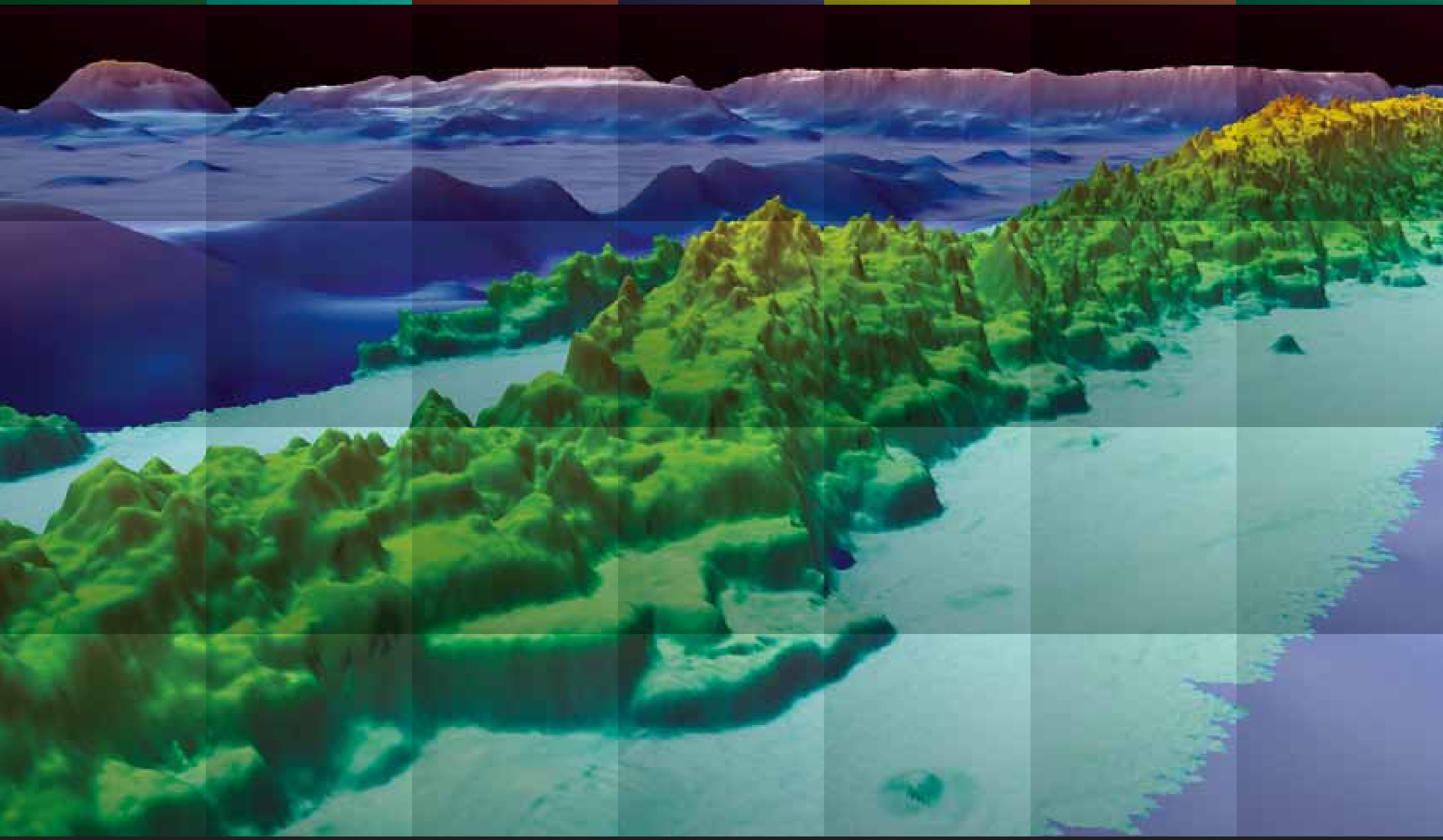
UNH/NOAA Joint Hydrographic Center

Performance and Progress Report



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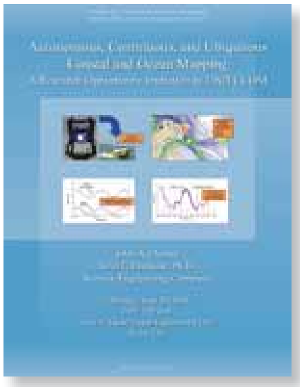

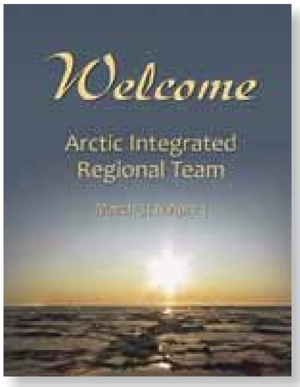

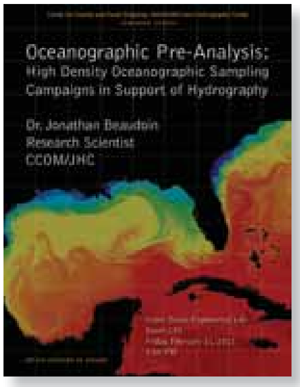

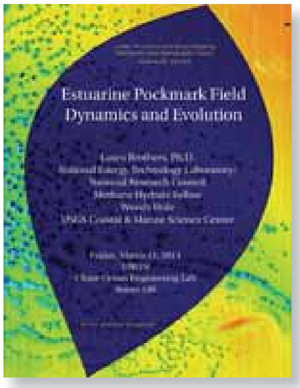

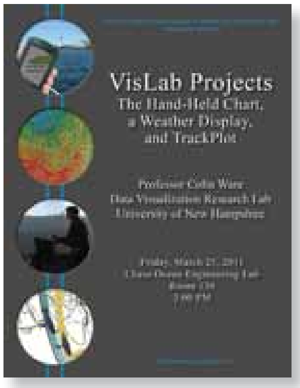

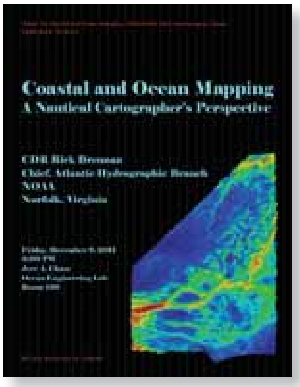

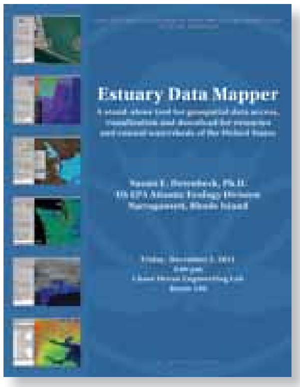

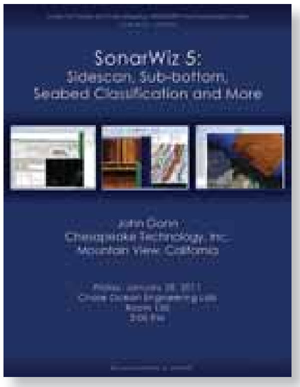

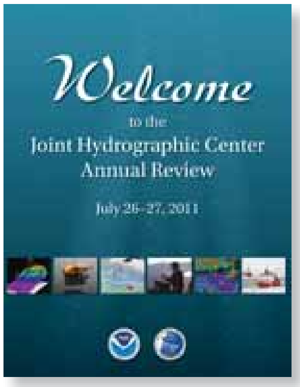

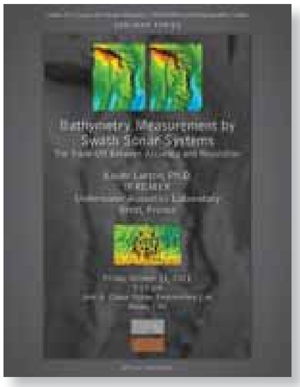

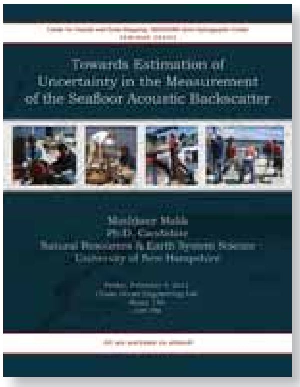

Flyers from the 2011 JHC/CCOM Seminar Series and welcome signs.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded twelve 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. Cooperative Agreements with NOAA, the most recent being the result of a national competition, fund the Center for the period of 1 July 2010 until 30 December 2015. An initial goal of the Center was to find ways to process the massive amounts of data from these multibeam and side scan 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 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 the Integrated Ocean and Coastal Mapping (IOCM) Processing Center 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 more than 80 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, after careful verification and evaluation, our automated processing algorithm (CUBE) and our new database approach (The Navigation Surface) were 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 soon the rest of the ocean mapping community) is doing hydrography. These techniques can reduce data processing time by a factor of 30 to 70 and provide a quantification of uncertainty that has never before been achievable in hydrographic data. The result: "gained efficiency, reduced costs, improved data quality and consistency, and the ability to put products in the hands of our customers faster." (Capt. Roger Parsons, former NOAA IOCM Coordinator and Director of NOAA's Office of Coast Survey). This year, we sadly note the death of Captain Parsons—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.*"

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 scientists to exploit these capabilities), it also allows careful identification of shallow hazards in the water-column and may obviate the need for wire sweeps or diver examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component in 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 has also been demonstrated by our work with Stellwagen National Marine Sanctuary which aims to facilitate 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 of Our 2011 Program

Our efforts in 2011 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 new 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 our data-fusion and Chart of the Future 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, our progress report maintains the thematic divisions.

