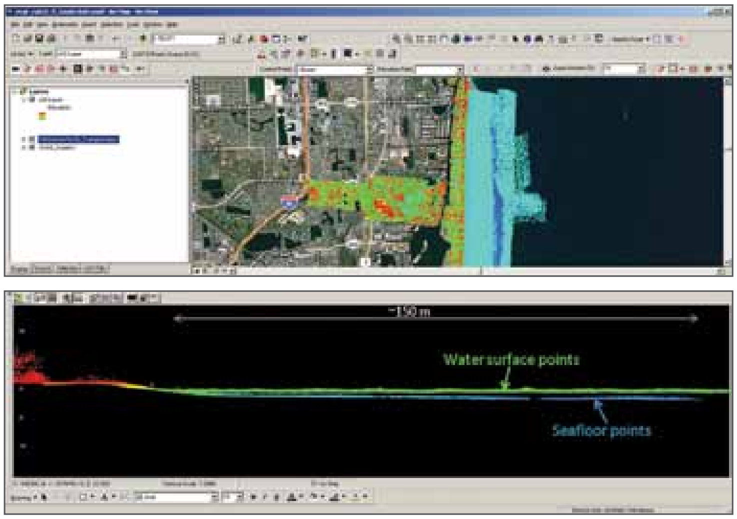


Figure 3-13. Riegl VQ-820-G data evaluation. Top: topo-bathy coverage obtained in Ft. Lauderdale, FL project site. Bottom: profile of lidar returns in a transect starting on land and extending ~150 m offshore. The point at which the extinction depth is reached can be seen toward the right end of the transect.

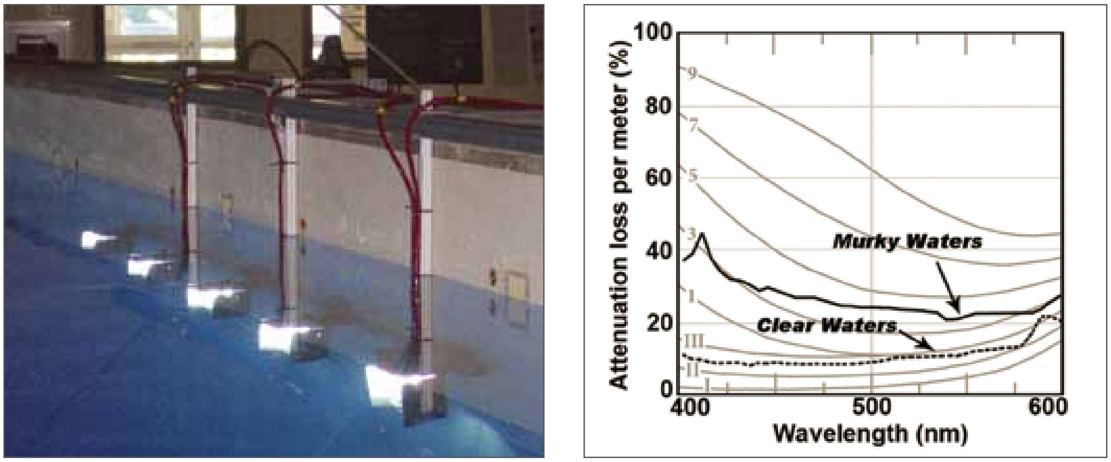


Figure 3-14. Light wall that produces an illumination that simulates natural daylight and diffuse attenuation co-efficient plot of the Cener's tank environment calculated from the irradiance measurements overlaid on the Jerlov plots.

Sound Speed Sensors

One of the fundamental measurements required to make accurate bathymetric measurements is a detailed understanding of the spatial and temporal distribution of sound speed. Our inability to capture the spatial and temporal distribution of sound speed at high enough resolution is ultimately one of the largest contributors to uncertainty in our bathymetric measurements. Thus, the Center has invested much effort into exploring new and better ways to make sound speed measurements as well as to predict the variability in the sound speed field when no measurements or not enough measurements are available (see PROCESSING theme).

Automated Underway Profiler “Auto-Pilot” Algorithms and MVP Simulator

One of the most exciting recent developments addressing the question of the spatial and temporal variability of the sound speed structure of the water column is the ability to rapidly collect closely spaced sound speed profiles through the use of automated underway profiling systems. One of the key questions facing those using these systems is the profiling interval needed for capturing the true variability of the water column. Too few profiles can lead to poor data quality and too many can lead to degradation and possibly loss of the instrument. Jonathan Beaudoin, NOAA student, Matt Wilson and others have been collaborating to implement algorithms that monitor refraction based sounding uncertainties and provide automated feedback mechanisms that allow for the adjustment of the sampling interval of automated underway profiling systems such as the Rolls Royce Moving Vessel Profiler (MVP). Algorithms first proposed by Beaudoin in 2008/09 have been implemented and tested by Wilson in a standalone software application that communicates with the Rolls Royce MVP controller software to assess the MVP measurements and to prescribe a sampling interval based on the cast-by-cast comparison assessment (Figure 3-15). The algorithm uses the measurements of the MVP system itself to provide guidance on whether or not to increase or decrease the sampling interval in reaction to the oceanographic conditions observed by the MVP system. For any SSP input, ray tracing calculations are performed to determine the depth and position of sound as a function of the elapsed travel time across the entire swath. Ray traces from successively acquired SSPs are then compared, providing a quantitative estimate of the effect of refraction on sounding uncertainty. The algorithm then uses the calculated sounding uncertainty from the previous step, the existing sampling interval, and a specified error tolerance, to recommend a new sampling interval.

This addresses two problems that are often encountered in MVP operations: under-utilization of the system—a minimal number of casts are collected for fear of grounding/fouling of the towfish at the expense of poor sounding data quality in dynamic oceanographic environments; and over-utilization of the system—an excessive amount of casts are collected to guarantee sounding accuracy at the expense of wear and tear on the system and increased likelihood of towfish grounding/fouling or loss.

The aim of the algorithm is to strike a balance between these two scenarios and to guide the user of the MVP system to collect a sufficient number of sound speed casts such that a desired sounding accuracy is maintained while minimizing wear on system components and reducing risk of fouling or loss of the towfish.

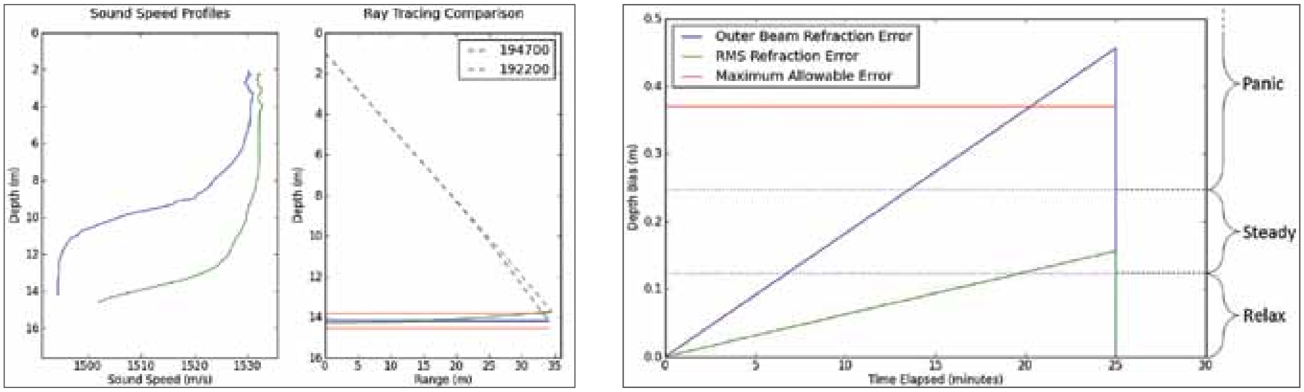


Figure 3-15. a: The SSP comparison used in the real-time tool, with the profiles (left) and their derived seafloors (right)) drawn by connecting the termination points of each ray. Only the outermost rays of each SSP are drawn (dashed). Note the time stamps (HHMMSS) of the SSPs given in the upper right hand corner, and the bounds of NOAA allowable error due to refraction (red lines). b: The maximum allowable error is divided into thirds (dotted lines), which define the bounds of "Panic," "Steady," and "Relax" algorithm modes. In this example, the maximum depth bias falls within the "Panic" mode.

Collaboration with Rolls Royce has led to the design and development of a remote triggering protocol that allows third party applications, such as Wilson's software, to control the operation of an MVP. In this case, the protocol allows for an automated feedback mechanism to control the MVP sampling interval in reaction to changing oceanographic conditions without operator intervention. The protocols established in this work enhances the ability of Center researchers, and other MVP users, to rapidly develop, test and deploy algorithms to enhance the functionality of MVP systems, allowing for streamlined deployment of research ideas into the field.

Wilson's software, named CastTime, was tested in the field by Wilson and Beaudoin with an MVP100 system on NOAA Ship *Ferdinand R. Hassler*, in September. Wilson successfully integrated his software with the vessel's MVP system such that a closed feedback loop could direct MVP sampling operations with the only operator involvement being confirmation prior to collecting a cast. Testing was conducted during normal survey operations with good results. Wilson's algorithm routinely indicated that the sampling interval could be significantly relaxed from the initial set point of 15 minutes. Beaudoin participated in the cruise to use the MVP200 to validate oceanographic models, however, he also spent significant time refactoring Wilson's research software into a set of modular core algorithms that facilitate future collaborative development between NOAA, Rolls Royce and the Center.

It is anticipated that Wilson and Beaudoin will test the software with a small subset of NOAA field units during the 2013 field season in anticipation of a fleet wide deployment in 2014. A preliminary graphical user interface (GUI) developed for CastTime is shown in Figure 3-16. Operator controls involve starting and stopping the monitoring algorithm as desired. The operator can force a cast to happen early if, for example, the next cast will occur during a turn between survey lines. The operator is also prompted to confirm every cast deployment. The mission information display informs the operator of the time of the next anticipated cast, along with a countdown. The currently prescribed sampling interval is also displayed along with the number of casts acquired during the mission.

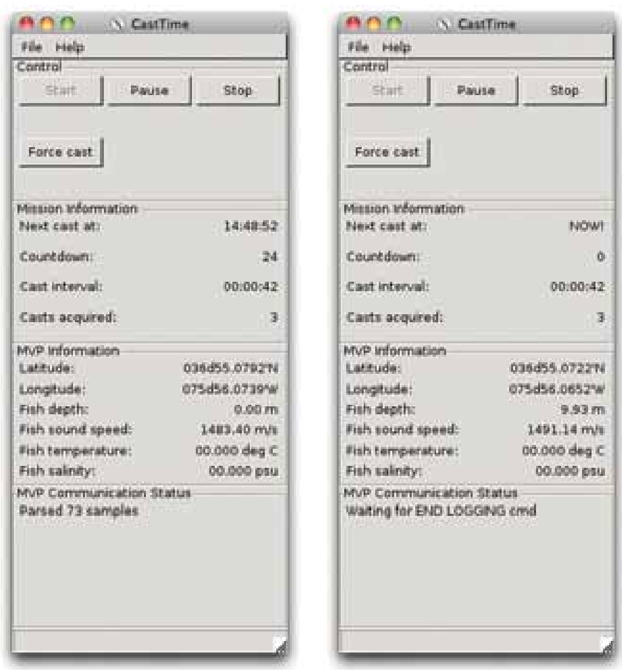


Figure 3-16. Early version of the CastTime graphical user interface showing countdown and casting modes (left and right, respectively).

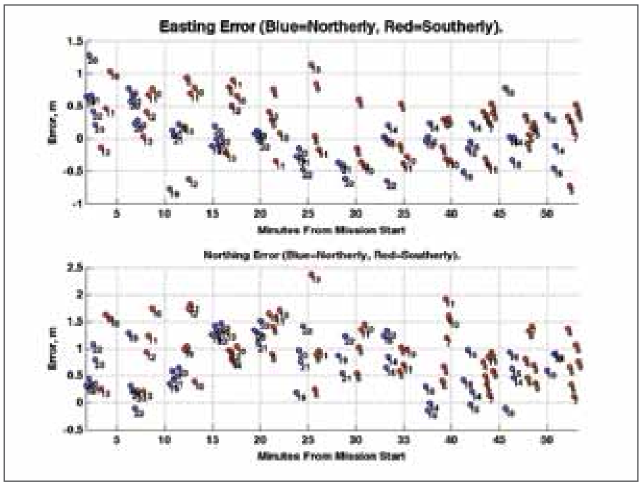


Figure 3-17. Navigation errors from seafloor fidcuials during a magnetometer survey showing no net drift in the navigation over this 55 minute survey.

Development of Wilson's CastTime routines required the use of the Moving Vessel Profiler (MVP) control and acquisition software. The MVP software can be run in simulator mode, however, its ability to recreate realistic scenarios is limited in that only archived profiles can be replayed with the sensors that were used to acquire the data in the first place. Natural extensions of Wilson's work will involve more complex algorithms whose development will be constrained by the MVP software's simulation abilities and an alternate solution was desired.

To facilitate further development and research directions in this field, an MVP simulator was implemented that (a) responded appropriately to command and control protocols and (b) simulated realistic data streams from the oceanographic and navigation sensors that would normally be configured with an MVP system. The navigation feed is simulated via a user-specified vessel track and ship speed, the navigation module of the simulator then calculates the position of the vessel and outputs this as a navigation data stream that client software can access via MVP communication protocols. The oceanographic data are simulated through the inclusion of oceanographic models such as the Chesapeake Bay Operational Forecast System (CBOFS) or the Global Real-Time Operational Forecast System (Global RTOFS) from NOAA. The simulator responds to cast START, STOP, RESET and RECOVER events and provides realistic data feeds in each case to enable development and testing of advanced functionality to improve MVP utility in the field.

The combination of realistic I/O abilities and the oceanographic models provides the ability to bench-test oceanographic sampling algorithms that are being designed to improve the efficiency of systems like MVPs. Wilson's CastTime work is easily extended and the MVP simulator now provides the ability to validate and tune the various algorithms prior to field testing in order to benefit as much as possible during field work where costs can be prohibitive or where testing may interfere with surveying operations.

AUV Activities

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

Val Schmidt is providing support to both the Center and the University of Delaware AUV operations and has established a series of Standard Procedures and checklists for AUV operations and has written a considerable amount of software to monitor and support the Gavia, including code to explore an alternative, and hopefully improved and more deterministic, pipeline for processing phase-measuring bathymetric sonar data.

In 2012, a new total field magnetometer module, acquired by Trebanis in collaboration with Weston Solutions and Geometrics through a Department of Defense grant under the Environmental Security Technology Certification Program (ESTCP) was integrated into the Gavia and the system had several very successful field deployments. Engineering trials were conducted in January in Lewes, DE, during which the first missions were run with the new fully integrated magnetometer module. A full field trial was subsequently conducted in March in St. Petersburg, FL. The field trial consisted of both calibration and blind test sites, each seeded with approximately 20 targets consisting of expended mortar rounds ranging in size from 60 mm to 150 mm. After seeding, the target locations were established with a multibeam survey to 10 cm (rms) horizontal uncertainty. These targets presented a tremendous opportunity to establish the long-term navigational uncertainty and drift of the AUV. The seed targets observed in the AUV's sidescan data were used as known fiducial markers allowing us to assess the drift in the navigation solution during the survey. Figure 3-17 shows the navigation error in Easting and Northing for a typical 55 minute mission. Average relative positional drift over the total duration is 0.15 m in Easting and 0.88 m in Northing with standard deviations of 0.43 m and 0.54 m, respectively. This is the first time we have been able to ground-truth the AUV's navigation with this fidelity and we are encouraged by the results.

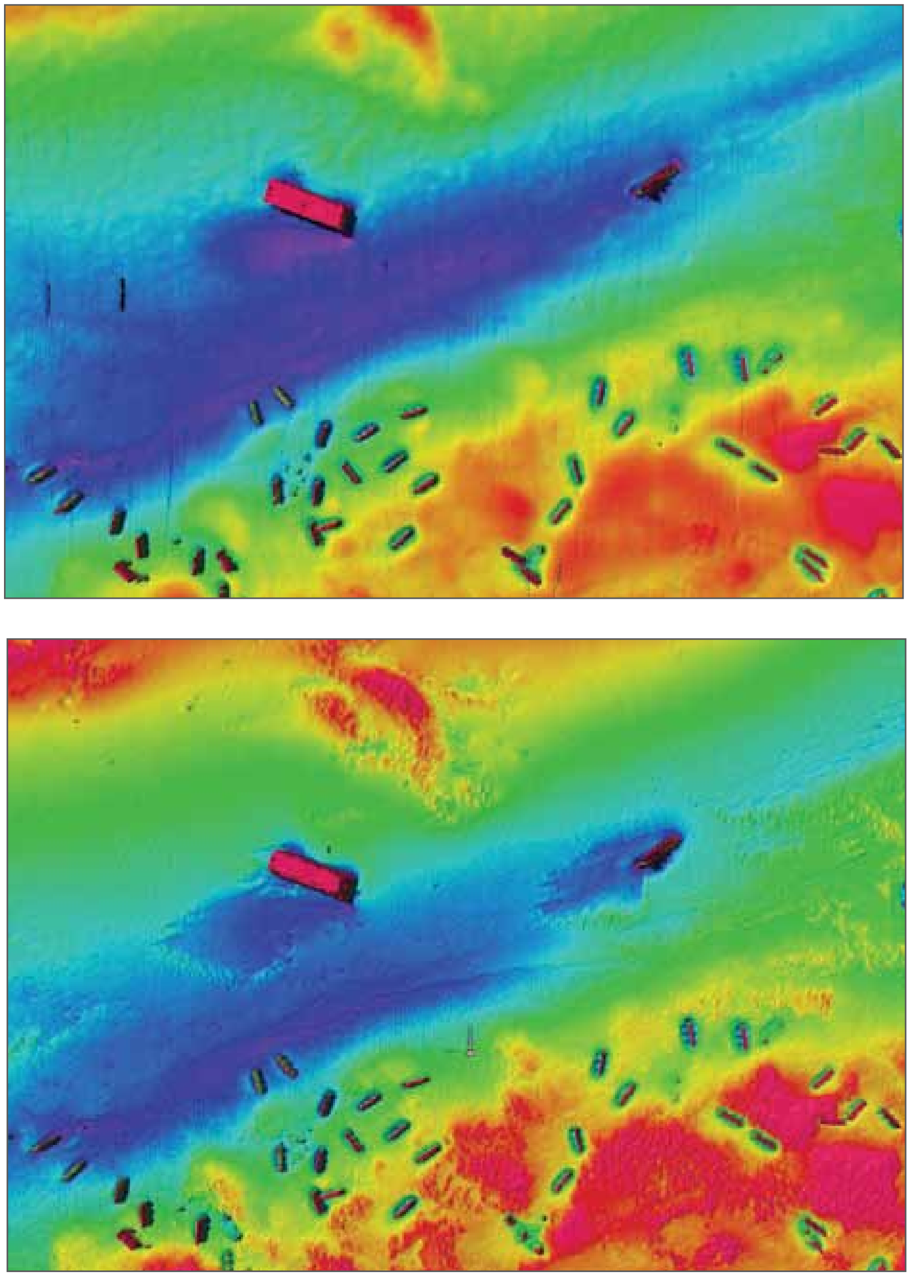


Figure 3-18. Seafloor surveys of "Redbird Reef" from before Hurricane Sandy (above) and after (below) with the R/V SHARP's Reson 7125. The horizontal extent of the seafloor shown is approximately 425 m with depths ranging from 27.8 to 30.1 m with the exception of the sunken barge and tug. Some subway cars may have moved as much as 10 m during the storm while others appear to have collapsed.

In 2012, the Gavia was also deployed for surveys of Conch Reef, Key Largo FL., and as part of an ONR-funded study of bedform movement and seafloor characterization off Delaware Bay at a site known as "Redbird Reef" where numerous subway cars from the New York City Redbird Line were used to create an artificial reef fish habitat. The first survey for this effort was conducted in late October, 2012, but was cut short due to the Superstorm Sandy's approach to the eastern seaboard. Before the storm hit collocated surveys were accomplished with both the Gavia AUV with its Geoacoustics Geoswath phase-differencing sidescan and the R/V *Sharp* using a Reson 7125 multibeam). Reorganization of the R/V *Sharp's* schedule after the storm afforded a second cruise in early November to resurvey the now storm-pummeled area. Although final processing of these data sets is ongoing, they are proving to be of terrific value for the investigation of many questions of direct interest to NOAA. These surveys also provide an opportunity to do a head-to-head comparison of the capability of a phase-measuring bathymetric sonar deployed on an AUV to a traditional hull-mounted high-resolution multibeam sonar over what can be deemed a set of potential navigational hazards.

The subway cars appear as small tic-tac like objects in the southern portions of Figure 3-17 along with a larger sunken barge and tugboat more central to the image. Preliminary investigation shows that the many of the subway cars may have been moved as much as

10 m by strong seafloor currents (estimated at more than 1.2 m/s during the height of the storm using a locally deployed ADCP mooring). In addition, in many places where smooth seafloor once existed, 0.2 cm amplitude, 1.5 m wavelength bed-forms were created, as well as scour and debris fields around the seafloor objects. Seafloor backscatter, bottom samples and ADCP mooring data are still to be analyzed.

The combination of surface ship and AUV navigated surveys also affords us an opportunity to compare survey quality and to consider alternative methods for the processing of AUV collected data. For example, the many subway cars provide a means to assess the navigation quality of the system. We found that after a bulk shift of the AUV navigated survey to account for GPS errors prior to submergence offsets between features identified in both surveys were found to be smaller than 2 m. Efforts are ongoing to improve the navigation further using these offsets. These studies provide a clear path forward for methods that would enable routine AUV navigated surveys that would meet IHO special order survey requirements.

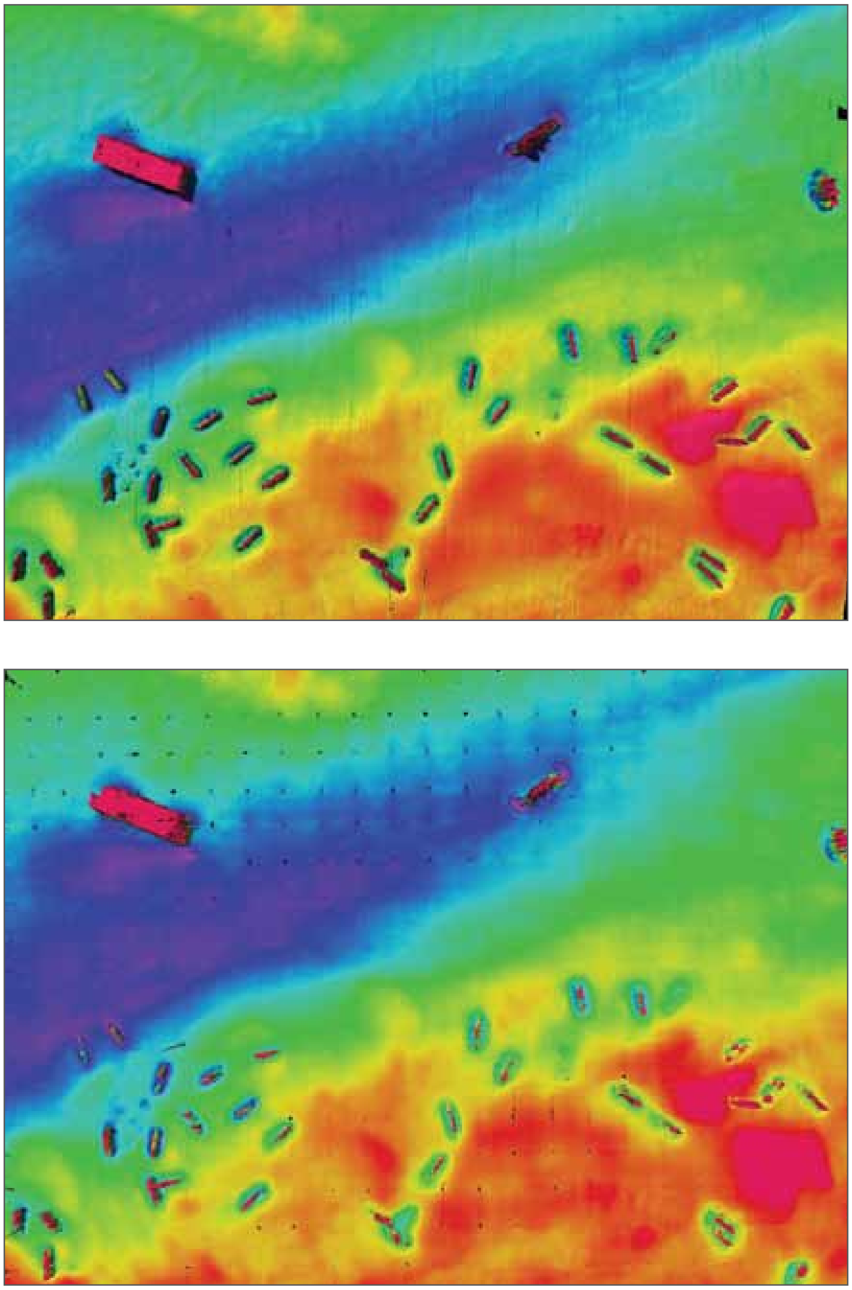


Figure 3-19. Seafloor surveys of "Redbird Reef" from before Hurricane Sandy using the R/V *Sharp*'s Reson 7125 (above) and the Gavia AUV's Geoacoustics Geoswath (below). These surveys have provided a unique view into the quality of survey that is possible with submerged vehicles when compared directly with surface collected data.

In addition to assessing the navigation quality of the AUV, these surveys provide for the ability to directly compare the quality of the data collected by the Geoacoustics Geoswath and the Reson 7125 and to tune automated processing methods for phase-differencing sidescan systems whose copious outliers and dense data provide many challenges. Figure 3-19 shows the two surveys conducted before the storm from the two systems. A detailed comparison of these figures is premature, because the grids have been created with different software packages and no tuning of the automated phase-differencing sidescan methods has been conducted. Nonetheless, we find the general consistency between the surveys encouraging. Results from the Conch Reef survey will be discussed under the DATA PROCESSING theme when we provide an update on Schmidt's Most Probable Angle algorithm for processing phase measuring bathymetric sonar data.

Finally in 2012, Schmidt hosted a very successful "AUV Hydrographic Bootcamp," bringing more than 25 people from NOAA, the Naval Oceanographic Office, the University of Delaware, the Monterey Bay Aquarium Research Institute, Lamont Doherty Earth Observatory of Columbia University, Teledyne-Gavia, Kearfott, CARIS, QPS/FM, Ocean Imaging Consultants, NCS Survey, UTEC Survey and the hydrographic offices of Japan and Nigeria for a six-day, hands-on workshop focused on the collection of hydrographic data from AUVs. Details of the AUV Bootcamp are discussed under the Education section of this report.

Theme 2 :: Processing

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

Developing better and more efficient means to process hydrographic data has been a long-term goal of Center activities. As the suite of sensors that we are involved in and the definition of ocean mapping expands, so does the range of processing challenges facing us. In this section we begin with our "bread and butter"—a discussion of bathymetric processing tools that we have and are developing for both traditional multibeam echo sounders and phase measuring bathymetric sonars. We then explore processing approaches for minimizing uncertainty associated with the temporal and spatial variability of sound speed in the water column (typically the major source of uncertainty in a modern hydrographic survey) and then look at processing tools being developed to extract bathymetric, shoreline and other data from satellite and other imagery. In parallel with our work on bathymetric data processing we are also investigating approaches to understanding the uncertainty associated with the backscatter provided by swath mapping systems and applying this understanding to efforts to characterize the seafloor. Finally, we recognize our critical responsibility to manage and deliver the data that we collect in an appropriate fashion and thus discuss our efforts to develop state-of-the-art data management and delivery systems.

Improved Bathymetric Processing

CUBE and Improved Uncertainty Management

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

CUBE was subjected to detailed verification studies in 2003 as part of a cooperative research effort with NOAA that compared the automated output of CUBE to equivalent products (smooth sheets) produced through the standard NOAA processing pipeline. Verification studies were done in three very different environments (Snow Passage, Alaska; Woods Hole, Massachusetts; and Valdez, Alaska) involving surveys in various states of completion and comparisons done by NOAA cartographers. In each case, the CUBE-processed data agreed with the NOAA processed data within IHO limits. CUBE processing took from 30 to 50 times less time than the standard NOAA procedures in use at the time.

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

NGA, CUBE and its sister development, The Navigation Surface:

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

In light of NOAA's acceptance of CUBE, most providers of hydrographic software have now implemented CUBE into their software packages (CARIS, IVS3D, SAIC, Kongsberg Maritime, Triton-Imaging, Reson, Fugro, GeoAcoustics, HyPack, QPS, and IFREMER). Dr. Calder continues to work with these vendors to ensure a proper implementation of the algorithms as well as working on new implementations and improvements. The progress made in 2012 is described below.

Multiresolution Grids—CHRT

Calder's efforts with respect to CUBE in 2012 have focused on the CHRT (CUBE with Hierarchical Resolution Techniques) algorithm. CHRT is a software architecture for robust bathymetric data processing that takes the core estimator from the CUBE algorithm and embeds it in a system that allows for variable resolution of data representation that is data adaptive, meaning that the density of data collected is reflected in the resolution of estimates of depth generated. The architecture is also designed to be efficient, parallelizable, and distributable over a network. As part of the ongoing effort, Calder has extended the algorithm by improving the accuracy of the resolution prediction, improved the stability and accuracy of the algorithm as part of the testing program, has implemented a parallelized version of the core algorithm, and is implementing a distributed (multi-computer) version for blade-server deployment.

The first phase of CHRT was to estimate the density of data available, and thereby compute resolutions at which to estimate depth; the core estimation is for area occupied by the observed soundings. Previous methods had approximated this computation in a number of ways that minimized the data accesses required (judging that data access was the most expensive cost), but the approximation required limited the accuracy of the estimate, particularly in areas where limited data was available. Although the accuracy could be improved to acceptable levels, this required much auxiliary processing, and analysis of repetitive data-use patterns revealed that caching strategies at the OS level, particularly on large-memory machines such as those used for hydrographic data processing, meant that re-reading data was not now as expensive as was previously the case. The first phase of the algorithm was therefore re-implemented to directly estimate the area covered by the sonar swath at each stage, maintaining sub-cell accuracy through the use of super-sampling anti-aliasing techniques and leveraging the hardware parallelism of the system's graphics card to accelerate the data rendering required. This results in estimates of density that are more stable in one pass than any previous results after multiple phases of estimation, and allows for software-level parallelism that overlaps the data preparation phase of the next line with the graphics hardware rendering of the previous line. In addition to improving the estimates, the performance was improved to approximately 2.5 million soundings

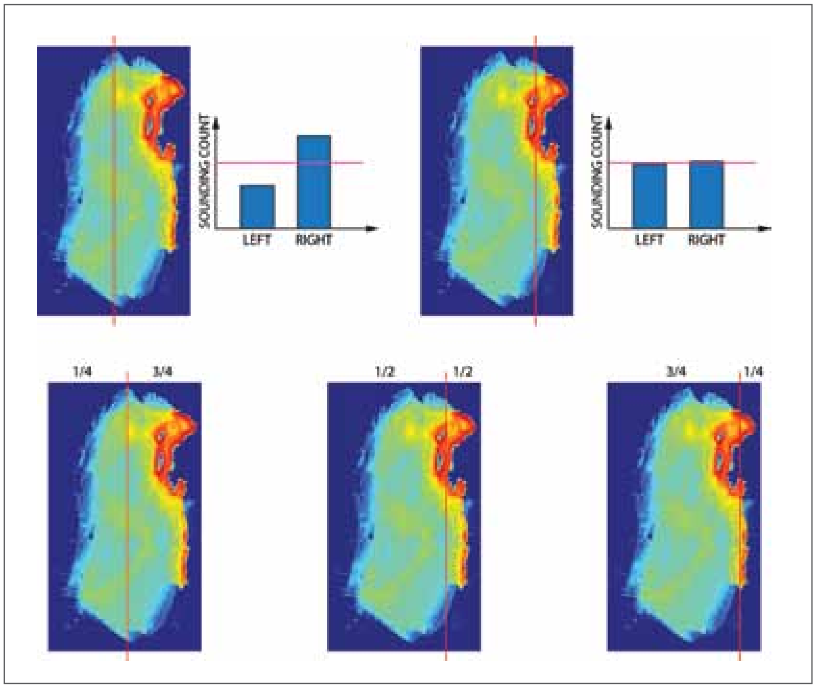


Figure 4-1. Partitioning of the computational problem in parallel versions of CHRT. The images (in the top row) show color-coded sounding counts for a test problem, and the goal of the partitioning algorithm is to estimate the split point (in this case in the north-south direction) that most equitably splits the soundings between left and right segments. The process is then repeated in the horizontal until the appropriate number of segments have been created. Multiple possible partitions are possible (bottom row) depending on the number of segments required, and the algorithm has to test all possibilities to find the optimal partition for highest efficiency. A number of techniques are used to minimize the number of computations required to achieve this goal.

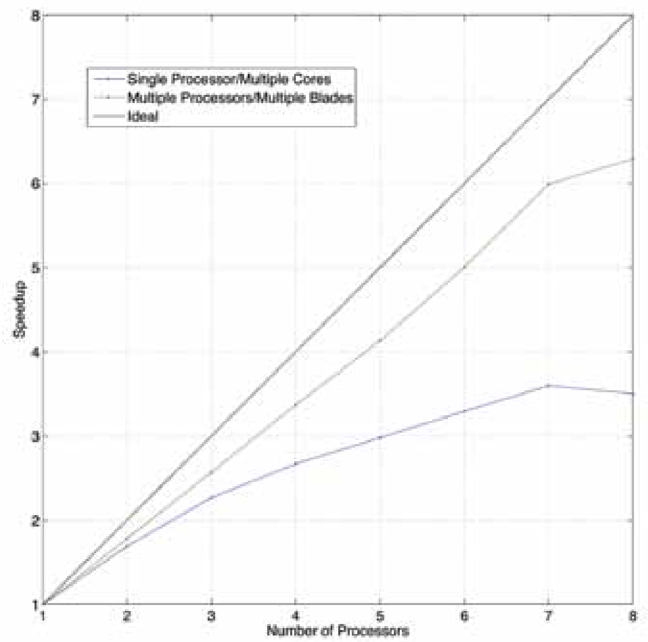


Figure 4-2. Observed and theoretical speed-up for second phase of CHRT. The black line indicates ideal speed-up as a function of committed resources, the blue line indicates the observed performance on a single processor with multiple execution units, and the green line indicates predicted performance on multiple processors. Predicted performance is based on the nominal observed performance with a single thread being replicated on multiple processors where there would be no resource contention.

per second in single-threaded mode, and approximately 4.3 million soundings per second in parallel mode while at the same time reducing the memory management requirements. Limitations on graphics hardware rendering contexts mean that it would be difficult to parallelize further on a single machine, but opportunities exist to distribute the computation across an array and further improve the performance. This extension is currently under development.

Most modern CPUs are now equiped with multi-core processors, each of which have multiple execution pipelines or hyper-threading units. An overall goal of the CHRT project is to design the algorithm to take advantage of such structures. Therefore Calder re-implemented the second phase of the computation (where most of the computational cost resides) to operate in parallel. The goals were to examine the implications for the algorithm of running in parallel on a single machine, and to act as a test-bed for a future distributed (i.e., multiple machine) version. The key issue in parallel implementation is how to partition the whole problem so that it can be tackled by multiple computational units simultaneously, with the constraints that this partitioning has to be data adaptive, and that it must minimize the communications required between computational units so that they do not waste time waiting for each other.

In the context of CHRT, the simplest method to achieve this is to (spatially) split the survey area being processed into segments that contain approximately the same amount of work, which is currently approximated as meaning the same number of soundings. The algorithm has been extended to analyze the density of data after the first pass, and compute the optimal partition of the area (in the sense of mean absolute deviation from the nominal count of soundings per processing element), subject to the constraint that the partition be conducted along north-south and east-west lines so that the divisions correspond to cell edges in the underlying data structure (Figure 4-1). This constraint ensures that the segments of the problem can be computed in isolation at the marginal cost of a number of extra soundings being processed around the edge of each segment in order to ensure that no edge effects occur.

Theoretical performance of this partitioning scheme can be shown to be in the 90-95% range, and the computation is carefully constructed to minimize the number of repeated possible partitions so that the computation for even large numbers of potential solutions can be accomplished in at most a few seconds for the test dataset. Practical performance is limited by resource contention within a single processor, so that mean performance per thread drops from approximately 0.37 million soundings per second with a single thread to approximately 0.21 million soundings per second with eight threads (corresponding to one for each hyper-threading unit on the quad-core test CPU), although the net performance on all threads does still increase, albeit sub-linearly (Figure 4-2).

Tests indicate that the drop-off in performance is due to contention for unique resources within the single test CPU, and hence this might be less important with a distributed version of the algorithm running on multiple CPUs. Even so, however, what might be a more significant limitation is in how finely the problem can be partitioned and still be efficient. Changing from a seven-segment partition to a twenty-segment partition indicates that committing more and more resources to a single problem might become ineffective: as the partitions become smaller, the extra processing required to avoid edge effects increases in scope, and becomes a larger proportion of the computational effort within each segment. It is not currently clear therefore, to how many processors a given problem can be scaled, or if the scaling will be consistent. If current rates are maintained, however, we might expect a small, distributed cluster of ten blade servers might achieve peak throughput (perhaps on multiple problems) of around 35 million soundings per second or, alternatively, *~30 s to process a billion soundings.*

Calder has begun to investigate this opportunity by constructing a distributed version of the algorithm, which implements the first pass, refinement and second pass over a variable number of processing nodes and actively manages a multi-node distributed cache of source data files, with pre-emptive pre-fetch and persistent caching of location information. This configuration means that each node expects to contain all of the data files that it needs for the portion of the overall computation assigned to it, and can fetch those files from a neighboring node if they are not present when required. Careful management of the files that are expected to be used allows the nodes to pre-emptively fetch them (based on information held in a persistent database at the lead node) in order to minimize the number of cache misses that occur, and careful placement of the files during the first pass attempts to minimize the number of inter-node transfers that occur at the start of the second stage (when distribution of data is known and the partition of the data is conducted). This development is intended to be a test-bed to investigate the behavior of the algorithm in a distributed environment, and to assess the potential for expansion of the algorithm to larger distributed systems.

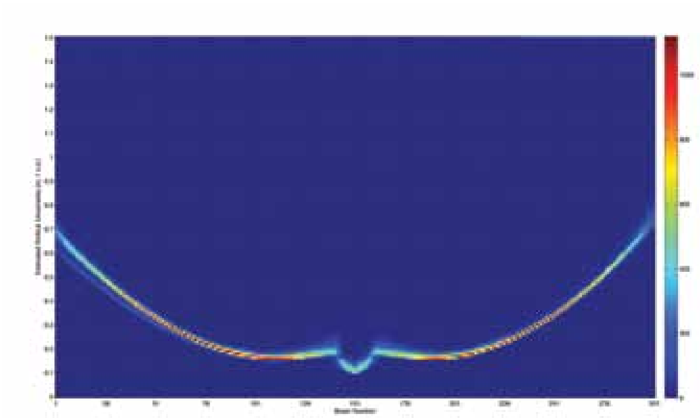


Figure 4-3. Probability of occurrence of vertical uncertainties computed through IFREMER-provided Quality Factors. Vertical axis indicates estimated vertical uncertainty (at one standard deviation), and the horizontal the beam-number of the echosounder. Color-coding represents count of occurrence of each bivariate pair. Uncertainties are computed using the HGM survey system uncertainty model, with the acoustic measurement uncertainty component replaced with the IFREMER quality factor computations. These data are for a Reson 7111 in approximately 100m of water.

Corresponding code to read back and then assemble the data into a composite product (in parallel) has also been designed and demonstrated. Balancing of the load is accomplished automatically by the second pass partitioning, so the algorithm is relatively efficient without further modification. Partitioning on the cell-boundaries in the low-resolution underlying CHRT grid means that the partitions are also disjoint over the output array, and therefore the processing can proceed without interlocks, leading to further efficiency gains.

In addition to technical advances in the algorithm, Calder has led development of an alternative transition strategy for the CHRT algorithm. In the co-development model, instead of licensing the source code for the algorithm to each implementer individually, all of the implementers agree to assist in the development of a test suite that defines what it means for an implementation to be called 'CHRT,' and that an implementation cannot be called 'CHRT' unless it passes the test suite; implementers will all share the same basic code base, and are expected to contribute to the development of the code. In addition to giving stronger guarantees of correctness of implementations, this will achieve a stronger research code base on which to innovate, and provide a mechanism for greater diversity of contribution (e.g., from non-profit organizations who could not otherwise contribute). The current CUBE licensees have accepted a Memorandum of Understanding on the proposed scheme, and the agreement from the University was distributed on 2012-11-09. The potential partners are now in the process of reviewing and signing licenses. As part of this process, the CHRT source code has been re-packaged in a Mercurial distributed source-code control repository, re-configured with a portable build system to assist in transitioning the source code to different build environments, and re-hosted on bitbucket.org in order to facilitate the collaboration. The source code has also been ported to the Windows platform in both 32-bit and 64-bit forms (with the assistance of Masetti), and has been supplied both in source and executable form to NOAA/HSTP in order to assist in their testing program for the software.