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. Amongst the highlights of this year's efforts are the calibration of a Reson 7125 multibeam echo sounder (MBES)—the workhorse of the NOAA fleet—and a much closer look at the behavior of Phase Measuring Bathymetric Sonars (including the GeoSwath, the Klein Hydrochart 5000, and the EdgeTech 4600). Our work with these systems has often identified specific problems and resulted in changes to either hardware or software by the manufacturers. 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 and a formulation of this through funding from the National Science Foundation for Center researchers to establish a national Multibeam Advisory Committee with the goal of ensuring that consistently high-quality multibeam data are collected across the U.S. Academic Research Fleet (UNOLS vessels). A part of this 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.

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 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 Parrish 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.

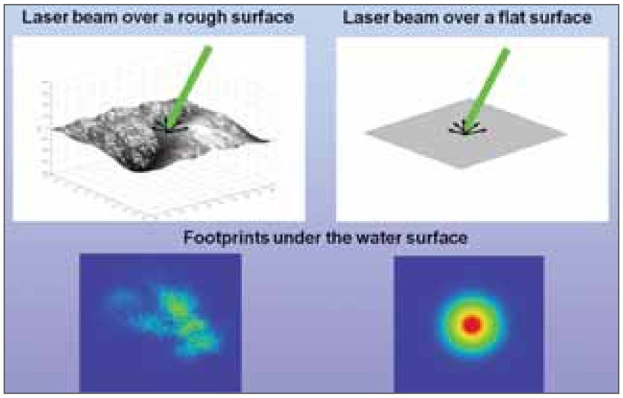

Figure ES-1. Scattering pattern simulations of the behavior of a laser beam illuminating rough water surface (left) vs. smooth water surface (right). These differences may have significant impact on the resolution of an Airborne Bathymetric lidar and its ability to detect features on the seafloor.

Amongst the issues being examined (both empirically and theoretically) are the impact of sea state on the resolution of the lidar pulse (Figure ES-1) and the influence of substrate on the lidar return. Parrish and Pe'eri are also exploring the potential of using Raman scattering from lidar as a means of making underway measurements of the temperature and salinity of near-surface waters. If this proves to be viable, it could provide a powerful addition to the suite of ocean mapping tools.

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. This year, Tom Lippmann has further enhanced the development of 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 now with the inclusion of a small multibeam echo-sounder (Figure ES-2). We are also, through collaboration with Art Trembanis at the University of Delaware, exploring the viability of using Autonomous Underwater Vehicles (AUVs) as a platform for hydrographic measurements.

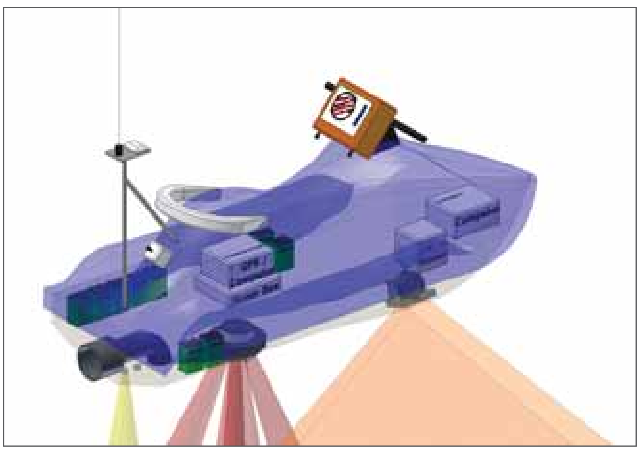

Figure ES-2. Scaled CAD drawing showing the location of the MBES (peach), SBES (yellow), and ADCP (red) with acoustic beam patterns on the CBASS.

Processing

In concert with our efforts focused on understanding the behavior and limitations of the sensors we use, we are developing a suite of processing tools aimed at improving the efficiency of producing the end products we desire and, as importantly, are 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. One of the ongoing issues with CUBE has been the choice of the appropriate resolution with which to grid that data. Calder and NOAA LTJG Glen Rice (currently assigned to the JHC/CCOM IOCM Processing Center) have developed an approach that uses the data density as a means to drive the choice of resolution. The goal is to have a simple set of criteria that will result in robust and efficient data processing. As part of this effort, Calder has developed a new multi-resolution grid structure (CUBE with Hierarchical Resolution Techniques, or CHRT). This year's efforts focused on testing and development of the core algorithms to reliably estimate data density, adapt the multi-resolution representation and compute depths at variable resolution; and infrastructural improvements to the core algorithms, the flexibility of the estimator, and the structure of the client-server applications which implement the algorithm. Once implemented, this multi-resolution capability should greatly improve the speed and accuracy of multibeam data processing in regions of rapid depth changes. In parallel with this effort, Calder and graduate student Rohit Venugopal are looking at ways to implement the multi-resolution grid and other aspects of multibeam sonar processing on parallel processors. Initial studies are complete and suggest substantial time savings if processing can be carried out in this environment. Calder is also working with visiting scholar Xavier Lurton (from IFREMER) to incorporate newly-derived quality factors for MBES data into the CUBE algorithm.

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. 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 sonar processing ("Most Probable Angle" algorithm) and, with this, have been quantifying the uncertainty associated with these measurements. This year, Schmidt has experimented with using an estimation of the trend of the seafloor and retention of soundings within some bound of that trend (Figure ES-3). The method works well at rejecting outliers at the far edges of the swath during which time the signal to noise ratio is low and self-noise within the sonar is often tracked rather than the bottom.

It has become 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 we work in. Jonathan Beaudoin is looking at a number of approaches to capture and understand the uncertainty associated with the sound speed structure of the water column, to use 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. Beaudoin has used a Monte Carlo approach to understand the effect of sensor bias and/or noise on the ultimate accuracy of the sounding. His results have been compared to a more theoretical approach taken by visiting scholar Xavier Lurton and their agreement will lead to a much better prediction of the uncertainty associated with sound speed estimates. Working with Industrial Associate Rolls Royce, Beaudoin has developed sound speed profile pre-processing algorithms that interface directly with Kongsberg Maritime (KM) multibeam echo sounders allowing the automatic extension of a hydrocast to a depth of 12,000 m (as required by the MBES) and the reduction of the number of data points to meet KM input criteria that casts contain less than 1,000 data points.

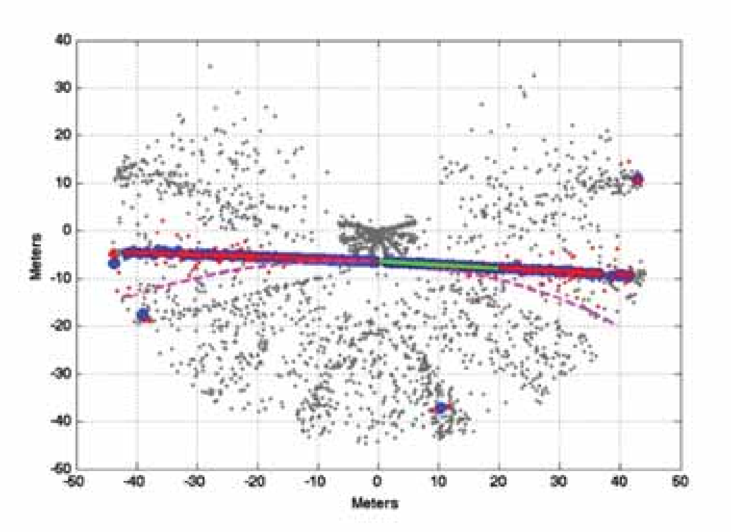

Figure ES-3. Phase-measurement sonar data outlier rejection algorithm showing a single ping of data overlaid with algorithm results (red) and bottom trend (green) and trend rejection boundary (pink).

A particularly difficult situation is when MBES data is collected but insufficient sound speed data exists. We have found this to be the case when fisheries vessels collect MBES data for fisheries rather than seafloor mapping purposes or when vessels are transiting and not regularly collecting sound speed profile data. With a new focus on multi-purpose data collection (the IOCM concept of "map once – use many times"), there is a critical need to find ways to make the appropriate corrections to these data for sound speed in the water column (needed to convert the acoustic measurement to an accurate depth measurement). To address this, Beaudoin has developed the SVP Server (Figure ES-4), an application that subscribes to the ship's position datagram from the multibeam echo sounder and does a lookup for temperature and salinity profiles in either the World Ocean Atlas of 2009 (WOA2009) or the Global Real-Time Ocean Forecast System (Global RTOFS). Using tools and approaches like this, we have been able to produce near-hydrographic quality bathymetry from archived fisheries MBES data (see the IOCM discussion below).

Carrying the approach to 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 multibeam systems. The result of this effort is something akin to a weather map for hydrographers. The basic

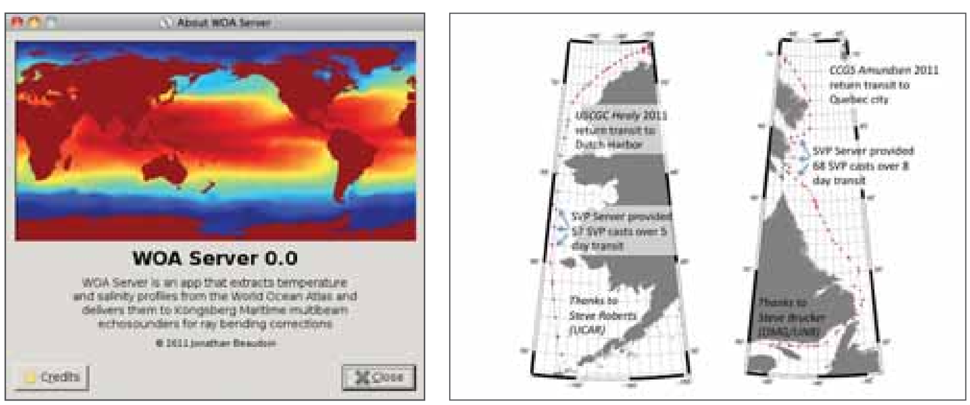

Figure ES-4. Early version of the SVP server and results of locations where sound speed profiles were provided for transits during the 2011 USCG HEALY and CCGS AMUNDSEN cruises during which the software was tested (with the WOA2009 data source only).

idea is that oceanographic models of temperature and salinity may be able to provide us with some idea of where and when spatial variability in the water column can be problematic. Given a sufficiently high resolution model, this approach can be used to provide guidance in the selection of appropriate sound speed sampling technologies and field procedures (e.g., sampling intervals).

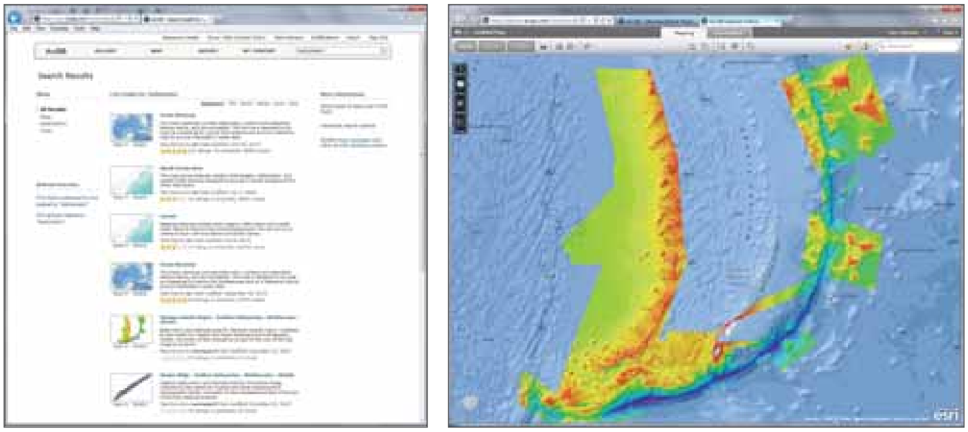

Figure ES-5. JHC data being served through the ArcGIS cloud.

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 comes with the bathymetric data but that has long been ignored by hydrographic agencies. These data are becoming more and more important as we recognize the potential for seafloor mapping approaches to provide quantitative information about seafloor type or character 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? In part, this issue is being addressed in the Ph.D. thesis of Mashkoor Malik but it is so critical that we have, this year, initiated a lab-wide effort called the Newcastle Backscatter Experiment, an effort aimed at testing our ability to collect 'calibrated' backscatter using hydrographic multibeam echo sounders.

This project, which involves close collaboration with NOAA's Glen Rice and Briana Welton, 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). 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 is work done by Jonathan Beaudoin to determine why backscatter data collected on the NOAA vessel *Fairweather* in the Olympic Coast National Marine Sanctuary was fraught with artifacts. Beaudoin's research determined there was a discrepancy between expected transmission losses and the time-varying gain applied in real-time. Working with the manufacturer, these issues were resolved and the backscatter data was corrected and was able to serve its purpose as a tool for guiding seafloor sampling.

Included in the processing theme is our renewed effort in data management that has been facilitated by the filling of a long-vacant data management position this year with Paul Johnson from the University of Hawaii. The value and usefulness of the data we collect is inextricably linked to the ability of others to discover and work with the data. Metadata (data about the data) is a key component to ensuring that full value can be derived from data. To support the creation of metadata, Johnson is developing a series of scripts and tools designed to extract information out of gridded, raw and processed multibeam data and to then turn this information into usable products that can be easily incorporated into a database run through a GIS server that provides easy access to the user community (Figure ES-5).

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 corrected backscatter mosaics and calculate a number of backscatter statistics) and the ARA (Angular Response Analysis) software package 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, 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 been involved directly in acoustic habitat mapping studies in the context of our IOCM efforts, as Jodi Pirtle, Tom Weber and Glen Rice participated on cruises on the NOAA fisheries vessel *Oscar Dyson* and used the ME70 fisheries sonar designed for mid-water mapping of fish stock to extract bathymetry (see IOCM discussion) and seafloor backscatter. Pirtle was able to quantitatively analyze the mean backscatter values and found that she could identify regions likely to contain deep sea coral and sponge ecosystems (DCSEs) which are areas vulnerable to anthropogenic activities and thus was able to discriminate between trawlable and untrawlable seafloor (Figure ES-6).

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 have the ability to simultaneously map the seafloor and the water column. Combining the ability to image the water column and the seafloor over wide swaths with high-resolution offers great opportunities for new applications and increased survey efficiencies. The Center has been very active in developing tools to capture, analyze and visualize water column data 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 last year's Deepwater Horizon (DWH) crisis (see last year's annual report for a full description of our activities related to Deepwater Horizon). As a continuation of our efforts related to Deepwater Horizon, analysis of the data

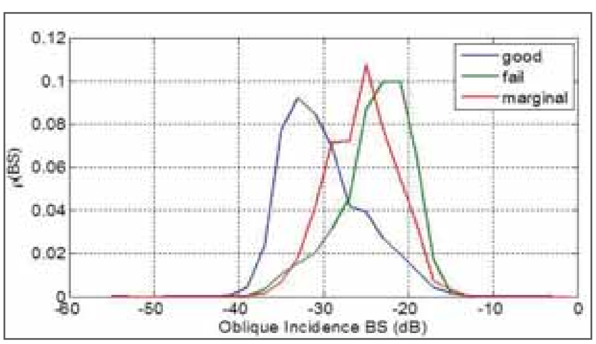

Figure ES-6 . Histograms describing the distribution of oblique incidence backscatter values (45 degrees) at locations in the GOA previously towed (1996-2011) by the AFSC bottom trawl survey and classified as good, failed, or marginal (left). Stereo Drop Camera (SDC) image collected on August 12, 2011 on Albatross Bank with Sebastes spp. associating with untrawlable habitat composed of rock ridge, boulders, corals, and sponges (right).

we collected there was conducted in order to develop and test a methodology for estimating the oil concentration and flow rate based on high frequency acoustic measurements. Although our estimate of the uncertainty in the result is high due to the lack of absolute knowledge of the properties of the oil droplets (e.g., the size distribution of the droplets), the flow rate estimate is remarkably consistent with those made at the wellhead by other means. The results of this analysis demonstrate a methodology for acoustically assessing oil in the water column that can be used to help quantitatively assess the fate of spilled oil for future incidents. One of the highlights of this project is the collaborative effort between The Center, NOAA NMFS, and NOAA OCS, all of whom played important roles in the DWH response and in this subsequent analysis. Should the need for a similar response arise, this NOAA/Academic team will be well poised to contribute with specific (and documented) methodologies. A manuscript describing these efforts has been published in the Proceedings of the National Academy of Science.

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

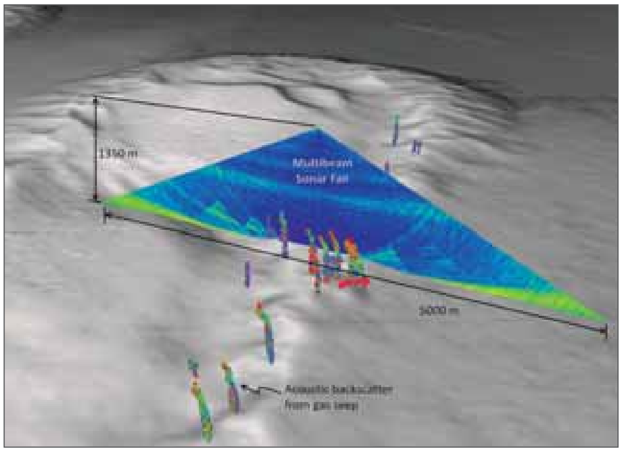

Figure ES-7. Seeps imaged with the EM302 on the NOAA Ship *Okeanos Explorer* on the Dauphin Dome in the northern Gulf of Mexico. The blue dots indicate locations of seeps.

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 km^2 of the northern Gulf of Mexico making 573 seep observations (Figure ES-7). 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.

IOCM—Integrated Ocean and Coastal Mapping

A critical component of the Center's new proposal was to maintain an Integrated Ocean and Coastal Mapping Processing Center that would support NOAA's new focused efforts on Integrated 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 been partnering with a number of Center members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. In addition, Glen provides a direct link when specific operational difficulties arise in the field, allowing Center personnel to take part in designing an appropriate solution.

Epitomizing the IOCM concept has been our efforts on the NOAA fisheries vessel *Oscar Dyson*. While the *Dyson* was conducting routine acoustic trawl surveys this summer, we were able to simultaneously extract bathymetry data (to date more than 100 sq. miles

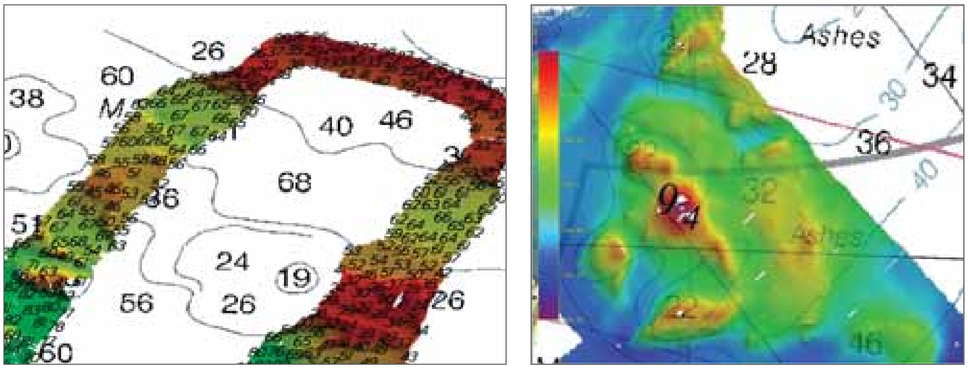

Figure ES-8. An example of data collected with the Simrad ME70 MBES on the NOAA Ship *Oscar Dyson* (left) in support of safety of navigation. ME70 data (color, small font) are overlaid on existing chart data (all depths in fathoms). Danger to Navigation (right) mapped using the Simrad ME70 during a cruise on the NOAA Ship *Oscar Dyson*, mapped by Glen Rice and Jodi Pirtle.