Quality Factors for Uncertainty Estimation

One of the significant improvements in hydrographic data processing in the last decade has been the widespread adoption of uncertainty quantification for data collected and its use in quality control, product creation and quality reporting. However, most methods for assessing the uncertainty of multibeam echosounder soundings rely on models for the measurement uncertainty of the acoustic portion of the survey system that were developed in the early 1990s for then-current systems. Much has changed since then, and in particular there are now newer semi-empirical models, developed primarily at IFREMER, that use the observed behavior of the acoustic signal to assess the uncertainty of the range estimation within an echosounder. Lurton refers to these as 'Quality Factors,' which are a dimensionless number that estimates the relative uncertainty of a depth estimate in a manner that allows comparison between different echosounders, and different methods of estimating range within the same echosounder system. These measures only assess the uncertainty of the acoustic portion of the survey system, however, and Calder therefore started working on a mechanism to integrate them with the best-available (Hare-Godin-Mayer—HGM) model for survey system uncertainty in collaboration with Lurton and Ladroit during Lurton's period as a visiting scholar at the Center.

Based on interpretation of the current HGM uncertainty model, Lurton and Calder have adapted the HGM model to accept the IFREMER quality factors, and constructed a proof-of-concept algorithm to re-compute the uncertainty associated with a dataset and thereby allow the integration to be tested. Test runs of this algorithm with IFREMER-supplied bathymetric datasets have been conducted and appear to provide reasonable uncertainty estimates, (Figure 4-3); further analysis of the data is now being conducted by IFREMER.

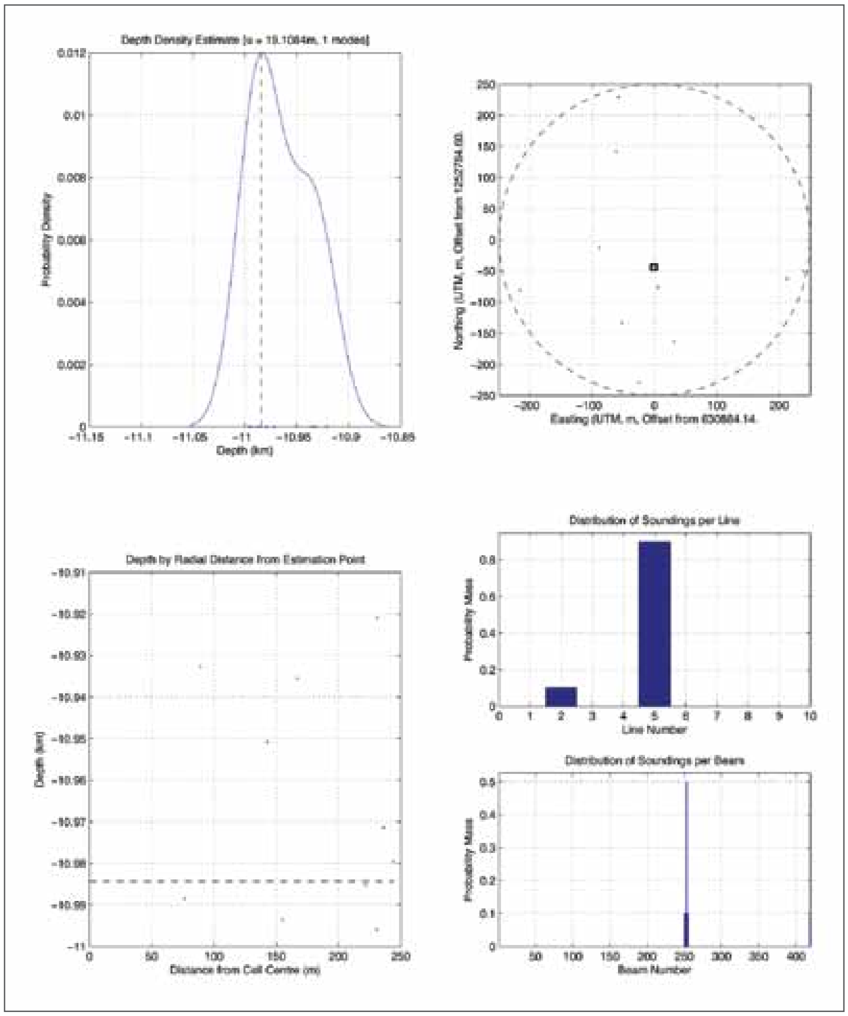


Figure 4-4. Analysis of the data at the deepest point in the World Ocean, Challenger Deep. The analysis shows (CW from top left) the depth distribution of the soundings, along with the modal location, the spatial distribution of soundings along with centroid location (black square), the distribution of sounding sources by survey line, the distribution of soundings by multibeam echosounder beam, and the depths of the soundings as a function of radial distance from the analysis point.

Determining the Deepest Depth in the World Ocean and Associated Uncertainty

Subsequent to the Extended Continental Shelf Project mapping of the Marianas in 2010, Calder, Gardner and Beaudoin have been investigating the location and most reliable depth of the deepest part of the Marianas Trench, the Challenger Deep. A number of different locations and depths have been reported in the literature from prior surveys and physical inspections, but there is wide inconsistency in both location and depth reported, along with implausible claims of accuracy in depth that make it appropriate the determine a more substantiated estimate. While a subject of great public interest (and much press coverage—see the OUTREACH section), developing a robust approach to finding the deepest (or shoalest) depth with a multibeam survey and establishing the uncertainty associated with this depth, has much broader implications with respect to hydrographic data processing.

The recent multibeam surveys of the Mariana Trench conducted by the Center in support of our ECS activities had very well controlled positioning and a best-of-breed high-resolution deep water multibeam echosounder, providing much higher accuracy, and much denser, depth observations than in any prior survey. Recognizing, however, that data processing methods can significantly affect both depth and uncertainty estimates, a full uncertainty analysis was conducted using the observations themselves, rather than simply constructing a grid of depth estimates. This allowed for the estimation of biases in the data as well as random uncertainties and provides more nuanced descriptions of uncertainties than are generally available from most analysis methods.

The analysis was conducted in two stages: first, an approximate location of the deepest area was constructed at low resolution, then an accurate analysis was conducted at high-resolution to identify the lowest supportable depth in the data, and to identify its uncertainty and location. The high-resolution analysis used the Lomb-Scargle periodogram to determine the spatial frequencies present in the data, and concluded that the seafloor was flat in the vicinity of the lowest depth on the order of 500m wavelength. (The Lomb-Scargle periodogram does not require regularly sampled data, and therefore avoids any gridding effects on the estimate.) Then, at a series of test points around the approximate location, an estimate of the distribution of depths was constructed, and the mode (or modes) of the distribution were determined. The data were then partitioned among the modes found, and those associated with the primary (highest probability) mode were used to determine the uncertainty of the depth. Since the data associated with each mode were possibly from multiple passes of the multibeam, they could be affected by different biases due to refraction effects. A theoretical biphase model of bias was constructed that allows for estimation of the relative bias between two passes, and this estimate along with an estimate of survey system effects from the Hare-Godin-Mayer model (without acoustic or refraction uncertainty) and an estimate of refraction using Beaudoin's model were combined to provide an estimate of the overall uncertainty of the depth predicted, including the small-sample effects on the distribution of the sample mode. The location of the depth was computed as the centroid of the data used. This analysis, Figure 4-4, shows that the deepest location was at 142°11′57.50″E, 11°19′47.65″N at a depth of 10984±25m (95%) on 9 d.f., in the neck of the western-most depression of the Challenger Deep.

This analysis was intende as an ad hoc method for this dataset. However, the techniques used have wider applicability, and a number of interesting theoretical advantages. For example, they are inherently variable resolution, very robust, adapt to the data distributional properties, and are both reversible and commutative. These are extremely desirable properties in a general bathymetric estimator, and this suggests that these techniques may form the basis of alternatives to CUBE/CHRT in the future.

Improved Processing for Phase-Measuring Bathymetric Sonars

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

Val Schmidt has taken the lead in exploring problems with (and new approaches to) processing PMBS bathymetric data. Working with data collected by the 500 kHz GeoSwath system aboard the Gavia AUV (see AUV section), he has collaborated with Weber and others to understand the uncertainty associated with PMBS data and develop robust processing tools. GeoSwath data is particularly difficult to process, because no filtering is done during data acquisition that might mitigate the volume and complexity of data. The system produces almost 4000 raw measurements per port/starboard ping pair. Data from phase differencing systems tends to be noisy when compared with multibeam systems, which average many measurements with each bottom detection, and outlier prone, because the long shadows desirable for sidescan data produce many bathymetric outliers. The volume and quality of the data make the processing task long, error prone and almost impossible to repeat where standard methods are used. Therefore we have endeavored to create a semi-automated, physics based processing package capable of filtering the data for outliers, estimating the uncertainty of the remaining measurements and combining the measurements in an optimal way to produce seafloor sounding estimates similar to that of multibeam systems.

Schmidt's algorithm, written in MATLAB begins with the Most Probable Angle Algorithm including a despiking routine for filtering. Uncertainty is estimated for each sounding using a method similar to the Quality Factor method proposed by Xavier Lurton (visiting scholar from IFREMER Brest, France) for multibeam systems (see discussion above). Finally, given a user specified maximum depth uncertainty, individual

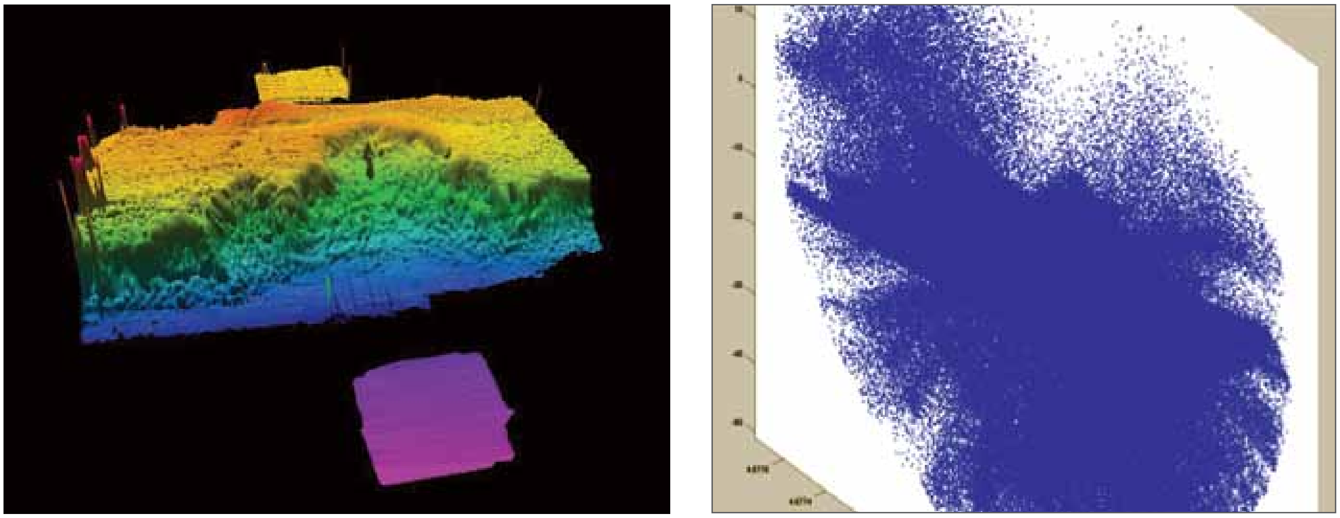


Figure 4.5. A small survey of Conche Reef near Key Largo, FL was processed with the MPAA algorithm and associated bathymetric estimation package. The resulting GSF files were loaded directly into Fledermaus for gridding with no manual editing to produce this image. By comparison, just 100 pings of unfiltered data is shown in the inset below.

measurements are combined in a weighted mean until their combined uncertainty falls below the desired depth uncertainty. Sounding estimates are then written to GSF files for further processing in CARIS or other similar software packages.

Because data are processed to meet a depth uncertainty requirement, this new model inverts the goals of traditional survey methods. Rather than producing a survey and subsequently inspecting the survey to see what portion meets the desired IHO requirement, one may specify the IHO requirement and process the data to meet it. Such a method may be extensible to standard multibeam systems and is a subject of ongoing research.

These methods were applied to a Gavia survey conducted on Conch Reef off Key Largo FL (Figure 4.5) and in the processing of data collected at the Redbird Reef site, discussed under the AUV section of the SENSORS theme.

Additional work has begun (again in collaboration with Lurton) focusing on the modeling of phase-differencing sidescan sonar systems—specifically those that utilize variants of the Computed Angle-of-Arrival Transient Imaging (CAATI) algorithm. Commercial systems using this method or a variation thereof include the Benthos C3D, the SEA SwathPlus and the Edgetech4600. The hope is to understand the advantages of the CAATI method and to properly represent the processing methodology in a model that can be used to predict the uncertainty in the results as well as allowing for improvements on the method.

Sound-Speed Profile Uncertainty Estimation and Management

It is becoming increasing apparent that our ability to measure and compensate for the spatial and temporal variability of the sound-speed profile is a fundamental limitation in our ability to collect consistently high-quality seafloor bathymetry data and the largest single source of uncertainty within our measurements. With the arrival of Jonathan Beaudoin to the Center, our efforts focused on developing methods to assess the uncertainty in sounding due to the variability in the sound-speed profile (SSP).

SVP Editor/Server/Refraction Monitor

As part of these efforts, and in conjunction with an NSF-sponsored project to support the UNOLS multibeam fleet (see discussion of MAC under the SENSORS Theme), Beaudoin has developed an "SVP Editor" (Figure 4-6). The SVP Editor is 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 software, which supports import and export of several sensor and software formats, allows for interactive graphical data editing for removal of outliers and/or addition of points for vertical extrapolation (Figure 4-6). Oceanographic data sets, such as the World Ocean Atlas (WOA), are used when appropriate for tasks such as: salinity augmentation for Sippican XBT probes, temperature and salinity augmentation for Sippican XSV probes and SVP sensors, vertical extrapolation of measured profiles, and creation of synthetic sound speed profiles where required. Although there are piecemeal commercial solutions to some of these processing problems, it is the intent of this software to allow the community to improve and augment the "SVP Editor" through release of the underlying source code. By exposing the details of algorithms and by providing a modular, object-oriented software architecture, it is envisioned that this will foster and encourage the development of best practices for this particular aspect of multibeam echosounding.

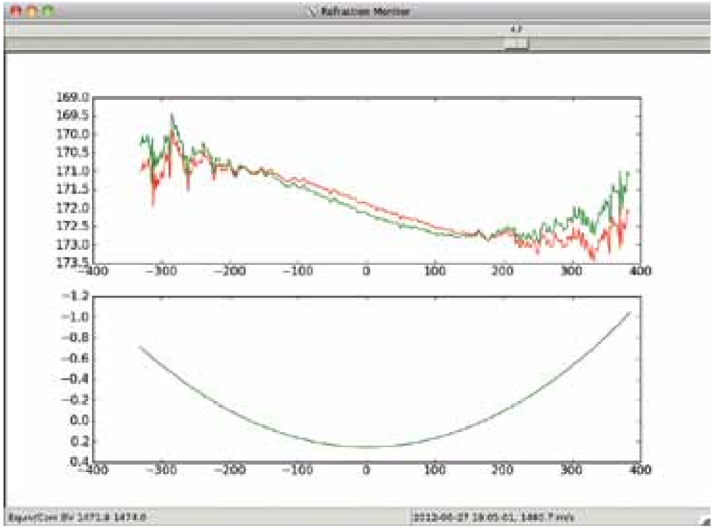


Figure 4-7. Upper plot is a swath editor view (depth and across track) of the current ping in red with potential change associated with new sound speed profile plotted in green. The difference in correctors is plotted in the lower plot. The operator can adjust the refraction corrector with the slider bar at top, this adds a bias corrector to the new sound speed profile (decim/s).

Because the software was designed primarily to support the US academic fleet, it provides key functionality to streamline the delivery of processed sound speed profile data to Kongsberg Maritime multibeam echosounders (most of the vessels in the US academic fleet are outfitted with Kongsberg multibeam echosounders). Kongsberg Maritime's acquisition system (Seafloor Information System, or SIS) offers numerous network datagram input/output transmission protocols; these have been leveraged to allow the SVP Editor to integrate with SIS in such a way that data from the SVP Editor can be transmitted automatically to SIS with little user intervention. From the standpoint of SIS, the incoming data stream of sound speed profiles is treated like any other sensor and is applied immediately to the echosounding data without further user interaction. Other SIS-related functionality includes the augmentation of sound speed profiles with the measured surface sound speed as transmitted by SIS.

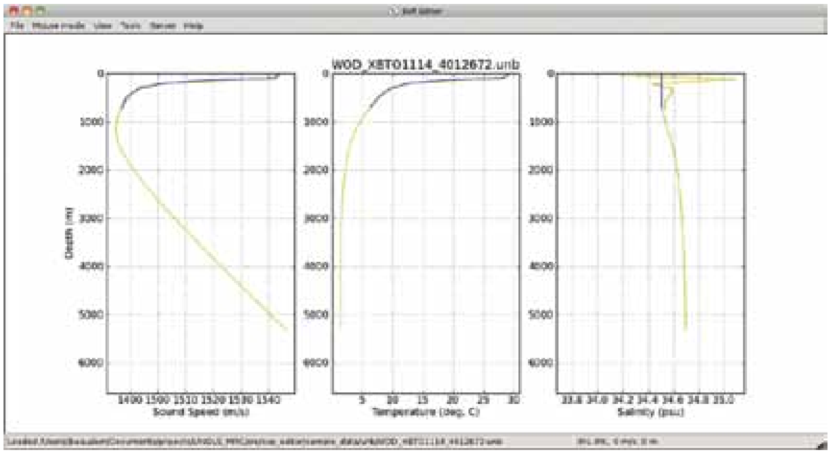


Figure 4-6. SVP Editor main graphical user interface showing plots of sound speed, temperature and salinity versus depth (left to right, respectively) for a CTD (yellow) and XBT (blue). In this particular scenario, the CTD is a reference cast that can be used to (a) augment the XBT measurement with salinity and (b) vertically extend the XBT to greater depth.

The SVP Editor also offers the user the option to run the software in "Server" mode whereby a synthetic sound speed profile is delivered to the echosounder based on oceanographic models such as the World Ocean Atlas (WOA) or the Real-Time Ocean Forecast System (RTOFS). The SVP Editor uses SIS position datagram network broadcasts to establish the date and position of the vessel, which are then used to form a query for the oceanographic model of choice to establish estimates of the temperature and salinity profiles for the desired location. A sound speed profile is constructed from these and then delivered to the multibeam echosounder. This is done continuously while in transit, enabling opportunistic underway mapping such that echosounding data collected in transit 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 of applying the new sound speed profile to data in real-time prior to delivery to the sounder. This particular tool, called the Refraction Monitor, runs in real-time and is fed with the echosounder bottom detection output for each ping. These soundings are displayed in a traditional swath editor view and are dynamically adjusted to demonstrate the difference between the refraction correctors associated with both the existing sound speed profile and the sound speed profile that is about to be sent to the sounder. This allows for an important verification step in which the operator can correct or adjust the profile to minimize refraction residuals in real-time as shown in Figure 4-7.

The software, including the source code, is publicly available online (**http://mac.unols.org**). Early testing of the server functionality was done in 2011 by Steve Roberts of USCGC *Healy* and Steve Brucker of CCGS *Amundsen*. Since then, the SVP Editor has been installed on R/V *Kilo Moana*, R/V *Marcus G. Langseth*, R/V *Hugh R. Sharp*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor*, NOAA Ship *Ronald H. Brown* (Armstrong, Calder), NOAA Ship *Pisces* (Weber, Beaudoin, Rice, Wilson) and R/V *Atlantis* (Welton).

Hydrographer's Weather Map

Carrying the approach to using oceanographic models in aid of seafloor mapping one step farther, Beaudoin is working 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 multibeam systems. 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 may be able to provide some idea of where and when spatial variability in the water column can be problematic. Early work by Beaudoin focused on spatially and temporally coarse oceanographic models such as the World Ocean Atlas (WOA); the same methods have now been applied to time-varying, mesoscale resolution oceanographic models. Beaudoin has continued to develop the concept of the Hydrographer's "Weather Map" by applying his ray tracing spatial variability analysis to the Real Time Ocean Forecast System (RTOFS). The procedure is to express local oceanographic variations in terms of resulting sounding uncertainty through a ray tracing simulation using a set of sound speed profiles derived for a selected location and the immediate neighboring grid cells in an oceanographic model grid. The discrepancy amongst the final ray traced depths indicates the impact of the spatial variability at that location; this value is then computed throughout the spatial domain of the model and presented as a "weather map" which highlights areas of high spatial variability as uncertainty fronts where hydrographers must work harder to sample oceanographic variability. With models such as RTOFS, it is possible to compute forecasts with higher spatial resolution and with, hopefully, increased fidelity over products generated from analyses using models such as WOA that provide only historic monthly means and thus have no nowcasting or forecasting capability. Figure 4-8 provides an example of such a "Weather Map" product generated for a single day of the RTOFS model and Figure 4-9 shows a higher resolution map of the Gulf Stream region.

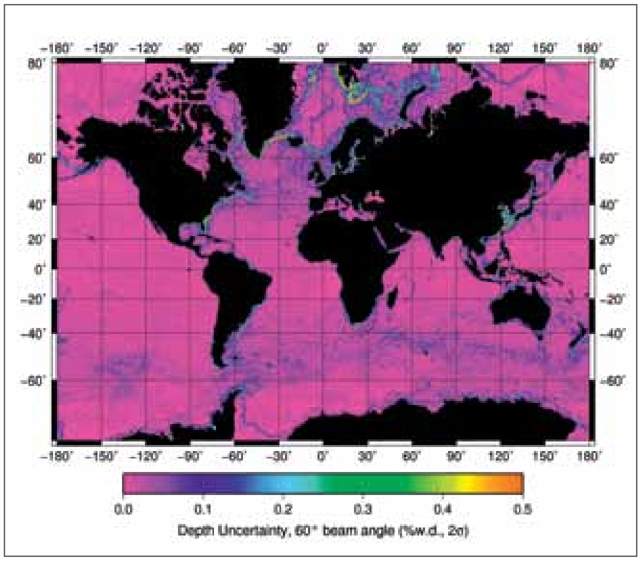


Figure 4-8. Global SVP "Weather Map" for February 17th, 2012, based on ray tracing analysis of NOAA's Real-Time Ocean Forecast System nowcast for the same date.

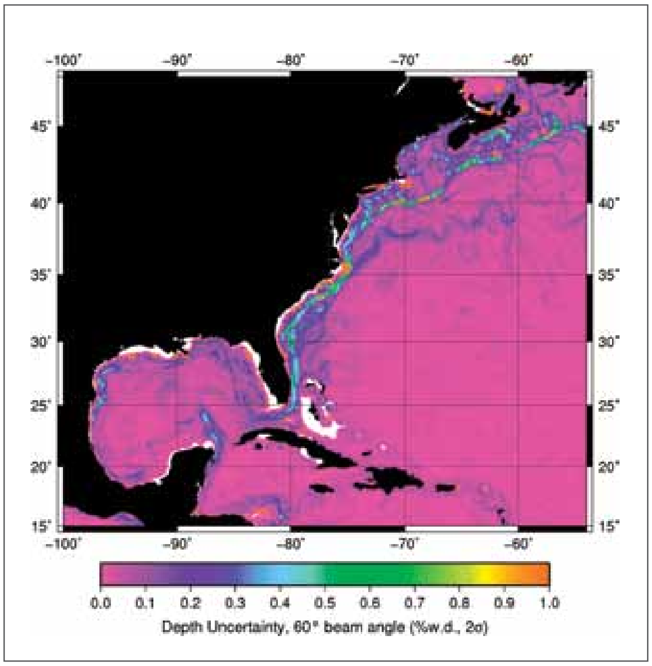


Figure 4-9. High-resolution SVP "Weather Map" of the Gulf Stream region, based on ray tracing analysis of NOAA's Real-Time Ocean Forecast System nowcast for February 17th, 2012.

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

Also within the “PROCESSING” theme are various efforts aimed at developing better ways to extract information about bathymetry, navigation and shorelines from photogrammetry or satellite imagery.

Shoreline Uncertainty Analysis

The National Shoreline depicted on NOAA nautical charts serves a multitude of purposes, from supporting safe marine navigation, to legal boundary determination, to use in a variety of coastal management and science applications. To support the accurate depiction of the national shoreline, NOAA’s National Geodetic Survey (NGS) needs to understand the uncertainty associated with their determination. Initial collaborative work between NGS and Center researchers focused on lidar-derived shorelines and resulted in new empirical and stochastic approaches to assessing their uncertainty.

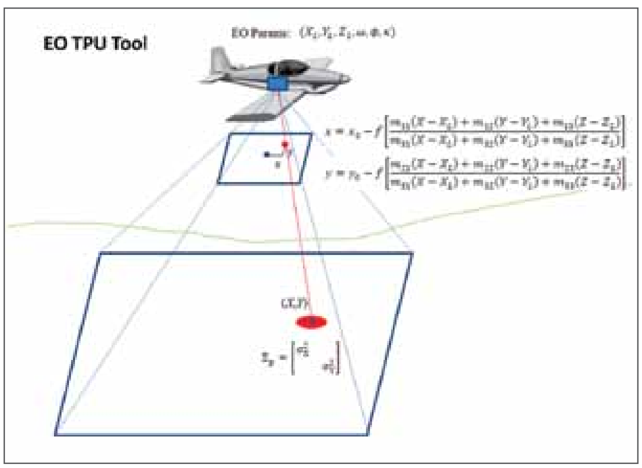


Figure 4-10. Theory underlying EO TPU Tool.

One of the most successful examples of research collaboration between the Center and NGS to date is the ongoing work on shoreline uncertainty modeling. The first phase of research collaboration between NOAA/NGS and the Center on shoreline Total Propagated Uncertainty (TPU), conducted in 2010-2011, focused on NGS’s lidar-based shoreline mapping workflow. Since then, Parrish and Center colleagues have extended this work to compute TPU of photogrammetrically-measured, fixed points, based on uncertainty in camera position and orientation parameters and image measurement. This work resulted in development of the “EO TPU Tool” (Figure 4-10) and a set of standard operating procedures (SOP) for production use of directly-georeferenced aerial imagery in NGS’s Coastal Mapping Program (CMP). In the October 2012 meeting of NGS’s Coastal Mapping Board (CMB), these procedures were approved for use in the CMP, enabling use of directly-georeferenced imagery, without aerotriangulation, in certain coastal projects. CMP coastal compilers have begun using the new SOPs and the EO TPU Tool, and report that time savings are already being achieved. Simultaneously, LTjg Russell Quintero, NOAA’s JALBTCX representative, is adapting the tool for possible use by the U.S. Naval Oceanographic Office.

Graduate student Fang Yao is currently working on the next phase of the shoreline TPU research. Yao’s work involves considering additional component uncertainties (e.g., water level uncertainty and human compilation uncertainty) and propagating them through NGS’s end-to-end shoreline mapping process to estimate final shoreline positional uncertainties. The model is being coded in MATLAB, and experiments for estimating the additional component uncertainties are now being developed.

Although the techniques being developed by Parrish and collaborators are useful where modern technologies are being applied to delineation, they may not be applicable in developing countries or in regions where modern techniques have not yet been applied. To address this question, graduate student Olumide Fadahunsi (also a Nigerian Naval Officer), under the guidance of Andy Armstrong, Shachak Pe’eri, Chris Parrish, and Lee Alexander, is developing ArcGIS tools to address the adequacy of coastline mapping and classification data that is based on satellite imagery. Coastline change rate estimates depend on the uncertainty of the current and historical coastlines used in the analysis, and on the surveying technologies and techniques that were originally used. Current techniques for coastline mapping include photogrammetric delineation using tide-coordinated aerial imagery. However, in many developing countries, the charted coastlines are poorly mapped due to limited resources. A procedure was developed to computerize coastline mapping and classification based on satellite imagery. A spectral analysis using different image bands was used to define the land/water boundary, and to characterize the immediate coastal area. The satellite-based coastline was compared to the charted coastline to assess the adequacy and consistency of the charted coastline. The satellite-based coastline was also compared to coastlines derived from historical maps in order to assess changes and rates of change. The procedure was developed in a GIS environment using a calibration

Figure 4-11. (Left) Admiralty Chart of Lagos Harbor. (Right) Classification of man-made features over Lagos Harbor, Nigeria based on satellite imagery (Landsat 7). Key features in the harbor are circled in both images.

site on the northern coast of Massachusetts, USA and applied to different types of coasts in Nigeria (Escravos, Pennington and Lagos) (Figure 4-11). The motivation is that this procedure should be suitable for mapping coastal areas in other developing regions.

Bathymetry from Imagery and Evaluating Chart Adequacy for Navigation

NOAA and others are constantly looking for more efficient ways to collect bathymetric data in very shallow water where multibeam sonars are least efficient. Along with the lidar techniques described above, Shachak Pe'eri, Chris Parrish and others at the Center are currently assisting NOAA in evaluating the ability to use bathymetry estimated from satellite imagery for survey reconnaissance, change detection, and project planning. An initial phase of this research began with the master's thesis research of Chukwuma Azuike. Azuike's work made use of an algorithm for depth retrieval from satellite imagery developed by Dr. Rick Stumpf of NOAA. Center researchers, led by Shachak Pe'eri, are currently extending these methods to WorldView-2 (WV-2) imagery for independent evaluation of results of a WV-2 bathymetric mapping project being conducted by the private sector under contract to NOAA.

As an important component of this research, Parrish developed a total propagated uncertainty (TPU) model for the satellite-derived bathymetry. Following an approach used by Brian Calder in a previous project, a Monte Carlo method was employed and implemented in MATLAB. Input to the TPU program includes the parameters of the probability distributions that model the uncertainties in image pixel values and reference soundings used in tuning the depth estimation algorithm. The output includes histograms and standard deviations of computed depths, corresponding to different realizations of the random errors in the Stumpf algorithm input variables (Figure 4-12). The results agree with those of empirical accuracy assessments where recent reference data exist. This approach provides an efficient and reliable method of assessing the uncertainty of satellite-derived bathymetry where reference data are unavailable.

Graduate student Chukwuma Azuike, working with Pe'eri, Parrish, and Armstrong, is using these algorithms to assess the adequacy of hydrographic surveying and nautical charting coverage for prioritization of nautical chart updates in developing countries. Indications of chart adequacy and completeness as depicted on current charts or sailing directions are spatially correlated with significant maritime sites/areas associated with social, environmental and economic factors. However, analysis based solely on these datasets is limited to data available at the time of last survey. The procedure was developed in a GIS environment using charts from Belize and Nigeria. Azuike then used publicly-available, multi-spectral satellite imagery and the algorithms described above to derive estimates of the relative bathymetry in shallow, clear waters. The potentials of this method were evaluated for supplementing the survey prioritization procedure in assessing the adequacy of hydrographic surveying and nautical charting coverage. Preliminary results show that this approach is also potentially beneficial as a reconnaissance tool prior to a acoustic hydrographic survey and for marine spatial planning.

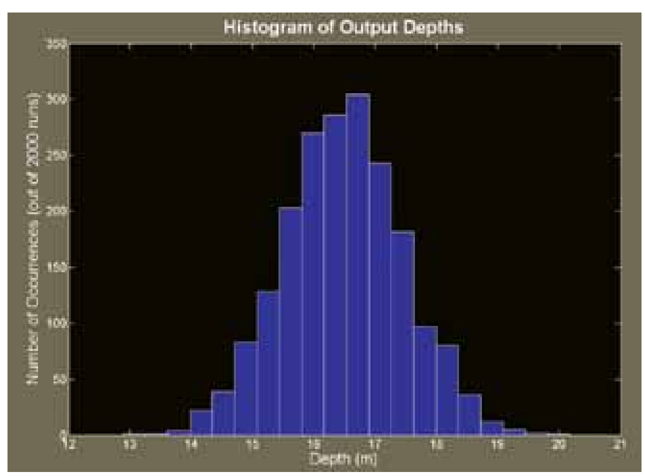


Figure 4-12. Output of satellite bathymetry TPU algorithm: histogram of output depths. In this case, the number of trials in the Monte Carlo algorithm was set to 2000, and the program executed in under 5 seconds on a standard Windows PC.

Improved Backscatter Processing

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

Uncertainty of Backscatter Measurements: NEWBEX

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

This effort has manifested itself in the "Newcastle Backscatter Experiment" (NEWBEX) a new (or renewed, from the laboratory perspective) effort aimed at testing our ability to collect "calibrated" backscatter using hydrographic multibeam echo sounders. The project is a collaboration of many Center and NOAA participants including Tom Weber, Jonathan Beaudoin, Glen Rice (NOAA), Briana Welton (NOAA), Val Schmidt, Brian Calder, Yuri Rzhanov, Larry Mayer, Larry Ward, and Carlo Lanzoni. It is important to note that the term "calibrated" takes on multiple meanings in the context of this work, ranging from the calibration of settings to ensure we are operating the system in a linear regime to a full absolute calibration where the output of the multibeam echo sounder can be used as estimates of the true seafloor scattering strength. This project brings together several different existing lab efforts: Malik's thesis work, Carlo Lanzoni's work toward an absolute backscatter calibration for MBES, Sam Greenaway and Glen Rice's efforts toward field procedures for proper backscatter data collection, backscatter mosaicing (Fonseca's GeoCoder), backscatter inversion (Fonseca's ARA algorithms), and backscatter ground truth (e.g., optical imagery, bottom sampling, high accuracy positioning).

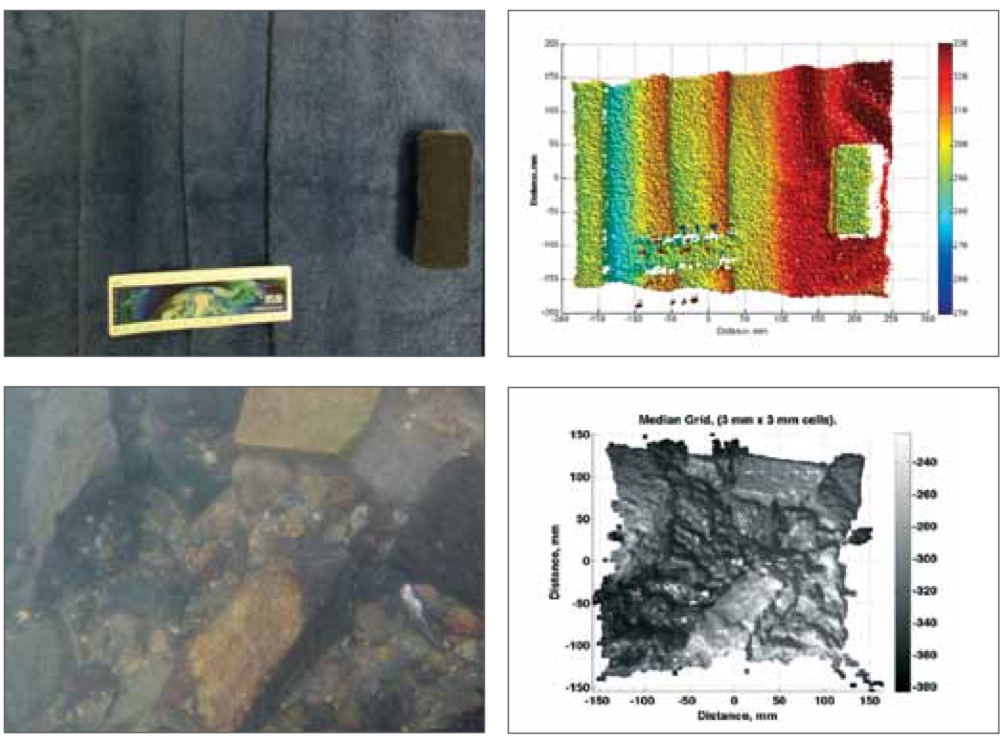


Figure 4-13. Upper images are a pair of stereo test images captured with a GoPRO stereo camera rig (above) and a grid of the resulting topography produced by point cloud processing methods. The method will be used for underwater imagery to measure micro-bathymetry. Bottom images are seafloor images using the same approach.

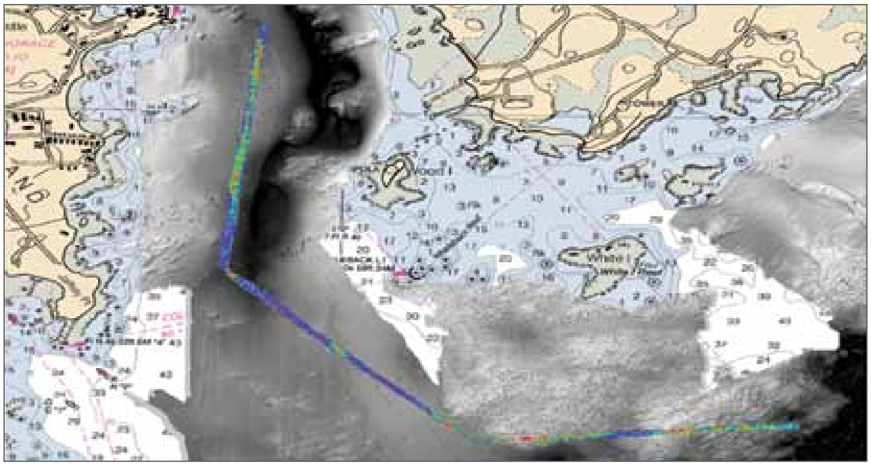


Figure 4-14. Backscatter repeatability measured with 10 passes of a standard line. The color represents the range within which 75% of the data fall over the 10 passes, with blue representing 2 dB or lower variation and red representing 5 dB variation or higher. High backscatter values seem to be associated with shallow bedrock outcroppings (cause unknown but possibly related to macroalgae), moving bedforms such as sand waves, and boundaries between different types of seabed substrate.

The NEWBEX project has made significant progress during 2012 as the overall effort continues to ramp up. A Reson 7125 on loan from the NOAA Ship *Fairweather* has been calibrated at the center, and then returned to the field in exchange for a second system that has generously been made available by NOAA for the NEWBEX project. The calibration work for the system now in the field included analysis of source level, pulse length, transmit/receive beam pattern, receiver gains, and receiver sensitivity. A technical document describing the calibration is in preparation; a conference paper describing the beam pattern measurement methodology and results was presented by Carlo Lanzoni at the 2012 European Conference on Underwater Acoustics in Edinburgh, Scotland in July.

These calibration results will ultimately be applied to data collected with the system at a Puget Sound backscatter reference surface, and then used to perform a relative calibration for other NOAA OCS systems that surveyed the same reference surface. In this way, it is hoped that the calibration performed at the Center can be propagated throughout the fleet without requiring a lengthy calibration procedure at the Center. This effort—which sounds simple but is imbued with myriad difficulties—is the current focus of Briana Welton as she works toward her Masters's degree at UNH.

The efforts described above are anticipated to provide relatively fast-paced improvements to backscatter quality associated with NOAA OCS surveys, but questions remain about the level of accuracy of the tank (or field) calibrations for hydrographic MBES in general. A two-stage approach—which in many respects is similar (or symbiotic) to the Ph.D. work done by Mashkoor Malik at the Center with a Kongsberg EM3002—has been established to assess these questions. First, tank calibration results will be applied to data collected from a man-made extended surface target in the tank for both a 200 kHz Reson 7125 and a far-simpler (and hence more easily 'calibratable') 200 kHz Kongsberg split-beam EK60, with the hope being that the two vastly different systems will provide identical surface scattering strengths. If this can be accomplished it will greatly increase our confidence in both our calibration procedures and our backscatter data processing pipeline. John Heaton has worked to quantitatively assess the acoustic characteristics of this extended surface target, first as an undergraduate through our SURF program and now as a graduate student. He will present his results at the 2013 Acoustical Society of America conference in Montreal.

When agreement has been established between the simpler EK60 system and the more complicated Reson 7125 in the ideal tank setting, the same procedure will be repeated in a more realistic field setting in Portsmouth Harbor. To help understand the acoustic data collected in the field, work on groundtruthing methodologies designed to measure parameters of interest (e.g., roughness, volume scatter, grain size) has begun (most notably, a stereo camera system developed by Val Schmidt and Yuri Rzhanov—Figure 4-13). Initial data collection efforts were conducted in the fall of 2012 and will continue in the summer of 2013.

As part of the NEWBEX project, there is also interest in the development of a local backscatter reference surface as well as several related lines of inquiry that include: issues of anisotropy in backscatter, repeatability of seabed backscatter over time and testing of post-processing software, etc. To help with this, the 2012 summer hydro camp team (see EDUCATION section) offered their support by running a standard line with a Kongsberg 2040 as they left and returned to port each day during their survey efforts. An initial assessment of the repeatability of this line was performed showing high variability in places where there is a combination of high currents and moving bedforms, as expected, but also high variability in areas thought to be bedrock (see Figure 4-14). Ray Grizzle has conducted a video tow in this area and is currently analyzing the data for both grain size and fauna in an attempt to understand the sources of variability.