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 ME70 data of a previously uncharted shoal that led to a chart update and Danger to Navigation (DTON) warning (Figure ES-8). 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. We have indeed mapped once, and used many times. Several other NOAA fisheries vessels are now interested in collecting bathymetry with their ME70s and some work has begun to formalize the sounding extraction portion of the workflow. OMAO is looking into making this process standard aboard NOAA vessels with ME70s as part of the NOAA R2R program.

Other aspects of our IOCM efforts involve close work the Ocean Exploration program and their vessel of exploration the NOAA Ship *Okeanos Explorer.* Center staff have worked closely with OER staff to develop protocols for multibeam data collection, processing and archiving and to provide support and guidance during NOAA Ship *Okeaonos Explorer* expeditions through the Telepresence Console (see the Facilities section).

Visualization

We continue to focus strongly 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. With the addition of postdoctoral research associate Tom Butkiewicz to the team this year, he and Ware have collaborated to develop 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/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 which leverages a smart particle system.

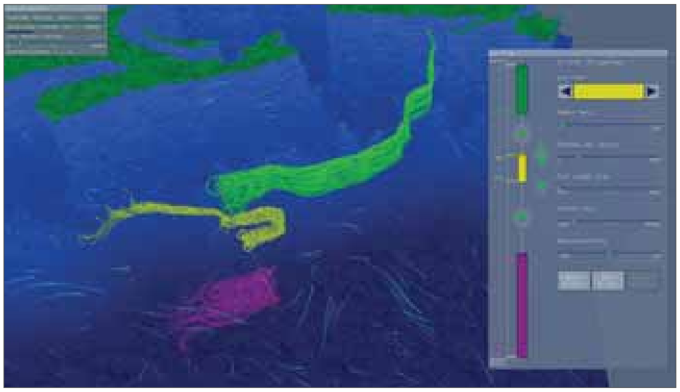

Figure ES-9. A screenshot from the 3D flow visualization. Here a dye-pole has been added off the coast of Nova Scotia. Using the dye-pole editor associated with it, the user has configured three custom dye-emitters at different regions along the pole. Each releases different colored dye particles into the model which are carried away by the currents at the particular depths. You can see that the flow directions and velocities vary significantly at the three different depths. It looks even better with stereo glasses!

Figure ES-10. NOAA's NowCoast utilizing JHC/CCOM's FlowVis2D software to show shaded sea surface height.

As part of this toolset, illustrative dye particles can be introduced into specific areas of interest through the use of dye-pots and dye-poles. Multiple custom dye particle emitters can be configured along each dye pole, to reveal the often quite different flow patterns found at different depths in any particular location (Figure ES-9).

The new visualization environment is remarkably efficient in providing the user a clear indication of full multi-level 3D flow from point source at any depth and would have been tremendously useful for incidents like the Deepwater Horizon spill or the Fukushima reactor disaster (both of which have been used as example datasets). Additionally, the tool provides an ideal environment for planning AUV or glider missions in full 3D, including the consideration of surrounding flow patterns so that realistic energy budgets can be calculated.

Ware and graduate student David Pilar are exploring new ways to display wind and wave patterns using newly developed wind "glyphs." The results of their studies show their new design to be superior to the classic, and also that the classic barb can be redesigned and substantially improved. Pilar has applied this new wind barb concept to wave model forecasts using coded symbols to show wave height. The lines in the figure represent wave orientation and these are orthogonal to the direction of travel. Through collaboration with NOAA's John Kelley, these new concepts will eventually be incorporated into NOAA's NowCoast portal displays (Figure ES-10).

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 about and demonstrations of this technology have been presented at both scientific and policy meetings. This year, Ware has extended this work with the further development of TrackPlot, an application designed to help visualize and analyze data from tagged marine mammals. One of the most recent developments has been the ability to show two tracks simultaneously (Figure ES-11). This has been valuable in the analysis of social interactions between animals. TrackPlot has now been used for the following species: humpback whales, blue whales, pilot whales, beaked whales, killer whales, spotted dolphins and Florida manatees.

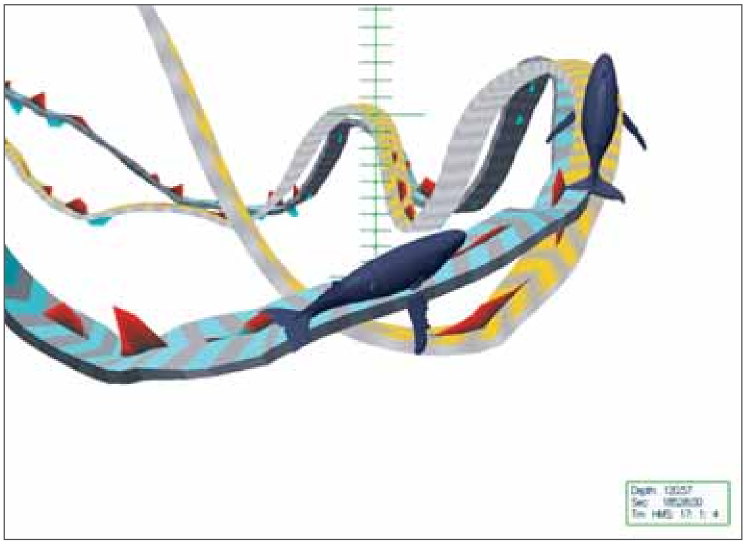

Figure ES-11. Visualization of the tracks of two humpback whales, a mother (orange track) and her calf (blue track).

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 with 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. This past year, Center researcher Kurt Schwehr developed an iPad application that will display on the iPad and other hand-held devices (Figure ES-12).

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

Figure ES-12: iOS development of Whale Alert with EarthNC, Trail-Behind, and IFAW (top), Whale Alert iPad application running in the simulator with real data (bottom).

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, with the click of a mouse, any object identified in the text and see a pictorial representation (in 2D or 3D) of the object in 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 ES-13).

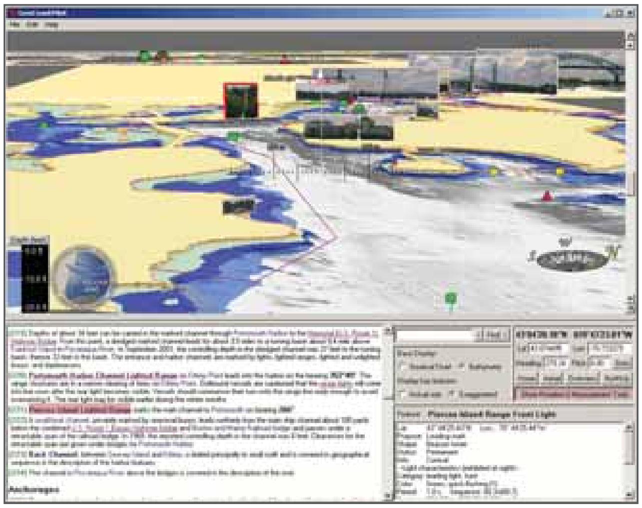

Figure ES-13a. Image captured from the "GeoCoastPilot" showing the approach to a bridge in Portsmouth Harbor.

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. 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, efforts are focused on developing automated techniques for incorporating Local Notice to Mariners into the GeoCoastPilot and on exploring the viability of using a spatially aware "hand-held device" as the display device (Figure ES-14).

Figure ES-14. Mobile version showing S57 chart data to test viability of using spatially oriented hand-held devices.

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. The initial portion of this complex study was carried out in less than six months and a report was submitted to Congress on 31 May 2002 (**http://www.ccom.unh.edu/unclos**). Following up on the recommendations made in the UNH study, Congress funded the Center (through NOAA) to collect new multibeam sonar data in support of a potential submission 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 1,784,462 km^2 of bathymetry and backscatter data that have provided an unprecedented high-resolution view of the seafloor. These data are revolutionizing our understanding of many geological processes on the margins and will result in significant additions to a potential U.S. claim under UNCLOS, particularly in the Arctic.

In 2011, the Center carried out a Law of the Sea cruise on the Necker Ridge off Hawaii and once again took part in a major two-ship operation in the high Arctic. The Necker Ridge cruise, led by Jim Gardner, focused on the northeast end of Necker Ridge in the immediate vicinity of the Hawaiian Ridge to determine whether Necker Ridge actually is joined to the Hawaiian Ridge. The survey was conducted aboard the University of Hawaii's R/V *Kilo Moana*. The ship is equipped with a Kongsberg Maritime EM122, the latest generation of their deep-water multibeam echo sounder (MBES). During the cruise, which took place in August, approximately 48,000 km^2 of seafloor was mapped providing critical data that will be analyzed by the State Department's Extended Continental Shelf Task Force to evaluate the potential for an extended continental shelf in this region. As always, the newly collected multibeam sonar data reveals many scientific sur-

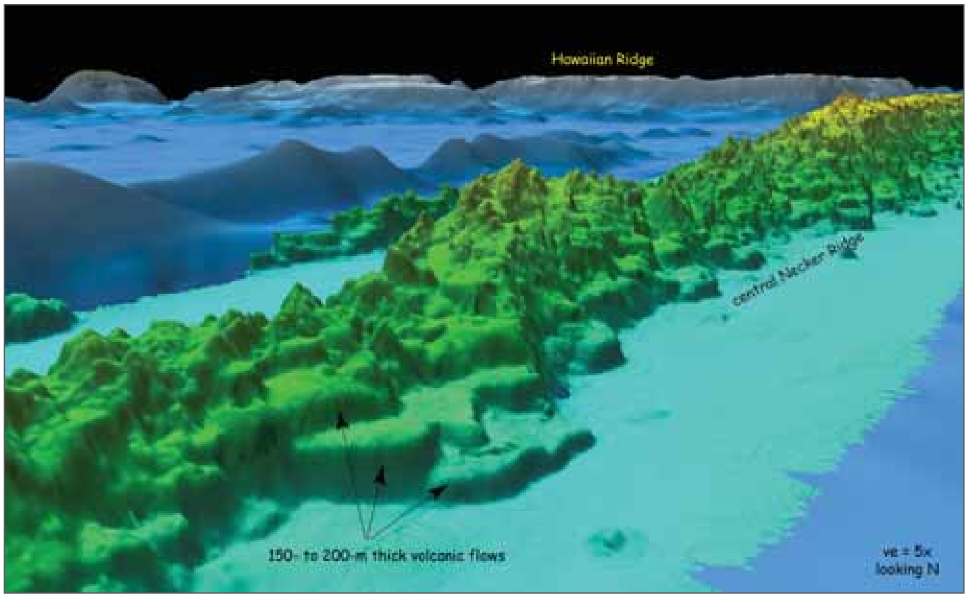

Figure ES-15. Oblique view of the central region of Necker Ridge, showing the typical stacked construction of volcanic flows. Vertical exaggeration is 5x, looking N.

prises, including the observations of stacked volcanic flows (Figure ES-15) and three erosional plateaus that appear at different water depths indicating that the ridge did not subside as a single feature.