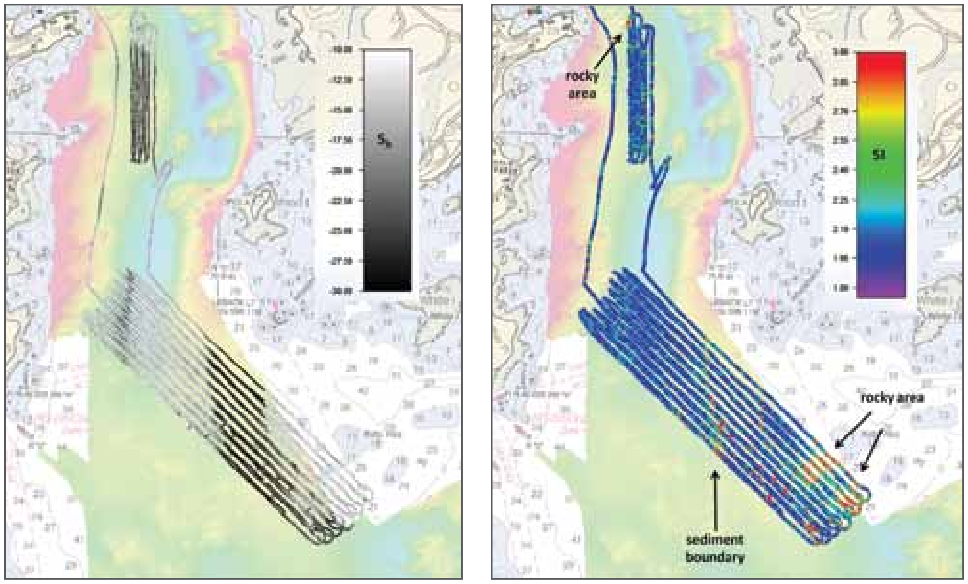


Figure 4-15. Benchmark seafloor backscatter (Sb) collected with an EK60 mounted at a 45˚ angle (left). Scintillation index (variance of backscatter intensity divided by the mean backscatter intensity scattered), with a value of 2 indicating Rayleigh statistics and higher values suggesting a small number of strong scatterers are dominating the return.

In November 2012, the summer hydro ‘standard line’ site was re-surveyed with both a Reson 7125 (200/400 kHz) and an EK60 split-beam echo sounder (200 kHz) mounted at a 45˚ angle. The latter was calibrated using standard fisheries methods and is being used to provide an acoustic benchmark for seafloor backscatter (Figure 4-15). Bottom samples and optical imagery were also collected for this study area. This survey work was done in anticipation of running a repeat survey through the area during the 2013 field season in order to assess the variability in seafloor backscatter over a variety of time scales as we establish a backscatter reference area that can be used by the summer hydro class, Center researchers testing new systems, the NOAA Ship *Hassler* when in residence, and any other interested parties. In addition to the creation of a backscatter reference surface, this work is providing an opportunity to do in-depth studies of seafloor backscatter at higher frequencies than has been traditionally studied and is expected to result in several contributions to this general field of study, including the study of seafloor backscatter statistics.

The EK60 data has been examined to find regions where the data (i.e., the envelope of the scattered return) are non-Rayleigh distributed, as measured by the scintillation index (SI - the normalized variance in the backscatter intensity). As shown in Figure 4-15, the seabed is acting as a Rayleigh scatterer throughout much of the survey area (the blue area in Figure 4-14), but exhibits non-Rayleigh statistics in areas that are rocky as well as on sediment boundaries (the latter is likely to be a processing artifact). Comparison of both the seabed backscatter and the SI show that the region of high backscatter in the vicinity of the rocky areas extends beyond the region associated with non-Rayleigh statistics. This suggests that measures of SI may add discriminatory power to habitat characterization.

Restructured GeoCoder

With the departure, several years ago, of Luciano Fonseca, the developer of our backscatter processing software GeoCoder, the Center needed to re-evaluate its approach towards backscatter processing and seafloor characterization. Research efforts have resumed in full force at the Center this year through collaboration with Industrial Associate IVS3D (now QPS). In this revitalizing effort, IVS3D has restructured their implementation of GeoCoder and has developed a new internal architecture that allows Center researchers (and others) to access data in the backscatter processing path and replace, improve, and add key modules through a plug-in interface. This removes the software engineering overhead from Center researchers and allows us to focus on much smaller scope problems for which we have expertise. It is important to note that in taking this approach, the algorithms and software modules developed by Center researchers will be available to all Center Industrial Associates. The hope is that this approach will provide a flexible and extensible R&D tool that will enable us to carry on in the field of seabed characterization research.

This year, Jonathan Beaudoin and QPS's Moe Doucet have continued to expand and flesh out the Fledermaus GeoCoder Toolbox (FMGT) “plug-in” architecture. This partnership allows Center researchers to take advantage of QPS’s efforts to retool the original GeoCoder software framework into a robust, stable and modular software tool. The key to this partnership is the retooling, or refactorization, of the GeoCoder processing pipelines into software modules; these modules honor the algorithms implemented in the original GeoCoder framework but with clear boundaries being set between the various data flows and processing stages such 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.

As described above, this approach was proposed in 2010/2011 as an alternative to maintaining the original GeoCoder code base. Researchers in the seafloor characterization group at the Center agreed to try this new approach, with Beaudoin being an early adopter in 2011 with plug-ins for R2Sonic multibeam echosounders, bug fixes for Kongsberg Maritime newer generation echosounders, and Reson 7125/7111 TVG re-calculation allowing for improvement in backscatter products from all three examples. The plug-in interface, designed and implemented by QPS, has undergone several iterations since the initial proposal but finally settled on a stable application programmer interface (API) in 2012.

In mid-2012, Doucet visited the Center to provide training sessions to Beaudoin and several other Center researchers (Weber, Schmidt, Rice, Skarke and Jerram) with the intent being to bring all involved up to a common level of ability in plug-in development. Training was held over three days in June at the Center with several mock-up example plug-ins being developed, including an FMGT plug-in allowing for bathymetric data extraction and reduction from ME70 fisheries sonars (see IOCM theme discussion). The plug-in architecture has been expanded to include QPS's FM Midwater product, allowing for another avenue to rapidly develop research solutions and deploy them in the field. In this case, an example plug-in was developed by the group to allow for geometric extraction of targets from EK60 split-beam echosounder data. During the training, Beaudoin began development on a plug-in to allow for more refined control over the Kongsberg backscatter correction stage in FMGT, an example of the plug-in dialog is shown in Figure 4-16. Plug-ins such as this will be developed in the future and will help researchers, commercial software vendors and the user community to better understand the finer details of the GeoCoder code base.

Doucet visited Beaudoin at the Center in November to begin documenting the various algorithms in the GeoCoder code base. During this effort, a substantial re-factoring effort was completed that collapsed redundant code into a GeoCoder library, including removal of duplicated algorithms for varying sensor types. The resulting code base is becoming much leaner and easier to trace through and to understand.

Data Management

After five years of searching for an appropriate data manager for the Center we are delighted to report that we filled the position in 2011 with the very capable Paul Johnson who comes to us from the University of Hawaii's Mapping Research Group. Paul hit the ground running and is well on his way to ensuring that our data holding are protected, documented, organized and easily accessible to our researchers and to any others who need access to them. While working with Paul this year, Tianhang Hou has been focusing on creating appropriate metadata and areal coverage polygons for two our largest databases—the seven seasons of Arctic multibeam sonar data collection (see LAW OF THE SEA theme), as well as 11 years of hydrographic field camp surveys). Tianhang has also been working with Paul in developing automated ways of bringing our multibeam data into the ArcGeodatabase.

Data Migration from the Center's Existing SAN to a New Higher Capacity SAN

During the spring of 2012, the Center installed a new Storage Area Network (SAN) for safe and secure data storage and with it developed a new organizational model and set of policies for data storage on the SAN. A strict naming convention will now be used for shares created on the SAN. The share name will include type of data (engineering, mapping, academic, IT, research, administrative, or miscellaneous), year of the project or creation of the share for a multiyear project, and the name of the project.

To allow for flexibility in naming and access, the IT group also began using a DFS (Distributed File System) that will allows users to access data in the manner to

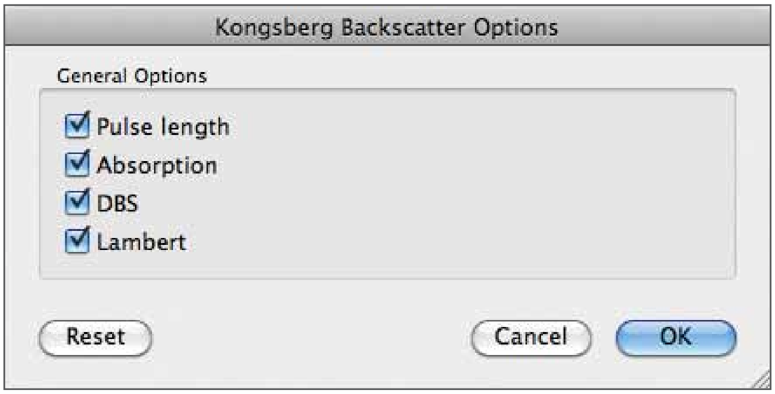


Figure 4-16. Example plug-in configuration interface implemented for the Kongsberg Backscatter processing stage. This dialog allows for fine-grained control over the corrections that are applied in processing.

which they have grown accustomed to over the years. By doing this, we make gains in organization and ease of search, without the loss of easy access by the users.

With the new SAN we have also instituted a database to track projects and data stored on the SAN. The Center now tracks the following information for all shares:

- Network Share Name
- Size of the Share (TBs,GBs, MBs, etc.)
- Quota Size (limit of space available for a share)
- Physical Path (where the share is on the SAN)
- DFS Path (share path through the DFS server)
- Alternate DFS Path (alternate path through the DFS server)
- Old Share Name (former share name if it is a migrated share)
- Old Physical Path (former direct path to the share)
- Principal Investigator
- Data Steward (individual currently responsible for the data)
- Geographic (Name) Location
- Acquisition System (if available)
- Storage Date (date share was initiated)
- Expiration Date (date share will expire for temporary shares)
- Data Status (raw, processed, etc.)
- Funding Agency
- Description

Tracking this information allows the Data Manager to more rapidly process user's request for access to data, it aids in identifying datasets by their type and processing status, and it allows the IT staff to track and manage the storage resources of the Center.

Starting in early September the actual process of migrating the data from the existing storage solutions to the new SAN began. During this process, the IT staff also maintained a page on the Center's Wiki where all migration information could be tracked, including date of transfer, old share path, new share path, quota, etc. could be tracked.

By the end of 2012 all data will have been migrated to the new SAN. This data has been mirrored from the older storage solutions to the new SAN, but has been held apart in a separate staging area until its level of importance and/or need for continued storage has been determined.

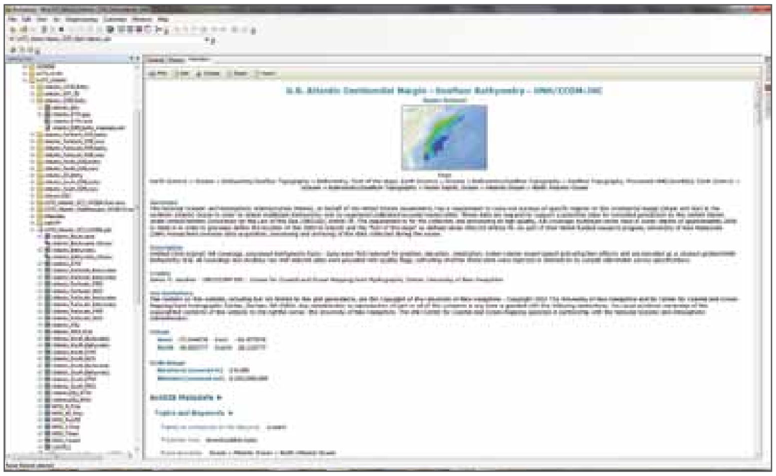


Figure 4-17. ArcGIS GUI with metadata (left) and search page (right).

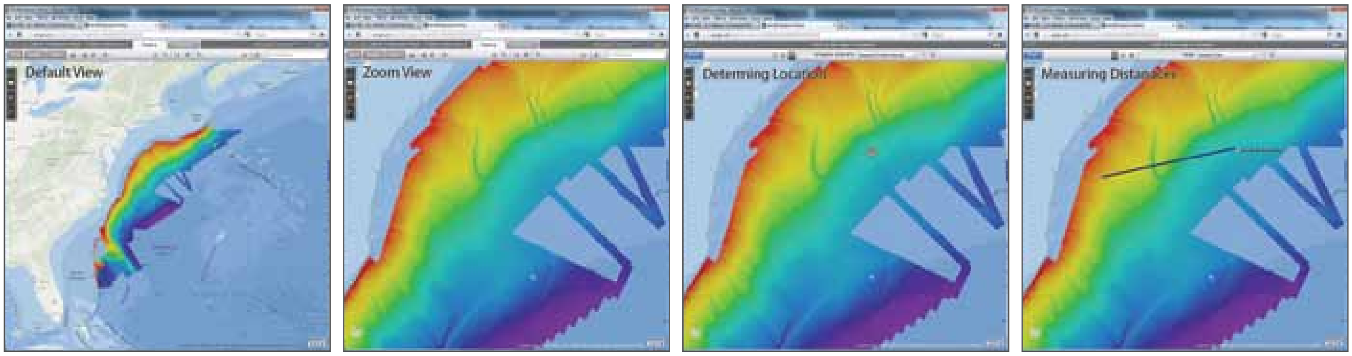


Figure 4-18. Pan, zoom, query, and distance measuring features of served data.

ArcGIS Data Server

Throughout the spring of 2012, development continued on improving the capabilities of the Center's ArcGIS server. This server is meant to distribute data and maps through the JHC's website, as well as through local access. During the spring, the existing Law of the Sea bathymetry and backscatter data was transitioned from being served as individual grids stored directly on the hard drives of the GIS server to being delivered from an ESRI geodatabase located on the Center's new SAN. This has allowed for improved organization of the data, rapid distribution of the data from the server, and greater ease in managing the data holding of the GIS server. During this transition metadata content was embedded into each of the grids in order to fully document the data being distributed.

Following completion of the geodatabase migration, mapping services were set up to share data from the Center's GIS server. Making the data publicly available allowed sharing of the grids through ESRI's interactive data and mapping portal (**http://www.arcgis.com**). The ArcGIS.com site allows users to rapidly search for data based on dataset names, data types, or other keywords (see Figure 4-17). Users may then add the data to their own GIS projects, view the full metadata of each dataset, and bring up dynamic maps that they can pan, zoom, and query location and distances from the data (see Figure 4-18).

All of these features allow for easy access for multiple users to the Center's bathymetric and backscatter data, and as an added benefit, the rapid development of dynamic maps that are now being served through the Center's webpages (see Figure 4-19). Visitors to any of the Law of the Sea study areas are now able to interact with the data the same way they can through the ArcGIS.com site.

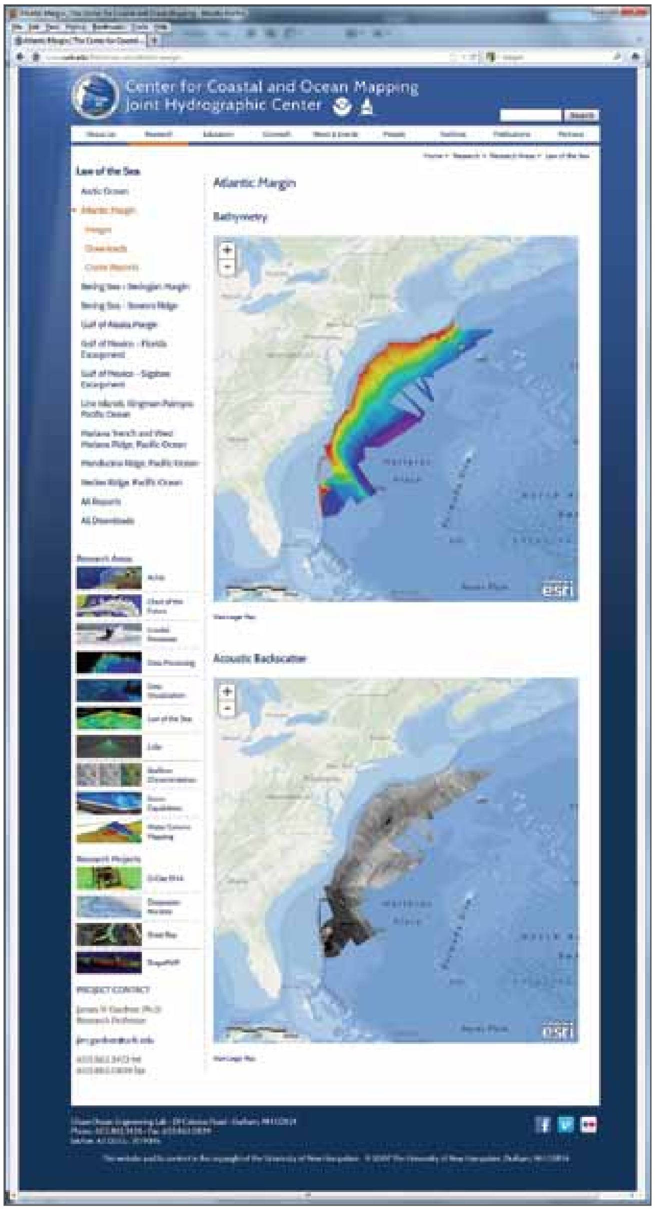


Figure 4-19. Linked dynamic maps being served on the Center's website.

One downside of using the ArcGIS.com interface is its lack of control over display projections and toolsets. Because of this, the Center has begun to develop a custom mapping solution for the website. This will allow complete control over the look, functionality, and branding of the site. Further development will continue through 2013.

During the fall of 2012, development of the Center's GIS server continued with experimentation on the use of different mapping services with various test datasets. Currently the Center has just begun to offer web image services for some of the Law of the Sea data. The advantage of ESRI's Image Service over a Mapping Service is that the server is actually distributing the data as gridded values instead of an image tile. Users within the the Center or worldwide can discover these services through the ArcGIS.com website or by visiting the Center's GIS server through its REST (Representational State Transfer) protocol. The REST protocol is designed for distributing web services through simple URLs.

For users accessing the data through the REST interface, they will need to simply click on the link on the webpage for "ArcMap" and the gridded dataset will open up within their desktop program. At this point, the user will be able to fully interact with the data, including changing color palettes, querying depths, calculating hillshades, etc. This method of distribution allows a user to link to online resources where the data is stored and interact with it without needing to store a local copy.

Potentially Polluting Marine Sites (PPMS GeoDB) and Marine Site Risk Index (MaSiRI)

In 2012, several of our students finished theses related to Data Management. Italian Naval Officer and graduate student Giuseppe Masetti worked with thesis advisors Brian Calder and Lee Alexander to develop a data structure specifically designed for Potentially Polluting Marine Sites (PPMS GeoDB). This is an approach to analyzing risk

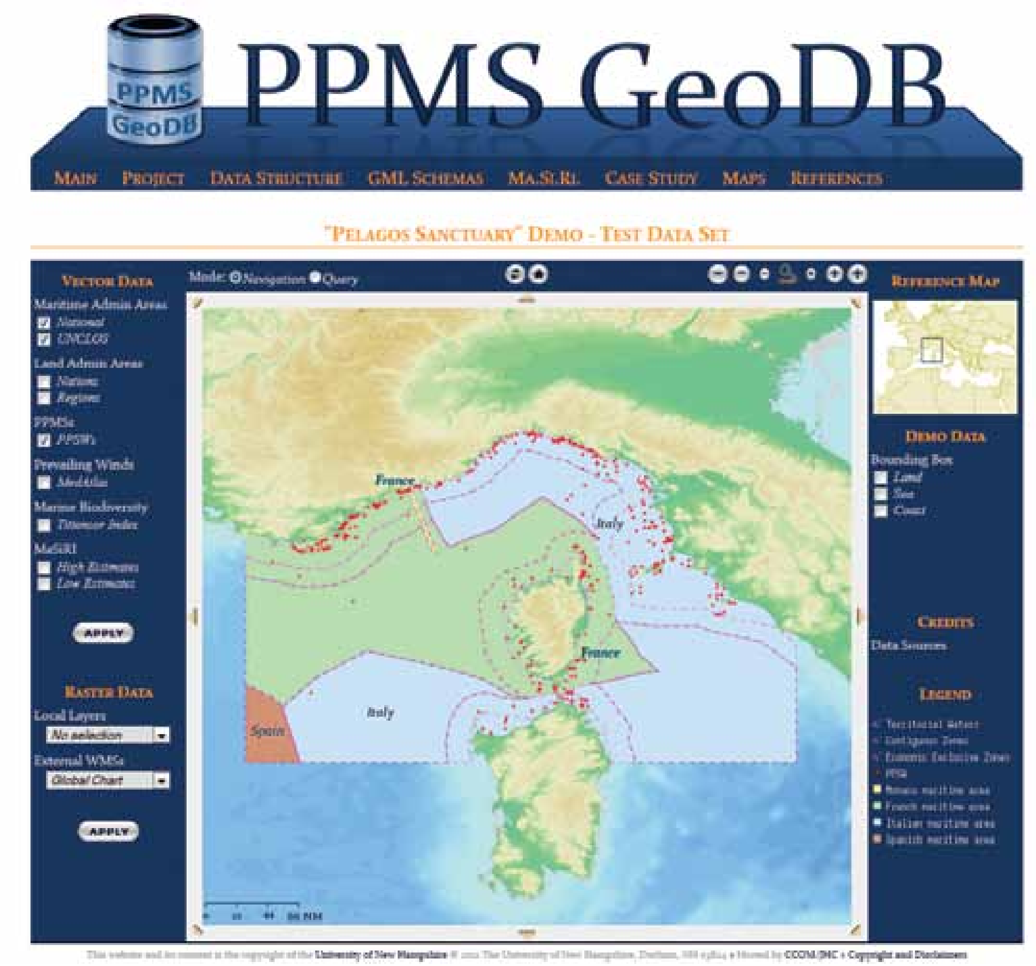


Figure 4-20. A web-based GIS is fully integrated into the PPMS GeoDB website showing example layers coming from a test data set.

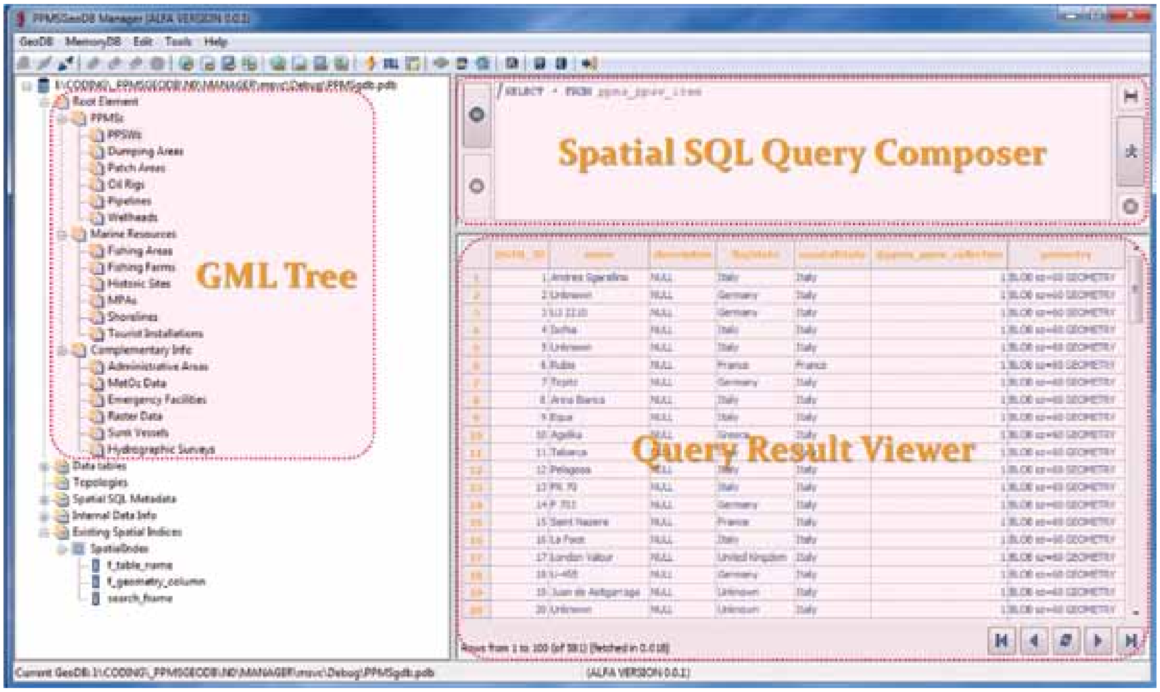


Figure 4-21. The developed PPMS GeoDB Manager provides the following main features: 1. A GML tree to visualize the data as if it was still in GML format; 2. An SQL query composer that permits creation and execution of run-time Spatial SQL queries; 3. A viewer to display the results provided by the created queries.

associated with marine sites (MaSiRI). Masetti's PPMS GeoDB is designed to manage information about potentially polluting sites, and making it available for use and exchange in a uniform manner, since this is critical to effectively supporting a proactive approach to monitoring and remediation. In particular, the GeoDB is designed to be generic enough to handle different types of potential polluters and auxiliary information; enable easy exchange and re-use of information; and be standards-based to allow for ready adoption into available tools. In particular, it is designed to be compliant with the Universal Hydrographic Data Model (IHO S-100) recently adopted by the International Hydrographic Organization. The resulting prototype has been modeled using the Unified Modeling Language (UML), with the Geography Markup Language (GML) chosen for the physical implementation.

An adaptation of ISO 19115 Metadata as well as Metadata Collections, was used to provide links to existing databases, with a GML-enabled relational database embedded into the outlined PPMS GeoDB project. Finally, a web GIS deployment of a PPMS GeoDB was selected as the simplest way to communicate to the public the possibility of using the data as a Web Map Service in almost any GIS allowing for better development and integration with other regionally and locally available datasets (Figure 4-20). This deployment required the development of a means to visualize the risk indices and associated confidence factors generated by MaSiRI. A composite Quality Symbol was developed that combines these parameters in a readily accessible manner.

Based on the information collected in the PPMSGeoDB, Masetti has also developed an approach to calculating a Marine Site Risk Index (MaSiRI). Its main aim is to provide an index that evaluates possible environmental impacts of each Potentially Polluting Marine Site (PPMS) on the surrounding area and shoreline, analyzing and 'weighting' some of the information present in the PPMS GeoDB PS.

To reduce the intrinsic subjectivity of any risk assessment process, the proposed risk index follows a fixed series of steps and defines look-up tables to identify resources at risk, additional threats, distance of available assets, coastal observations, etc. The basic idea is to establish a rough indication of the risk index based on three elements common to each typology of PPMS; distance from the shoreline, the volume, and the type of pollutant.

The hazard represented by the polluting volume is scaled as a function of the distance from the coast. The resulting Scale Factor (from 0.1 to 10) is combined with four pollutant categories (related to hydrocarbons and chemical materials) providing a first evaluation of the risk index. The refinements are mainly PPMS type specific. They have the double role to evaluate a series of elements related to the PPMS (e.g., corrosion effects, marine biodiversity, distance from emergency facilities, site depth, shoreline characteristics, socio-economic indexes, meteo-oceanographic elements, etc.) and to increase the level of confidence in the resulting MaSiRI. The refinements are clustered in order to reduce cross correlation into three groups: site-specific, socio-economic, and coastal. A prototype implementation was provided by scripts containing spatial SQL statements in an open-source cross-platform C++ application called PPMS GeoDB Manager (Figure 4-21). A PPMS GeoDB created using the PPMS GeoDB Manager is natively supported as a Spatialite layer in Quantum GIS (Fgure 4-22), and can be exported in popular geographic formats (e.g., ESRI shapefile, Google kml, etc.).

Development of a Data Management System for Hydrographic Survey Data for the Royal Thai Navy

As part of his graduate work at the Center, Royal Thai Naval Officer Kittisak Nilrat, under the supervision of Capt. Andrew Armstrong, and with guidance from Paul Johnson, developed a prototype data management system to serve the significant bathymetric data holdings of the Royal Thai Navy. The prototype uses an ISO-standard, XML-based metadata for capturing, describing, and recording the fundamental information and operational procedures that

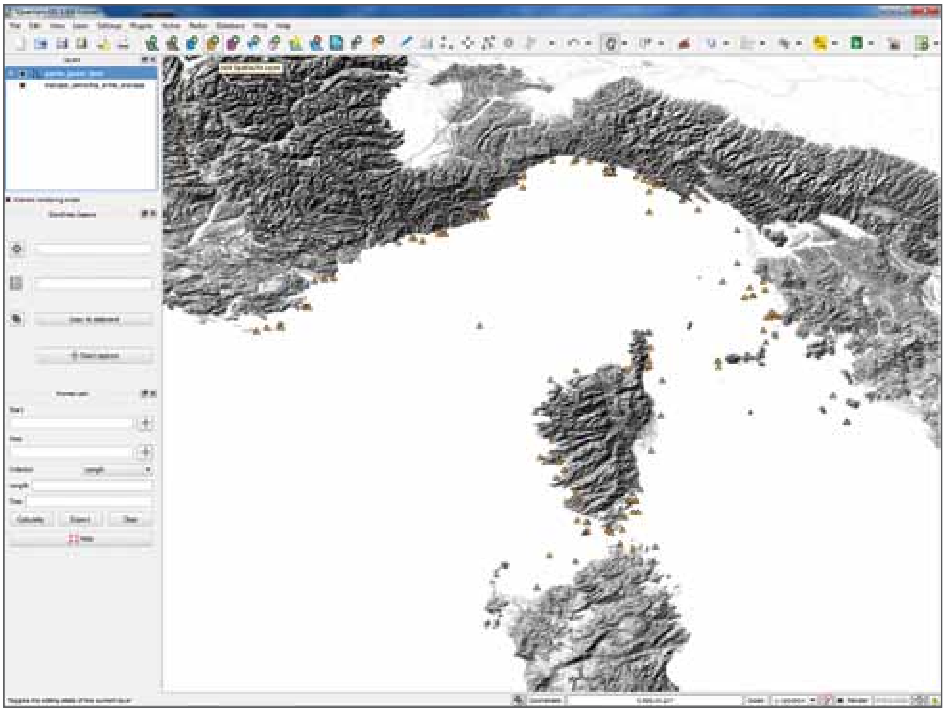


Figure 4-22. Screenshot of a PPMS GeoDB natively opened as a data layer in Quantum GIS.

are implemented throughout the survey life cycle. The Bathymetric Attribute Grid (BAG) format was chosen to be the format for validated modeled data. Other types of digital hydrographic data (e.g., validated depth points, contours, etc.) are modeled as Geographic Information System (GIS) geodatabase feature classes and stored centrally in a GIS data repository. The geodatabases are developed using Arc Spatial Database Engine (SDE) on a Microsoft SQL Server Express 2008 R2 platform. A Storage Area Network (SAN) was chosen for the network storage system so that data processors, connected to the network, can store and back up data easily and efficiently. Lastly, the ArcGIS Data server was chosen for presenting the spatial data, metadata and derived products associated via the web. The prototype was tested on multibeam datasets collected as a part of the Summer Hydrographic Field Course demonstrating its usefulness and appropriateness for the Hydrographic Department of the Royal Thai Navy.

Theme 3 :: Habitat and Water Column Mapping

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

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

Habitat Mapping

While "habitat mapping" is a desired end product of many seafloor mapping efforts, just what habitat mapping means is poorly defined. Our response to the question of habitat mapping is to focus on developing approaches for characterizing the seafloor through the analysis of data we can derive from the sensors that we work with (sonars, lidar and hyperspectral scanners). As we perfect these techniques (which are currently far from perfect) we work more closely with biologists and fisheries scientists to see how the data we provide can be used to answer the critical questions they face. From a seafloor perspective, the key parameter that offers the best chance for quantitative characterization of the seafloor is acoustic backscatter. If sonar backscatter data are to be used to correctly characterize seafloor properties, however, the measured backscatter must represent changes in the seafloor rather than instrumental changes or changes in the geometry of ensonification. Although many system and geometric corrections are applied by the manufacturers in their data collection process, some corrections are not applied (e.g., local slope), and for others, many questions remain about how and where the corrections are applied. As described under the SENSORS Theme and in the Backscatter Processing section of the DATA PROCESSING Theme, we have been working closely with NOAA and the manufacturers to fully and quantitatively understand the nature of the backscatter data collected and to develop tools (e.g., GeoCoder) that can properly make the needed adjustments to the data. Once such corrections are made, the resulting backscatter values should be much more representative of true seafloor variability and thus be an important contributor to efforts to remotely characterize the seafloor.

ARA (Formerly AVO) Analysis—GeoCoder

Our efforts in acoustic seafloor characterization have focused around the GeoCoder software package developed by Luciano Fonseca (designed to make fully corrected backscatter mosaics and calculate a number of backscatter statistics) and the Angular Response Analysis (ARA) software package—also developed by Luciano Fonseca to analyze the angular response of the backscatter as an approach to remote seafloor characterization. The ARA package uses a fully constrained iterative inversion model that is based on both empirical data sets (Hamilton) and theoretical approaches (Jackson and Biot). There are many advantages derived from this integration; for instance, the prediction of the bottom type provided by the ARA can help remove the backscatter angular response, which is sediment specific, making it possible to assemble backscatter mosaics with fewer angular artifacts. Additionally, backscatter mosaics can be segmented based on texture and statistics, so that it should be possible to calculate an average angular response not just for a stack of consecutive pings (a patch), but also for a segmented region in the backscatter mosaic.

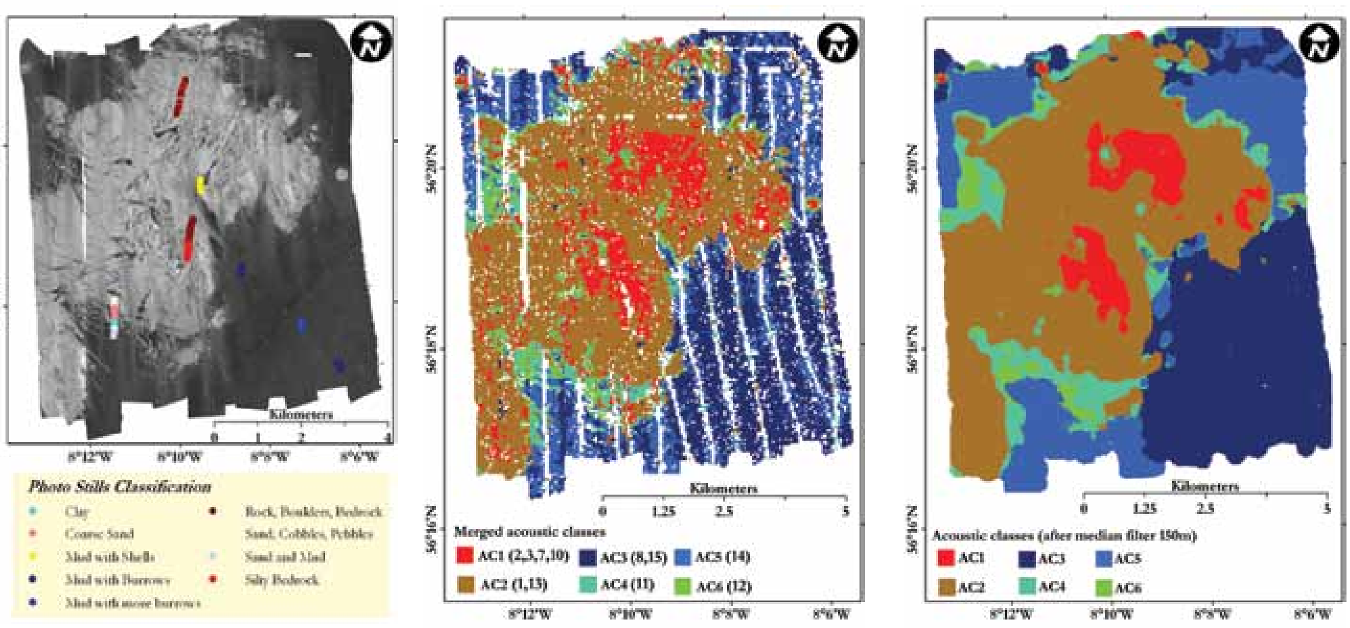


Figure 5-1. Classification results for the mosaic embodying all the available corrections. From left to right: 1) the "best" mosaic and the ground truth samples with their classification, 2) the 6 meaningful acoustic classes (ACs) discriminated by Sonar Class, assigned with certain bottom types according to their occurrence to the ground truth samples, 3) smoothed ACs delineation after median filter application with 150m radius.

In 2006, the concept of "theme analysis" was added to GeoCoder and the ARA software. With a theme analysis, average backscatter angular responses can be calculated for specified areas of the seafloor, referred to as themes, rather than for fixed patches of stacked pings in the along-track direction. The average angular response of the theme, and not of the patch, can then be analyzed with the ARA tools, so that an estimate of the seafloor properties of an area can be calculated. Similarly, the average angular response of the theme, and not one along-track moving average, can now be used to calculate the angle vs. gain (AVG) tables necessary to build an enhanced backscatter mosaic. With these new AVG tables, the mosaics show fewer artifacts in the along-track direction. The themes can be generated manually with image-processing editing tools or can be generated automatically. The automatically generated theme areas are segmented and clustered directly in the angular response space and not in the image textural space.

As discussed in the Backscatter section of the PROCESSING theme, the departure of Luciano Fonseca led to a rethinking of our approach to seafloor characterization research. We have formed a very active team (Weber, Beaudoin, Rzhanov, Calder, Schmidt, Mayer, Rice, Lurton) that meets regularly to discuss and address issues of seafloor characterization. A series of experiments are underway (see the NEWBEX discussion under Backscatter Processing) and collaboration with our Industrial Associates will allow the development of new capabilities for GeoCoder through the creation of plug-in modules (see the Backscatter Processing discussion).

As described in the Backscatter Processing section, Beaudoin has already created plug-ins for GeoCoder for sonar calibration. Yuri Rhzanov is also looking into the sensitivity of many of the assumptions made in GeoCoder. He is collaborating with E. Fakiris, a doctoral candidate at the University of Patras, Greece, on the analysis of relative importance of backscatter strength corrections built into GeoCoder. Many corrections (such as spherical spreading) have clear physical meaning and have to be applied to the raw backscatter data to obtain measurements that are close to actual values. However, there are other corrections that are phenomenological and are applied to improve visual consistency of the mosaic or reduce seams between areas covered by different swaths. The importance of these corrections is questionable and their validity requires careful investigation. Another issue that requires clarification is the importance of resolution of the underlying Digital Elevation Model (DEM) used for mosaic building. Without an associated DEM, GeoCoder assumes a flat seabottom model and corrects for the grazing angle accordingly. Steep slopes obviously change correction values and can have significant effect on the resulting mosaic. Usually, the resolution of the DEM is lower than that of the backscatter mosaic due to multiple measurements of backscatter strength within each beam footprint. However, the DEM can be built with a variety of resolutions, but it is not obvious that a higher resolution DEM improves the quality of the mosaic created by GeoCoder.

A test data set from Stanton Banks (where a good ground truth data set exists) is being used to investigate the relative importance of corrections employed by GeoCoder. More than a dozen mosaics with different sets of corrections applied, have been built for a variety of DEMs and subjected to semi-automatic analysis. A typical result showing a five-division characterization (sand, bedrock and boulders, sand with pebbles or mud with shells, mud with burrows, and sand and mud) is shown in Figure 5-1.

Due to scarcity of available ground truth data (and especially tight spatial clustering of grab samples) it has been assumed that the mosaic that embodies all possible corrections represents the best result and its classification has been compared to the ones from all other mosaics (with various corrections applied). The comparisons between the classification results obtained by the "best" mosaic and the mosaics corresponding to all other levels of correction were performed on the basis of the Cohen's kappa coefficient. The results of the comparison between the "best" classification map (using only 3 classes) and the ones generated by all the other 23 mosaics are shown in Figure 5-2. In general the observations are as expected, meaning that adding corrections leads to an increase in the accuracy of the classification product, while angle varying gain (AVG) consideration leads to the best possible results.

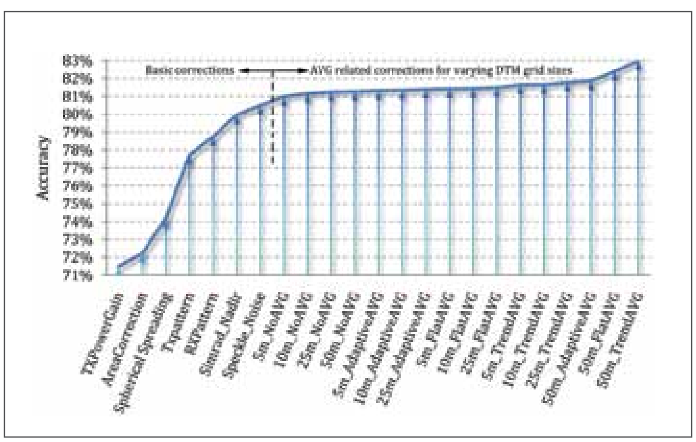


Figure 5-2. Diagram showing the accuracy (Cohen's kappa coefficient) of the classification results concerning all available 23 mosaics, compared to the "best" one.