The Arctic cruise, led by Larry Mayer and Andrew Armstrong, was carried out on board the USCG Icebreaker *Healy* from 18 August to 28 September. This cruise was the fourth in a series of two-ship, joint Canadian/U.S. Extended Continental Shelf (ECS) mapping programs carried out by the *Healy* and the Canadian Coast Guard Icebreaker *Louis S. St. Laurent* (*LSSL*). The primary objective was to take advantage of the presence of the two very capable icebreakers to collect seismic and bathymetric data in support of delineating the extended continental shelf for both Canada and the United States in regions where a single vessel would have difficulty due to ice. The cruise was remarkably successful—the total track covered was 11,447 km with 9188 km of multibeam sonar data and 875 km of seismic data collected in support of ECS purposes (Figure ES-16). These data were collected in average ice conditions of 9/10's ice cover and at an average speed of 3.5 knots in the ice. ECS multibeam data collection covered an area of approximately 58,000 km^2 adding approximately 20% to the U.S. Arctic multibeam sonar data holdings. Ancillary studies carried out during the cruise included meteorological, oceanographic (including ocean acidification studies), wildlife and ice studies; the *LSSL* carried a large Autonomous Underwater Vehicle (AUV) to test the feasibility of using AUVs deployed from an icebreaker.

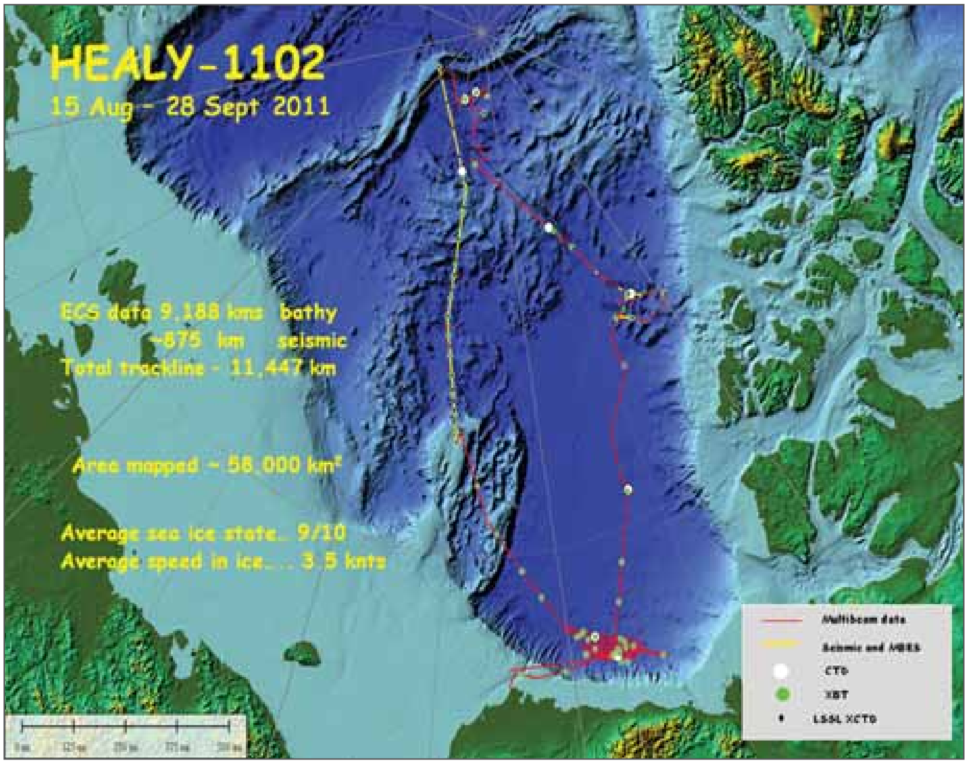

Figure ES-16. Trackline for HEALY-1102. Cross-hatched lines represent seismic data collection lines. Multibeam sonar data were collected on all lines.

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 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 (including a Facebook page and Flickr photostream that currently has 1,138 photos). Our seminar series is widely advertized and webcast, allowing NOAA employees and our industrial associates around the world to listen in and participate. The seminars are also recorded and the videos are uploaded to the Center's Vimeo site.

We have actively expanded our outreach activities and staff (Tara Hicks Johnson, an experienced outreach specialist, joined our staff this year) and have hosted a number of community groups (high-school students, marine docents, etc.). Our activities have been featured in many international, national, and local media outlets, including *Nature*, The Associated Press, BBC, *Toronto Star*, *Popular Mechanics*, and *The Boston Globe*.

We have created special events to bring young people into the lab and introduce them to science and technology, including the SeaPerch Program where students learn to construct small Remotely Operated Vehicles (ROVs) and then put them through their paces in our test tanks (Figure ES-17) and "Know the Coast Day," a University-wide event where visitors get a chance to see and experience some of the exciting marine research happening in the Seacoast region. We also remain active participants in Bob Ballard's E/V *Nautilus* and its "Educators At Sea" and "Educators Ashore" programs which brought two New Hampshire middle-school teachers (Michelle Martin and Stephanie Ward) to the Center for many weeks during the summer where they manned the Telepresence Console and communicated with students across the country (many at Boys and Girls Clubs), and the researchers on the *Nautilus*, and took part in the Mystic Aquarium's Nautilus Live Theater and the Nautilus Live website.


Figure ES-17. Middle school children building and testing small ROVs as part of the SeaPerch program.

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 until December 2015.

This report is the sixteenth 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 2011. As such it represents the second 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, there will inevitably be changes. In 2011, Paul Johnson joined our research staff as a data manager. Johnson comes to us from the Hawaii Mapping Research Group with a strong background in the management and processing of multibeam sonar data and the creation of innovative data delivery products. Additionally in 2011, Carlo Lanzoni joined our engineering staff providing support for our calibration facility and other acoustic operations, Tara Hicks Johnson joined our outreach team, and Dan Trefethen became part of our administrative staff. Beginning in August 2011, we also hosted Xavier Lurton from IFREMER as a visiting scholar. Xavier is one of the world's preeminent marine acousticians and has been working collaboratively with Center staff on a number of projects. Finally, Adam Skarke joined the IOCM Center at the Joint Hydrographic Center as a NOAA employee working with the NOAA Ocean Exploration Program.

Faculty

Lee Alexander is an Associate Research Professor actively involved in applied research, development, test and evaluation (RDT&E) projects related to the implementation of electronic chart-related technologies. Lee chairs or participates on a number of international committees defining electronic chart standards and serves as a technical advisor to U.S. Navy, U.S. Army Corps of Engineers, and the U.S. Coast Guard.

Brian Calder is the Associate Director of the Center and an Associate Research Professor in Ocean Engineering. He has a Ph.D. in Electrical and Electronic Engineering, having completed his thesis on Bayesian methods in side-scan-sonar processing in 1997. Since then, he has worked on a number of signal-processing problems, including real-time grain-size analysis, seismic processing, wave-field modeling for shallow seismic applications, methods for textural analysis of seafloor sonar data, as well as innovative approaches to target detection and seafloor property extraction. His current research is focused on methods for error modeling, propagation and visualization, adaptive sonar-backscatter modeling, statistically robust automated bathymetry processing approaches, tracing uncertainty in hydrographic data, and approaches to constructing and handling multi-resolution data sets.

Semme Dijkstra holds a Ph.D. in Ocean Mapping from the University of New Brunswick. He is a certified (Cat A) hydrographer from the Netherlands who has several years of hydrographic experience with both the Dutch Navy and industry. From 1996 to 1999, he worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam sonar processing. His thesis work involved artifact removal from multibeam sonar data and development of an echo-sounder processing and sediment classification system. His research focuses on applications of single-beam sonars for seafloor characterization, small object detection and fisheries habitat mapping. In 2008 Semme was appointed a full-time instructor and he has taken a much larger role in teaching courses and in evaluating the overall JHC/CCOM curriculum.

Jim Gardner received his Ph.D. from Lamont-Doherty Earth Observatory, Columbia University in 1973 in marine geology. He was the Chief of the USGS Pacific Mapping Group until he retired from the USGS and joined the Center in the summer of 2003. He presently is also an Emeritus Senior Geologist with the USGS, as well as an Honorary Associate in the School of Geosciences at the University of Sydney, Australia. At the USGS, he was responsible for the multibeam-sonar mapping of a number of areas off California and Hawaii and has pioneered innovative approaches to the dissemination and interpretation of these data. Jim has had a long career making important contributions in a number of areas of marine geology and geophysics including leading the U.S. effort to map its EEZ with the GLORIA long-range sidescan sonar. He is leading our field efforts in support of Law of the Sea studies. Jim is a Research Professor in the Center and in the Department of Earth Sciences.

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

Tom Lippmann is an Associate Research Professor with affiliation with the Department of Earth Sciences and the Ocean Engineering program. He received a Ph.D. in 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 (1995-1999) in the Center for Coastal Studies, and retains a Research Associate position with the Integrated Oceanography Division at SIO. 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 focuses on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning inner continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 16 nearshore field experiments and spent over 24 months in the field.

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

Dave Monahan is the Program Director for the Nippon Foundation's General Bathymetric Chart of the Oceans (GEBCO) training program in oceanic bathymetry. Prior to joining the Center, he served 33 years in the Canadian Hydrographic Service, working his way up from Research Scientist to Director. During that time, he established the bathymetric mapping program and mapped most Canadian waters, built the Fifth Edition of GEBCO, led the development of LIDAR, developed and led the CHS Electronic Chart production program, and was 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. in Geophysics from Tel Aviv University. His Ph.D. research was on monitoring the current uplift and deformation of Mt. Sedom salt diapir using Interferometric Synthetic Aperture Radar (InSAR). The research was done with Stanford University and the Hebrew University of Jerusalem. Other research includes measuring the current plate motion across the Dead Sea Fault using continuous GPS monitoring. Dr. Pe'eri's areas of interest are: remote sensing, geophysics and geodesy. Currently he is focusing on understanding the behavior of lidar pulses as a function of changing environmental conditions and looking at the viability of lidar for a wide range of hydropgraphic applications including shore-line delimitation.

Yuri Rzhanov, with a Ph.D. in Physics and Mathematics, is an Associate Research Professor in the Center and in the Dept. of Ocean Engineering. He has a very wide range of computing skills and has built a number of applications for higher education that are presently in use at universities around the world. At the Center, Dr. Rzhanov has been developing software for automatic mosaicking of video imagery and sidescan-sonar data and works closely with a number of researchers to develop a range of imagery and seafloor characterization applications. Yuri has also taken over support of the GeoCoder software.

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, and Mars Exploration Rovers. 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 is working on a range of projects including the Chart of the Future, visualization techniques for underwater and space applications, and sedimentary geology. He has been particularly active in developing hydrographic applications of AIS data.

Larry Ward has been affiliated with UNH for many years, but joined the Center in 2007. He has a Ph.D. from the University of South Carolina (1978) in Marine Geology. His primary interests include estuarine, coastal, and inner shelf sedimentology and surficial processes. Dr. Ward's most recent research has focused on estuarine sedimentological processes and depositional environments, coastal geomorphology and erosion, the physical characteristics of inner shelf bottom habitats, and the stratigraphy, sea-level history and Holocene evolution of nearshore marine systems. His teaching interests range from introductory geology and oceanography courses to graduate level coastal and estuarine sedimentology and surficial processes course.

Colin Ware is the Director of the Center's Data Visualization Research Lab and a Professor in the Ocean Engineering and Computer Science Departments. Dr. Ware has a background in human/computer interaction (HCI) and has been instrumental in developing a number of innovative approaches to the interactive 3D visualization of large data sets. As a member of the UNB Ocean Mapping Group, Dr. Ware was the developer of many of the algorithms that were incorporated into CARIS HIPS, the most commonly used commercial hydrographic processing package.

Thomas Weber is an Assistant Research Professor in the Center and in the Ocean Engineering Program. He earned his Ph.D. in Acoustics at Penn State University. His areas of interest include (in no particular order): bubbles in the ocean and their effect on sound propagation and scattering; bubble mediated air-sea gas exchange; underwater optical tomography; the use of multibeam sonar for measurements of fish, bubbles, and other scatterers in the water-column; benthic habitat mapping; and ocean sensor design.

Research Scientists and Staff

Roland Arsenault was an M.S. student and part-time research assistant with the Human Computer Interaction Lab of the Dept. of Computer Sciences, UNB before coming to UNH. His expertise is in 3D graphics, force-feedback and other input techniques and networking. He is currently working on the development of the GeoZui3D and GeoZui4D real-time environments as well as software to support AUV and fisheries applications. He is also currently a part-time Ph.D. student.

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 further developed his Ph.D. research on estimating sounding uncertainty from measurements of water mass variability. His research plans include an examination of oceanographic databases such as the World Ocean Atlas and the World Ocean Database to see how the data contained in these comprehensive collections can be turned into information that is meaningful to a hydrographic surveyor. Other plans involve 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 is also active in the Geocoder project, bringing his experience in processing and normalization of backscatter measurements from Kongsberg and Reson multibeam echosounder systems.

Thomas Butkiewicz received his undergraduate degree in Computer Science at Ithaca College in 2005, where he focused on computer graphics and was involved with virtual reality research projects. He designed and developed new interactive geospatial visualization techniques throughout graduate school at The University of North Carolina at Charlotte, receiving a Masters in Computer Science in 2007 and a Ph.D. in Computer Science in 2010. He joined the Center as a full-time post-doctoral research associate in January 2011. He specializes in creating highly interactive visualizations, which 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 3D ocean flow 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.

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 provides workstation support for JHC/CCOM and its staff. He has a B.A. in Political Science from UNH, and worked previously for the University's Department of Computing and Information Services.

Tianhang Hou was a research associate with the UNB 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 associate 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 data and new techniques for sidescan sonar processing.

Jon Hunt is a Research Technician II working with Tom Lippmann on the continued development of the Coastal Bathymetry Survey System and making field observations in shallow marine waters. Jon graduated from UNH in 2010 with a B.S. in Environmental and Resource Economics with a Minor in Oceanography.

Tara Hicks Johnson has a B.S. in Geophysics from the University of Western Ontario, and an M.S. from the University of Hawaii at Manoa in Geology and Geophysics where she studied Meteorites. Tara was the Outreach Specialist for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa where she organized the biennial Open House event, handled media relations for the school, and ran the Hawaii Ocean Sciences Bowl, the Aloha Bowl. She has also worked for the Bishop Museum in Honolulu and the Canadian Broadcasting Corporation in Toronto (where she was born and raised). At JHC/CCOM, she will be a critical component of the outreach team.

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, Southwest of Easter Island. Since finishing his masters, he has spent time in the remote sensing industry as a scientist processing and visualizing hyperspectal imagery associated with coral reefs, forestry, and downed aircraft detection. 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, where he has taken up the role as data manager and is also hoping that the winters will not be too bad.

Carlo Lanzoni has a B.S. (2002) and an M.S. (2007) in Electrical Engineering from the University of New Hampshire. His M.S. research was the design of a teaching platform for digital communications using software-defined radio concepts. Carlo has recently completed a second Master's degree in Ocean Engineering at UNH where he developed techniques to calibrate vessel-mounted multibeam sonars from the vessel. He is now working as a Research Engineer supporting our calibration facility and other acoustic experiments.

Andy McLeod is our Ocean Engineering Lab manager. Andy spent nine years in the U.S. Navy as a leading sonar technician and then earned a B.S. in the Dept. of Ocean Studies at Maine Maritime. He is finishing his Master's degree in Marine Geology from the University of North Carolina. At UNH, Andy is responsible for maintenance and upgrading of the major laboratory facilities including the test tanks, small boat operations and assistance with some courses.

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 (ERG) at UNH in 1999. In July 2009, Colleen joined JHC/CCOM as the Center's graphic designer. She is responsible for the graphic identity of the Center and, in this capacity, creates ways to visually communicate the Center's message in print and electronic media.

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, received her Human Resources Management certificate at the University of New Hampshire.

Lester Peabody received a B.S. in Computer Science from the University of New Hampshire in 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 received her Ph.D. in Fisheries from the University of Alaska Fairbanks, Juneau School of Fisheries and Ocean Sciences in 2010. Jodi received a B.S. in Biology from Western Washington University in 2001 and an M.S. in Environmental Science from Washington State University in 2005. Jodi joined the Center in 2011 as a postdoctoral research associate working on seafloor mapping applications to fish habitat and fisheries assessment.

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. He then joined the Navy and served as an officer in the submarine fleet aboard the USS *Hawkbill*. Aboard the *Hawkbill*, his duties included Radiological Controls Officer, Reactor Controls Officer and Sonar Officer. In 1998 and 1999 he participated in two NSF-sponsored "SCICEX" missions to conduct seafloor mapping from the submarine under the Arctic ice sheet. Val left the Navy in 1999 to work for Qwest Communications where he lead a team of engineers in designing their then nascent Voice over IP networks. In 2002, Val began work as a research engineer for the Lamont Doherty Earth Observatory of Columbia University, providing technical and engineering support under contract to several research vessels in the academic research fleet. Val acted as a technical lead aboard the U.S. Coast Guard Icebreaker *Healy* over several summer cruises in this role. Val returned to school in 2005 and completed his Master's Degree in Ocean Engineering here at CCOM in 2008. His thesis work included 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. His research focuses on seafloor and water column mapping from autonomous underwater vehicles, sensor development and sonar signal processing.

Ben Smith is the Captain of the JHC/CCOM research vessel *Coastal Surveyor*. He is also a research technician specializing in programming languages and UNIX-like operating systems and services. He has years of both programming and marine experience and built and captained his own 45-foot ketch, *Mother of Perl.*

Briana Sullivan received her M.S. in Computer Science at UNH in 2004. At JHC/CCOM, she has two major responsibilities. The first one is in the Data Visualization Research Lab where she is currently working on human factors research and the Chart of the Future. She is also working on the design and maintenance of the website, adding an outreach section to the website, and helping design and build museum exhibits for marine/science centers.

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.

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 nine NOAA employees (or contractors) to the Center.

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

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 was part of the IT group at the Center but became a full-time NOAA contract employee in 2007, working with John Kelley on further development of his project (http://nowcoast.noaa.gov). Jason is a native of Madbury, NH and graduated (spring 2006) from UNH with a B.S. in Computer Science and a minor in French.