As a further extension of GeoCoder, Rzhanov is working with collaborator Alex Schimel at the University of Wakaido, NZ to further develop techniques introduced last year for the automatic delineation of acoustically homogeneous facies. These techniques are critical for an objective segmentation of the backscatter mosaic into regions of common behavior upon which the ARA analysis can be done. This year, an "aggregating" approach has been introduced, where neighboring segments are joined together if data for both segments are sufficiently close in some metric. The study site chosen was the Tapuae Marine Reserve, off New Zealand, with the ground-truth dataset collected at 248 stations located within the limits of a multibeam sonar survey. GeoCoder was used to construct a backascatter mosaic, which then was over-segmented with segment sizes sufficiently large to contain not less than 100 soundings. These soundings were represented as a 2D histogram (backscatter strength vs. grazing angle), and the similarity between these two distributions was calculated on the basis of the two-sample Kolmogorov-Smirnov statistics. The aggregating approach works appears to work well in areas with sharp transitions from one type of facies to another, but it can fail when the sediment changes gradually over large number of segments. Approaches to overcome these limitations are being investigated.

Multibeam Mapping to Support Habitat-Based Groundfish Assessment and Deepwater Coral Research in the Gulf of Alaska

As part of our IOCM activities (see IOCM theme), we are also exploring means of extracting multiple datasets from a single sonar survey/system. To this end Jodie Pirtle and Tom Weber are collaborating 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 using multibeam acoustics. 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. The ME70 installed on the NOAA Ship *Oscar Dyson* was originally designed for mapping pelagic fish schools but in the spirit of IOCM, the ME70 is now routinely being used for seabed mapping purposes, using software developed at the Center (in collaboration with NOAA Fisheries) over the last few years.

In 2011, the AFSC conducted a GOA-wide biennial acoustic-trawl survey for walleye pollock from the Islands of Four Mountains in the Aleutian Islands to the eastern side of Kodiak Island with the *Oscar Dyson*. During the survey, the ME70 was opportunistically used for bathymetric mapping and to collect absolute seafloor scattering strength (Figure 5-4). Additional ME70 data were also collected during an acoustic-trawl survey in the winter of 2012 from between Sanak Island the eastern side of Kodiak Island (Figure 5-4). The ME70 multibeam data were collected opportunistically during the winter surveys using protocols developed in 2011. Pirtle participated in two of the three cruises, during June and August 2011. Pirtle and Weber provided support remotely from the Center during the winter 2012 surveys.

ME70 data were collected continuously during the surveys along the ship trackline. In addition, several ME70 fine-scale surveys were conducted in 2011 over localized areas having no groundtruth seafloor data, but that were suspected of being untrawlable (e.g., high relief) or characterized by some other unique habitat features (e.g., canyon, bank) based on historical information from AFSC groundfish surveys. The fine-scale ME70 surveys also targeted localized areas where seafloor information had been collected earlier with other devices (e.g., cameras, submersibles) that could be used to groundtruth the ME70 data. A total of 42 previously sampled video dive locations were intersected by the 2011 *Oscar Dyson* trackline or fine-scale ME70 surveys.Single drop- or stereo drop-camera deployments were conducted at stations in the fine-scale survey areas to characterize the seafloor for comparison with ME70 data. Substrate observed in the underwater video from these deployments was characterized as trawlable or untrawlable, where untrawlable areas were defined as any substrate containing boulders reaching higher than 20 cm off bottom or any substrate with exposed bedrock that was so rough that the standard bottom trawl footrope would not pass easily over it. A total of 27 drop- and stereo drop-camera stations were characterized as trawlable and 20 stations were characterized as untrawlable, including areas of Albatross Bank on the south Kodiak Shelf with rock ridge, boulders, sponges and corals, and associated rockfishes (*Sebastes spp*.) (Figure 5-5).

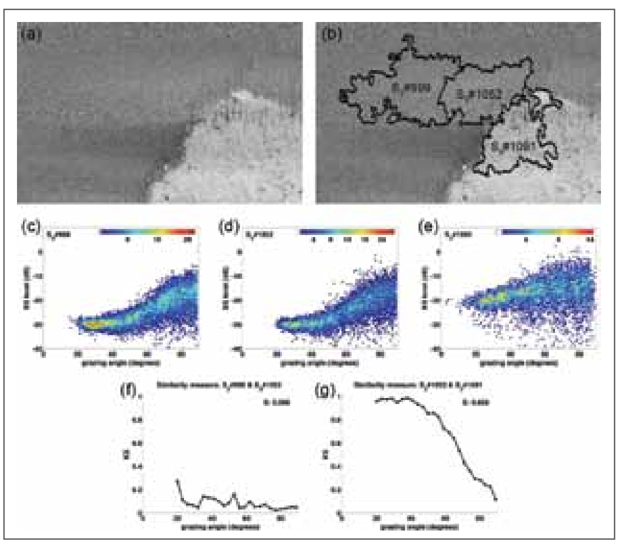


Figure 5-3. Computation of the similarity measure S between the 2D histograms of segments S3#999 and S3#1052, and between the 2D histograms of segments S3#1052 and S3#1091. (a,b) The boundaries of the segments are shown overlaid on the mosaic. (c,d,e). (f) The low value (S=0.069) in the first example indicates the strong similarity between the 2D histograms of S3#999 and S3#1052. (g) The high value (S=0.656) in the second example indicates the weak similarity between the 2D histograms of S3#1052 and S3#1091.

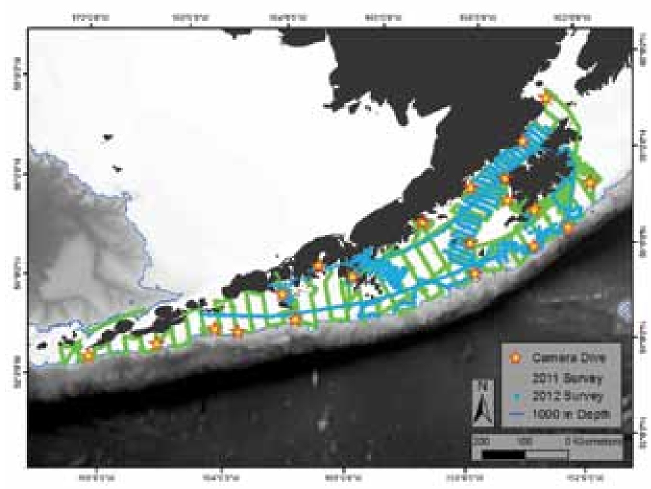


Figure 5-4. *Oscar Dyson* GOA ME70 survey footprint, including 2011 (green), 2012 (blue), and the locations of fine-scale surveys with groundtruth video (yellow stars) conducted in 2011.

Figure 5-5. Stereo Drop Camera image collected on August 12, 2011 at Albatross Bank with *Sebastes spp*. associating with untrawlable habitat composed of rock ridge, boulders, corals, and sponges.

ME70 data were matched to the spatial location of previously conducted AFSC bottom trawl survey hauls from 1996-2011 to discriminate between trawlable and untrawlable seafloor types in the region of overlap between the trawl path and ME70 data (Figure 5-6).

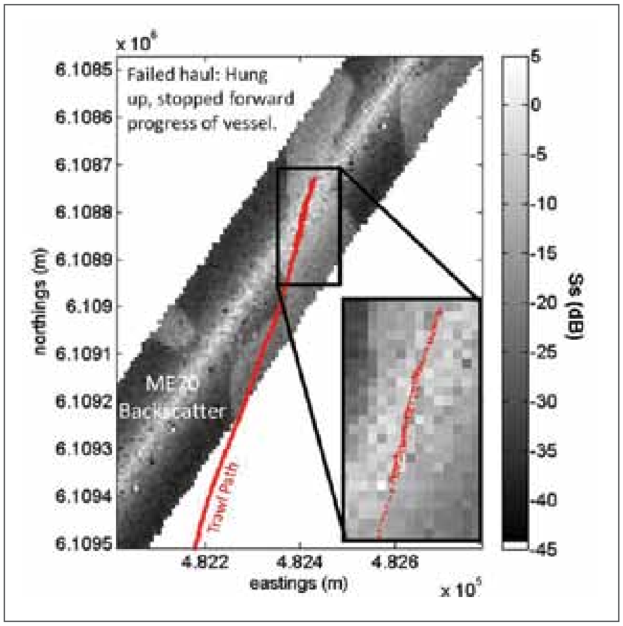


Figure 5-6. Angle-dependent seafloor backscatter strength (Ss) from the *Oscar Dyson* ME70 survey and a corresponding failed trawl haul path location.

Hauls had been previously classified as successful, marginally successful, or unsuccessful (failed) by AFSC researchers based on the level of gear damage sustained from contact with the seafloor. The ME70 survey data corresponded with the location of 582 hauls, including 487 successful hauls and 95 marginal or failed hauls. Angle-dependent seafloor backscatter strength (Ss) from the ME70 data were extracted at haul locations for the area that the trawl contacted the seafloor, taking into account the trawl warp length, trawl width, and the positional uncertainty of the survey vessel. Ss was also determined at the drop- and stereo drop-camera stations of the fine-scale survey sites in 2011. Areas of untrawlable seafloor generally exhibited higher Ss than areas with trawlable seafloor. The three haul performance categories show separation in Ss across incidence angles, with successful haul locations having lower values overall, corresponding to finer grain size, or the lack of strong scatterers such as boulders and rock on the seafloor (Figure 5-7a). Likewise, areas of trawlable seafloor at camera stations generally have lower Ss values across the range of incidence angles sampled by the ME70 (Figure 5-7b).

Backscatter mosaics are commonly used in seafloor habitat studies and have the potential to simplify interpretation of seafloor properties (as opposed to retaining and analyzing the full angle dependent Ss). Mosaics were generated by normalizing values across the swath to the range of observed values at oblique angles from 30 to 50°. We analyzed the maximum Ss from the mosaics at haul locations and camera stations based on performance. The distributions of maximum normalized Ss at successful and failed haul locations begin to deviate near -20 dB Figure 5-8a; a similar pattern was observed for trawlable and untrawlable camera stations Figure 5-8b.

In addition to the backscatter mosaics, we have extracted other metrics from the multibeam data to determine if we can improve discrimination between trawlable and untrawlable seafloor. Oblique incidence Ss is the average Ss measured at an incidence angle to the seafloor between 30° and 50° degrees. Ss slope near normal incidence is the difference in the slope of the angular response curves between 0° and 10°. Normal incidence Ss is measured directly under the transceiver

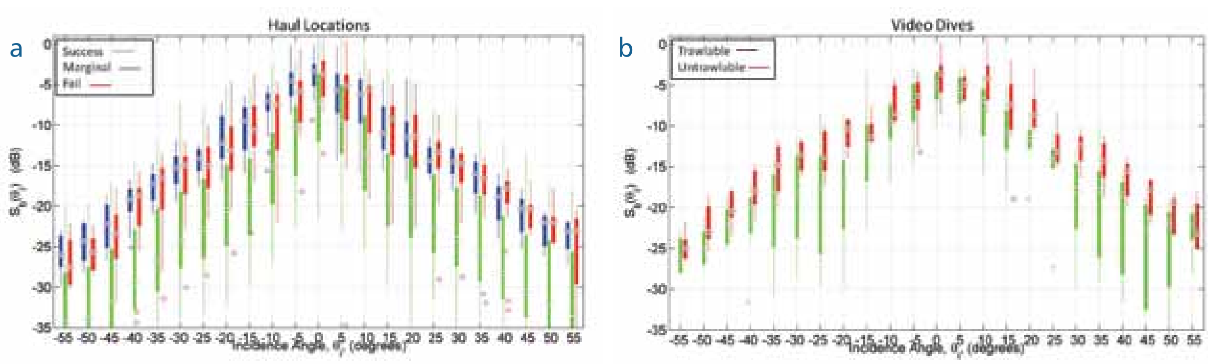


Figure 5-7. a) Angle-dependant seafloor backscatter strength (Ss), representing the ME70 beam configuration used in the GOA, sampled at haul locations from the AFSC bottom trawl survey (1996-2011) and classified by performance as successful, marginally–successful, or failed due to gear damage. b) Angle-dependent seafloor backscatter strength (Ss), representing the ME70 beam configuration used in the GOA, at camera stations sampled in 2011 and characterized from video as trawlable or untrawlable.

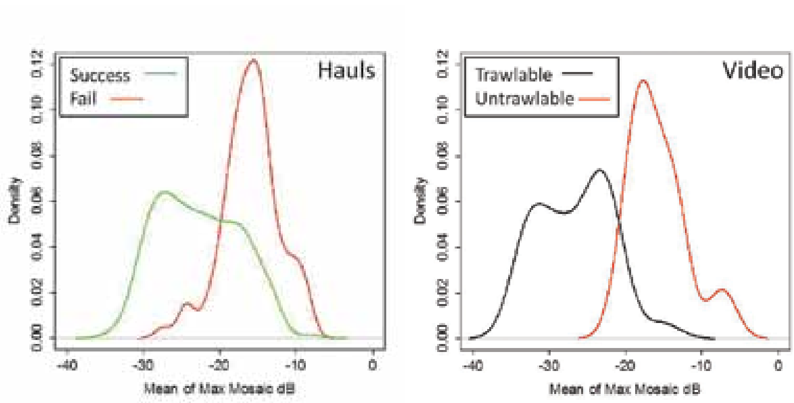


Figure 5-8. (Left) Histograms describing the distribution of seafloor backscatter strength (Ss) (mosaic values normalized to oblique incidence angles of 30-50°) at locations in the GOA previously sampled (1996-2011) by the AFSC bottom trawl survey and classified by performance as successful (success) or marginally successful and failed due to gear damage (fail) and at camera stations characterized as trawlable or untrawlable based on video (right).

at an incidence angle of 0°. In addition, four measures of seafloor roughness were extracted from the bathymetry data, where the bathymetry was binned at a scale of 0.25, 0.5, 1, and 2 m. The scintillation index (SI) was calculated, as the fourth moment of the Ss envelope, which measures how the backscattered acoustic intensity fluctuates over an area of the seafloor (see discussion of Backscatter Processing). The SI may be useful to identify areas of the seafloor that are untrawlable due to the presence of isolated rock outcrops and boulders surrounded by otherwise trawlable seafloor.

Continued opportunistic collection of ME70 multibeam data during *Oscar Dyson* operations in the Gulf of Alaska will provide more information to develop and test seafloor trawlability metrics over a potentially broader range of seafloor types as well as to collect this information in new areas throughout the Gulf of Alaska to help refine existing classifications of untrawlable and trawlable areas.

Seafloor Characterization and Habitat Studies—Jeffreys Ledge and Merrimack Ebb-tide Delta

Jeffreys Ledge, a major morphologic feature in the Gulf of Maine, is extremely important to regional bottom fisheries (a large portion of Jeffreys Ledge is inside the Western Gulf of Maine Closure Area). Knowledge of the seafloor characteristics and controlling geologic processes is important for evaluating bottom habitats on Jeffreys Ledge, which in turn are important to fisheries management. In addition, insights into the morphology and sedimentology of Jeffreys Ledge is important to the overall understanding of the evolution and geology of the Gulf of Maine. Previously (2002-2005), a significant field campaign by an multidisciplinary group was conducted at Jeffreys Ledge including high-resolution bathymetry, extensive bottom sampling for sediment and benthic infauna analysis, and videography for assessment of bottom type and benthic epifauna. A significant portion of this work was presented in a M.S. Thesis and two scientific journals (Malik 2005, Malik and Mayer 2007, and Grizzle et al. 2009). However, an overall synthesis of the seafloor characteristics, sedimentology, and controlling processes for the UNH study area has not been completed.

During the last year, a significant effort was invested in continuing the analysis of the Jeffreys Ledge database. A review and upgrade of the sediment database (~125 locations) was completed. In addition, the video for the stations in the study area (~150 stations) was re-analyzed for a sediment grain size classification. Although preparation of these upgraded databases for sediment characteristics and classification was a major investment in time, the information is now available for integration with the high-resolution multibeam bathymetry and subbottom seismics that are available for the study area.

A second area of focus for habitat mapping and ground-truth studies has been the ebb-tide delta region of the Merrimack River where video imaging, sampling and grain-size analyses have been conducted in conjunction with colleagues at the U.S. Geological Survey. These data provide a local test site for remote sensing tools. Its proximity to the Center (about an hour boat ride) is crucial for future studies because it is easily accessible. This site has already been used for ALB research in collaboration with the USGS and Fugro Pelagos (Michael Broadbent) as part of an ongoing study evaluating the use of the intensity of the lidar return as a means of remotely identifying sediment type.

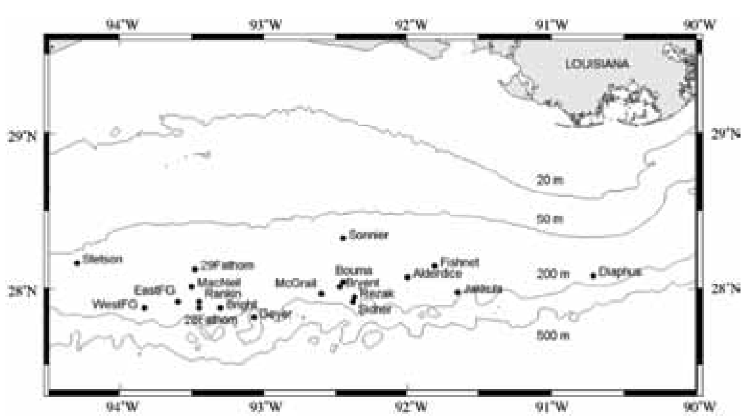


Figure 5- 9. Map of the northwestern Gulf of Mexico showing the locations of continental shelf-edge banks discussed within the text.

Extracting Ecological Biozones for Hardgrounds in the Gulf of Mexico from Multibeam Sonar Data

Jim Gardner is working with several graduate students at Texas A&M who have devised a multivariate technique that they show can predict ecological biozones of hardgrounds on the outer continental shelf of the Gulf of Mexico (Figure 5-9) from bathymetric parameters.

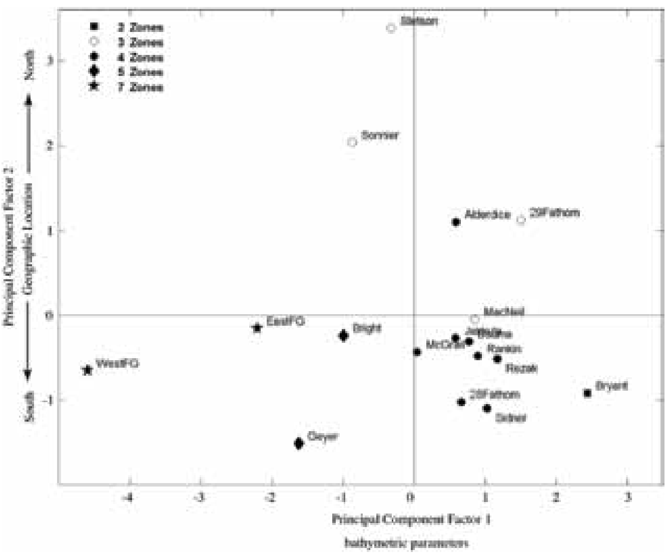


Figure 5-10. Scores of the first two principal components (PCs). Bank symbols indicate the number of biotic zones present.

Cluster, multidimensional scaling, and principal component analyses were performed on the multibeam sonar data (Figure 5-10) and it was found that the three types of analyses produced similar results. After detecting patterns based on the bathymetry parameters, results were compared with the number of biotic zones present at each site. The comparison showed similar patterns, so the multivariate results were used to predict the number of biotic zones at a site based solely on six bathymetric parameters: distance to nearest hardground, regional depth, shallowest depth, area of the site, number of terraces, and number of pinnacles. The model was then validated with two additional sites (Diaphus and Fishnet Banks). A manuscript describing the approach is presently under review in Continental Shelf Research.

Lidar, Hyperspectral, and Optical Approaches to Habitat Characterization

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

Benthic Habitat Mapping from Lidar

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

- Demand for the products currently exceeds resources and capabilities needed to generate them.
- Downstream users typically lack specialized software and training to be able to generate end products themselves.
- Existing procedures are specific to certain sensors or sensor types.

To address these challenges, Center researchers are initiating a research project with Steve Rohmann of the NOAA Office of National Marine Sanctuaries (ONMS) to develop tools and workflows that will enable wide-scale use of remotely-sensed data for 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. In particular, we seek to develop and test standardized, sensor-independent (e.g., LADS, SHOALS, CZMIL, EAARL-B, VQ-820-G, Chiroptera) processing procedures, based on open-source and/or low-cost COTS software, for producing benthic habitat maps to support conservation and management of marine ecosystems and associated organisms. The procedures must be designed to work with readily-available data and must not assume access to data types that would not typically be provided (e.g., raw lidar waveforms or interim downstream products). Another key goal is ensuring that the products generated from these procedures are consistent with existing benthic habitat maps developed by NCCOS and others, so that change analysis can be performed.

The initial phase of this work focuses on the production of benthic habitat maps from lidar-derived bathymetry and pseudo-reflectance data using open-source and available COTS software, as well as custom-developed tools and workflows that can be used by ONMS personnel. Key goals include minimizing the steps in the

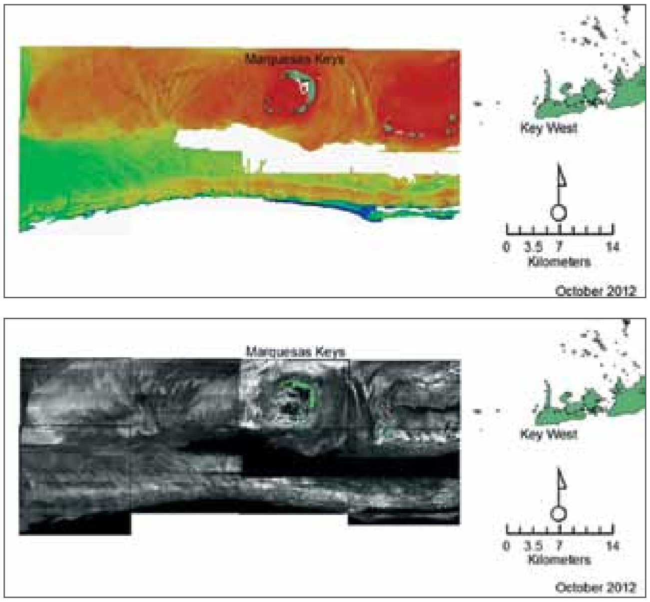


Figure 5-11. Marquesas Keys lidar data. Top: bathymetry; bottom: relative reflectance.

workflow, as well as the level of expertise required by the user, while simultaneously ensuring an accurate, useful end product. This research uses data collected in the Marquesas Keys region (Figure 5-11), including SHOALS bathymetric lidar data, lidar-derived relative reflectance, and ground truth, consisting of reflectance spectra for a variety of benthic habitat types.

Reconstruction of Detailed 3-D Surfaces from Multi-View Underwater Imagery

As part of the NEWBEX project (see the DATA PROCESSING Theme) and as part of our general need to have tools for ground truthing the detailed shape of the seafloor, Yuri Rzhanov, working with Val Schmidt, has been looking at the viability of generating very high-resolution 3D images for estimating seafloor microbathymetry from a stereo pair of still photo images. The imagery was collected with GoPro underwater stereo cameras that have been carefully calibrated. Due to extremely wide field of view of the cameras (and hence strongly varying spatial resolution) only the central part of the frames were used for calibration and subsequent matching. Lens-corrected rectified frames were segmented into a number of smaller areas with the assumption that each area represents a locally smooth patch and thus the distribution of horizontal disparities in any area is unimodal. Any conjugate pairs of pixels with disparities outside the mode were considered incorrectly matched and were either corrected or ignored. The output of the matching procedure was then used for triangulation and creation of a point cloud representing the imaged surface. For frames taken at ~45 cm above the surface the average spatial data density was estimated at 13 measurements per square millimeter with an r.m.s. uncertainty of 3 mm (see NEWBEX discussion for an example).

In many cases video data coming to the Center with processing requests have been acquired with a single camera. Without knowledge of camera motion (as in a fixed stereo rig) between two consecutive frames, translation and rotation need to be determined prior to triangulation. This can be achieved by correction of frames for lens distortion and then finding a set of point matches for the pair. Conjugate pairs are related by the rules of epipolar geometry, allowing for solution of a translation vector and a rotation matrix. The length of the translation is typically not known (or known with insufficient accuracy for quantitative range reconstruction), so the reconstruction can be done only up to a scale factor, but the detection of three or more feature points in three successive frames allows for establishing a common scale for the whole sequence.

Solution for the epipolar geometry requires a set of reliable matches (with a relatively low percent of outliers). This is done by employing a Scale-Invariant Feature Transform (SIFT) algorithm, finding salient features in both images and matching them by comparing local descriptors for each feature (Figure 5-12a).

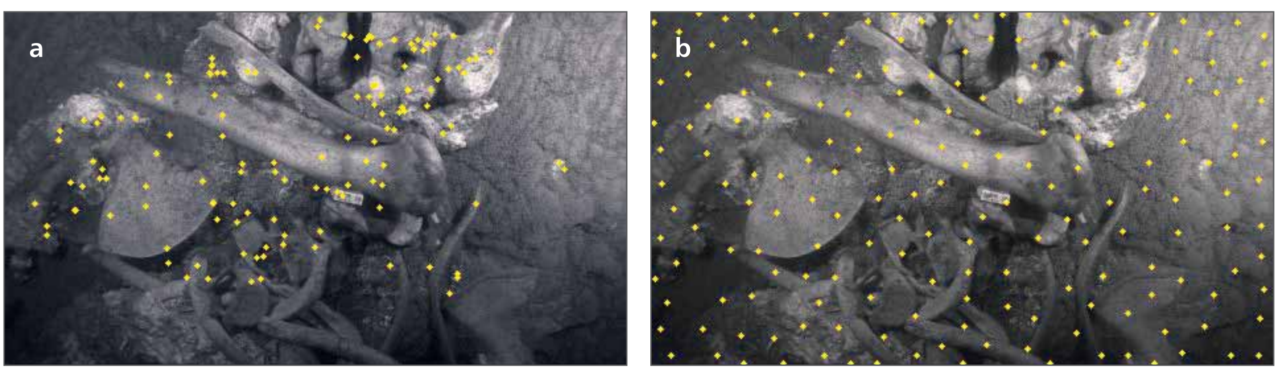


Figure 5-12. a) Yellow dots show location of salient features detected by SIFT algorithm. b) Yellow dots show locations of an (almost) equidistant grid consisting of pixels with a relatively strong "cornerness."

Figure 5-13. Preliminary result of rendering of a 3D scene.

Salient features often are concentrated in one (feature rich) area of the image. For the construction of a sparse 3D model (consisting of a reasonable number of triangles) the nodes are needed in other areas of the image as well, although probably less densely than in a feature-rich part. To generate such a grid the local "cornerness" strength is calculated for each pixel, and pixels with local maxima of this function are kept as potential candidates for grid nodes (Figure 5-12b). The strongest peaks, which have the highest probability to find a match in another image, become nodes and weaker peaks in the neighborhood of accepted nodes are removed from consideration.

Once the epipolar geometry has been determined for each point in image , the line in the image 2 can be found on which the same 3D feature is located. Once conjugate points are found with subpixel precision, they are triangulated in 3D space. Some outliers (incorrect matches) can be immediately detected, e.g., a negative Z coordinate signals an outlier. The remaining inliers are used to construct a TIN (with Delauney triangulation) (Figure 5-13).

Water Column Mapping

While fisheries sonars have imaged the water column for some time, this capability is new to multibeam sonars. 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 and these tools proved extremely valuable in our efforts to map the deep oil plume and monitor the integrity of the Macondo well-head during 2010's Deepwater Horizon crisis (see the 2010 annual report for a full description of our activities related to Deepwater Horizon). Our demonstration of the viability of using sonar systems for mapping natural gas seeps and leaking well-heads in the Gulf of Mexico during the Deepwater Horizon spill have led to several follow-up studies aimed at attempting to move these techniques from qualitative descriptions to quantitative techniques.

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

Immediately following the Deepwater Horizon explosion and leak of the Macondo well head, we proposed the use of a 30 kHz multibeam sonar with water column mapping capability (Kongsberg Maritime EM302) as a potential tool for mapping deep oil and gas spill and monitoring the well head for leaks. At the time of the spill, such a system was not available (the *Okeanos Explorer* equipped with an EM302 was deployed in Indonesia) and thus we used 18 and 38kHz fisheries sonars. These sonars proved very effective at identifying gas seeps and leaks but have limited areal coverage and limited spatial resolution as compared with the multibeam sonar. In August/September 2011, we finally had the opportunity to bring NOAA Ship *Okeanos Explorer* to the Gulf of Mexico in order to test the EM302 water column mapping capability for detecting and characterizing methane gas

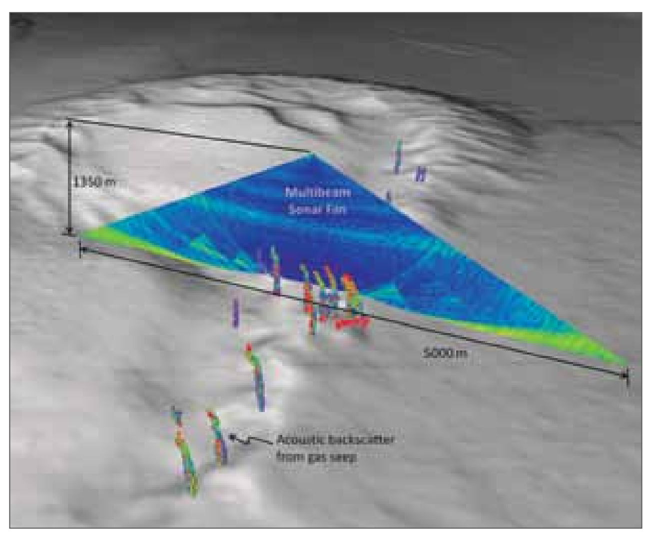


Figure 5-14. Seeps imaged with the EM302 on the *Okeanos Explorer* on Dauphin Dome in the northern Gulf of Mexico. The blue dots indicate locations of seeps.

seeps. We also carried out comparisons against data collected with a Simrad 18 kHz EK60 split-beam echo sounder (a system known for finding seeps in the Gulf of Mexico) which was purchased and installed on the *Okeanos Explorer* for this cruise. During this relatively short cruise (less than two weeks of active mapping), a Center team led by Tom Weber and including Jonathan Beaudoin, Glen Rice, Kevin Jerram and Maddie Schroth-Miller mapped 17,477 km2 of the northern Gulf of Mexico making 573 seep observations (some of which were repeat observations of the same seep) with the EM302. Working in 1200-2500 m water depth, Weber developed seep detection algorithms while Beaudoin developed software that allowed the precise geolocation of the targets for presentation in a 3D context. We found that we were able to most reliably detect seeps over a swath that was approximately twice the water depth (Figure 5-14); at farther ranges reverberation from the seafloor tended to dominate the return from the seep, significantly reducing the likelihood of detection. The results from this cruise demonstrate a new midwater mapping technology for the *Okeanos Explorer*, and also suggest that widescale mapping of seeps in the deep Gulf of Mexico—an objective that is important for both scientific and industry management perspectives—is viable. This cruise also resulted in a NOAA press release: **www.noaanews.noaa.gov/stories2011/20110915_okeanosexplorer.html**.

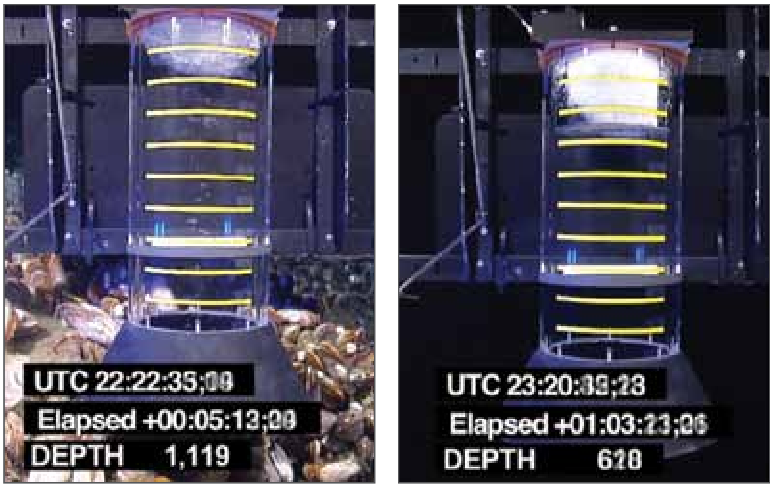


Figure 5-15. A methane capture device used to assess methane flux from a seep in the Gulf of Mexico. Note the hydrates forming in the top of the cylinder, which dissociate to form gas and water as the ROV rises to shallower depths and warmer waters.

In 2012, we followed up these studies with another program on the *Okeanos Explorer*. In April 2012, Tom Weber, Larry Mayer and Kevin Jerram, guided the science (from shore) behind ROV dives aboard the *Okeanos Explorer* aimed at groundtruthing the midwater acoustic mapping efforts. Center involvement led to the development of a direct methane flux measurement device (Figure 5-15), which was successfully deployed during the cruise from Little Herc (thanks to some outstanding engineering efforts by the NOAA Office of Ocean Exploration (OER) ROV team), as well as a calibrated bubble grid aimed at measuring bubble sizes and some general methane gas seep exploration using EM302 and EK60 data as acoustic 'guides' for the ROV expeditions. Data collected during this cruise has greatly increased our ability to properly interpret and analyze acoustic data collected during midwater mapping expeditions in the same area. Work is currently underway to measure the flux of gas from a seep using both optical and acoustic methods. Work also continues to establish rigorous seep positioning algorithms using EK60 split beam echo sounders (master's degree research of Kevin Jerram), and to establish automated methods for detecting seeps in EM302 midwater data.

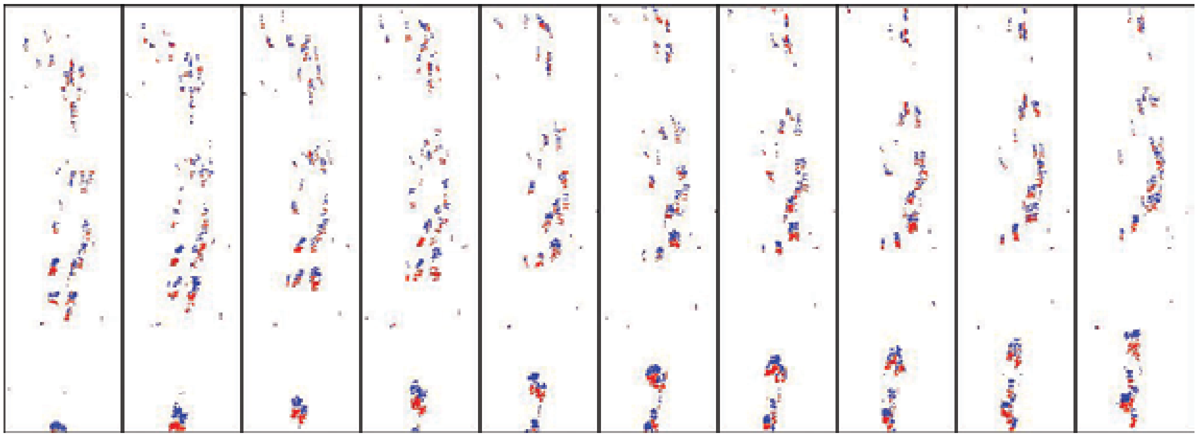


Figure 5-16. Formation and rise of bubbles from a seep: ten consecutive difference frames. Red pixels show locations where bubbles exist in the previous frame; blue in the next one.

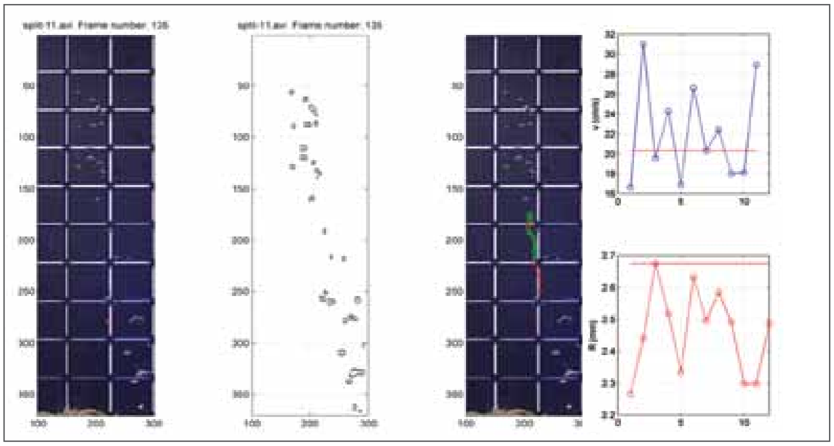


Figure 5-17. Imagery of bubbles rising used for analysis of rise rate and bubble diameter.

The primary focus of Kevin's research is to improve visualization of the plume and positioning of the seep source on the seafloor by integrating all available vessel attitude and sound speed data with raw echosounder data and employing attitude compensation and refraction correction methods similar to those of multibeam echosounder processing routines. As with multibeam echosounders, estimates of installation offsets of the transducer relative to the vessel inertial navigation system (usually determined by 'patch testing') are of critical importance for accurate positioning; one recent effort has been the development of a 'patch test' methodology for the EK60 using simultaneous seep observations in the aforementioned (and 'patch test calibrated') Kongsberg EM302 multibeam echosounder.

In some cases, the combined effects of seafloor relief, layers of benthic fish, and wide footprint of the EK60 on the seafloor cause ambiguity in acoustic observations of the bubble trail near the seafloor; estimates of seep base position are thus made by extrapolating the plume trail through the high-uncertainty near-bottom layers to the seafloor using signal-to-noise (SNR) values for plume targets and a linear least-squares best-fit estimator. The MATLAB routines developed for this processing will be used to determine spatial and temporal variability in the base positions of seeps observed repeatedly during *Okeanos Explorer* cruises EX1105 and EX1202.

Another component of this effort is the development by Yuri Rzhanov of techniques to determine the size and rise rate of bubbles recorded by the ROV cameras during the *Okeanos Explorer* experiment. Bubbles seeping from the seafloor need to be quantified in terms of size distributions, total amount of gas seeped, rise speed, etc. Gas bubbles have two distinct characteristics; they have a round shape and they are rising. In stationary setups the second characteristic can be formulated more simply: "bubbles are moving." However, this is not true in most examples of video clips at the Center's disposal because the camera is often also moving with respect to the imaged area. Hence the detection of bubbles begins with the stabilization of imagery by a pair-wise registration of sequential frames, warping the second frame to the image space of the first and calculating the pixel-wise difference between the first and warped second frames. Stationary (or stabilized) features give zero difference, whereas non-compensated features (like bubbles, representing a very small portion of all detected salient features and thus not affecting the stabilization procedure) stand out as positive (where bubble appears in the first frame and not in the second), or negative (the other way round).

Figure 5-16 shows the sequence of difference images created from ten consecutive frames (each separated by 20 dropped frames so that the sequence covers around 7 seconds).

The detailed measurements of bubble size, rise rate (Figure 5-17) and acoustic backscatter are currently being analyzed to attempt to relate acoustic backscatter to gas flux.

Mid-Water Mapping of Atlantic Bluefin Tuna Using Multibeam Echosounder and Photographic Imagery

Traditionally, the abundance of juvenile bluefish tuna (part of an important fishery) is determined by estimates made by pilots in spotter planes. In collaboration with Molly Lutcavage of the University of Massachusetts and Mike Jech of NOAA, we have been exploring approaches of using both sonar and imaging techniques to provide more quantitative estimates. Graduate student Maddie Schroth-Miller, under the supervision of Tom Weber, has been analyzing Reson 7125

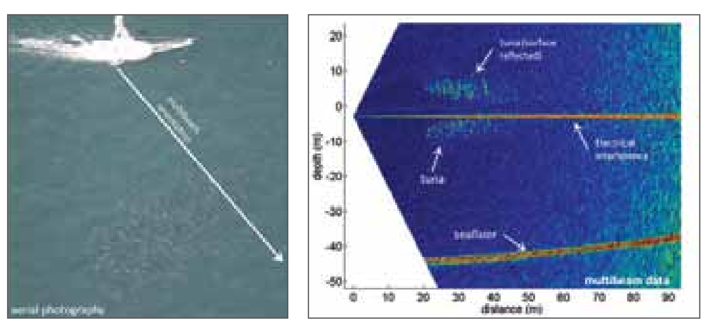


Figure 5-18. Orientation of 400 kHz multibeam sonar for tuna sounding (left) and an example of a single ping (right).

(400 kHz) multibeam data of Atlantic Bluefin Tuna fish schools to help develop a method for determining fish spacing, school size, school morphology, and most importantly, fish number density (funded by the Northeast Consortium). The data was collected in August 2009 and the fish of interest were juvenile Northern Atlantic Bluefin Tuna (*Thunnus thynnus*). The multibeam sonar was oriented on the F/V *Lilly* in such a way as to ensonify a vertical slice of the water column where tuna may or may not have been present. (Figure 5-18).

The bulk of Maddie's thesis work is focused on developing a method of using the multibeam sonar data to determine fish density. She applied a method described by Denbigh (1991) to look at the normalized second moment of intensity of the images to estimate fish number and comparing it to a method developed that includes noise contributions. Example outputs of the two methods are presented in Figure 5-19.

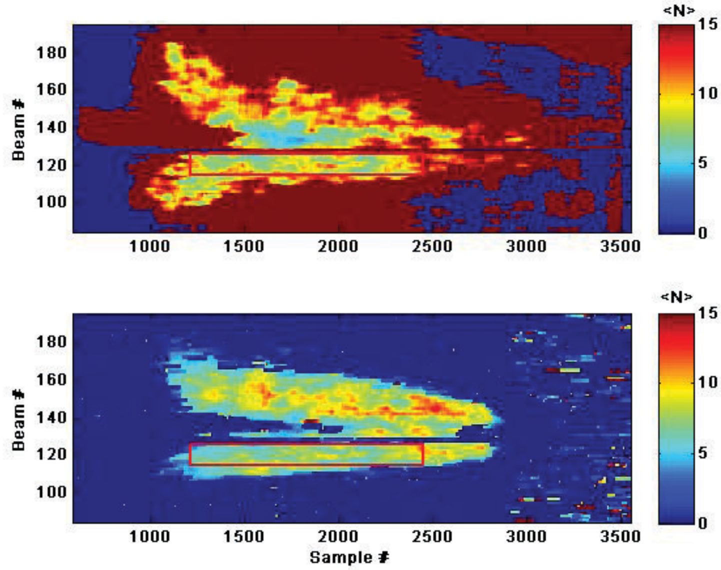


Figure 5-19. Estimate for the average number of fish from two different models.

In concert with the acoustic techniques, Yuri Rzhanov is working on ways to detect bluefin tuna schools in the photographs taken from an airborne platform and process the acquired images to provide counts of individual organisms, estimates of their size, depth, and size and shape of the whole school. Automatic detection of tuna juveniles in an aerial imagery remains a challenge due to the highly irregular appearance of fish bodies, depth variability in their location and clutter factors such as sun glint and white caps. Recently, a combination of processing steps was found that is able to detect most of the organisms distinguished by a human operator. An image of a tuna school is shown on the left of Figure 5-20, while the right side shows outlines of detected organisms.

Although the result appears to be satisfying, some portion of organisms remain undetected. It is still unclear whether the detection rate can be improved by the choice of a more suitable matched filter, by more sophisticated adaptive thresholding, or by the inclusion of other processing steps. This year, the flight team collected imagery of leatherback turtles, sharks and other large organisms, and automatic algorithms for detection of these organisms are being developed.

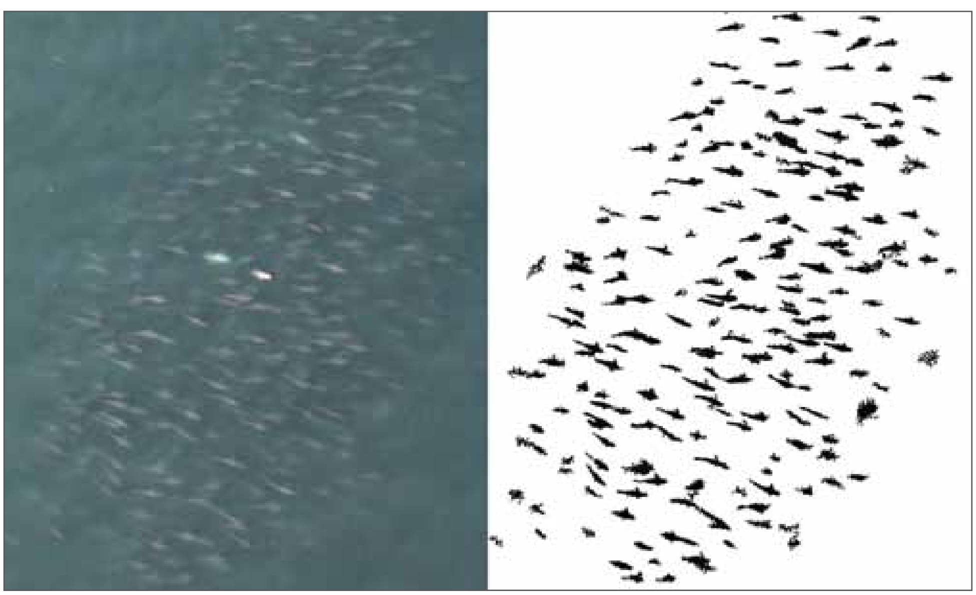


Figure 5-20. Original photo frame and automatically detected fishes.

Theme 4 :: IOCM

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

A critical component of the Center's new proposal is to maintain an Integrated Ocean and Coastal Mapping Processing Center that will support NOAA's new focused efforts on Integrated Ocean and Coastal 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 while, conversely, establishing ways to ensure that data collected for non-hydrographic purposes (e.g., fisheries) will be useful for charting. Our plan is to invite NOAA employees from several different NOAA lines and divisions (NOS Coast Survey, Sanctuaries, Fisheries, Ocean Exploration, etc.) to the new Center and have them work hand-in-hand with our researchers to ensure that the products we develop at the Center meet NOAA needs. The NOAA employees will develop skill in the use of these products so that they can return to their respective divisions or the field as knowledgeable and experienced users. Eventually, we envision that nine to eleven NOAA employees will be assigned to the IOCM Processing Center.

In 2012 our IOCM efforts focused on collaborations with the Office of Coast Survey, Office of Ocean Exploration and Research, National Marine Fisheries Service and with NOS's Marine Modeling and Development Office. Representing the Office of Coast Survey at the Center, LTJG Glen Rice has partnered with a number of Center staff members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. In addition, Glen provides a direct link when specific operational difficulties arise in the field, allowing Center personnel to take part in designing an appropriate solution.

Backscatter from Hydrographic Vessels

Center efforts to generate high-quality backscatter data (from NOAA vessels *Oscar Dyson* and *Fairweather*) in direct support of IOCM efforts have been described in the HABITAT Theme (the work of Jodi Pirtle and Tom Weber using *Oscar Dyson* data) and in the Backscatter section of the PROCESSING Theme (the work of Jonathan Beaudoin to correct *Fairweather*-derived backscatter data). In 2011 the Center more than exceeded its IOCM deliverables, producing more than 100 square nautical miles of backscatter imagery for part of the Olympic Coast National Marine Sanctuary survey conducted by NOAA Ships *Fairweather* and *Dyson* to meet the NOAA milestones. In 2012, while the IOCM deliverable was another 100 square nautical miles, the Center was able to deliver 352 square nautical miles of processed backscatter imagery from the *Oscar Dyson*. As a result of lessons learned from this effort, Glen Rice has created a new set of Standard Operating Procedures for use by the NOAA hydrographic field units and branches for the acquisition and processing of backscatter data. These were presented at the 2012 NOAA Field Procedures Workshop. Glen has also used the lessons learned from tank calibrations of the Reson 7125 sonar (Sam Greenaway's thesis work) to create a backscatter saturation monitor that will help field teams ensure they collect backscatter data that remains within calibration parameters. As described below, this has been put into practice in the fleet.

The collection of quality backscatter data from Office of Coast Survey hydrographic multibeams is a primary focus for the NOAA Integrated Ocean and Coastal Mapping effort. This includes the acquisition of useful backscatter data with all the information needed for post processing as well as a streamlined workflow to quality check the data acquired. This also supports preliminary products for advertising data availability because many past projects had no backscatter included.

The limited dynamic range of the Reson 7000 series multibeam, commonly in use in the NOAA hydrographic fleet, combined with typical sonar operation procedures often leads to irrecoverable degradation to the received acoustic signal that results in artifacts in the final backscatter products. LT Sam Greenaway suggested during his graduate work at the Center that a monitor for multibeam receiver saturation could be implemented to improve backscatter collection. Recent progress in the implementation of such a tool has resulted in a field-deployed tool with initial qualitative results.

To implement a monitor for echosounder receiver saturation, an intuitive display comparing the real time receiver measurements relative to the saturation point must be provided to the sonar operator. This requires communication with the multibeam sonar for real time data and an understanding of the receiver saturation as a function of multibeam settings. Building on previous work to automate Greenaway's method for obtaining a saturation curve in the field, Glen Rice has created a saturation monitor that allows for the collection and processing of the data to extract and save a saturation curve from either frequency of the Reson 7125 or the Reson 7111. The monitor then compares the appropriate curve to incoming data so the operator gets real-time feedback on the state of operation of the system (Figure 6-1).

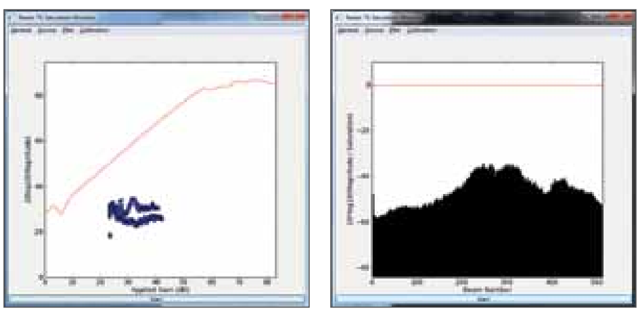


Figure 6-1. The Saturation Monitor Display.

At the beginning of the 2012 field season, the saturation monitor was distributed through Pydro (NOAA's Hydrographic Systems and Technology Program's data processing application) to NOAA field units. Updates for improved saturation curve processing and residual sonar data feeds have also been provided through the established Pydro update process. Documentation is now distributed with the application and is updated with improvements as they are made. Field unit success has varied, but successful use has been reported aboard NOAA Ships *Nancy Foster*, *Thomas Jefferson*, *Ferdinand Hassler*, and *Rainier*. Qualitative observations indicate that power settings are lower and gain settings higher with a decreased frequency of bathymetry misdetections. In noisy environments maintaining consistent bottom detections can be more difficult. Most significantly, settings can be changed during survey operations for improved bottom detection without creating backscatter artifacts, a practice that was previous problematic because the echosounder was operated in a saturated state (Figure 6-2).

Research interests in the saturation monitor could also impact how new systems are accepted and old system performance is measured. Inter-year and inter-vessel comparison of the saturation curve could be an indicator of sonar properties. The infrastructure of the saturation monitor has also been leveraged to record and process element level data, a possible indicator of system health. Through this kind of tool we believe that our understanding of hydrographic multibeam sonars is expanding and data quality is improving.

An effective workflow for quality checking backscatter has also been established. The missing link between the NOAA hydrographic workflow and a solid backscatter processing algorithm was developed in 2012 through Fledermaus GeoCoder Toolbox plug-ins (see DATA PROCESSING Theme). This workflow combines bathymetry from CARIS HIPS with raw backscatter files collected from a number of sources. While improvements to this backscatter workflow continue to be implemented, a procedure and introductory training has been provided to the NOAA hydrographic branches.

Bathymetry from the NOAA FSVs - SEFIS Red Snapper Habitat Work on *Pisces*

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

This year also saw an IOCM success on the NOAA Fisheries Vessel Pisces where Center-developed algorithms to extract bathymetry and backscatter data from the ME70 proved extremely useful to the NOAA teams conducting a Red Snapper stock assessment.

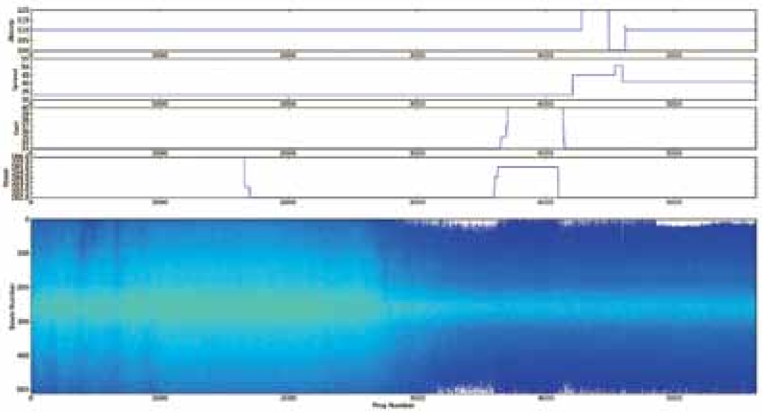


Figure 6-2. Changing multibeam settings with no changes to backscatter in unsaturated system. The saturation monitor continues to improve with field use and user feedback. Reson has expressed interest in implementing a similar approach in future systems, and Hypack and QPS have expressed interest in implementing this tool for current systems.

In late July, NOAA physical scientist and Center graduate student Matt Wilson, along with Jonathan Beaudoin, and Glen Rice embarked onboard the NOAA Ship *Pisces* to install Center-developed bottom detection algorithms into the workflow of the ship's Simrad ME70 and outlined a new workflow for producing bathymetric and backscatter products from the ME70. The new workflow took the raw data output from the ME70 into FMGT (Fledermaus GeoCoder Toolbox), provided corrections to the data, and produced GeoTIFFs of both multibeam bathymetry and backscatter images (Figures 6-3) in near real-time. Using these products, NOAA fisheries scientists were able to quickly and accurately identify areas of Red Snapper habitat suitable for setting their traps. Trap locations were identified using both bathymetry (e.g., ledges and other areas of relief) as well as backscatter (areas of hardbottom) providing complementary data that was, according to scientists aboard the ship, 'invaluable in helping accomplish our trapping objectives on this trip.' The standardization of a setup and workflow will benefit the science teams unfamiliar with these systems as well as secondary users of the collected data. The development of follow up documentation for the rest of the FSV fleet is currently underway.

While the Center has developed protocols for the collection of bathymetry from the fisheries sonars, the regular collection of bathymetry and backscatter data from the NOAA FSV ME70s, continues to be a challenge. The primary hurdles still to overcome include proper integration and setup of the system, collection of supporting sound speed profiles, and having the system turned on and logging data during each cruise. Each of these obstacles can be overcome, but in each case some level of buy-in from both the science team and the personnel aboard the ship needs be established.

Collaborations with OER

In 2012, the Center continued to provide support for NOAA OER employees Meme Lobecker, and Adam Skarke in their work supporting the *Okeanos Explorer* and the Ocean Exploration program. In 2012, Meme led or participated in four cruises on NOAA Ship *Okeanos Explorer*. Two cruises, EX1201 and EX1204, focused on exploration of U.S. Atlantic canyons as part of OER's Atlantic Canyons Undersea Mapping Expeditions multi-year effort. Once completed this program will produce full bathymetry, bottom backscatter, and water column backscatter mapping coverage of the entire network of canyons on the U.S. Atlantic Margin from South Carolina to the U.S.-Canadian border. This mapping extends from canyon heads at the inshore shelf break seaward to previous Extended Continental Shelf mapping coverage offshore (see LAW OF THE SEA Theme below). These missions included collaboration with NOAA Ships *Ferdinand R. Hassler* and *Henry B. Bigelow.* The data collected will be used for a multitude of purposes, including habitat modeling by NOAA National Marine Fisheries Services; the Bureau for Ocean Energy Management, and Mid-Atlantic state regional partners for coastal zone management.

Additionally, Lobecker participated in a two telepresence-enabled missions, including EX1202 Leg 2

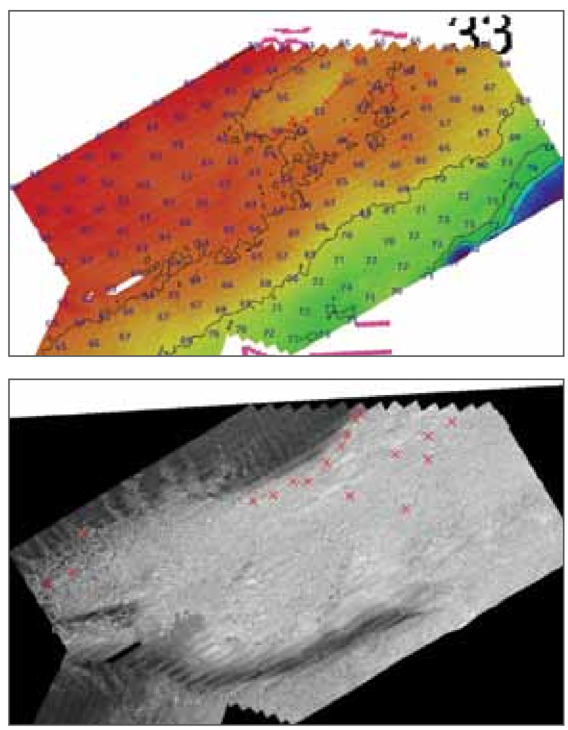


Figure 6-3. Bathymetry and backscatter mosaic used to determine areas of hard-bottom for optimal trap locations. Red "Xs" mark actual spots of trap drops.

in the northern Gulf of Mexico exploring seeps and deep water coral with the Little Herc ROV, and EX1205 Leg 2 exploring the Blake Ridge Diapir complex using the Sentry AUV. Exploration dive targets for both Little Herc and Sentry were determined based on analysis of Kongsberg EM 302 water column and bottom backscatter data to find anomalies worthy of focused exploration.

Adam Skarke also served as cruise mapping lead/expedition coordinator on the *Okeanos Explorer* for four cruises. He was responsible for operating the vessels hydrographic survey equipment, as well as managing shipboard data acquisition, processing, and storage. When not at sea, Adam was responsible for *Okeanos Explorer* data archival procedures as well as the development and production of advanced mapping products. Included in these activities were collaboration with Jonathan Beaudoin in the implementation of Jonathan's SVP Server on the *Okeanos Explorer* (see discussion under PROCESSING Theme), and working with Kevin Jerram and Tom Weber mapping seeps in the Gulf of Mexico as part of the *Okeanos Explorer* Cruise EX1202.

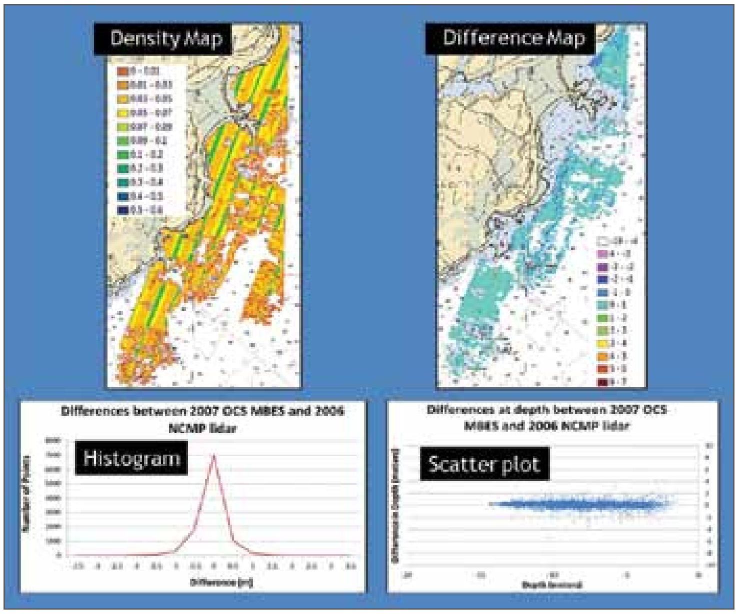


Figure 6-4. Statistical results on the National Coastal Mapping Program (NCMP) dataset over Kittery, ME. (Top left) Density map of laser measurement in laser measurements per square meter. (Top right) Difference map between NCMP lidar survey and NOAA Office of Coast Survey (OCS) multibeam survey. (Bottom left) Histogram plot of the depth difference values between the NCMP and OCS datasets. (Bottom right) Scatter plot of the depth difference values between the NCMP and OCS datasets as a function of depth.

All data collected on the *Okeanos Explorer* were processed in near real time and updated daily, and mapping coverage was publically provided through the *Okeanos Explorer* Digital Atlas at **www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm**. The telepresence console at the UNH/JHC was utilized throughout the year. Through this medium, Center scientists provided technological and scientific support to shipboard scientists throughout the *Okeanos Explorer* field season.

The Center also continued to provide support for the further development of the Ocean Exploration 6000 m ROV system. In 2012, the Center provided a secure work facility, engineering and machining support and the use of our acoustic test tanks for testing components. Progress on the ROV is reported under the FACILITIES section.

Nearshore Bathymetric Estimation from Lidar-based Airborne Imagery

While many issues still remain regarding the use of using Airborne Lidar Bathymetry (ALB) data for hydrographic purposes (see the SENSOR Theme), there is no question that this approach provides the potential for the rapid collection of bathymetric data collection in very shallow water where traditional multibeam sonar surveys are least efficient. The Center is collaborating with NOAA in investigating the use of existing third party lidar bathymetry data from the U.S. Army Corp of Engineer's National Coastal Mapping Program (NCMP) and other non-NOAA ALB sources. The goal of this research is to analyze the potential to apply the ALB portion of non-NOAA shallow bathymetric lidar data to NOAA charts, including filling in the data gap shoreward of the Navigational Area Limit Line (NALL), which is currently those areas outside of 0-4 m depth. The research will start with the comparison of third-party ALB data to NOAA-derived bathymetric data in places where both exist (Figure 6-4). This research will also analyze, though to a lesser extent, the potential of applying these data to nearshore areas ranging from 4-10 m and those deeper than 10 m. In doing so, it will be necessary to understand the USACE NCMP and other outside ALB source standards and operations to compare and evaluate the quality of these datasets to NOAA and international hydrographic survey standards. The study is being conducted by Gretchen Imahori, who is on detail with the NOAA National Geodetic Survey (NGS), in collaboration with Christopher Parrish and Shachak Pe'eri. The procedure may be adapted in the future for working with ALB systems acquired by NOAA for shoreline mapping and integrated ocean and coastal mapping (IOCM) programs.

Theme 5 :: Visualization

New and Innovative Approaches for the 3- and 4D Visualization of Hydrographic and Ocean Mapping Data Sets, Including Better Representation of Uncertainty, and Complex Time- and Space-Varying Oceanographic, Biological and Geological Phenomena

We continue a very strong focus on the development of innovative approaches to data visualization and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team (Arsenault, Plumlee, Sullivan, Pineo, Schwehr and Butkiewicz), under the supervision of Lab Director Colin Ware, have produced a number of novel and innovative 3D and 4D visualization tools designed to address a range of ocean mapping applications (see earlier Annual Reports). This year, great progress has been made in the development of a new interactive 3D/4D visualization environment specifically designed to help oceanographers and biologists interpret complex data from a variety of sensors and models and the teams research into better symbology has resulted in an exciting new way to display wind and wave information on charts.

Interactive Exploration/Visual Analysis System for Complex Time-Dependent Flow and Other Models

Thomas Butkiewicz and Colin Ware continue to refine their advanced flow visualization techniques that are critical for successfully 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.

The various ocean flow simulations currently running are outputting multi-layer 3D datasets, however many oceanographers are still only viewing one depth at a time (typically the effect at the sea surface) with traditional 2D visualization methods. For many survey missions and research projects, however, awareness of conditions across a range of depths is critical. Therefore, developing effective 3D visualization tools is vital to ensuring that end users can extract needed insight from these simulations.

The Center's next generation flow analysis system addresses these needs by providing a dynamic ocean visualization environment that combines stereoscopic 3D display technology, multi-touch interaction, and a variety of visual analysis tools. The stereoscopic rendering provides essential depth cues that remove visual ambiguity, facilitating perception of complex 3D scenes. Multi-touch interaction streamlines the navigational process by allowing for a wider variety and range of motion than traditional mouse/keyboard interfaces,

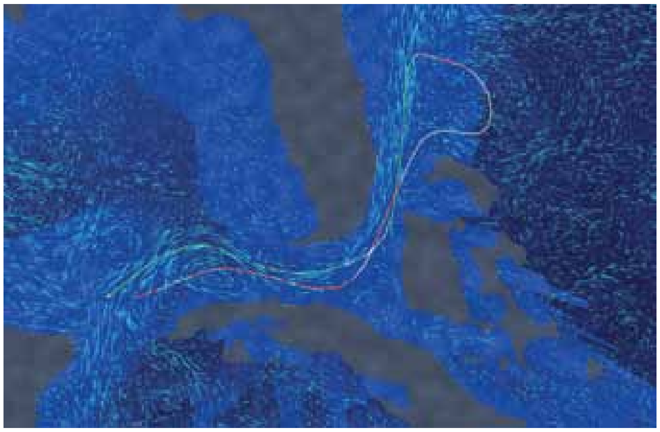


Figure 7-1. AUV mission planned within 4-D flow model. Color-coding on path represents AUV energy usage.

and provides the intuitive ability to directly select and manipulate onscreen objects. Interactive tools permit complex visual analyses to be performed within the context of the ocean model in an exploratory fashion. One does not need to rigidly define exactly what or where they wish to investigate. Instead, one can rapidly experiment by adjusting locations and parameters until a desirable result is achieved.

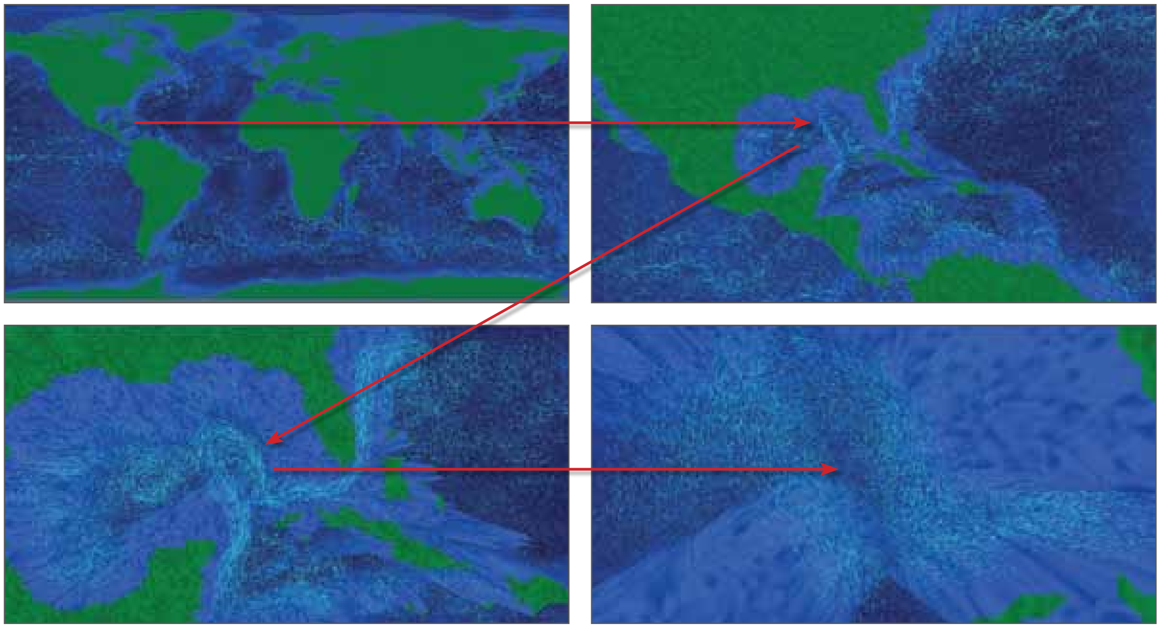


Figure 7-2. Seamless zoom from global to Gulf of Mexico.

Example analyses that can be performed within the system include simulating pollutant releases by releasing particles configured with specialized behaviors such as vertical movements induced by density differences (e.g., spills or leaks of oil or other contaminants) and decay over time. Habitat mapping can be supported by modeling larval transport, etc., in this manner. Planning survey missions for autonomous underwater vehicles can be enhanced by the context of the forecasted flow conditions. Imported or multi-touch plotted pathlines can be automatically evaluated against the surrounding flow patterns, resulting in energy efficiency estimates along the pathline (Figure 7-1). Paths can then be adjusted to avoid areas of resistance. Through this process, a survey mission can cover more area with the same energy budget.

In February 2012, Colin Ware visited Hendrik Tolman, the Branch Chief of Marine Modeling and Analysis National Centers for Environmental Prediction (NCEP) in Camp Springs, MD. The result is an agreement to collaborate on adapting the 3D environment so that it can display the global Real Time Ocean Forecast System (RTOFS) model (a very high-resolution ocean flow model) and in this context show Argo float and glider data. In order to do this, over the last year, the core components and code supporting the system were significantly redesigned and rewritten in order to support the loading of significantly larger RTOFS results and other large and more complex datasets, as well as to address some of the various challenges that arise from increases in scope and size. The original application was designed to handle moderately sized

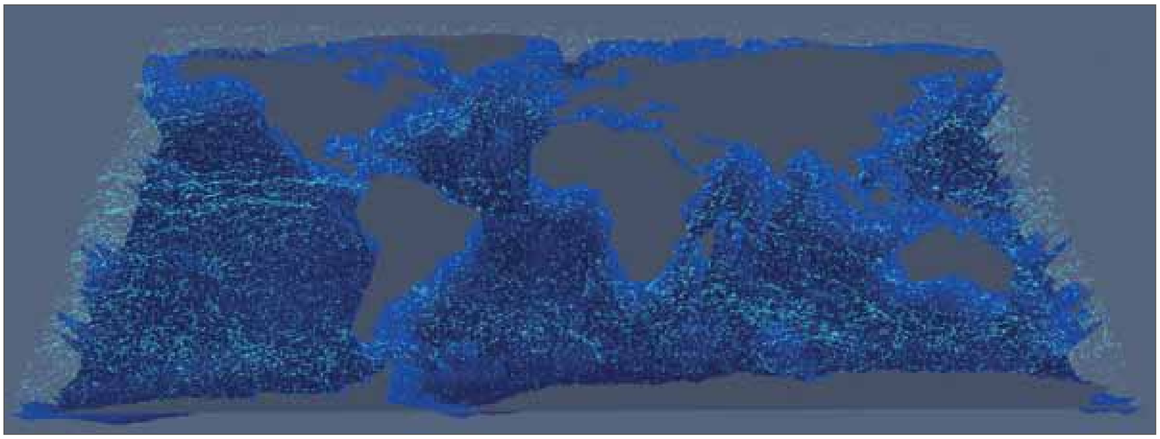


Figure 7-3. Global RTOFS model.

flow models, notably the U.S. Naval Operational Global Ocean Model (NCOM) regions. For example, the NCOM North Atlantic regional model most commonly used was 561 (latitude) x 401 (longitude) x 34 (depth layers) = 7.6 megavoxels. When looking to expand capabilities to handle larger models, such as the RTOFS Global model, significant changes needed to be made. The RTOFS Global model for example is 3298 (latitude) x 4500 (longitude) x 33 (depth layers) = 489.7 megavoxels, more than 64 times the size of the NCOM regional model. Each timestep requires more than 8 gigabytes of disk-space for just the four critical variables (U andV vectors, temperature, salinity). This increase in data size required significant modifications to the application.

To address the needs of handling larger flow models, the application was ported to a 64-bit environment, which allowed full utilization of the available system memory (32-bit is limited to 3.4 GB per system and ~1.5GB per application, whereas 64-bit is currently limited only by hardware, currently at ~32GB). The core data handling functions of the system were re-written to accommodate the larger flow models. Even with a larger amount of memory now available, it is often impractical and unnecessary to load the entire model into memory at full resolution. After much experimentation with various methods of model representation (which has benefited other researcher's efforts) a compromise on speed and accuracy was found. During initial loading, the full-size model is examined, and a slightly lower resolution model is generated to match the entire bounds of the model. During run-time, the user can then select regions within the flow model that they are most interested in and the system will automatically load the full, highest resolution data available for that location. While the different resolutions can be seen on demand, the distinction is generally hidden from the user; that is, illustrative particles and calculations seamlessly flow between data grids at differing resolution.

An additional benefit of the new data handling methods is that they can accommodate and transform data in many different forms. Previously, the application only worked for flow data contained in a regular grid form. This was a problem for models such as the NOAA Operational Forecast Systems (e.g., DBOFS, CBOFS, etc.), that store their data in curvilinear grid form (which concentrates horizontal resolution in narrow areas) and use sigma-based depth layers (which concentrate z resolution in shallow areas). RTOFS uses a hybrid format with a standard Mercator projection south of 47N, combined with an Arctic bi-polar patch covering the area north of 47N. This flexibility could even allow for the fusion of flow data from multiple simulations, for example a high-resolution estuarine model that empties particles into a global model.

Because of the extreme range of zoom levels at which these global models can be viewed, the existing method for converting particle positions into visual streaklets was no longer sufficient. What looked good at a fully-zoomed out global view, looked scattered and lacked detail when zoomed-in, and what looked good fully zoomed into an area, looked slow and sparse when zoomed-out. A new view-dependent illustrative technique was necessary. This technique considers the viewing distance at all times and automatically adjusts the number of particles, where they are spawned, their relative speeds, and their visual renderings (e.g., trail length). This allows for a seamlessly informative visual presentation as the user changes zoom-levels within the application (Figure 7-2).

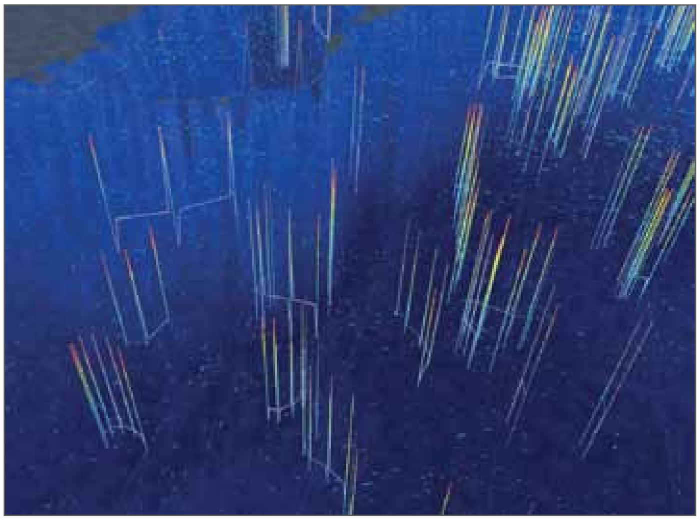


Figure 7-4. Paths of Argo floats in the Atlantic Ocean, showing repeated dive/resurface cycles with observed temperature color coded on their ascent profiles.

Another addition is the introduction of basic multi-threading to take advantage of modern multi-core processors. Experiments within using OpenMP within the new codebase has shown that some tasks can be successfully distributed across the available processing cores. This should allow the program to recalculate the positions of particles at a faster rate, and/or allow it to maintain a greater number of particles at interactive speed.

Comparing Simulation Forecasts with Observational Data

A new analytical feature is the ability to evaluate the predictions within the Global RTOFS forecast model through comparison with collected observational data. This is accomplished by loading the newest profiles and position data from Argo's global network of 3000 autonomous floats. Each Argo float drifts underwater for nine days, and then ascends to the surface while collecting temperature and salinity profiles, which it

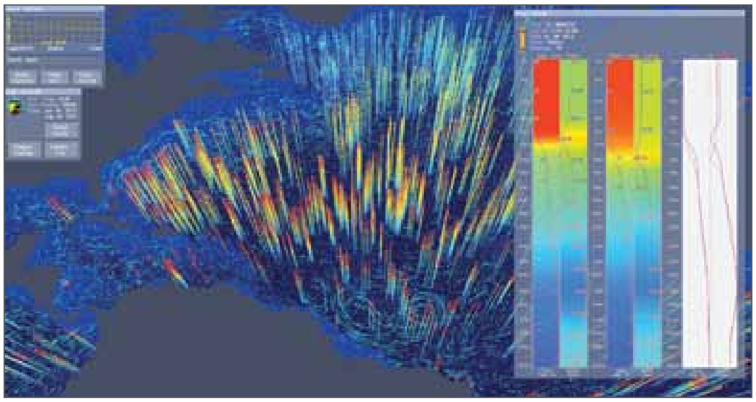


Figure 7-5. Profile explorer window showing the observed and predicted temperature and salinity profiles from an Argo float and the RTOFS model. The rightmost graph plots them against each other to highlight deviations.

transmits along with its current location before diving again. Figure 7-4 shows the 3D paths (with temperature profiles) of a number of Argo floats as they repeatedly dive and resurface over roughly a month.

Analysts can select Argo profiles in the 3D view, which spawns profile explorer windows (Figure 7-5) that present the Argo profile data, along with corresponding profiles automatically extracted from the RTOFS model at the same location. By comparing the observed temperature and salinity values to those in the forecast model, simulation designers can gain critical insight regarding where and how their model succeeds or fails in its predictions. Furthermore, the accuracy of the model's flow forecasts can also be evaluated by comparing the float's observed position data to predicted trajectories generated using the model's forecasted flow vectors. The Argo float analysis is just one example; we envision that this new visualization environment will become a powerful analytic tool for the exploration and evaluation of many types of complex 3D and 4D oceanographic data sets.

Enhanced Flow Visualization Glyphs

Most professional wind visualizations show wind speed and direction using a glyph called a wind barb in a grid pattern. Research into flow visualization has suggested that streamlines better represent flow patterns but these streamlines lack a key property; unlike the wind barb they do not accurately convey the wind speed. With the goal of improving the perception of wind patterns, and at least equaling the quantitative quality of wind barbs, graduate student David Pilar and Ware designed two variations on the wind barb and designed a new quantitative glyph (Figure 7-6). All of our new designs integrate glyph elements with equally spaced streamlines. To evaluate these designs they used a North American mesoscale forecast model. They tested the ability of subjects to determine direction and speed using two different densities in three new designs as well as the classic wind barb. A second experiment evaluated how effectively each of the designs represented wind patterns. The results showed that the new design is superior to the classic, but they also showed that the classic barb can be re-designed and substantially improved. They are currently investigating ways of using the new glyphs to show wave patterns from the WaveWatch III model and current patterns.

FlowVis2D

The FlowVis2D application developed by Colin Ware at the Center has now been an operational part of the NOAA NowCoast portal for more than two years (Figure 7-7). FlowVis2D underwent a major software upgrade by Matthew Plumlee over the summer. The capability to show wind data, and wave data has been added, and transparent layers can now be written. In addition, the quality of the code is substantially improved.

FlowVis2D has been extended to handle new operational forecast system (OFS) models based on the Finite Volume Coastal Ocean Model (FVCOM). This is not straightforward because the model output format for these estuaries is radically different than for the other operational forecast models. Some of the data points are at the vertices of a triangular mesh, some are at the centers. There are now three different data formats being supported just for the OFS models of estuary and great lakes.

Chris Paternostro's group at NOAA Center for Operational Oceanographic Products and Services (CO-OPS) have expressed an interest in using the software to show HF radar and we have developed prototype examples to do this.

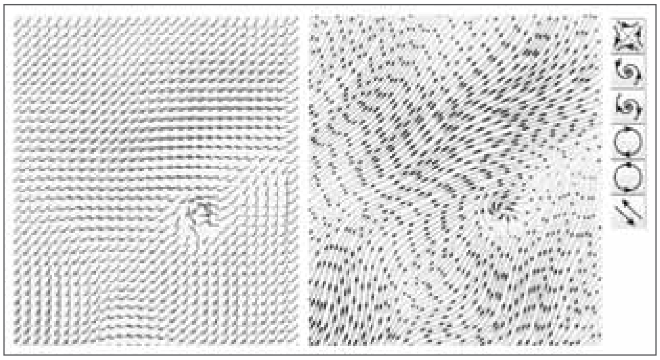


Figure 7-6. A wind pattern shown using the traditional method (left) and using our new method (right). This is part of a study of pattern perception using different portrayal methods.

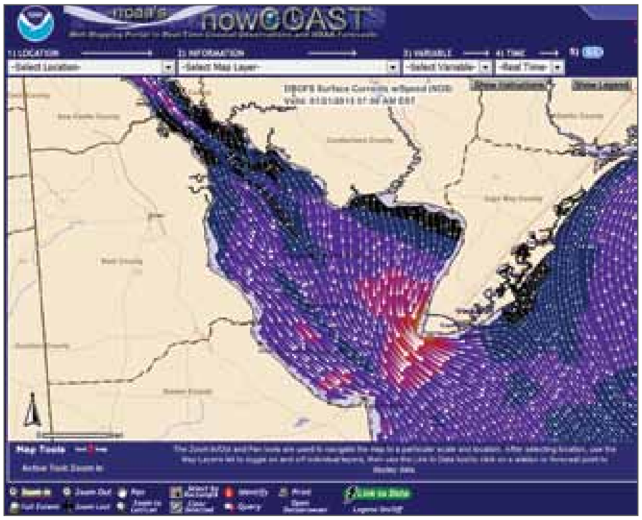


Figure 7-7. FlowVis2D showing new surface currents in Delaware Bay.

Whale Tracking

Over the past few years, we have reported on the exciting work of Ware and Arsenault using GeoZui4D to visualize the underwater behavior of Humpback whales and the applications of this work in support of both basic science and policy decisions. Humpback whales are an endangered species whose decline is attributed to ship collisions and fishing-gear entanglement. NOAA and Woods Hole Oceanographic Institute (WHOI) scientists have developed suction-cup-mounted tags that are attached to a whale that record depth, pitch, roll and sound for as long as the tag remains on the whale. Our visualization team has taken these data and created fully georeferenced 4D displays of the whale's diving and swimming behavior in the context of the bathy-metry, other vessels and ambient sounds. A vessel-tracking component combines digital data from radar and AIS with visual sightings to better understand the effect of vessels on whale behavior. The result has provided unprecedented insight into the diving and feeding patterns of the whales as well as their response to the approach of vessels. Numerous papers on, and demonstrations of, this technology have been presented at both scientific and policy meetings.