Carl Kammerer is an oceanographer with the National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS) seconded to the Center. He is a specialist in estuarine and near-shore currents and presently the project manager for Southeast Alaskan surveys. In addition to Alaskan surveys, his recent projects include a robust survey to ascertain the effects of large bulk cargo ships in Las Mareas, Puerto Rico. 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.

Elizabeth "Meme" Lobecker works through ERT, Inc. as a Physical Scientist for the NOAA Office of Ocean Exploration and Research (OER) and is assigned to the Integrated Ocean and Coastal Mapping (IOCM) center at UNH where she works to generate procedures for data collection on the NOAA Ship *Okeanos Explorer*, and data archival procedures with the National Coastal Data Development Center and the National Geophysical Data Center. She spends approximately two months per year at sea supporting the mapping efforts on the *Okeanos Explorer*. Meme completed her master's degree in Marine Affairs at the University of Rhode Island in 2008, where her interests focused on the recent string of Californian and U.S. Supreme Court cases attempting to manage the potential effects on marine mammals from the U.S. Navy mid-frequency sonar testing in the Southern California Range Complex. She holds a Bachelor's degree from The George Washington University in Environmental Studies, with minors in geography and biology.

Mashkoor Malik received his M.S. degree from the University of New Hampshire in 2007 and was hired by NOAA (through ERT) as a physical scientist assigned to the 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 is works at NOAA Headquarters in Silver Springs, MD. Mashkoor also continues to be a Ph.D. student at the Center where his research focuses on understanding the uncertainty associated with backscatter measurements.

Chris Parrish has a Ph.D. in Civil and Environmental Engineering with an emphasis in Geospatial Information Engineering from the University of Wisconsin-Madison. His primary research interests are in remote sensing, in particular, full-waveform lidar, 3D object detection, sensor modeling and calibration, uncertainty analysis, and sensor fusion for coastal mapping applications. Chris is also an Affiliate Professor at JHC/CCOM beginning since the fall of 2010, in addition to his current position as Lead Physical Scientist in the Remote Sensing Division of NOAA's National Geodetic Survey (NGS). Chris' responsibilities in NGS including leading research in remote sensing systems, platforms, and software in support of NOAA programs, as well as serving as NGS's Project Manager for Integrated Ocean and Coastal Mapping (IOCM). His current work focuses on new lidar waveform post-processing strategies, and shoreline uncertainty modeling.

Glen Rice is a Lt. JG in the NOAA Corps and has joined the Center on a three-year assignment as the Integrated Ocean and Coastal Mapping Team Lead. In this capacity, he has been extending the use of data collected for charting to other fields and improving the workflow for outside source data to be applied to the charts. Glen came to the Center from NOAA Ship *Fairweather*, a ship primary tasked with surveying in Alaskan waters, where he focused on topics concerning sounding processing algorithms and ellipsoidally referenced surveying. Glen graduated from the University 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 conducting seafloor mapping in support of the ocean exploration mission of the NOAA ship *Okeanos Explorer*. Adam is also 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 continues to collaborate with scientists at JHC/CCOM, Margaret joined the faculty of the UNH Earth Science Department in 2009. 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.

Luciano Fonseca received an undergraduate degree from the University of Brasilia and his Ph.D. from the University of New Hampshire (he was the first Ph.D. produced by the Center). Luciano's research focuses on developing tools for extracting quantitative seafloor-property information from multibeam backscatter and on database support. He was supported by ONR on a project aimed at understanding how multibeam backscatter can be used to remotely predict seafloor properties. More recently he focused on developing the GeoCoder tool for the rapid production of sidescan-sonar and backscatter mosaics. In June 2009, Luciano took a position as a Program Specialist, Ocean Science Section for UNESCO-IOC in Paris and, in 2011, he returned to an academic position in his native Brazil. He maintains an affiliate faculty position with the Center.

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

Lloyd Huff retired from the Center in 2010 but maintains an affiliate professor position. He has almost 40 years in the private sector and the federal government, working with acoustic instrumentation and oceanographic equipment. He received his Doctorate in Ocean Engineering in 1976 from the University of Rhode Island and was one of the lead professionals in the Office of Coast Survey (OCS) working to bring multibeam sidescan sonars and multibeam bathymetric sonars into standard practice for shallow-water hydrography. He was Chief of the OCS Hydrographic Technology Programs from 1988-1999. Dr. Huff is working on new approaches for a range of hydrographic activities including the development of a long-range fisheries sonar.

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 time 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 with the Center. John has been a major player in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher’s Ice Island (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.

Dr. 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 specializing in underwater acoustics and has been the Ph.D. advisor of about 15 students. Presently, he is spending six months as a visiting scholar at UNH, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

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.

In this 18,000-square-foot 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 seats 45 students and has three high-resolution LCD projectors capable of widescreen and stereo display. There is a total of 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, not including NOAA students. The Center has 27 student offices (seven of which are for GEBCO students) and we typically have three or four NOAA students. Two additional NOAA offices 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 itself 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 10 printers scattered throughout the lab, including a newly acquired 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 15 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* and 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 Computing Facilities section. Our visualization lab includes an ASL eye-tracking system, an ultra-high-resolution stereoscopic setup with 3840 x 2400 pixel displays, space for human factors' research, force-feedback and six-degree-of-freedom tracking devices, and a 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.

Figure 1-2. The Telepresence Console.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120′ long, 12′ wide, and 8′ deep. It provides a 90′ length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5′. Wave absorption is provided by a sawtooth 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.

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 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 happily filled the long-vacant position of Data Manager in May. Paul Johnson came to the Center from the University of Hawaii where he was the Interim Director of the Hawaii Mapping Research Group. He will focus on formally organizing and cataloging the Center's vast data stores, ensuring that data is accessible and searchable by the widest array of users possible. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and Federal standards.

In addition to Paul, the IT Department has three additional full-time staff, 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 Center network and server infrastructure. He is also responsible for leading the development of the Information Technology strategy for the Center. The Desktop and Backup Administrator, William Fessenden, is responsible for the administration of all of the Center's 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. Lester Peabody is the Desktop Support Technician. In addition to his desktop support duties, Lester leads the development of the Center's Intranet and a project to modernize the JHC/CCOM public website.

The Center continues its development and implementation of server virtualization, for both decreased administrative overhead and increased cost efficiency. Virtual servers also allow the same level of security as separate physical computers. In the event that a virtual server is compromised, the damage is isolated to a single virtual server instance and can be contained. VMware serves as the primary virtualization technology for the Center. The VMware vSphere infrastructure hosts the JHC/CCOM email server, Vislab web server, Certification Authority server, several Apache web servers, a Windows 2008R2 domain controller, version control server, Request Tracker server, a JIRA project management server, and IPS management server. The IT Group continues to utilize an OpenVZ/Red Hat Linux platform for several of the Center's production servers. The OpenVZ server currently hosts three virtual servers including web file transfer services, the Center Wiki, and production website. The Center plans to complete the migration from OpenVZ to the VMware vSphere infrastructure by the end of Q1 of 2012. 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 three Dell servers capable of hosting dozens of virtual machines. The vSphere infrastructure 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.

The Center currently utilizes two separate version control mechanisms—SubVersion (SVN) and Mercurial (Hg). The Mercurial system went online in 2011 and the Center IT Group now encourages developers to use Mercurial for new projects, while continuing to support SubVersion for existing projects. Mercurial uses a decentralized architecture which is less reliant on a central server, and also permits updates to repositories without direct communication to that server. This allows users in the field to continue software development while still maintaining version history. For collaboration between developers, the Center's IT staff has implemented a JIRA project management and issue tracking server.

The IT Group is currently developing the next iteration of the JHC/CCOM website. The new website utilizes the Drupal content management system as its framework to allow content providers to make changes and updates without the assistance of a web developer. The flexibility of the new framework also allows the creation of a data content portal, which can serve any dataset hosted through the Center's ArcGIS Server dynamically. Development is nearly complete and the site is currently in beta testing. It is expected that the new website will be launched in the first half of 2012.

In addition to developing a new website, the IT Group is spearheading the development of a Center-wide intranet service, built on a Ruby on Rails/Apache/MySQL platform, and using a virtual machine in the vSphere environment. When completed, this will provide a centralized framework for a variety of new network services, such as progress reporting and purchase tracking. Apart from providing new functionality, the Intranet will integrate many of the Center's existing information silos, such as wiki, web mapping, inventory controls, and library services. The Intranet framework is now complete and module development continues. The inventory module was completed in September 2010, and the purchasing module entered beta testing in March 2011. The next priority is to complete the library module, which is planned for the first half of 2012.

Request Tracker, formerly used only for the IT Helpdesk, 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 amongst the staff. Center staff, students, and faculty have submitted over 2900 Request Tracker tickets since its inception in mid-2009. In 2011, the IT Staff was able to resolve 90% of tickets within three days.

With the completion of the New Castle, NH Pier Support Building in 2009, JHC/CCOM expanded its network presence out of the lab through the use of a Cisco ASA VPN device, the Center's first implementation of VPN technology. This allows for secure network connectivity over public networks between the support building and the Center's main facility on campus. With this system fully implemented, it will allow the IT Group to easily manage systems at the facility using remote management and, conversely, systems at the facility will have access to Center-specific resources. Both of the JHC/CCOM research vessels are located at the pier adjacent to the Support Building. The R/V *Coastal Surveyor*'s computer systems were upgraded in the summer of 2010, and wireless network connectivity has been implemented for both Center launches while docked at the pier. Plans are in place to replace the R/V *Cocheco's* computer systems in 2012.

In January of 2010, the Center installed a new Cisco Adaptive Security Appliance. This device has increased the external security of the Center's network, and also serves as an internal firewall, protecting the most sensitive networks from both internal and external threats. The firewall 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. While this is a secure and workable solution, it requires end-user configuration, a dedicated computer on the Center 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 Center network from anywhere in the world, allowing them to use many of the Center's network-specific resources on their local computer.