Ware has extended this work with the development of TrackPlot, an application designed to help visualize and analyze data from tagged marine mammals (Figure 7-8). It has evolved over the past eight years in close collaboration with marine mammal scientists and has become a significant research tool resulting in a number of journal papers detailing the kinematic behaviors of various species. Development of TrackPlot is ongoing and the user base of TrackPlot continues to expand. It has at least 14 users from different groups and it has been applied to 11 different species. A current effort is to better understand the kinematics of bottom feeding behaviors in humpbacks foraging on Stellwagen Bank. This behavior is interesting because it represents a form of feeding that does not involve lunging and is the first clear documentation of non-lunge feeding behavior in humpbacks. A paper on this topic is has been submitted to the journal *Behaviour*. TrackPlot has now resulted in major publications describing the kinematics of surface (Wiley et al., 2011), Midwater (Ware et al., 2011) and bottom (Ware et al., submitted) feeding by humpback whales.

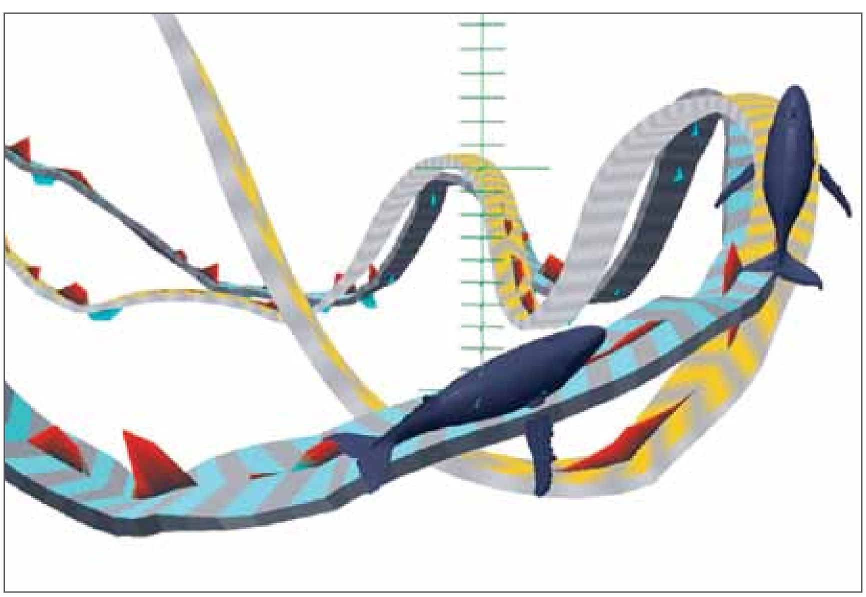


Figure 7-8. Visualization of the tracks of two humpback whales, a mother (orange track) and her calf (blue track).

Ice Coverage Camera—geoCamera

In 2010, the VisLab initiated a new project to use a georeferenced camera to map ice. The idea is to take into account ship attitude, heading and position sensing, combine these with imagery from a digitally controlled camera, and mosaic the result onto an orthorectified image. This system was developed and first deployed on the R/V *Nathaniel B. Palmer* in Antarctica in the spring of 2010. It consisted of a Canon SLR mounted on a digital pan-tilt head attached to the railing on the Palmer's Ice Tower approximately 60 m above the waterline. This project was conducted in collaboration with

Figure 7-9. Starboard geoCamera on the USCGC *Healy*.

Patrick Halpin of Duke University with Roland Arsenault as the primary Center developer. The preliminary results were encouraging. A set of 750 m radius images was created along the path of the ship with minimal distortion. Halpin successfully demonstrated that a supervised image segmentation method could be used to classify ice types (grease ice, brash ice, and consolidated ice).

In 2011, the geoCamera v2.0 was developed and deployed on our Extended Continental Shelf cruise on board the USCGC *Healy* in the high Arctic (see LAW OF THE SEA Theme). GeoCamera V2.0 was developed based on an Axis Q6034-E PTZ Dome Network Camera, an off the shelf security camera capable of operating in cold climates. Camera control as well as data collection and processing was done on a Dell Precision M6300 located in the *Healy's* Future Lab. The camera was installed outside of the Aloft Coning Position (i.e., the crow's nest) on the forward rail at an approximate height of 30 m above the water line.

In 2012, the geoCamera saw its third iteration. Now known as geoCamera 3.0, it is a combination of low-cost, off-the-shelf cameras and custom software designed to capture imagery from a platform equipped with a motion sensor to produce georeferenced maps of the sea surface, in our case, ice coverage. Weaknesses in previous designs were identified and an updated design was specified and developed for deployment during the HLY1202 cruise on the USCGC *Healy*. The major change was going from a single camera with computer controlled pan, tilt and zoom capabilities to multiple fixed cameras. On the *Healy*, an existing fixed camera pointing forward has been operating successfully for multiple cruises, so it was decided to augment that existing camera with two similar side facing fixed cameras (Figure 7-9).The result has been positive and the system is now capable of automatically capturing raw imagery with associated navigation data and produce ice geoTIFF images ready for integration in GIS applications or web based map server systems (Figure 7-10). Typical ranges are 1-2 km to either side of the vessel with pixel resolution of between 4 and 7 m. As can be seen in Figure 7-11, geoCamera is also valuable at identifying marine mammals.

Figure 7-11. GeoCamera image from *Healy* indicating ability of geoCamera to resolve and georeference marine mammals.

There is still room for improvement in the processing of the imagery to produce maps. Proper calibration of the camera position and orientation is one example. The current calibration approach involves matching fixed features seen by the cameras from multiple positions. During the cruise, no such features were seen after the installation of the cameras until our return to port. An ad-hoc calibration using recognizable ice features was used during the cruise and a more precise calibration was done post-cruise.

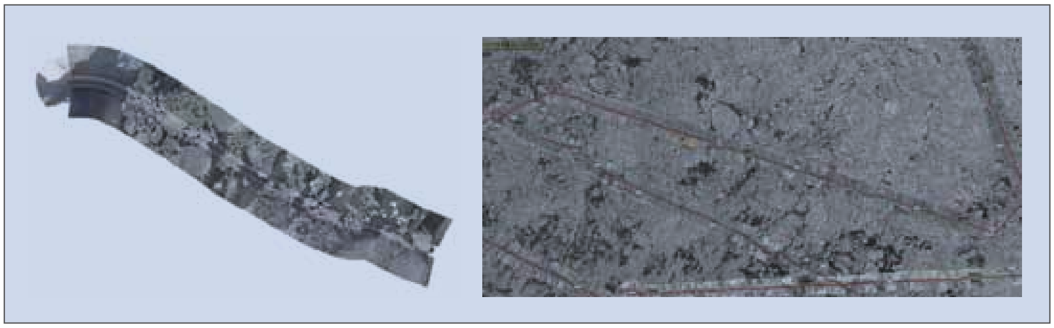


Figure 7-10. Calibrated geoCamera image from *Healy* (left)—swath width approx 3 km, pixel resolution 4-7 m. Right is geoCamera imagery superimposed on Radarsat imagery.

Theme 6 :: Chart of the Future

Developing Innovative Approaches and Concepts for the Electronic Chart of the Future and E-Navigation

The Chart of the Future project is an evolution of the Navigation Surface concept that also takes advantage of our expertise in visualization and data processing. We are taking a two-pronged approach to trying to define the electronic chart of the future. One track of this project is an evolutionary approach to see how additional, non-standard layers (e.g., the navigation surface bathymetric grid, real-time tide information, etc.) can be added to existing electronic charts. This approach requires careful attention to present-day standards and the restrictive constraints of today's electronic charts. This work is being done in conjunction with the standards committees (represented by Center faculty member Lee Alexander) and the electronic chart manufacturers and is intended to provide short-term solutions for the need to see updated electronic charts. In concert with this evolutionary development, we also have embarked on a revolutionary development with researchers in our Visualization Lab exploring new paradigms in electronic chart design, unconstrained by existing standards or concepts. This exercise takes full advantage of the psychology-based human-computer interaction expertise of our visualization researchers to explore optimal designs for displays, the role of 3D, flow visualization, stereo, multiple windows, etc. From this research, we hope to establish a new approach to electronic charts that will set the standards for the future. Throughout this project (both the evolutionary and revolutionary efforts), experienced NOAA mariners are playing a key role, ensuring that everything that is developed will be useful and functional.

Evolutionary

An Electronic Chart Display Information System (ECDIS) is no longer a static display of primarily chart-related information. Instead, it has evolved into a decision-support system capable of providing predicted, forecast, and real-time information. To do so, Electronic Nautical Chart (ENC) data is being expanded to include both vertical and time dimensions. Using ENC data produced from high-density hydrographic surveys (e.g., multibeam sonar), a tidal value can be applied to ENC depth areas or contours at arbitrarily fine intervals. The ENC data is not changed, only the display of safe or unsafe water depending on under-keel clearance of the vessel (a parameter set by the ECDIS user) or changes in water levels (e.g., predicted or real-time values).

Lee Alexander is leading our effort to support current ECDIS and ENCs with new data layers through his work with our Industrial Partners on a prototype "Tide Aware" ENC and his work with US Coast Guard, Canadian Coast Guard, and the International Association of Lighthouse Authorities (IALA), looking at the role that electronic charting will play in the e-Navigation concept of operations. E-Navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment.

As Chair of the IALA Information Portrayal Working Group, Alexander is facilitating a review of existing performance standards for shipborne and shore-based equipment, systems and services that have been adopted by the International Maritime Organization (IMO), International Hydrographic Organization (IHO), and IALA to determine their compatibility with the e-Navigation concept of operation. Particular attention is being given to IMO performance standards on the "Presentation of Navigation-related Information on Shipborne Displays." Criteria for evaluation will be the "Guiding Principles" recently adopted by IMO for Automatic Information System (AIS) Application-Specific Messages (IMO SN/1/Circ.290).

Additionally, Alexander is working with NOAA's John Kelley, to investigate the process and infrastructure required to broadcast NOS and NWS meteorological and hydrographic information to shipborne maritime users in major U.S. ports and coastal areas via AIS Application Specific Messages. A review is being made related to the data contents and parameters that are currently used to convey NOAA PORTS and nowCoast (meteorological and hydrographic) information. Recommendations are being prepared regarding:

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

b) The four basic means of displaying NOAA PORTS meteorological and hydrographic AIS ASMs (alphanumeric; graph; point, line, or polygon; symbol or icon) as specified in the new IMO standard for displaying AIS ASMs (IMO SN.1/Circ.290).

Finally, Alexander is working with Dr. Sanghyun Suh of the Korea Ocean Research and Development Institute to investigate the process required to produce a Dynamic ENC in the Approaches to Asan Man and Port of Pyeongtaek-Dangnin Hang in the Republic of Korea. The production and use of a dynamic ENC is intended to facilitate safety-of-navigation and decision-support for under-keel clearance in a portion of a main shipping channel where significant water level changes occur. The dynamic ENC would be produced from high-density MBES survey data and used in shipborne and shore-based electronic charting systems (e.g., ECDIS) and Portable Piloting Units (PPUs). Real-time or forecast water level information will be broadcast via AIS ASM binary message format. Hopefully, this effort will serve as an example for a similar test-bed to be established for the Piscataqua River and Little Bay, New Hampshire.

Open Navigation Surface

Efforts to standardize formats for the distribution of full-density bathymetric data to be included in ENC's is continuing 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. His role is primarily as facilitator, but he also serves as release manager for the library, and keeps the website updated as appropriate. The Open Navigation Surface Working Group released V1.5.1 on August 20, 2012, and is currently working on the next candidate release (V1.6.0). Version 1.5.1 addresses additional layers for QA/QC purposes. The last development meeting was conducted as a side-meeting to the Canadian Hydrographic Conference in Niagara, ON on May 15, 2012, concluding that release 1.6.0 would include essentially incremental improvements, delaying the major change to a variable resolution surface until the release of CHRT. The standard-compliant version of BAG (IHO S-102) was recently adopted by the IHO as a new standard.

Right Whale AIS Project

The Right Whale AIS Project that the Center has been supporting for a number of years is 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. This year, WhaleALERT—an iPhone app—was developed to augment existing ship navigation tools that inform mariners of the safest and most current information to reduce the risk of right whale collisions.

The Center's role is to aggregate buoy data from Cornell University and sightings and Dynamic Management Areas (DMAs) from NOAA and transmit them via both Automatic Identification System and the Internet using the IMO Circ. 289 Area Notice message format. For many years, Kurt Schwehr laid the ground work for this project. This year, Roland Arsenault took over the management of the Center's infrastructure in January and expanded the system to support DMAs and sightings. To expand the availability of the AIS based notices and to provide a debugging tool while developing and supporting the message transmission, code to display area notices was contributed to OpenCPN, a cross-platform open source chart display application.

Optimal Arctic Projection

With the rapid melting of Arctic sea ice and renewed hydrocarbon exploration in the Chukchi and Beaufort Seas, there is a growing need for updated hydrographic data in the Arctic. NOAA has been called upon to collect these data and in support of these efforts the Center has teamed with Lysondros Tsoulos of the Cartography Laboratory of the National Technical University of Athens (and a former Visiting Scholar at the Center) to explore optimal projections for navigation charts in the Arctic. The fundamental goal of this effort was to find a projection for which the extreme distortions are smaller than would occur in any other projection used to map the same area. An analysis was carried out and the distortion associated with many different projections was calculated and displayed as ellipses of distortion. As a result of this analysis it was concluded that different optimal projections were necessary for Arctic and sub-Arctic regions. For Arctic regions the optimal projections are the Azimuthal Polar Equidistant projection or the Azimuthal Polar Stereographic projection;

Figure 8-1. WhaleALERT iPad display as seen by a mariner approaching Boston Harbor. Credit: NOAA

for sub-Arctic regions, the Lambert Conic Conformal projection or the Conic Equidistant projections are proposed. All of these projections can be used in either traditional nautical charts or ECDIS systems; however, most ECDIS systems do not support these projections and specifications will have to be established for them.

Revolutionary

Within the context of the "revolutionary" effort, Colin Ware, Tom Butkiewicz, Matt Plumlee, Briana Sullivan and Roland Arsenault have been developing specific applications for the Chart of the Future. Many of these capabilities were described in past progress reports; we will only highlight 2012 developments here.

GeoCoastPilot

In 2007, we started a project to create a relatively simple focal point for demonstrating some of the Chart of the Future capabilities in a tangible, testable form that would not be too radical a change for mariners. GeoCoastPilot is 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. We started by asking: "What might a digital application based on the NOAA Coast Pilot look like if other marine data sources were combined with it?" GeoCoastPilot is intended primarily for operators of smaller vessels; those not under the Safety of Life at Sea (SOLAS) regulations. The concept is to design a fully digital and interactive version of the commonly used Coast Pilot books. With such a digital product, the mariner could, in real-time on the vessel or before entering a harbor, 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 geospatial context. Conversely, a click on a picture of an object will link directly to the full description of the object as well as other relevant information (Figure 8-3). GeoCoastPilot turns the NOAA Coast Pilot manual into an interactive document linked to a 3D map environment, providing linkages between the written text, 2D and 3D views, web content and other primary sources such as charts, maps, and related Federal regulations.

GeoCoastPilot introduces two new capabilities to existing marine information products: multiramas and hyperlinks. A multirama is a collection of photos of a landmark or a navigation aid taken from multiple vantage points. The multiamas are situated inside a simplified 3D representation of a port. As a mariner explores the virtual port, only the image that best represents the object from the current virtual perspective is shown. Additionally, the size of an image is exaggerated according to its relevance to navigation, simulating what it might look like to observe with binoculars focused on each important object. This visualization technique helps the mariner become familiar with the relative location of critical navigation-related features within a port before ever going there.

GeoCoastPilot also now includes the ability to deal with maps at multiple scales (this is necessary to implement a larger and more complex geographic region). In 2012, EarthNC became an Industrial Associate of the Center and expressed an interest in pursuing the GeoCoastPilot effort. Through this collaboration, a mobile version of the GeoCoastPilot has been developed enough to showcase new techniques for seamlessly changing from a traditional top down chart view to a first person perspective view. We expect that further development will be done this way.

Local Notice to Mariners

The Local Notice to Mariners (LNM) contains information relating to navigational aids, bridges, construction, local events, and at least 11 other related topics. It is a rich and useful resource for all types of mariners. One of the biggest challenges in working with the LNM is its PDF format. We believe that disseminating this kind of data in an XML format would make it easier to parse

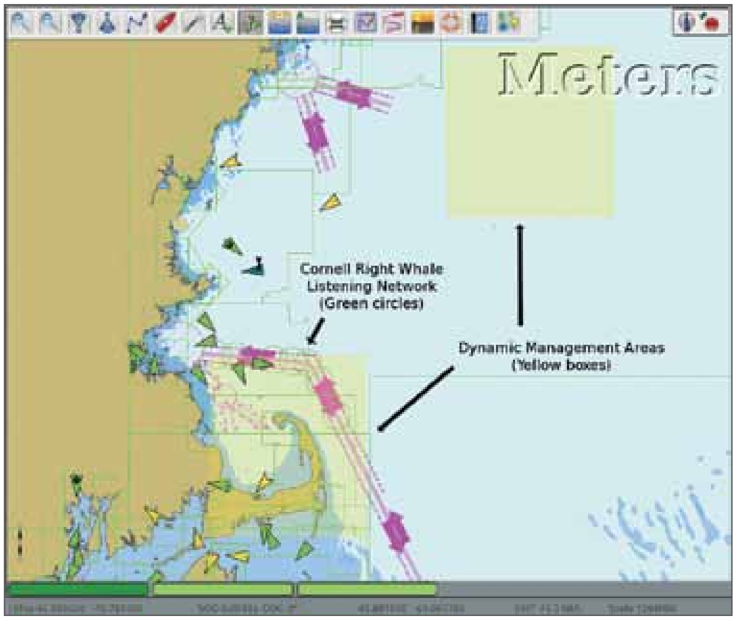


Figure 8-2. OpenCPN showing DMAs and Right Whale Listening Network information received via AIS.

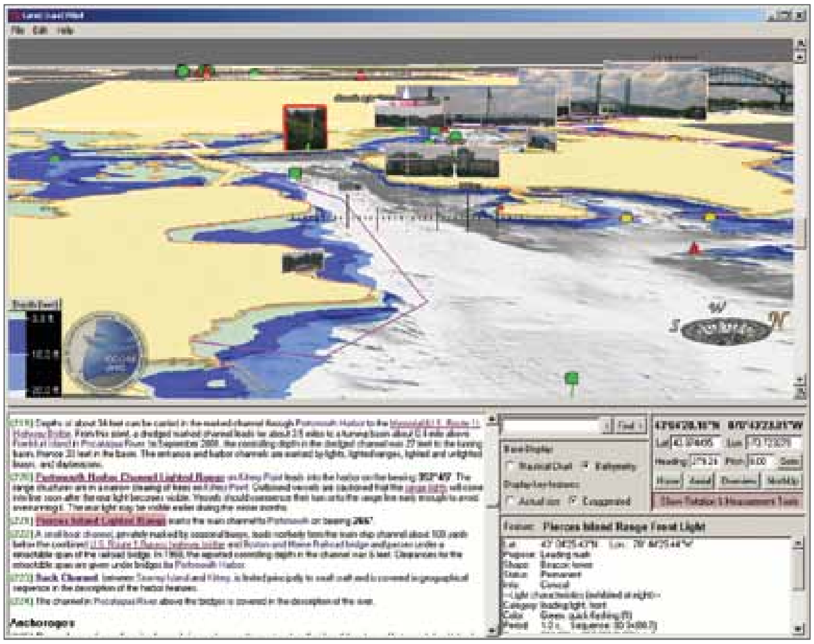


Figure 8-3. Image captured from the "GeoCoastPilot" showing approach to bridge in Portsmouth Harbor.

the data and allow programmers to be able to experiment with creative ways to display the data. To support this vision, Briana Sullivan has been working to create a database system, where changes to aids can be tracked and histories viewed and made available to mariners via the web. Briana has set up a database to store LNMs, imported the entire light list for the Coast Guard First District and began the process of incrementally adding the local notices that are updated weekly online. The database was then used to dynamically generate XML that is easily used by the Google Earth, Google Earth Plug-in and Google Maps interface.

Currently this web application is capable of the following (Figure 8-4):

1. generating a list of nautical chart available within the viewing area of the Google map,
2. showing outlines of all nautical charts available within the viewing area,
3. setting a home button to easily return to a specific location,
4. showing an up-to-date nautical chart (taken directly from the NOAA web server and
5. generated into tiles by the Nautical Chart API from the University of California, San Diego) selected from the generated list of charts,
6. displaying a table of all critical corrections from the Local Notice to Mariners (directly from the OCS website),
7. displaying the critical corrections from the table as markers on the map,
8. displaying notice to mariner data for each marker as an info box on the map,
9. displaying the associated Coast Pilot for the chart selected (using the search feature from the OCS website to find Coast Pilots for specific charts),
10. providing an input box in the chart options that allows for viewing historical notice to mariners,
11. dynamically setting the transparency of the nautical chart and there is a search box that allows for searching of and zooming to geographic locations.

The Local Notice to Mariner project has matured to the point where Sullivan presented it to Craig Winn at OCS in May. He and others from the charting division were given a demonstration of its current cabailities. It is based on the Google Map V3 API and accessible online at **vislab-ccom.unh.edu/~briana/ncapiui-v2/**.

Some of the notable aspects of the critical corrections table are: each column is sortable; the table is searchable (filterable), and it is cross-linked with the markers on the map that will highlight (via a bouncing marker on the map) which marker has been focused on in the table. Each marker displayed in the map is shown depending on the filter set on the table. So, for example, if a filter is entered with the string 'delete' then only the 'delete' markers will appear on the map. The associated Coast Pilot text also generates links for latitude/longitude positions and for geo-coded locations (using Google geo-location service) that will center and zoom the map to the associated location.

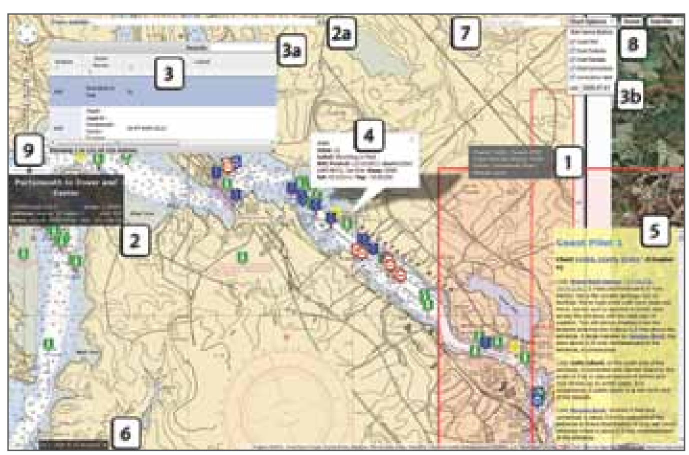


Figure 8-4. Local Notice to Mariner Google Maps Mashup, web application.

Theme 7 :: Law of the Sea

Being National Leaders in the Planning, Acquisition, Processing, Analysis and Interpretation of Bathymetric Data Collected in Support of a Potential Submission by the U.S. for an Extended Continental Shelf Under Article 76 of the United Nations Convention on the Law of the Sea

Growing recognition that implementation of United Nations Convention on the Law of the Sea (UNCLOS) Article 76 could confer sovereign rights to resources over large areas of the seabed beyond our current 200 nautical mile (nm) Exclusive Economic Zone has renewed interest in the potential for U.S. accession to the Law of the Sea Treaty. In this context, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding the nation's EEZ with emphasis on determining their usefulness for substantiating the extension of resource or other national jurisdictions beyond the present 200 nmi limit. This report was submitted to Congress on 31 May 2002 and can be found at **http://www.ccom.unh.edu**.

Following up on the recommendations made in the UNH study, the Center has been funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than two million km^2 of new high-resolution multibeam sonar data on 24 cruises including six in the Arctic, six in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, two in the Gulf of Alaska, two on the Necker Ridge area off Hawaii, one off Kingman Reef and Palmyra Atoll, four in the Marianas region, and one on Mendicino Fracture Zone (Figure 9-1). Summaries of each of these cruises can be found in previous annual reports and detailed descriptions can be found at **http://www.ccom.unh.edu/law_of_the_sea.html**. These raw data products and derived grids are provided to the National Geophysical Data Center and other public repositories within months of data collection and will provide a wealth of information for scientific studies for years to come.

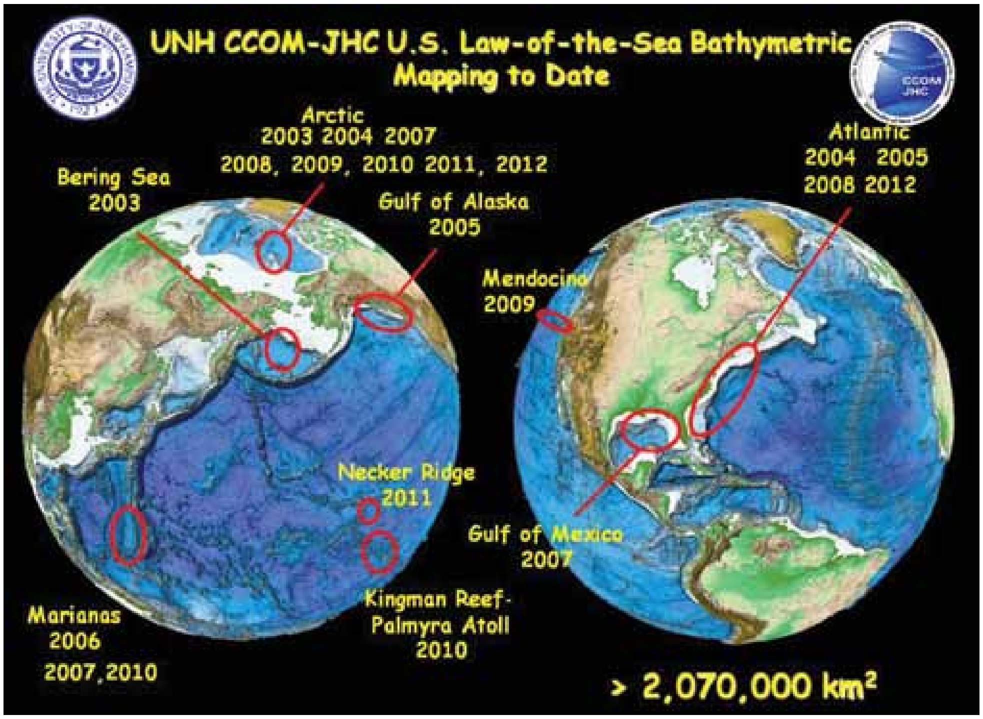


Figure 9-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center to date. More than 2.07 million km^2 of data has been collected.

2012 Law of the Sea Activities

In 2012, the Center organized and ran two Law of the Sea cruises—one in the Atlantic to continue mapping out the location of the foot of the slope and the second, in the high Arctic around the northern extension of the Chukchi Cap. Andy Armstrong, Brian Calder and former graduate student and NOAA CDR Shep Smith were co-chief scientists of the Atlantic cruise while Larry Mayer, Andy Armstrong, and Brian Calder were co-chief scientists of the Arctic cruise. With the addition of these cruises, the total area mapped by the Center in support of Extended Continental Shelf (ECS) efforts is now more than 2,000,000 km^2 (Figure 9-1). In addition to their at-sea activities, Jim Gardner, Larry Mayer and Andy Armstrong have been very involved with a range of shore-based ECS activities.

Atlantic Margin Survey

The 2012 Atlantic margin survey work is a continuation of mapping started in 2004 and continued in 2005 and 2008 (see Progress Reports for those years or cruise reports at **http://ccom.unh.edu/theme/law-sea/cruise-reports**). These earlier cruises identified multiple possibilities for the location of the foot of the slope,a critical component for establishing an

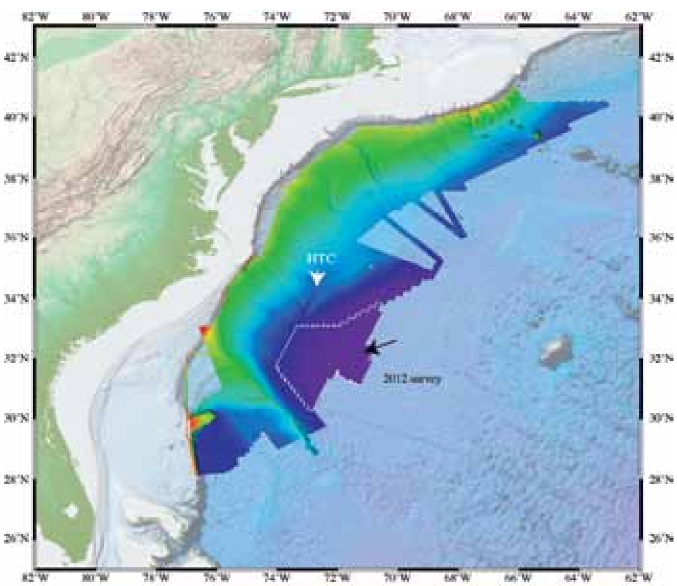


Figure 9-2. Location of the 2012 survey and Hatteras Transverse Canyon (HTC) and depositional lobe.

extended continental shelf. Based on meetings with the ECS Task Force, additional mapping work was deemed necessary. A 30-day ECS cruise was planned to map the distal area from 30˚N to 38˚N, an area that had not been mapped by during the earlier cruises. The 2012 cruise was scheduled to depart Charleston, SC on June 16 and return to Miami, FL on July 15, using the NOAA Ship *Ronald H. Brown*. The ship experienced repeated generator breakdowns and the cruise was finally cancelled on June 25 after 12 days of failed repairs at the dock. A curtailed cruise (17 days) was scheduled after repairs were finally completed with Armstrong, Calder, and Smith on board and with a truncated cruise plan concentrating on the depositional lobe downstream of Hatteras Transverse Canyon (Figure 9-2).

The cruise eventually mapped 65,000 km^2 of area with multibeam bathymetry and simultaneously collected multibeam backscatter. Preliminary processing occurred aboard ship but Jim reprocessed the entire dataset once the shipboard party returned to the Center. The data clearly show the two previously known large-scale mass failures (Cape Fear and Cape Lookout Slides) as well as the depositional lobe of Hatteras Transverse Canyon (Figure 9-3). Jim's analyses of the new bathymetry clearly show that the Cape Lookout Slide is older than the Cape Fear Slide and the distal parts of the Cape Lookout Slide are buried by the Cape Fear Slide. The upper 40 km section of the depositional lobe of Hatteras Transverse Canyon has the appearance of a series of 3 to 5 km long domed steps that descend at a slope of ~0.07˚ with each step separated from its neighbor by a 10 to 15 m deep. Each step in plan view has an arcuate form and stretches from 23 to 60 km long across the deposit. The remainder of the deposition lobe has a eastward slope of 0.009˚ or less and has a stringy backscatter texture that suggests numerous rather linear distributary channels that continue beyond the eastern limit of the data.

The distal nose of the Cape Fear Slide tapers from ~30 m thick to where it merges with the abyssal sediments with a slope of ~1˚. A Knudsen CHIRP profile collected across the lower slide shows the tapered eastern side as it merges with an overbank levee from the distal HTC channel (Figure 9-4). The high backscatter of the Cape Fear Slide sediments have acoustic backscatter values that range from -28 to -26 dB whereas the adjacent deep-sea sediments range from -35 to -30 dB. The higher backscatter of the slide demonstrates that the carbonates of the upper slope have been transported at least 380 km out onto the distal continental margin.

The seaward termination of Blake Ridge had never been mapped before this cruise. Although the area where any relief from Blake Ridge disappears was not mapped, almost all of the eastern-most section of the ridge was mapped and shows a bifurcation of the ridge

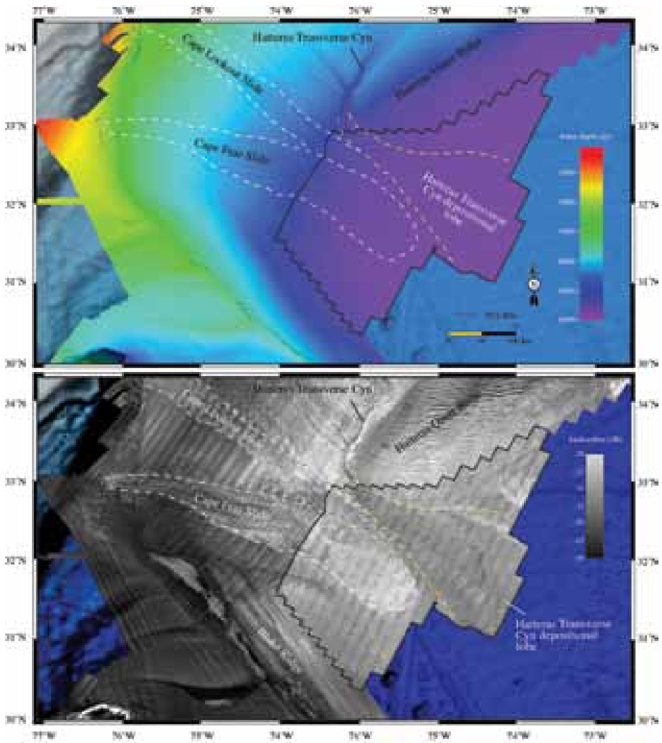


Figure 9-3. Bathymetry (upper) and backscatter (lower) of the complete area that includes the Cape Fear and Cape Lookout Slides and the Hatteras Transverse Canyon system. White line is CHIRP profile shown on Figure 3.

crest. The ridge extends as a single-crested feature for 450 km before the pronounced split (yellow arrow head in Figure 9-5). The bifurcation are likely related to the interaction of the ridge sediments to the dynamics of the Western Boundary Current as it maneuvers around the bathymetric feature.

Healy 1202

The 2012 *Healy* cruise (HLY 1202) was the first single-ship Arctic ECS mapping program since 2008. The primary objective of this leg was to collect high-resolution multibeam sonar data in the region north of Chukchi Cap leading into Nautilus Basin in order to unambiguously locate the position of the foot of the slope as defined by Article 76 and to better understand the morphology of the northward extension of Chukchi Cap into Nautilus Basin. Secondary objectives included the collection of high-resolution chirp subbottom profiles to help in the determination of the location of the foot of the slope, the collection of dredge samples to better understand the geologic nature of Chukchi Cap and its northern extension, and the collection of underway gravity data. Ancillary projects were also carried out including oceanographic, wildlife and ice studies.

The scientific party of HLY1202 began embarkation by helicopter from Barrow AK, onto *Healy* on 25 August as scheduled, but complications with the unexpected on load of ship's stores delayed departure until approximately 1500L on the 26th of August. Enroute to the Chukchi Cap, the *Healy* deployed two "EARS" acoustic buoys on behalf of DARPA/Lockheed Martin at locations approximately 122 and 152 nm north of Barrow in water depths of 3126 and 3751 m, respectively (Figure 9-6). Upon completion of the buoy deployments, *Healy* continued on into the Canada Basin to the base of the Northwind Ridge for the performance of a patch test to calibrate the offsets entered into the multibeam sonar. Before the patch test was conducted a deep (3850 m) CTD cast was made including water sampling for the USGS ocean acidification program. An XBT and XCTD were also deployed at the same site to inter-calibrate these sensors. The patch test was completed and indicated no modifications were necessary to the configuration of the sonar.

Healy then transited over Chukchi Cap to begin a series of surveys designed to unambiguously locate the foot of the slope on the western edge of Nautilus Basin. First indication of any ice (a few bergy bits) was seen at approximately 76° 40'N. By 79°N, larger chunks of ice were seen but still no indication of the ice pack. On the 29th of August, *Healy* reached the transition into the Nautilus Basin at approximately 81° 12'N with a clear foot of the slope at approximately 3800 m depth apparent in both the multibeam bathymetry and the chirp subbottom profiler. Large streams of broken ice impacted the quality of the multibeam sonar records but there was still no indication of a solid ice pack.

Between the 29th of August and the 6th of September, *Healy* continued to make a series of crossings in and out of Nautilus Basin, documenting the location of the foot of the slope in the transition from the Nautilus Basin to the Alpha/Mendeleev Ridge complex (Figure 9-5). During this time, ice conditions worsened with *Healy* eventually encountering 7/10–10/10 ice conditions for brief periods of time. On 4 September 2012,

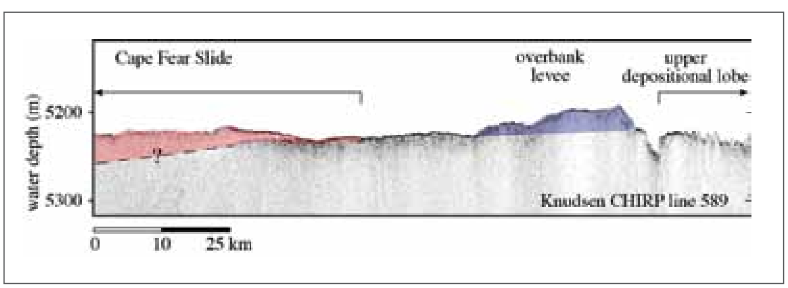


Figure 9-4. Knudsen CHIRP line 589 running E-W across lower Cape Fear Slide and onto the upper depositional lobe of HTC.

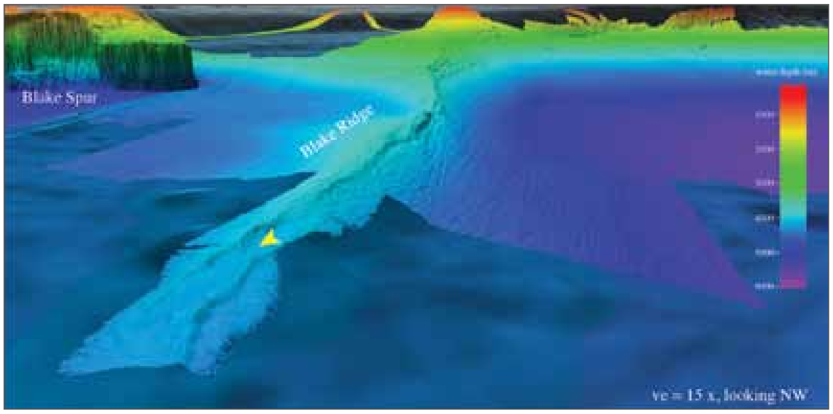


Figure 9-5. Perspective view of Blake Ridge showing a bifurcation in the ridge crest (yellow arrowhead).

the farthest point north of this expedition was reached at approximately 83° 32'N, 162° 36'W. A CTD station was occupied at this location with water and ice sampling for the ocean acidification project. On 5 September, an AXIB ice buoy was deployed by crane on a large flow and more ice samples taken (Figure 9-6).

With numerous foot of slope crossings around the periphery of Nautilus Basin, the mapping effort next focused on the northern extension of the Chukchi Cap that transitions into Nautilus Basin. The objectives here were to collect as complete mapping as possible to better understand the morphology of this area and to identify potential dredge sites that would allow sampling of bedrock in this region. Between September 6th and 17th, detailed mapping of this area was conducted. This mapping consisted of a series of north-south-oriented lines interspersed with several longer, east-west lines (Figure 9-5). During this time, *Healy* encountered variable ice conditions but mostly open water. Towards the end of this period, new ice was forming causing serious problems for the EM122. The new soft ice seems to scrape by and stick to the transducers causing very high noise levels and difficulty detecting the bottom.

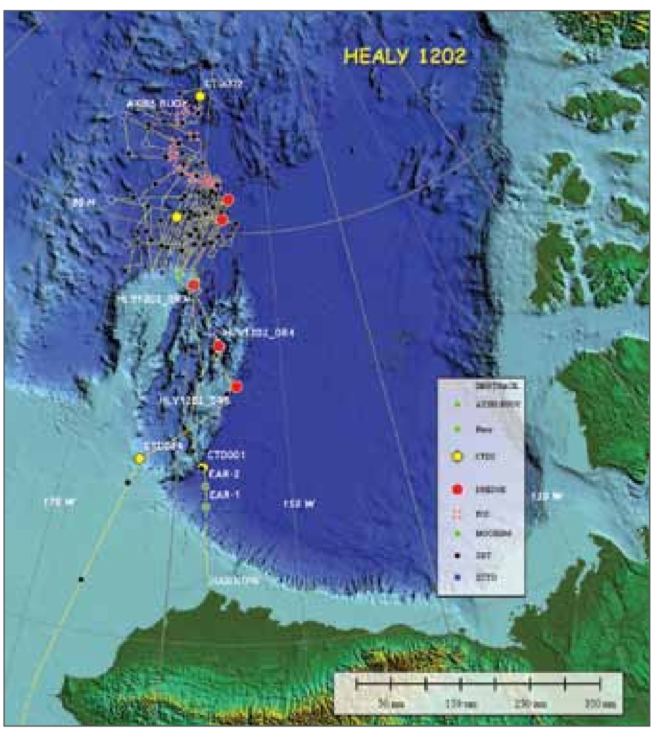


Figure 9-6. HLY1202 Shiptrack, XBT, XCTD, CTD, buoy, and dredge locations.

The initial surveys of the northern extension of Chukchi Cap indicated that the greatest possibility of finding suitable dredging sites (our criterion is a slope greater than 30 degrees) was in the eastern (Northwind) portion where steeper topography is present. Survey work was thus concentrated in this area but even here there were few potential dredge sites.

In the course of this mapping a spectacular submarine channel that drains from west to east over a distance of at least 160 km with an average gradient of about 0.18 degrees was mapped. The channel does not significantly meander but is complex with numerous small tributaries, hanging valleys and several bifurcations. The maximum depth of the channel is approximately 80 m (Figure 9-7).

At the conclusion of the mapping, no dredge sites could be identified in the middle of the northern extension of Chukchi Cap with slopes greater than 30 degrees. Instead, two dredge sites (DR-1 and DR-2) were selected on the northeast rim of the northern extension of the Chukchi Cap. The final three dredge sites (DR-3, DR-4 and DR-5) were located on the northern tip of Chukchi Cap (just west of Healy Seamount), in the middle of Northwind Ridge and on the eastern flank of Northwind Ridge respectively (Figure 9-8).

Dredges revealed a wide suite of morphologies with mostly basalts from the northern-most sites and metamorphic and metasediments from the sites within Chukchi Cap. At DR-3 (78° 42.215′ N, 160° 02.990′W) fragments of deep water coral were recovered in the dredge, likely the northern-most coral ever recovered. Analyses of both the rock and coral samples is ongoing. More detail on the dredge sites can be found in the in the HLY1202 Cruise Report at **http://ccom.unh.edu/theme/law-sea/cruise-reports**.

Upon completing the last dredge site, an "IceGoat Buoy" was deployed for the U.S. Naval Academy and

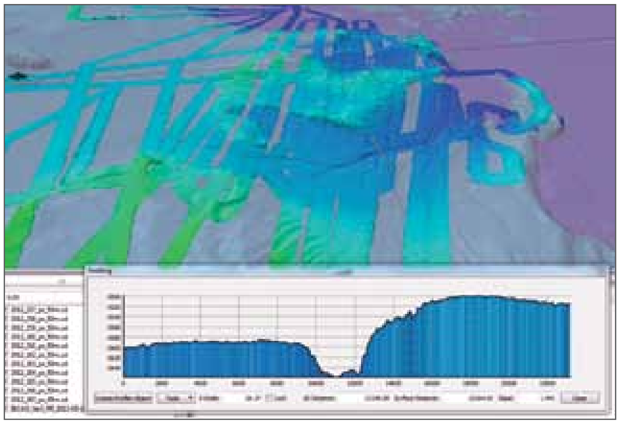


Figure 9-7. Submarine channel north of Chukchi Cap—overall length is approximately 160 km. Cross-section shown in figure is 23 km long.

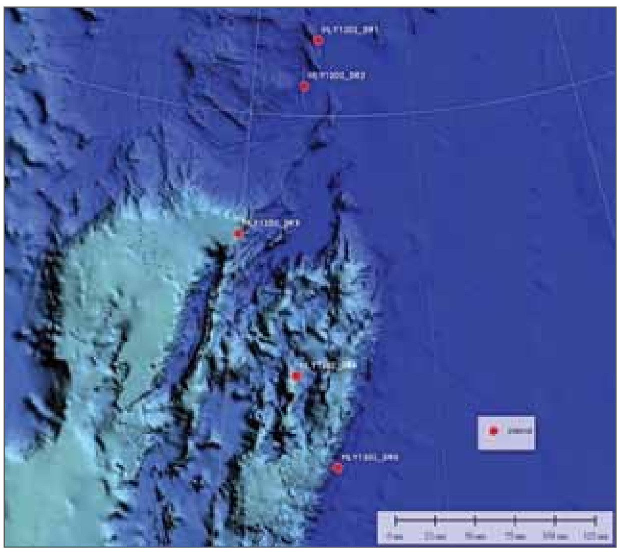


Figure 9-8. Healy-1202 dredge.

Healy departed for Dutch Harbor (23 September), arriving in Dutch Harbor on 27 September. Total track covered on HLY1202 was 11,965 km (6461 nm) with 10,030 km (5,416 nm) of multibeam sonar data collected in support of ECS purposes. These data were collected in average ice conditions of 6/10 ice cover and at an average speed of 7 knots in the ice. ECS multibeam data collection covered an area of approximately 68,600 km2 (20,000 nm2) adding approximately 25% to the U.S. Arctic multibeam sonar data holdings. In addition to the primary ECS mapping mission of HEALY-1202, six ancillary programs were accommodated on a non-interference basis. These programs included:

1. Gravity measurements made by Dr. Bernard Coakley, University of Alaska, Fairbanks.
2. Ice observations, analyses and reporting along with the deployment of one UpTempO buoy, one AXIB seasonal buoys, one Argo profiler, one USNA "Ice-Goat" ice buoy and five SVP TechOcean and MET-OCEAN buoys as part of the U.S. International Arctic Ice Buoy Program. The ice program on HEALY-1202 was under the supervision Dr. Pablo Clemente-Colon, National Ice Center.
3. A comparative study of modern vs historical ice terminology by Matthew Ayre of the University of Sunderland.
4. Deployment and development of a geo-referenced ice camera for ice and other studies (Roland Arsenault, see Appendix D and the VISUALIZATION Theme)
5. Ocean Acidification measurements under the supervision of Dr. Lisa Robbins, U.S. Geological Survey. These measurements include sampling of water bottles from four CTD stations, 625 discrete underway samples for pH, 614 discrete underway samples for alkalinity and 4000 continuous measurements of pH, pCO2, and TCO2.
6. Marine Mammal Observations by Mabel Smith, of the Umiaq Inupiat Corporation. During the 31 days of the ECS science program, three unidentified seals and five polar bears were seen. No whales were observed.

Details of these programs can be found in the HLY1202 Cruise Report at **ccom.unh.edu/theme/law-sea/cruise-reports**.

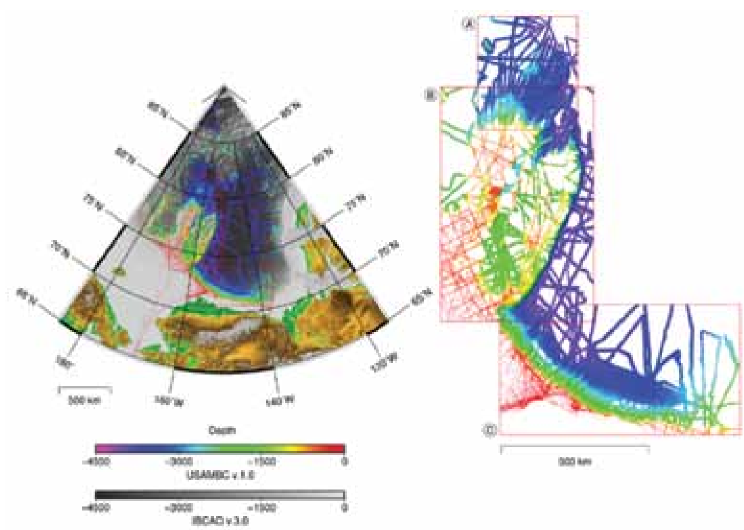


Figure 9-9. Compiled multibeam bathymetry within a region of US interest. Colored depths are from our preliminary United States Arctic Multibeam Bathymetry Compilation (USAMBC), grey-shaded depths are from IBCAO 3.0.

Arctic Bathymetry Compilation

As part of our efforts to compile all existing bathymetric data and understand the uncertainty associated with these data (necessary for an ECS submission), graduate student Ashton Flinder's has been collecting all available multibeam bathymetry in the Arctic and developing approaches to compile at full resolution and to analyze and display the uncertainty associated with these data. The compilation includes data from the NOAA National Geophysical Data Center (NGDC), and data from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). These data are supplemented with currently unpublished National Science Foundation (NSF)-supported surveys, specially requested from their respective principle investigators. Dedicated ECS surveys aboard the USCGC *Healy* comprise the majority of the compilation. Analyses of nadir multibeam crossings, both internally within a specific survey, and between all surveys, shows continuing correlation and reliability for Arctic multibeam bathymetry despite different years of collection, sea-ice conditions, survey platforms, and sonar systems (Figure 9-9).

Associated with this effort is an approach for creating a distributable post-script file that will allow the compilation to be zoomed so that all data can be viewed at its full resolution.

Other Activities Related to Law of the Sea

In addition to sea-going activities, the Center has also played an important role in managing and archiving the Law of the Sea data we have collected. Gardner, Mayer and Andy Armstrong spent much time analyzing ECS data, participating in ECS Task Force, Working Group, Integrated Regional Team and other Law of the Sea-related meetings. In particular, Gardner is involved with seven of the eight IRTs and has worked closely with the data managers to ensure that all bathymetric data holdings are available to IRTs. Working with Paul Johnson, Jim has ensured that all data returning from the summer field programs are transferred to the new SAN for safe and secure storage. Once all of the files are moved and verified, Paul and Jim generate FGDC-compliant metadata records for all of the raw multibeam files and for any raw chirp sonar SEGY (subbottom profiler) files that have been collected. The raw data files and associated metadata records were then copied to hard drive and delivered to NGDC for archiving. When all processing is finalized, Paul takes the resulting backscatter and bathymetry grids and generated a synthesis of all available Law of the Sea data for the U.S. Atlantic Margin (Figure 9-10).

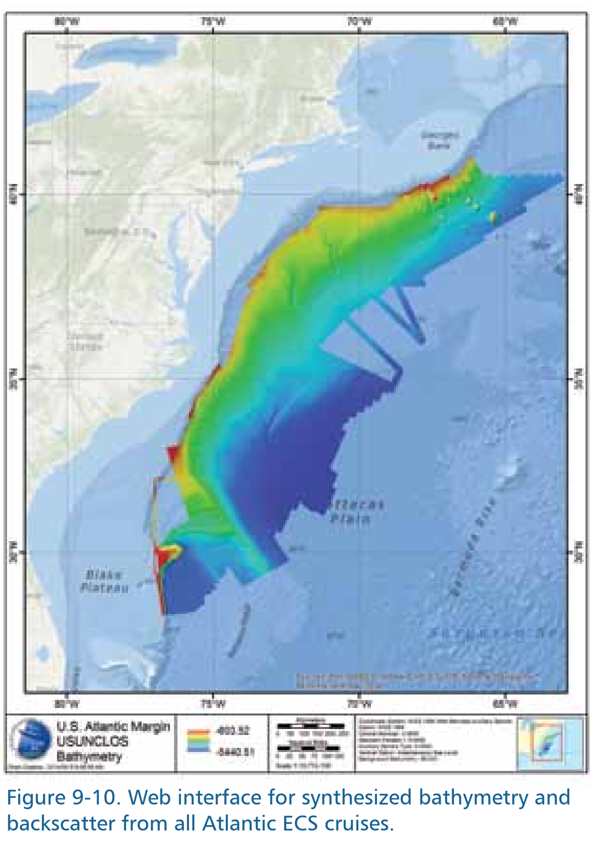


Figure 9-10. Web interface for synthesized bathymetry and backscatter from all Atlantic ECS cruises.

This allows easier use of the data for all users, because all bathymetry and backscatter data are now in single grids, instead of the multiple separate grids covering a region. ArcGIS grids, ASCII files, and Fledermaus SD files of the synthesis are now generated along with their associated metadata. These files are finalized and available for distribution through the Center's webpage.

Demonstrating the value of the ECS multibeam sonar data beyond the establishment of an extended continental shelf, Jim Gardner is actively working on three scientific manuscripts: one describing the geomorphology of Necker Ridge in the central Pacific Ocean, one detailing the determination of the maximum depth of the Challenger Deep, Mariana Trench in the western Pacific Ocean and the third on detailed bathymetric parameters on selected sites in the Gulf of Mexico to demonstrate a method of statistical identification of particular habitats.

The Center has also hosted a number of IRT and other ECS-related meetings including a meeting of the "Arctic V" in November with senior representatives from each of the five Arctic nations with potential extended continental shelves in the Arctic (Canada, Denmark, Norway, Russia and the U.S.). This meeting had approximately 50 participants including Ambassador David Balton, Chair of the U.S. Extended Continental Shelf Task Force.

Outreach

In addition to our research efforts, we also recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those that ultimately fund our work. We also recognize the importance of engaging young people in our activities so as to ensure that we will have a steady stream of highly skilled workers in the field. To this end we have been upgrading our web presence and expanding our outreach activities and staff (Tara Hicks-Johnson, an experienced outreach specialist has joined our staff in 2011). Tara now coordinates Center activities with UNH Media Relations to coordinate Center-related releases and media events and has begun working with NOAA media personnel in preparing releases featuring Center faculty. The Center continues to attract significant media attention. A partial list of media reports on CCOM activities is listed below.

Jan. 5, 2012	A Whale's Virtual Reality	*Science NOW*
Jan. 17, 2012	Sonar Uncertainty Instrument	*Hydro International*
Jan. 20, 2012	Heads-Up on a Whale's Gulp	*Science*
Feb. 2, 2012	Joint Hydrographic Center at University of New Hampshire Hosts NOAA Leadership	*National Geodetic Survey News*
Feb. 3, 2012	Subs patrol UNH pool: Sea Perch Program leads Barrington students in making submersibles; testing them at UNH	*Foster's Daily Democrat*
Feb. 13, 2012	UNH Scientists Explore, Map World's Deepest Point off Guam's Coast	*The New Hampshire*
Feb. 14, 2012	Hey, look what's down there...	NHPR - "Word of Mouth"
Feb. 23, 2012	Race to the Bottom of the Ocean: Why go down?	BBC
Feb. 23, 2012	Race to the Bottom of the Ocean: Ocean Trench	BBC
Feb. 27, 2012	The Final Frontier	*UNH Magazine*
Feb. 29, 2012	Survey Conference Wraps on High Note	*Voxy*
Mar. 16, 2012	Oil Spill Lessons	Alaska Public Radio
Mar. 20, 2012	Sea Study Aims to Avoid Wind Turbine Impacts	*Albany Times Union*
Apr. 1, 2012	Earth's Final Frontier	*Seacoastonline*
Apr. 4, 2012	New iPad, iPhone App Helps Mariners Avoid Endangered Right Whales	*NOAA News*
Apr. 4, 2012	New iPad, iPhone App Helps Protect Endangered Whales	*Sacramento Bee*
Apr. 5, 2012	New iPad, iPhone App helps Mariners Avoid Endangered Right Whales	*SeaDiscovery*
Apr. 5, 2012	New app signals that endangered whales are nearby	*R&D Magazine*
Apr. 12, 2012	Protecting Whales? Thanks to UNH, There's an App for That	*e! Science News*
Apr. 12, 2012	Gas Seep Exploration	*NOAA Ocean Explorer*
Apr. 12, 2012	New iPad, iPhone app helps mariners avoid endangered right whales	*Coordinates*
Apr. 12, 2012	UNH Smartphone App Helps Ships Avoid Endangered Whales	NHPR - "All Things Considered"

Apr. 13, 2012	UNH Just Saving Whales, No Big Deal	*SUMOskinny Magazine*
Apr. 14, 2012	Protecting whales? Thanks to UNH, there's an app for that	*Foster's Daily Democrat*
Apr. 14, 2012	New View of the Deepest Trench	NASA Earth Observatory
Apr. 16, 2012	Earth's Deepest Spot Revealed in Unprecedented Detail	*Our Amazing Planet*
Apr. 17, 2012	Mariana Trench Mapped – New View of the Deepest Trench	*The Watchers*
Apr. 18, 2012	Protecting Whales? Thanks to UNH, There's an App for That	*UNH Campus Journal*
May. 1, 2012	Exploring Ocean Flow Models With a Multitouch 3D Interface	*Sea Technology*
May. 22, 2012	Pioneering Expedition in the Arctic Ocean	*Norwegian Petroleum*
Jun. 7, 2012	NOAA to Commission East Coast Survey Ship	*Boston Globe*
Jun. 7, 2012	NOAA to Commission New Ocean-mapping Ship	*The Portland Press Herald*
Jun. 21, 2012	Diving Deeper: Safe Navigation	*National Ocean Service*
Jul. 20, 2012	Bathymetry in the Mariana Trench	*Geographical*
Jul. 25, 2012	Capturing the Seafloor's Rich History While Positioning America for the Future	NOAA Coast Survey's Blog
Aug. 14, 2012	NOAA Names Glang Nation's Hydrographer, Director of Coast Survey	*NOAA News*
Aug. 15, 2012	Wreck of Captain Scott's ship discovered off Greenland	*The Telegraph*
Aug. 21, 2012	Terra Nova Pictures: Antarctic Explorer's Shipwreck Found	*National Geographic*
Aug. 24, 2012	Expedition to Explore the Arctic	USGS Science Features
Aug. 29, 2012	UNH Researcher Aids in Discovery of Shipwrecked Antarctic Explorer	*UNH Campus Journal*
Sep. 2, 2012	UNH researcher aids in discovery of shipwrecked Antarctic explorer Terra Nova	*Foster's Daily Democrat*
Sep. 5, 2012	5 Questions with Jonathan Beaudoin	*Concord Monitor*
Sep. 7, 2012	Joint Canada-U.S. Mapping Cruise in the Atlantic Winding Up	NOAA Office of Coast Survey
Sep. 17, 2012	Alien Deep With Bob Ballard Episode 5: "Inner vs. Outer Space"	*National Geographic*
Sep. 20, 2012	Notes from the Top of the World	*UNH Today*
Sep. 26, 2012	Get to Know the Coast at UNH Marine Program Labs Oct. 20	UNH Media Relations
Oct. 20, 2012	Know the Coast Lets Kids Dive into Marine Science	*Seacoastonline*
Oct. 31, 2012	Gathering Multibeam Bathymetry Aboard Icebreakers	*Sea Technology Magazine*

Outreach Events

The facilities at the Center provide a wonderful opportunity to engage students and the public in the types of research that we do here, with a special emphasis, for school groups, on underwater robotics. Some of the events we hosted this year include tours of the Center for local schools and community groups, including a group of students and a resource teacher from Dover High School, students from local middle schools (Portsmouth Middle School, Oyster River Middle School, Cawley Middle School), a Rotary Club group of Germans participating in a study exchange, the kindergarten class from the Child Study and Development Center at UNH, and a visit from a group of 50 twelve-year-olds organized through Forest Watch, an educational research program at UNH through the NH Space Grant Consortium.

Several large and specialized events were organized by the Center outreach team, including several SeaPerch ROV events and the annual UNH "Know the Coast" event. Throughout the year, the Center has worked with the Portsmouth Naval Shipyard (PNS) to host participating schools that have built SeaPerch ROVs and want to test them in our facilities. Local schools have brought their students to test drive ROVs in our deep tank and tour both our Center and the engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center decided to hold our first competition between schools, the UNH SeaPerch Competition.

The UNH SeaPerch Competition is an educational outreach event organized by the Center and PNS. The schools involved in this regional event all participated in an ROV building exercise funded through the Shipyard's National Defense Education Program (NDEP). The SeaPerch program at the Shipyard is part of the National STEM Outreach Program to encourage students to pursue careers in Science, Technology, Engineering and Math. This year the Shipyard Team built vehicles with more than 700 local middle school students at 12 separate events. The regional competition was funded through the Center and PNS, as well as through generous donations from the New Hampshire Sea Grant Office and Liberty Mutual. Volunteer judges and crew from the Center, PNS, the UNH Cooperative Extension Office and the UNH Society of Women Engineers all helped the day run smoothly.

The first annual UNH SeaPerch Competition was held Saturday, May 12th, 2012 in the Swasey Pool on the UNH campus. Teams from local schools competed in this challenge using ROVs that they built themselves (Figure 10-1). There were two events in the challenge: an obstacle course, and a salvage operation. In the timed obstacle course event, teams had to maneuver their ROV through a series of underwater hoops, then trace their steps back. In the salvage operation, teams had to remove "debris" in the form of weighted buckets from the bottom of the pool and then retrieve them.

After the students completed the competition, they were treated to a demonstration by the UNH ROV team, a group of UNH undergraduate students who have built an ROV to compete in the 11th annual MATE (Marine Advanced Technical Education) International ROV competition in Florida in June. Following the demonstration, the students toured the Center, where they were able to see where the large OER ROV is being built, and visit the Center's Presentation Room where they saw highlight videos from NOAA's *Okeanos Explorer* and of the Hercules ROV as it explored the seafloor (Figure 10-1).

While volunteering at the UNH Seacoast SeaPerch competition, members of the UNH Cooperative Extension (CE) program saw the excitement and dedication that the students and teachers showed while participating in this ROV program, and wanted to expand the reach of the program to communities all over New Hampshire, both in school and in out-of-school settings.

Figure 10-1. Middle-school students participating the UNH SeaPerch Competition (left) and interacting with researchers on the *Okeanos Explorer* through the Center's Telepresence Console (right).

Figure 10-2. A variety of activities at Know the Coast Days 2012.

The Center and PNS have now partnered with UNH CE to form the Seacoast SeaPerch program in an effort to bring this quality STEM learning experience to students all over the state. Our first effort in this partnership is to hold an Educator Training Program in January 2013. This one-day training program at UNH will be open to educators, 4-H leaders, afterschool providers, community partners and others interested in coaching a SeaPerch club or team.

The SeaPerch program was also offered as part of the UNH Tech Camp, a summer camp where middle and high school students are invited to learn from professionals in the fields of Science, Technology, Engineering, and Math (STEM). Tara Hicks Johnson worked with the Portsmouth Naval Shipyard to host a week-long session about building ROVs (using the SeaPerch ROV kits) and then tested them in the Swasey Pool on campus. Students also toured the Center and were able, with the help of Paul Johnson, to use the Telepresence Console to chat with crew aboard the E/V *Nautilus* off the coast of Turkey. An ROV pilot spoke with the students about being an ROV pilot and the issues they have to deal with during deployment, and CCOM Graduate Student Lindsay McKenna (who was also on board) answered questions about being a student in the marine sciences and what it is like to go to sea. Being able to speak remotely with researchers who were on board the ship as it sailed in the Mediterranean Sea, from our classroom on campus, proved a highlight for the students.

A second major outreach event at the Center was UNH's "Know the Coast" days, an annual two-day event held both at the Chase Ocean Engineering Lab on campus and at the Judd Gregg Marine Research Facility in New Castle, NH. On Friday, October 19th, more than 500 students from school groups and home-school associations from all over New Hampshire came to visit our facilities and learn about the exciting research happening here at the Center. Activities and demonstrations for all ages highlighted research on acoustics, ocean mapping, ROVs, lidar, and ocean visualization (Figure 10-2).

Students and the public were able to tour the Center's engineering tanks in our High Bay, see video taken on the seafloor in our Telepresence room, and try their hand at mapping the ocean floor. They could sit on the jet ski that we use to map shallow coastal areas, see how scientists explore the ocean using sound waves, and test drive SeaPerch ROVs. Our visualization team showed off their interactive weather map and ocean visualization tools. Know the Coast is a joint outreach event run through the Center, the UNH Marine Program and the New Hampshire Sea Grant office, and relies on faculty, staff, and student volunteers from UNH and volunteers from UNH Marine Docent program.

Website Upgrades and Other Activities

Website

Colleen Mitchell and Les Peabody took the lead in 2011 on a complete redesign of the Center website. The graphic design, navigation and overall feel have been changed to reflect a more modern design and are being implemented using Drupal (an extensible management system). The redesign of the Center's website culminated in the public launch of the new site in late March 2012. Creating the new site was a group effort. Graphic designer Colleen Mitchell created the new design as well as the site architecture. New content was created and old content was reviewed, updated and rewritten as necessary. A good deal of the old site was migrated to the new site to help preserve the site's history. Peabody and Data Manager Paul Johnson, with the guidance of Dr. Jim Gardner, created the new interactive Law of the Sea section with data served up via ArcGIS (see DATA MANAGEMENT Section). Information Technologists Will Fessenden and Jordan Chadwick assisted, with Fessenden creating the new Facilities section and Chadwick posting all of the research special projects. In addition to coding the new site, Peabody successfully brought over the Center's entire publication catalog to the new site.

The simple, attractive design has been well received and the easy navigation has been remarked upon numerous times. The positive reaction to the new site can be tracked by Google Analytics revealing that 23,882 distinct people visited the Center's website in 2012. More than half of those people were first time visitors. The average visit duration was just over three minutes. Compared with 2011, 2012 visits are up more than 19% and, perhaps more importantly, visit duration is up nearly 35%.

Figure 10-3. The homepage of the Center's new website.

The website has several new features. The home page now has a slide show to showcase news stories, events, or current fieldwork. This feature was used to aggregate the extensive media exposure the Center received during the recent Mariana Trench dives, to announce the launch of the Whale Alert iPhone/iPad application, and to follow Prof. Tom Lippmann and his team as they conducted fieldwork in North Carolina. Science writer David Sims has written several "Spotlight" pieces about Center personnel. To date, NOAA Physical Scientist Meme Lobecker, graduate student (now alumna) Anastasia Abramova, IOCM Team Lead Glen Rice, and Facilities Manager Andy McLeod have been the subjects of these articles. In the future, the Spotlights will rotate through faculty, staff, students, and alumni. Graphic Designer Colleen Mitchell manages the content of the site, creating new content as required and keeping the site fresh and up to date.

Flickr and Vimeo

In addition to events, news articles and publications, the home page also contains featured images and featured videos. The images draw from the Center's Flickr photostream and the videos draw from the Center's Vimeo channel. It is interesting to note that the featured images and videos receive a significant uptick in views and plays at certain times. For instance, during the time period that the image of Tom Lippmann and graduate student Lindsay McKenna working on the beach in New River Inlet, NC has been featured, it has garnered 252 views.

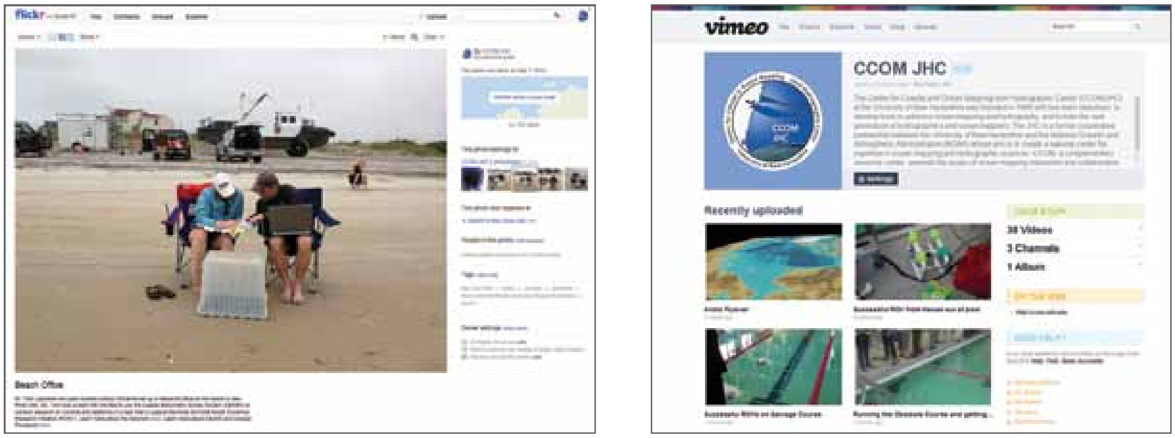


Figure 10-4. Example of Center's Flickr and Vimeo content.

The featured images' captions are associated with Center work and a link is provided that brings the viewer back to an appropriate place on the Center's website—a research area, a seminar, a publication, etc. There are currently 1,547 images in the Center's photostream. These images have received an all-time total of 5,571 views. There are currently 41 videos in the Center's catalog. In addition to broadcasting the seminar series as webinars, the talks are recorded as long as the speaker is amenable. Will Fessenden then edits the videos and uploads them to Vimeo (Figure 10-4). The Center's videos have been played 1,902 times in 2012. The most popular video is "Topo-bathy Lidar Demo" which was created by Affiliate Professor Chris Parrish and has been a featured video on the website.

Seminar Series

The 2012 seminar series comprised 32 seminars. Six of these seminars were master's thesis defenses by Center students and three were Directed Research presentations. The rest were given by Center researchers or experts from industry and academia. Graduate students Christy Fandel and Garrett Mitchell were the coordinators for the spring semester and were responsible for populating the schedule and interfacing with the speakers. Graduate students Kevin Jerram and Chris Englert took on the coordinating duties for the fall semester. Will Fessenden assisted in helping the speakers set up their presentations, making sure that the webinars ran smoothly, and recording the presentation's video and audio. Colleen Mitchell advertises the seminars with customized flyers that are posted on the Center's website and Facebook page and appear in the Center's kiosk slideshow in the lobby.

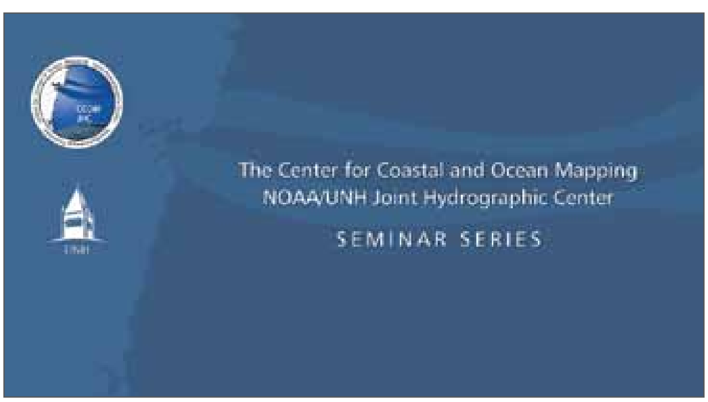


Figure 10-5. Title card for the Center's seminar series on Vimeo.

Figure 10-6. Center's Facebook page.

Facebook

The Center's Facebook page mirrors the website and also provides a less formal venue for posting Center news (Figure 10-6). For instance, we might post photos of a kindergarten class visit or the new bike rack on Facebook when those items would not be appropriate for the website. The page currently has 166 "likes." It's very rare that anyone resigns from the page. The new "timeline" format was made mandatory in March. Colleen Mitchell, who administers the page, plans to take advantage of this and add significant Center milestones, drawing from the 10-year article that David Sims wrote about the Center for *Sea Technology* magazine. Like the website, the Facebook page is vibrant and content-rich and the two sites work in tandem to increase the Center's digital presence.

AGU

In December, for the first time, the Center leased a booth at the annual American Geophysical Union (AGU) Fall Meeting in San Francisco. The meeting, the world's largest gathering of geophysicists, attracted more than 22,000 participants this year. It is a primary venue for recruiting graduate students and enhancing the visibility of the research and programs of the Center. The booth turned out to be very popular with more than 350 visitors and long lines to see demonstrations of our new interactive visualization environment presented by Tom Butkiewicz (Figure 10-7).

Figure 10-7. Tom Butkiewicz demonstrating new visualization software at the annual fall meeting of the American Geophysical Union.

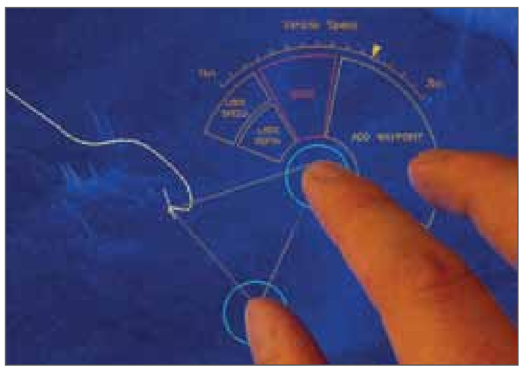


Figure 10-8. Close-up view of Tom Butkiewicz demonstrating multi-touch interaction.

Partnerships and Ancillary Programs

One of the goals of the Joint Hydrographic Center is, through its partner organization the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a $5 million endowment; $1 million of this endowment has been earmarked for support of post-doctoral fellows at the Center for Coastal and Ocean Mapping. Our interaction with the private sector has been formalized into an Industrial Associates Program that is continually growing.

- Airborne Hydrography AB
- AML Oceanographic
- Atlas Hydrographic-GmBH
- ATLIS Informatie Systemen BV
- C&C Technologies Inc.
- CARIS, Inc.
- Chesapeake Technologies
- EarthNC
- EdgeTech
- Environmental Systems Research Institute, Inc. (ESRI)
- Fugro LADS Inc.
- Geocap
- HYPACK, Inc.
- ICAN, Inc.
- IFREMER
- Instituto Hidrografico (IH)
- Kongsberg Underwater Technology, Inc. (KUTI)
- L-3 Communications Klein Associates
- Ocean High Technology Institute
- Ocean Imaging Consultants, Inc.
- Ocean Science
- ODIM Brooke Ocean Ltd. (ODIM)
- Odom Hydrographic Systems, Inc. (Odom)
- Ohmex
- Quality Positioning Services B.V. (QPS)
- Quester Tangent
- RESON, Inc.
- Science Applications International Corporation (SAIC)
- Seismic Micro Technology (no agreement necessary per LM)
- SevenCs
- Substructure
- Survice Engineering Company
- Teledyne Benthos, Inc.
- Triton Elics International, Inc.
- Tycom LTD
- YSI, Inc.

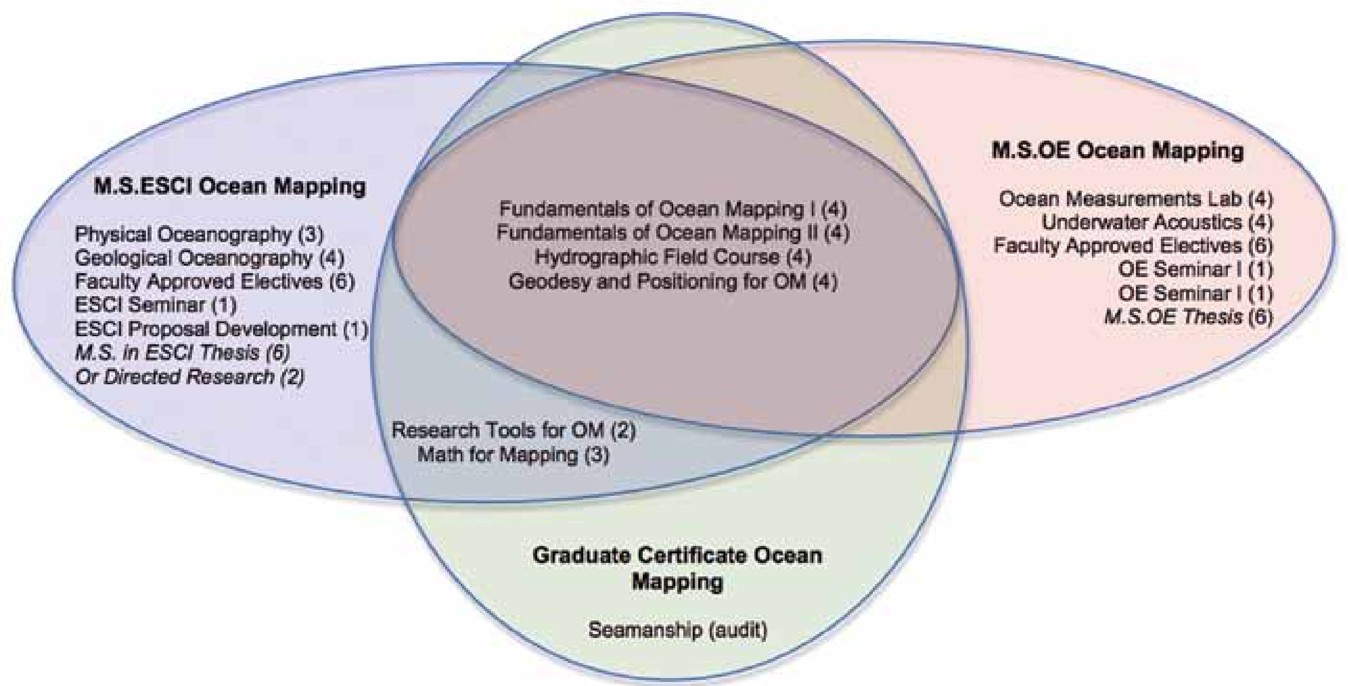
In addition, grants are in place with:

- Exxon Mobil (student scholarship)
- National Science Foundation
- Nippon Foundation/GEBCO
- Office of Naval Research
- UNH ADVANCE Collaborative
- U.S. Army Corps of Engineers
- Woods Hole Oceanographic Institution
- Oculus Info Inc.

The Center has also received support from other sources of approximately $1.48 M for 2012 (see Appendix C).

Appendix A: Graduate Degrees in Ocean Mapping

The University of New Hampshire offers Ocean Mapping options leading to Master of Science and Doctor of Philosophy degrees in Ocean Engineering and in Earth Sciences. These interdisciplinary degree programs are provided through the Center and the respective academic departments of the College of Engineering and Physical Sciences. The University has been awarded recognition as a Category "A" hydrographic education program by the International Federation of Surveyors (FIG)/International Hydrographic Organization (IHO)/International Cartographic Association (ICA). Requirements for the Ph.D. in Earth Sciences and Engineering are described in the respective sections of the UNH Graduate School catalog. MS degree requirements are described below.



Curricula for Master's Degrees and Certificates in Ocean Mapping at UNH JHC/CCOM.

Master of Science in Ocean Engineering–Ocean Mapping Option

Core Requirements		Credit Hours
OE 810	Ocean Measurements Lab	4
OE/ESCI 874	Fundamentals of Ocean Mapping I	4
OE/ESCI 875	Fundamentals of Ocean Mapping II	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	3
OE/ESCI 895	Underwater Acoustics	3
OE/ESCI 972	Hydrographic Field Course	4
OE 990	Ocean Engineering Seminar I	1
OE 991	Ocean Engineering Seminar II	1
OE 899	Thesis	6

At Least Six Additional Credits from the Electives Below

ESCI 858	Introduction to Physical Oceanography	3
OE 854	Ocean Waves and Tides	4
ESCI 859	Geological Oceanography	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geo-Statistics	3
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4
	Other related courses with approval	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences–Ocean Mapping Option

Core Requirements		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	3
ESCI/OE 875	Fundamentals of Ocean Mapping II	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4
ESCI 997	Seminar in Earth Sciences	1
ESCI 998	Proposal Development	1
ESCI 899	Thesis	6

Approved Electives

OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Master of Science in Earth Sciences (Non-Thesis Option)–Ocean Mapping Option

Core Requirements		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	3
ESCI/OE 875	Fundamentals of Ocean Mapping II	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4
ESCI 997	Seminar in Earth Sciences	1
ESCI 998	Proposal Development	1
ESCI 898	Directed Research	6

At Least Four Additional Credits from the Electives Below

OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Graduate Certificate in Ocean Mapping

Core Requirements

Course	Title	Credit Hours
MATH 896	Math for Mapping	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	4
ESCI 872	Research Tools for Ocean Mapping	2
ESCI /OE 972	Hydrographic Field Course	4

Approved Electives

ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
OE 810	Ocean Measurements Laboratory	4
OE 854	Ocean Waves and Tides	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 973	Seafloor Characterization	3
ESCI 895,896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 895	Time Series Analyses	4
OE 998	Independent Study	1-4

Where a course of equivalent content has been successfully completed as an undergraduate, an approved elective may be substituted.

Appendix B: Field Programs

Okeanos Explorer 2012 02, 9 February–10, NOAA Ship *Okeanos Explorer*, Install "SVP Server" and "SVP Editor" software in preparation for 2012 field season. Train operational staff on use of the software packages. (Meme Lobecker, Adam Skarke, Jonathan Beaudoin)

DY1201 Gulf of Alaska Winter Acoustic Trawl Survey, 12 February–22, NOAA Ship *Oscar Dyson*, ME70 MBES data was collected continuously while the NOAA Ship *Oscar Dyson* was underway, during the Gulf of Alaska Winter Acoustic Trawl Survey. This multibeam dataset was collected opportunistically during a fishery resource survey to support the Center's ongoing fisheries habitat research in collaboration with the Alaska Fisheries Science Center. (Tom Weber, Jodi Pirtle)

Okeanos Explorer 2012 EX1201, 14 February–23 February, NOAA Ship *Okeanos Explorer*, Annual ship shakedown and multibeam patch test cruise. Mapped several Atlantic shelf-breaking canyons. (Adam Skarke, Meme Lobecker)

Kilo Moana 2012 03, 9 March–23 March, R/V *Kilo Moana*, Review of EM710/EM122 multibeam system installation, mapping practices and protocols, and data management procedures. (Paul Johnson, Jonathan Beaudoin)

DY1203 Gulf of Alaska Winter Acoustic Trawl Survey, 15 March–26 March, NOAA Ship *Oscar Dyson*, Continuation of DY1201 Gulf of Alaska Winter Acoustic Trawl Survey (Tom Weber, Jodi Pirtle)

Okeanos Explorer 2012 EX1202 Leg 2, 19 March–7 April, NOAA Ship *Okeanos Explorer*, Telepresence enabled northern Gulf of Mexico ROV/mapping exploration cruise of *Okeanos Explorer*, including vents and deep water coral exploration. (Meme Lobecker)

Mary Sears 2012 03, 28 March–12 April, U.S. Navy Ship *Mary Sears*, Assess compliance of EM122 multibeam system with respect to expected performance levels. Funded by Naval Oceanographic Office. (Jonathan Beaudoin)

Nearshore Processes Great Bay Estuary Cruise, 4 April, R/V *Gulf Challenger*, Cruise for Nearshore Processes class to Great Bay Estuary to obtain CTD profiles and bottom sediments. (Jim Irish, Larry Ward)

EX1202 Leg 3, Gulf of Mexico Exploration, 11 April–29 April, NOAA Ship *Okeanos Explorer*, Exploration of the Gulf of Mexico including seep flux experiments. (Tom Weber, Kevin Jerram, Adam Skarke)

Okeanos Explorer 2012 02 Leg 3, 12 April–24 April, NOAA Ship *Okeanos Explorer*, Dr. Tom Weber coordinated seep mapping activities and directed seep characterization ROV dives via the UNH CCOM/JHC Exploration Command Center (ECC) during *Okeanos Explorer* cruise EX1202 Leg 3 in the northern Gulf of Mexico. (Tom Weber, Val E. Schmidt, Larry Mayer, Kevin Jerram)

River Mouth and Inlet Field Experiment, RIVET, 19 April–25 May, CBASS, Collaborative ONR sponsored Field Research Program to examine fine-scale seabed evolution within an inlet environment coincident with observations of the vertical structure of mean currents. (Jim Irish, Lindsay McKenna, Jon Hunt, Emily Terry, Tom Lippmann, Garrett Mitchell, Christina Fandel)

Falkor 2012 05, 3 May–21 May, R/V *Falkor*, Assess compliance of EM710 and EM302 multibeam systems with respect to expected performance levels. Funded by Schmidt Ocean Institute. (Paul Johnson, Jonathan Beaudoin)

Summer Hydro 2012 Hydrographic Field Course, 21 May–3 July, R/V *Coastal Surveyor*, R/V *Cocheco*, The summer of 2012 Hydrographic Field Course brought the R/V *Coastal Surveyor*, R/V *Cocheco*, 13 JHC/CCOM students, and several technical staff to the waters offshore of Gerrish Island, ME. (Andrew Armstrong, Andy McLeod, Ben Smith, Emily Terry, Semme J. Dijkstra, Matt Wilson, Giuseppe Masetti, Chris Englert, Tom Weber, Jonathan Beaudoin, Briana Welton, Xiao Guo)

"Wiring the Deep," 23 May–28 June, R/V *Thomas Thompson*, A NEPTUNE Canada cruise (TNT 282) that was carried out as a maintenance cruise to fix and install various sensors that are part of their seafloor fiber optic network. (Garrett Mitchell)

Okeanos Explorer 2012 EX1204, 29 May–13 June, NOAA Ship *Okeanos Explorer*, Exploration of NE Canyon and Continental Margins. (Meme Lobecker)

Ecuador Seismic Campaign, 4 June–24 June, A seismic and infrasound volcanology field school run through New Mexico Tech. The three week campaign involved installation, management and analysis of a six-station seismic array, and two six-station infrasound arrays, on the side of Tungurahua volcano, Ecuador. (Ashton Flinders)

ECS mapping, 17 June–16 July, R/V *Ron Brown*, U.S. extended continental shelf mapping cruise. (Andrew Armstrong, Brian Calder, Chukwuma Azuike)

Nancy Foster Whale Tagging, 17 June–29 June, R/V *Nancy Foster*, The purpose of this project is to better understand the behavior of Humpback Whales and their interaction with prey. We use tags attached to the animals with suction cups. This year there was a major focus on gathering video information using National Geographic's Crittercam tag. It is a continuation of a program begun in 2004. (Colin Ware)

Kilo Moana 2012 06, 21 June–24 June, R/V *Kilo Moana*, Assess compliance of EM710 and EM302 multibeam system with respect to expected performance levels. Funded by NSF. (Jonathan Beaudoin)

Falkor 2012 07, 1 July–15 July, R/V *Falkor*, Assess compliance of EM710 and EM302 multibeam systems with respect to expected performance levels. Funded by Schmidt Ocean Institute. (Jonathan Beaudoin)

Maine Department of Marine Resources: Multibeam Sonar and Visual Observations Work, Mid Coast Maine, 3 July–9 July, OSV Bold, This investigation was an effort to gain insight into a seafloor area pre-selected by an unsolicited bid for an offshore wind turbine farm. Efforts included multibeam, sidescan sonar, and bat, bird, and marine mammal observations. (Chris Englert)

Summer Hydro 2012 Groundtruth Cruise, 3 July, R/V *Cocheco*, Cruise to obtain video and sediment samples for groundtruth for features of interest from the area where the Summer Hydro 2012 class did a bathymetric and back-scatter survey. (Semme J. Dijkstra, Larry Ward)

Okeanos Explorer 2012 EX1205 Leg 1, 5 July–24 July, NOAA Ship *Okeanos Explorer*, Telepresence enabled exploration of Blake Ridge and Cape Fear Diapir complex, utilizing water column capabilities of mapping sensors. WHOI Sentry vehicle onboard. (Meme Lobecker, Adam Starke)

Marcus G. Langseth 2012 12, 11 July–24 July, R/V *Langseth*, Cascadia Open-Access Seismic Transects (COAST). (Ashton Flinders)

Cocheco 2012 01, 23 July–August 1, R/V *Cocheco*, Several day-trips in which the University of Delaware AUV was operated for AUV Bootcamp 2012 shakedown mission(s) and with macro algae habitat mapping near the Isles of Shoals. (Jenn Dijkstra, Val E. Schmidt)

E/V *Nautilus* - Anaximander Seamounts Leg 1, 24 July–13 August, E/V *Nautilus*, Transited the eastern Mediterranean exploring the Anaximander Seamounts and mud volcanoes. (Lindsay McKenna)

Pisces 2012 07, 24 July–26 July, NOAA Ship *Pisces*, Install "SVP Editor," assist in resolving data workflow issues with ME70, POSMV, CARIS HIPS, QPS FMGT. (Glen Rice, Matt Wilson, Jonathan Beaudoin)

EX1205 Leg 2, Northeast Canyon and Continental Margin Exploration, 28 July–13 August, NOAA Ship *Okeanos Explorer*, Exploration of the Northeast U.S. continental margin between Cape Hatteras and Cape Cod. (Adam Skarke)

MGL1214, 31 July–1 August, Multibeam Advisory Committee (MAC) ship visit for the R/V *Marcus Langseth*. The visit included planning a Multibeam Patch Test off the Oregon coast, conducting the test, determining and applying static offset values, inspecting and correcting acquisition computer parameters, and installing MAC multibeam tools and documentation on the ships computers. (Paul Johnson)

Paphos Cyprus to Paphos Cyprus Exploration of Eratosthenes Seamount, 11 August–20 August, E/V *Nautilus*, Paphos Cyprus to Paphos Cyprus Exploration of Eratosthenes Seamount. (Larry Mayer)

AT22-01 Canada-U.S. UNCLOS North Atlantic Mapping Cruise, 15 August–10 September, R/V *Atlantis*, The Canada-U.S. UNCLOS Joint Mapping Cruise was an effort to define the foot of the slope of the continental shelf in the North Atlantic Ocean, north of the U.S.-Canada border. (Briana Welton)

Eratosthenes Seamount Cruise (NA023), 18 August–28 August, E/V *Nautilus*, This cruise was to the Eratosthenes Seamount, Cyprus aboard the E/V *Nautilus* (Cruise NA023). (Larry Mayer, Garrett Mitchell)

Orion 2012 01, 19 August–24 August, R/V *Orion*, Several AUV surveys conducted as part of AUV Hydrographic Bootcamp 2012. These included engineering testing and repeat mapping missions. (Val E. Schmidt)

CTD Survey in Portsmouth Harbor, 20 August, Galen J, CTD survey with the Cast Away CTD. (Jon Hunt)

HLY1202 Barrow AK to Dutch Harbor AK - ECS Mapping of the Arctic, 25 August–29 September, USCGC *Healy*, ECS mapping of the Arctic. The USCGC *Healy* collected mapping and geologic data necessary to delimit the U.S. and Canadian extended continental shelf. (Andrew Armstrong, Ashton Flinders, Lindsay McKenna, Roland Arsenault, Giuseppe Masetti, Chris Englert, Derek Sowers, Kevin Jerram, Brian Calder, Larry Mayer)

Flathead Lake Current Observations, 3 September–7 September, R/V *Jessie B*, Deployed current meter mooring and conducted current profile surveys in Flathead Lake, Montana, in collaboration with University of Montana researchers. (Jim Irish, Jon Hunt, Tom Lippmann)

New England calibration site visit, 4 September, Visit to Cape Ann, MA in order to identify land cover types for the remote sensing procedure. (Olumide Fadahunsi, Lee Alexander, Shachak Peeri)

Ocean Mapping Geological Oceanography Module Cruise, 8 September, R/V *Gulf Challenger*, Cruise to demonstrate single beam acoustics, videography, and bottom sediment sampling for students in the Introduction to Ocean Mapping course. (Jim Gardner, Shachak Peeri, Larry Ward)

Hassler 2012 09, 9 September–14 September, NOAA Ship *Ferdinand R. Hassler*, Install and test Wilson's research project software (CastTime). (Matt Wilson, Jonathan Beaudoin)

WHOI FSM 2012 R/V *Ka Imikai-O-Kanaloa*, 19 September–13 October, R/V *Ka Imikai-O-Kanaloa*, The cruise was a hybrid academia/industry cruise, looking for manganese nodules 400 nm southeast of the big island of Hawaii for a Japanese company contracted to the Japanese government. (Meme Lobecker)

Benthic macroalgal habitat mapping, *Coastal Surveyor*, 24 October, R/V *Coastal Surveyor*, Day trip to sites off Gerrish Island to map/characterize benthic algal habitats using water-column data (Tom Weber, Jenn Dijkstra)

Sharp 2012 01, 26 October–27 October, R/V *Hugh R. Sharp*, Bedforms project involving repeat seafloor mapping to characterize the evolution of bedforms in the vicinity of the mouth of Delaware Bay. (Jonathan Beaudoin, Val E. Schmidt)

Recovery of Wave Energy Buoy, 26 October, Work on Neptune Wave Energy Buoy and the Ocean Observing Buoy which was located near the Neptune Buoy. (Jon Hunt)

Flathead Lake Current Observations, 29 October–2 November, R/V *Jessie B*, Recovered current meter mooring in Flathead Lake, MT, and conducted current profile surveys. (Jon Hunt, Tom Lippmann)

Mid-Atlantic and Northeast Canyon Exploration EX1206, Margin Exploration, 2 November–20 November, NOAA Ship *Okeanos Explorer*, Bathymetric and water column mapping between the continental shelf break and ECS coverage. (Adam Skarke)

Flathead Lake, Montana Field Work, 5 November–9 November, Recovery of moored current sensor which has been sitting at the bottom of the lake for two months. Plus completed a current survey of the lake through two transits. (Tom Lippmann, Jon Hunt)

Hugh Sharp 2012 11, 8 November–11 November, R/V *Hugh R. Sharp*, ONR Bedforms project, seabed mapping with Reson 7125 at 200 and 400 kHz. (Larry Mayer, Jonathan Beaudoin, Val Schmidt)

NEWBEX Groundtruth Cruise, 26 November, R/V *Gulf Challenger*, Cruise to Portsmouth Harbor to obtain video and bottom sediment samples for seafloor characterization and groundtruth for the NEWBEX field test area (Carlo Lanzoni, Garrett Mitchell, Kevin Jerram, Maddie Schroth-Miller, Larry Ward, Tom Weber)

CTD Survey in Portsmouth Harbor, 7 December, R/V *Coastal Surveyor*, Survey of the Portsmouth Harbor using a Cast Away CTD. This survey was intended to gain basic information of how the water mixes and circulated during the tidal cycle in preparation for a more extensive experiment next year. (Garrett Mitchell, Jon Hunt, Tom Lippmann)

Appendix C: Other Funding

Name of Project	PI	Grantor	FY Award	Total Award	Length
Electronic Chart Initiative	Alexander, L.	U.S. Army Corps of Engineers	-	30,000	11 months
Evaluations and Assessment of Acoustic Sensors Aboard R/V *Falkor*	Beaudoin, J.	Schmidt Ocean Institute	222,775	222,775	5 months
Collaborative Research: Optimizing Multibeam Data Aquisition, Operations and Quality for the US Academic Research Fleet	Beaudoin, J. Johnson, P.	National Science Foundation	131,330	597,194	3 years
Mapping Seafloor Uncertainty	Calder, B.	Office of Naval Research	-	96,593	4.5 years
Hydrographic Training	Dijkstra, S.	NOAA Coast Survey Development Lab	6,203	6,203	-
Bathymetric Surveying of Little Bay Estuary, NH	Lippmann, T.	NH Department of Environmental Services	49,641	49,641	10 months
Large Scale Observation of Fine Scale Seabed Morphology and Flow Structure of Tidally Modulated Inlets	Lippmann, T.	Office of Naval Research	132,093	327,107	2.5 years
Large Scale Observation of Fine Scale Seabed Morphology and Flow Structure of Tidally Modulated Inlets: Analysis of the New River Field Data	Lippmann, T.	Office of Naval Research	63,378	126,756	1 year
Expedition 343 JFAST, USSSP Support	Mayer, L.	COL/National Science Foundation	9,494	9,494	1 year
GEBCO 9th Year	Mayer, L.	General Bathymetric Chart of the Oceans	570,000	2,184,455	4 years
Machine Services for OKEANOS	Mayer, L.	University Corporation for Atmospheric Research	77,954	77,954	PO
Tyco Endowment Interest from Perpetuity	Mayer, L.	Tyco	46,772	-	Perpetuity
Bedform Parameterization and Object Detection from Sonar Data Application of Finger Print Algorithms	Mayer, L. Beaudoin, J.	UDEL/Office of Naval Research	40,966	58,148	18 months
Aerial Imagery of Bluefin Tuna	Rzhanov, Y.	U. Mass Amerhest/NOAA National Marine Fisheries Services	14,603	14,603	1 year
Seafloor Video Mosaic Research	Rzhanov, Y.	U.S. Geological Survey	10,000	30,000	3 years
StereoFish	Rzhanov, Y.	U.S. DOC NOAA	-	54,000	2.5 years
AUV Boot Camp 2012	Schmidt, V.	Teledyne Benthos	15,000	15,000	-
Investigation of Motion Cues for Linking Elements of Complex Visual Displays	Ware, C.	Oculus Info., Inc.	-	13,000	3 months
HCC Small Interactive Casual Networks	Ware. C.	National Science Foundation	-	147,931	3 years
Visualization Human Systems	Ware, C.	Systems & Technology Research, LLC	33,100	33,100	8 months
The Effects of Cluster Scatters on Volume Reverberation	Weber, T.	Office of Naval Research	-	89,693	2.5 years
Modeling Statistics of Fish	Weber, T.	Office of Naval Research	50,819	180,720	3 years
TOTAL			1,477,128	4,364,367	

Appendix D: Publications

Journal Articles

Adams, Thomas, Beets, Peter, and Parrish, Christopher E., "Extracting More Data from Lidar in Forested Areas by Analyzing Waveform Shape," *Remote Sensing*, Volume 4, pp.682-702.

Alexander, Lee, "AIS Application-Specific Messages: Expectation and Reality," *Sea Technology*, Volume 53, No. 3, p.69.

Bachmann, Charles M., Montes, Marcos J., Parrish, Christopher E., Fusina, Robert A., Nichols, Reid C., Li, Rong-Rong, Hallenborg, Eric, Jones, Christopher A., Lee, Krista, Sellars, Jon, et al., "A dual-spectrometer approach to reflectance measurements under sub-optimal sky conditions," *Optics Express*, Volume 20.

Butkiewicz, Thomas, "Exploring Ocean Flow Models with a Multitouch 3D Interface," *Sea Technology*, pp.44-46.

Forrest, A.L., Wittmann, M. E., Schmidt, Val E., Raineault, N.A., Hamilton, A, Pike, W., Schladow, S.G., Reuter, J. E., Laval, B. E., and Trembanis, A.C., "Quantitative assessment of invasive species in lacustrine environments through benthic imagery analysis," *Limnology and Oceanography: Methods*.

Hickman, Stephen H., Hsieh, Paul A., Mooney, Walter D., Enomoto, Catherine B., Nelson, Philip H., Mayer, Larry A., Weber, Thomas C., Moran, Kathryn, Flemings, Peter B., and McNutt, Marcia K., "Scientific basis for safely shutting in the Macondo Well after the April 20, 2010 Deepwater Horizon blowout," *Proceedings of the National Academy of Sciences*.

Jakobsson, Martin, Mayer, Larry A., Coakley, Bernie, Dowdeswell, J, Forbes, S., Fridman, B., Hodnesdal, H., Noormets, R., Gardner, James V, Armstrong, Andrew A, et al., "The International Bathymetric Chart of the Arctic Ocean (IBCAO) version 3.0," *Geophysical Research Letters*, Volume 39.

Jones, D. T., Wilson, C.D., De Robertis, A., Rooper, C.N., Weber, Thomas C., and Butler, J.L., "Evaluation of rockfish abundance in untrawlable habitat: combining acoustic and complementary sampling tools," *Fishery Bulletin*, Volume 110, pp.332–343.

Masetti, Giuseppe, and Calder, Brian R., "Remote identification of a shipwreck site from MBES backscatter," *Journal of Environmental Management*, Volume 111, pp.44-52.

Masetti, Giuseppe, Calder, Brian R., and Alexander, Lee, "Potentially Polluting Marine Sites GeoDB: An S-100 Geospatial Database as an Effective Contribution to the Protection of the Marine Environment," *International Hydrographic Review*, Volume 8, pp.27-40.

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Russel, Craig, Pinner, W., Lovalvo, D., Skarke, Adam, Lobecker, Elizabeth (Meme), Malik, Mashkoor A., and Nadeau, LT. M., "Technology: NOAA Ship *Okeanos Explorer*," *Oceanography*, Volume 25, pp.12-15.

Rzhanov, Yuri, and Pe'eri, Shachak, "Pushbroom-frame Imagery Co-registration: USACE's CHARTS," *Marine Geodesy*, Volume 35, pp.141-157.

Stockwell, J. D., Weber, Thomas C., Baukus, A.J., and Jech, J.M., "On the use of omnidirectional sonars and downwards-looking echosounders to assess pelagic fish distributions during and after midwater trawling," *ICES Journal of Marine Science: Journal du Conseil*.

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Book

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Ware, Colin, *Information Visualization: Perception for Design*. Edition III, Edition 3rd, Morgan Kaufman, Boston, MA, United States.

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Bell, K L, Ballard, Robert, Brennan, M. L., Raineault, Nicole, Shank, T M., Mayer, Larry A., Roman, Chris, Mitchell, Garrett, and Coleman, D. F., Exploration of the Black, Aegean, and Mediterranean Seas Aboard E/V Nautilus, 2012 Fall Meeting, American Geophysical Union (AGU), San Francisco, CA, United States, 3–7 December.

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Calder, Brian R., and Venugopal, Rohit, Hydrographic Data Processing on a Robust, Network-Coupled Parallel Cluster, 6th International Conference on High-Resolution Survey in Shallow Water, Wellington, New Zealand, 21–26 February.

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Jerram, Kevin, Weber, Thomas C., and Beaudoin, Jonathan, Exploring the Capabilities of an 18-kHz Split-beam Scientific Echosounder for Water Column Mapping and Seafloor Positioning of Methane Seeps in the Northern Gulf of Mexico, The Journal of the Acoustical Society of America.

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Butkiewicz, Thomas, A More Flexible Approach to Utilizing Depth Cameras for Hand & Touch Interaction, IEEE VR 2012, Workshop on Off-the-Shelf Virtual Reality, Orange County, CA, 4 March.

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Pirtle, Jodi, Weber, Thomas C., Wilson, C.D., Rooper, Chris, and Calder, Brian R., Seafloor Characterization for Trawlability Using the Simrad ME70 Multibeam Echosounder in the Gulf of Alaska, GeoHab, Marine Geological and Biological Habitat Mapping Meeting, Orcas Island, WA, 1–4 May.

Rice, Glen A., Greenaway, Samuel F., Weber, Thomas C., and Beaudoin, Jonathan, Methods for Collecting and Using Backscatter Field Calibration Information for the Reson 7000 Series Multibeam, 2012 Canadian Hydrographic Conference, Niagara Falls, Canada, 15–17 May.

Ringuette, G, Pelletier, S., Dagenais, D.A., and Alexander, Lee, e-Navigation on the St. Lawrence River in Canada: Past, Present and Future, e-Navigation Underway 2012, Copenhagen, Denmark, 18–20 January.

Schmidt, Val E., and Rzhanov, Yuri, Measurement of Micro-bathymetry with a GOPRO Underwater Stereo Camera Pair, IEEE Oceans, Hampton Roads, VA, 14–19 October.

Schmidt, Val E., Weber, Thomas C., and Trembanis, A.C., Automated Optimal Processing of Phase Differencing Side-scan Sonar Data using the Most Probable Angle Algorithm, IEEE OCEANS 2012, Hampton Roads, VA, 15–19 October.

Sullivan, Briana M., ChUM: Chart Update Mashup, IEEE Oceans, Hampton Roads, VA, 15–19 October.

Sullivan, Briana M., Using a Cruise Report to Generate XML Metadata, IEEE/MTS Oceans, Hampton Roads, VA, 15–19 October.

Trembanis, A.C., Cary, C., Schmidt, Val E., Clarke, D., Crees, T., and Jackson, E., Modular Autonomous Bio-sampler (MAB) - A prototype system for distinct biological size-class sampling and preservation, IEEE Oceans, Hampton Roads, VA, 14–19 October.

Weber, Thomas C., Jerram, Kevin, and Mayer, Larry A., Acoustic sensing of gas seeps in the deep ocean with split-beam echosounders, 11th European Conference on Underwater Acoustics, Edinburgh, Scotland, 2–6 July.

Reports

Alexander, Lee, and Casey, M.J., "Portable Piloting Unit (PPU) Replacement Study: Phase 2, Laurentian Pilotage Authority," Montreal, Quebec, Canada, p.14.

Beaudoin, Jonathan, and Johnson, Paul, "R/V *Kilo Moana* Multibeam Echosounder System Review," Center for Coastal and Ocean Mapping / Joint Hydrographic Center, Durham, NH, pp.1-48.

Beaudoin, Jonathan, Floc'h, Henri, and Lurton, Xavier, "SAT and Trial Cruise of the Acoustical Sensors Onboard R/V *Falkor*," Center for Coastal and Ocean Mapping / Joint Hydrographic Center & IFREMER, pp.1-18.

Beaudoin, Jonathan, "USNS Mary Sears EM122 Multibeam Echosounder Sea Acceptance Trials," Center for Coastal and Ocean Mapping / Joint Hydrographic Center, Durham, NH, pp.1-35.

Monahan, Dave, "Evaluation of Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA) Capability in Non-navigational Ocean Mapping," GEBCO, Valparaiso, CHL , pp.1-5.

Pirtle, Jodi, Weber, Thomas C., Wilson, C.D., Rooper, Chris, and Heifetz, Jon, "Essential Fish Habitat Project Status Report: Low-cost multibeam mapping to support habitat based groundfish assessment and deepwater coral research in the Gulf of Alaska," NOAA Alaska Fisheries Science Center, Seattle, WA, pp.1-12 .

Rice, Glen A., Weber, Thomas C., and Pirtle, Jodi, "Descriptive Report to Accompany NOAA Ship *Oscar Dyson* 2011," NOAA Office of Coast Survey.

Rzhanov, Yuri, "Methodology of Processing of Stereoimagery of Fish Underwater: Software and Algorithms," Center for Coastal and Ocean Mapping / Joint Hydrographic Center, Durham, NH.

Rzhanov, Yuri, "Review of Methods and Software for Processing of Underwater Imagery and Construction of Mosaics," Center for Coastal and Ocean Mapping / Joint Hydrographic Center, Durham, NH.

Thesis

Abramova, Anastasia, *Comparison and Evaluation of Global Publicly Available Bathymetry Grids in the Arctic*, Master of Science in Earth Sciences.

Denney, Sean, *A Tidal Study of Great Bay, New Hampshire,* Master of Science in Ocean Engineering with an Ocean Mapping Option.

Masetti, Giuseppe, A *Geo-database for Potentially Polluting Marine Sites and Associated Risk Index*, Master of Science in Ocean Engineering with an Ocean Mapping Option.

Pilar, David H.F., *Visualizing Magnitude and Direction in Flow Fields*, Master of Science in Computer Science.

Appendix E: Technical Presentations and Seminars

Seminars

Tom Weber, 18 January, "Here be Lobsters," Peaks Island, ME Lecture Series, Peaks Island, ME.

Adam Skarke, 3 February, "NOAA's Okeanos Explorer Program: Three Years of Telepresence Enabled Ocean Exploration," CCOM/JHC, Durham, NH.

Tom Weber, 1 March, "Multibeam echo sounder applications to fisheries science," Large Pelagics Lecture Series (UMass), Gloucester, MA.

Lindsay McKenna, Tom Lippmann, 6 April, "Observations of Currents and Bedforms in a Tidally Modulated Inlet," CCOM/JHC, Durham, NH.

Shachak Pe'eri, 26 April, "Light Field and Water Clarity Simulation of natural environments in laboratory conditions," SPIE Defense, Security and Sensing (Ocean remote sensing and monitoring IV), Baltimore, MD.

Shachak Pe'eri, 26 April, "The impact of sea state condition on Airborne Lidar Bathymetry measurements," SPIE Defense, Security and Sensing (Laser Radar Technology and Applications XVII), Baltimore, MD.

Shachak Pe'eri, 4 May, "Simulation of Optical Remote Sensing in a Laboratory Setting," CCOM/JHC, Durham, NH.

Chris Parrish, Lee Alexander, Andrew Armstrong, Shachak Peeri, 17 May, "Beyond the Chart: the Use of Satellite Remote Sensing for Assessing Chart Adequacy and Completeness Information," Canadian Hydrographic Conference, Niagara Falls, Ontario, Canada.

Yuri Rzhanov, Shachak Pe'eri, 18 June, "The sea state condition as a environmental factor in Airborne Lidar Bathymetry (ALB) surveys," JALBTCX, Chicago, IL.

Christina Fandel, 31 August, "Pockmark Flow Structure in Belfast Bay, Maine," CCOM/JHC, Durham, NH.

Derek Sowers, 12 September, "Exploring Economic Options to Protect Hampton-Seabrook Communities from Coastal Flooding Damages: A Climate Change Adaptation Planning Case Study," HEALY1201 Science Party, Barrow, AK.

Lee Alexander, 11 October, "IHO Standards Development and Implementation: Challenges and Opportunities," Mariners, Pilots, Companies, and Government Agencies, Seoul, Korea, South Korea.

Val E. Schmidt, 12 October, "Integration of a Geometrics Magnetometer into a Teledyne Gavia AUV," CCOM/JHC, Durham, NH.

Lee Alexander, 17 October, "Update on Some PPU, ECDIS and e-Navigation Developments," American & Canadian Maritime Pilots, Washington, DC.

Christina Fandel, Lindsay McKenna, Matt Wilson, Briana Welton, Garrett Mitchell, Chris Englert, 26 October, "Oh, the places you'll go! CCOM/JHC Student Field Experiences Summer 2012," CCOM/JHC, Durham, NH.

Lee Alexander, 13 November, "Evolution of Inland vs Maritime ENCs: Recommendations on IHO Standards to Deal with Dynamic/Fluvian River Systems, HOs, Waterway Mgmt Agencies, & Mariners," Iquitos, Rio Amazonas, Peru.

Giuseppe Masetti, 30 November, "A Geo-database for Potentially Polluting Marine Sites and Associated Risk Index," CCOM/JHC, Durham, NH.

Technical Presentations

Monica L. Wolfson, Invited, 4–6 January, Fault "Thermal Structure and Seismic Hazard on Segmented Oceanic Transform Faults," ExxonMobil, Houston, TX.

Brian Calder, Invited, 17–18 January, "Design and Implementation of CHRT," MBSystem User Group, Pallisades, NY.

Jonathan Beaudoin, Invited, 24–26 January, "New Developments in Backscatter," NOAA Office of Coast Survey (OCS), Newport, OR.

Jonathan Beaudoin, Invited, 24–26 January, "Sound Speed Corrections for Trackline Surveys," NOAA Office of Coast Survey (OCS), Newport, OR.

Brian Calder, Invited, 24–26 January, "CHRT (CUBE with Hierarchical Resolution Techniques)," NOAA/OCS, Newport, OR.

Yuri Rzhanov, 6–7 February, "Detection of Bluefin Tuna in Aerial Imagery," Large Pelagics Research Center, University of Massachusetts, Gloucester, MA.

Colin Ware, Keynote, 24 February, "Visual Thinking Algorithms," Rome, Italy.

Colin Ware, Invited, 15 February, "Improving the Display of Ocean Currents, Waves and Wind Patterns," NOAA NWS, Camp Springs, MD.

Colin Ware, Invited, 15 February, "Improving the Display of Ocean Currents, Waves and Wind Patterns," NOAA Office of Coast Survey, Silver Spring, MD.

Jim Irish, Lindsay McKenna, Tom Lippmann, 20–24 February, "Observations of Currents in a Tidally Modulated Inlet," AGU Ocean Sciences, Salt Lake City, UT.

Larry Mayer, Keynote, 20 February, From Whence We've Come and Where We Might Be Going, Shallow Survey 2012, Wellington, New Zealand.

Lindsay McKenna, 21 February, "Observations of Bedform Evolution in an Inlet," American Geophysical Union, Salt Lake City, UT.

Larry Mayer, Invited, 2 March, "Extended Continental Shelf in the Arctic," Salt Spring Island, British Columbia, Canada.

Thomas Butkiewicz, 4 March, "A More Flexible Approach to Utilizing Depth Cameras for Hand and Touch Interaction," Workshop on Off-the-Shelf Virtual Reality, Costa Mesa, CA.

Brian Calder, Tom Lippmann, Invited, 23 March, "Nearshore Processes Research and Shallow Water Mapping," Army STTR/SBIR Program Manager, Brad Guay, Durham, NH.

Larry Mayer, Invited, Eminent Lecture Series, 5 April, "New Directions in Ocean Mapping: From D-Day to Deepwater Horizon," University of South Florida, Tampa, FL.

Yuri Rzhanov, 9–11 April, "Optical Sensing and Reconstruction of Underwater Scenes for Habitat Classification," Uni Research, Bergen, Norway.

Larry Mayer, Invited, 12 April, "Mapping the Continental Shelf in a Changing Arctic," United States Coast Guard Academy, New London, CT.

Larry Mayer, Invited, 17 April, "Extended Continental Shelf on the Atlantic Margin," State Department, Woods Hole, MA.

Larry Mayer, Invited, 17 April, "The Meaning of Natural Prolongation in Article 76 of the Law of the Sea Treaty," State Department, Woods Hole, MA.

Colin Ware, Invited, 24 April, "Perceptual Theory and 2D Flow Visualization, Computer Science Department," Swansea University, Swansea, Wales, UK.

Colin Ware, Invited, 24 April, "Humpback Whale Foraging Kinematics: Midwater Lunges, Bubble Netting, Bottom Feeding," Biology Department, Swansea University, Swansea, Wales, UK.

Colin Ware, Invited, 27 April, "Visual Thinking and Visual Thinking Tools," Computer Science Department, Aberystwith University, Aberystwith, Wales, UK.

Colin Ware, Invited, 30 April, "Visual Thinking and Visual Thinking Tools," Computer Science Department, Bangor University, Bangor, Wales, UK.

Colin Ware, Invited, 3 May, "Visual Thinking and Visual Thinking Tools," Cardiff University, Computer Science Department, Cardiff, Wales, UK.

Colin Ware, Keynote, 8 May, "Perceptual Issues in Glyph Design," Oxford, UK.

Tom Weber, Jonathan Beaudoin, Glen Rice, 15 May, "Method for Collecting and Using Backscatter Field Calibration Information for the Reson 7000 Series Multibeams," Hydrographic Community, Niagara Falls, Ontario, Canada.

Brian Calder, Lee Alexander, Giuseppe Masetti, 15–17 May, "Developing a GIS-Database and Risk Index for Potentially Polluting Marine Sites," Niagara Falls, Ontario, Canada.

Jonathan Beaudoin, 15–17 May, "Establishing a Multibeam Sonar Evaluation Test Bed Near Sidney, British Columbia," Canadian Hydrographic Conference, Niagara Falls, Ontario, Canada.

Glen Rice, Tom Weber, Jonathan Beaudoin, 15–17 May, "Methods for Collecting and Using Backscatter Field Calibration Information for the Reson 7000 Series Multibeams," Canadian Hydrographic Conference, Niagara Falls, Ontario, Canada.

Tom Weber, Glen Rice, Kevin Jerram, Larry Mayer, Jonathan Beaudoin, 15–17 May, "Multibeam Echosounder System Optimization for Water Column Mapping of Undersea Gas Seeps," Canadian Hydrographic Conference, Niagara Falls, Ontario, Canada.

Larry Mayer, Invited, 2 June, "Adventures in Ocean Mapping," UNH Foundation, Portsmouth, NH.

Larry Mayer, Invited, 5 June, "Future Trends in Seafloor and Ocean Mapping," UNOLS Fleet Improvement Committee, Boston, MA.

Larry Mayer, Invited, 22 June, "Lessons Learned from Deepwater Horizon: Perspectives from the Field," Halifax, Nova Scotia, Canada.

Larry Mayer, Invited, 25 June, "Exploration of Eratosthenes Seamount on the E/V NAUTILUS," Narragansett, RI.

Larry Mayer, Invited, 28 June, "Atlantic Margin Extended Continental Shelf," State Department, Washington, DC.

Tom Weber, Carlo Lanzoni, 4 July, "Calibration of Multibeam Echo Sounders: A Comparison Between Two Methodologies," Institute of Acoustics, Edinburgh, United Kingdom.

Tom Lippmann, Invited, 7 August, "Ultra Shallow Water Surveying," NOAA Office of Coast Survey (OCS), Durham, NH.

Tom Weber, Carlo Lanzoni, Glen Rice, John Heaton, 10 August, "Acoustic Characterization of an Extended Calibration Target," CCOM/JHC, Durham, NH.

Colin Ware, Keynote, 5 September, "The Process of Visual Thinking," Annecy, France.

Tom Weber, Jodi Pirtle, Invited, 5–7 September, "Seafloor Characterization for Trawlability and Fish Habitat Using the Simrad ME70 Multibeam Echosounder in the Gulf of Alaska," NOAA Fisheries, Seattle, WA.

Tom Lippmann, 11–12 September, "Large Scale Observation of Fine Scale Seabed Morphology and Flow Structure in Tidally Modulated Inlets," Office of Naval Research, Denver, CO.

Tom Lippmann, Invited, 13–14 September, "Large Scale Observation of Fine Scale Seabed Morphology and Vertical Flow Structure in the Columbia River Mouth," Office of Naval Research, Denver, CO.

Colin Ware, Keynote, 25 September, "Visual Thinking Processes for Interactive Data Analysis," Copenhagen, Denmark.

Larry Mayer, Invited, 1 October, "Law of the Sea and Mapping in the Arctic (and Elsewhere)," National Academy of Engineering, Washington, DC.

Briana Sullivan, 17 October, "Using a Cruise Report to Generate XML Metadata," Oceans '12, Virginia Beach, VA.

Shachak Pe'eri, Invited, 18 October, "Beyond the Chart: The Use of Satellite Remote Sensing for Assessing Chart Adequacy and Completeness Information," NOAA/NESDIS/STAR, College Park, MD.

Briana Sullivan, 18 October, "ChUM: Chart Update Mashup," Oceans '12, Virginia Beach, VA.

Shachak Pe'eri, Invited, 18 October, "Light Field and Water Clarity Simulation of Natural Environments in Laboratory Conditions," NOAA/NESDIS/STAR, College Park, MD.

Larry Mayer, Keynote, 22 October, "Ocean Mapping: Exploring the Secrets of the Deep," Bedford Institute of Oceanography, Halifax, Nova Scotia.

Tom Weber, Jonathan Beaudoin, Kevin Jerram, 22 October, "Exploring the Capabilities of an 18-kHz Split-beam Scientific Echosounder for Water Column Mapping and Seafloor Positioning of Methane Seeps in the Northern Gulf of Mexico," Acoustical Society of America, Kansas City, MO.

Larry Mayer, Invited, 14 November, "Mapping in the Arctic in Support of Law of the Sea: Implications of Climate Change," Roger Williams Law School, Bristol , RI.

Larry Mayer, Invited, 16 November, "Call a Doctor: A New Paradigm for Ocean Exploration," Miami, FL.

WIll Fessenden, Les Peabody, 26 November–14 December, "Progress Report Deployment and Training Talks," CCOM/JHC, Durham, NH.

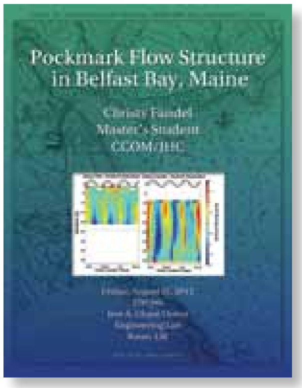
Tom Lippmann, Lindsay McKenna, 3 December, "Fine-scale Seafloor Topography and Mean Currents in a Tidally Modulated Inlet," AGU Fall Meeting, San Francisco, CA.

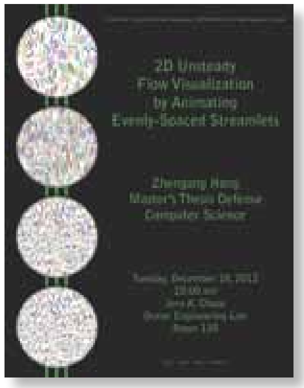
Monica L.Wolfson, Invited, 3–7 December, "Thermal Constraints on the Rheology of Segmented Oceanic Transform Fault Systems," AGU Fall Meeting, San Francisco, CA.

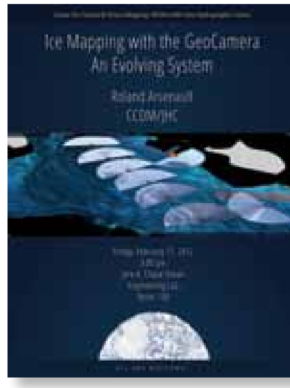
Jim Irish, Lindsay McKenna, Jon Hunt, Tom Lippmann, 4 December, "Observations of Currents in Two Tidally Modulate Inlets (Poster)," AGU Fall Meeting, San Francisco, CA.

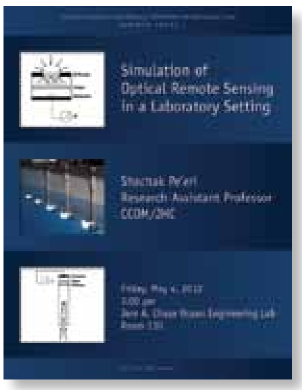
Paul Johnson, 7 December, "Improving Multibeam Data Quality Across the U.S. Academic Research Fleet," AGU Fall Meeting, San Francisco, CA.

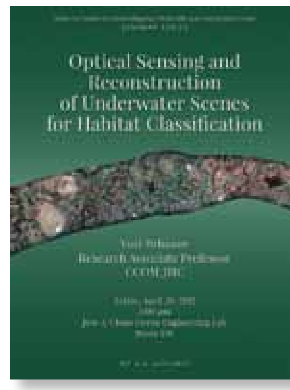
Shachak Pe'eri, Invited, 20 December, "Survey Priorities Assessment Methodologies and Case Study of Nigeria and Belize," NOAA OCS, Silver Spring, MD.

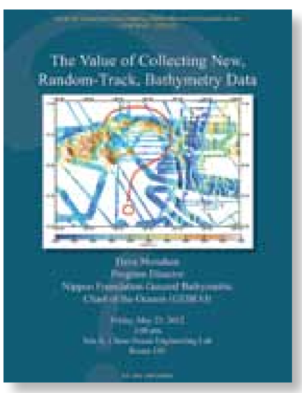


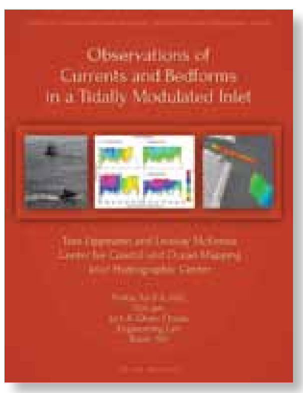


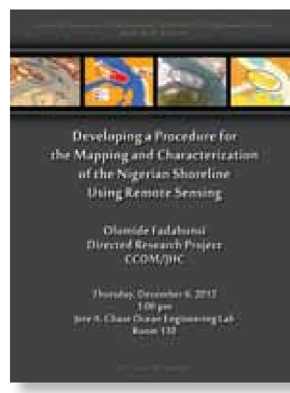


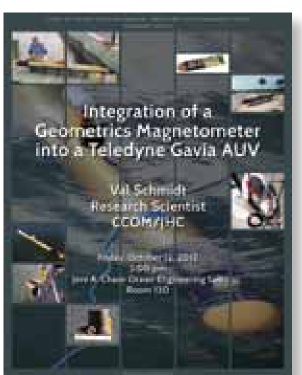


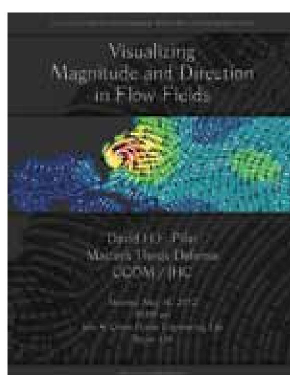


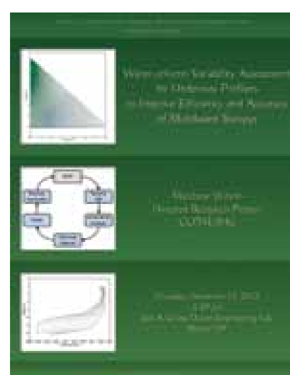












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