With the continuing expansion of the Center network, security remains a chief concern for the Center. Members of the JHC/CCOM staff have been working closely with OCS 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. The Center also utilizes Avira Antivir 10 antivirus software to provide virus and malware protection on individual servers and workstations. Avira server software allows for centralized monitoring and management of all Windows and Linux systems on the Center network, including the Center's email server. The IT Group operates a server running Microsoft Windows Server Update Services (WSUS). This server provides a central location for JHC/CCOM workstations and servers to download Microsoft updates. The IT Group is able to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems. In addition, the server allows for conservation of network bandwidth for more critical purposes. In an effort to tie many of these security measures together, the IT Group utilizes Nagios for service and general network monitoring. It has not only enhanced availability of services for internal Center systems, but has been a boon for external systems that are critical pieces of several research projects including AIS ship tracking for the U.S. Coast Guard. This server also serves 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 Center plans to improve physical security at Chase Lab with the installation of a biometric access system, which provides 24/7 monitoring and alerting of external doors and sensitive areas within the facility. This system should be in place by Q3 of 2012.

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

Efforts continue to expand the available storage for projects and research at the Center. This year, the Center has added 7TB of formatted storage to the NetApp FAS960c iSCSI Storage Area Network (SAN). An additional set of NetApp FAS960c filers was added to the SAN in order to allow expansion beyond 48TB of raw storage. The SAN now provides 64TB of raw storage capacity. In addition, the Center has 12TB of legacy direct-attached storage (DAS) which is in the process of being re-purposed and its data migrated to the SAN. With the addition of new additional SAN storage in recent years and the demand for the Center's DAS storage as swap space for the IOCM, the migration of all JHC/CCOM datasets to the SAN is nearly complete. The SAN provides higher throughput than conventional disk drives, decreasing processing time of research projects and has given the Center the ability to concentrate all research data in a single location. To further increase this performance, an upgrade of the file server that serves many of the SAN's shares was installed in May of this year.

As the SAN approaches its sixth year in service, the IT Group is pursuing a replacement for the existing system to be in place by the middle of 2012. Pursuant to this, the Center IT Group researched several potential solutions between August and September of this year. After defining deliverables and requirements, the project went to bid in October. The Center and USNH Purchasing accepted a bid from Berkeley Communications and awarded the contract for a NetApp 3240 SAN to be installed early in 2012. All data will be migrated from the old SAN to the new SAN, a process that the IT Group expects to complete by mid-2012.

Increased storage needs have created a greater demand on the backup system. The SAN is currently backed up by a Quantum Scalar 50 LTO4 backup library. The library has sufficient capacity to backup over 55TB of data without changing a single tape. Workstations and servers are backed up by a Quantum M1500 LTO3 backup library, which was formerly used to backup the SAN. Multiple tape libraries allow the Center to create faster backups that are easier to manage, and also provide hardware redundancy. An upgrade to the SAN tape library utilizing LTO5 Fibre-Channel tape drives was purchased in September of 2011, as well as a new server for centralized backup management at the Center. The new library will more than double throughput for SAN backups and will also provide more storage space per tape, decreasing the management headaches of a large pool of backup tapes. The LTO3 tape library is slated to be retired in 2012, while the LTO4 library will be redeployed to back up the workstations and servers. In addition, the Center IT Group is replacing its existing EMC Networker backup environment with a solution from CommVault. The CommVault Sempana product will provide all the features of the existing system, but will also enable local disk-to-disk backup, NDMP backup of the Netapp 3140 SAN, and provide easier, more powerful management and reporting.

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

Currently, all Center servers are consolidated into seven full height cabinets with one or more Uninterruptible Power Supply (UPS) units per cabinet. At present, there is a total of 41 servers, including 19 virtual servers, one SAN with four SAN directors and 11 storage arrays, the compute cluster consisting of seven nodes, and five DAS arrays. 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). The Center also hosts five dedicated servers for two field-related projects—NOAA's nowCOAST Web Mapping Portal and OpenECDIS.org. The nowCOAST project hosts a server that mirrors the primary nowCOAST web server, currently hosted in Silver Spring, MD.

At the heart of the Center's infrastructure lies its robust networking equipment. This consists of two Foundry BigIron RX-8 192-port enterprise-level switches, one 3Com 4924 24-port Gigabit Ethernet switches, one Dell PowerConnect 2924 switch, two Cisco PoE switches, four Brocade 7131N wireless access points, and one Brocade IronPoint 250. The two RX-8s are currently handling the bulk of the Center's network traffic and are responsible for all internal routing. The Dell and 3Com switches handle edge applications such as the Center's Electronics Laboratory, Geo Wall, and Telepresence Console. The Cisco PoE switches power the wireless access points as well as a set of 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. The IT Group will replace one of the Foundry BigIron switches by the middle of 2012 due to the age of the hardware.

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 the Center'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 of the server rooms employs a security camera, as well as natural gas generator to provide power in the event of a major outage. The IT lab provides ample workspace for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

The Center 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 a Powerware UPS to protect against power surges and outages. A generator provides backup power in the event of electrical and UPS failure. In 2011, the Center 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 and 2011 utilizing the Telepresence technology to process data and collaborate with scientists and educators ashore.

The IT Group collaborates with the JHC/CCOM seminar organizers and IVS 3D to provide both live webinar versions of the JHC/CCOM Seminar Series, and video and audio archives available through the web after each event. Building on the success of the seminar series this past year, the IT Group plans to make improvements to both the quality and accessibility of these seminars throughout the 2011-2012 Seminar Series.

The Center has continued to upgrade end users' primary workstations, as both computing power requirements and the number of employees and students have increased. The grand total of faculty/staff/student workstations is 197 high-end Windows 7/XP and Linux desktops/laptops, as well as 17 Apple Mac OS X computers and one SGI workstation. In 2011, the IT Group continued deploying Microsoft Windows 7, the current generation of Microsoft's desktop operating system, to new workstations and to older workstations that meet the Windows 7 hardware requirements. Deploying the 64-bit version of this operating system allows faculty, staff and students to take advantage of new, enhanced versions of scientific and productivity software, while maintaining interoperability with older applications.

The Center continues to operate within a Windows 2003 Active Directory domain environment. This allows the IT group to deploy policies via Active Directory objects, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of JHC/CCOM to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. The IT Group has begun to deploy Windows Server 2008 and 2008 R2 for use on new server and virtual server systems. Windows Server 2008 allows the Center to take advantage of the enhanced security and management features offered in Windows 7 and in Windows Server 2008 Active Directory. In addition, the Center maintains all low and moderate impact NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the Center with enhanced security and data protection.

A robust daily backup system is in place for all computers at the Center. Recently written tapes are held in a fire-proof safe, while archived datasets are sent offsite to an Iron Mountain data protection facility where they are stored in an environmentally controlled vault. The Center has a full suite of commercial software packages for both data processing and presentation. In addition to commercial software, faculty, staff and students are also actively engaged in the development of in-house software. A full suite of peripherals (4mm, 8mm, DLT, LTO, CD-R, DVD±R and Blu-Ray) are available so that data can be redistributed on a range of media types.

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 2011, the *Coastal Surveyor* operated for nine months (March through November) with much of its operation focused on collecting data in support of the Summer Hydrography Field Course. The *Cocheco* operated for ten months, focusing on over the side operations such as deploying buoys and bottom-mounted instruments, bottom sampling, and towing instruments. This will be the third 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 winter costs and added the advantage that vessels are at the ready throughout 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. While neither vessel is designed for offshore operations, they are ideally suited to nearshore and shallow water (as little as four meters).

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 the SENSORS discussion) 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 multibeam sonar data, and has a bow ram for mounting sonar transducers without hauling the vessel. C&C operated the *Coastal Surveyor* for a decade and a half, and then made a gift of her to JHC/CCOM in 2001. She has become a core tool for JHC/CCOM's operations in New Hampshire and 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 were installed and the HVAC seawater pump and manifold and engine room bilge pump were replaced. In 2011, the Isuzu-powered 20 kilowatt generator failed terminally 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.

R/V *Coastal Surveyor* Scheduled Research and Educational Operations for 2011

Month	Days	User
March 3		L3-Klein
March 1		WHOI
April 1		Jon Beaudoin
April		L3-Klein
May 5		Kongsberg 2040
May	5	Edgetech
June	2	L3-Klein w/Val Schmidt
June 18		Summer Hydro
August 2		Lippmann, McKenna
September 8		McKenna
October 5		McKenna
November 1		McKenna
November 3		Beaudoin, L3-Klein
November 2		L3-Klein
November 1		BAE Engineering

R/V *Cocheco*
(34 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed 16 of knots)

Figure 1-5. R/V *Cocheco*.

R/V *Cocheco* (Figure 1-5) 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 were installed and several battery banks were replaced and upgraded. This past year routine preventative maintenance was carried out (i.e., replacing fluids and filters, cleaning the bilge, etc.) and efforts have begun to design a universal sonar mount for the *Cocheco*.

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

Month	Days	User
March	3, 8, 22, 23	Klein
April	5	Ocean Mapping Course
April 6		Klein
April 18		Seamanship Course
April 28		Geodesy Lab
May 2		Seamanship Course
June	9 - 22	Summer Hydrographic Field Course
June 27		Christy Fandel
June 29,	30	ARGUS
July 12		Sean Denney
July 14		Shachak Pe'eri
July	19, 22-31	Christy Fandel
August 1		Christy Fandel
August 1		Sean Denney
August	11	Shachak Pe'eri & Jorge Alavera
September	16, 27	Tom Lippmann
October	15	Know the Coast Day
October 18		Tom Lippmann
November 8		Substructure
November	16	Fundamentals of Ocean Mapping Course

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 1-6), 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 provided a Knudsen 12-kHz echo-sounder, a four-element

Figure 1-6. R/H *Sabvabaa* deployed on the ice with ice drill. Note the polar bear observing operations.

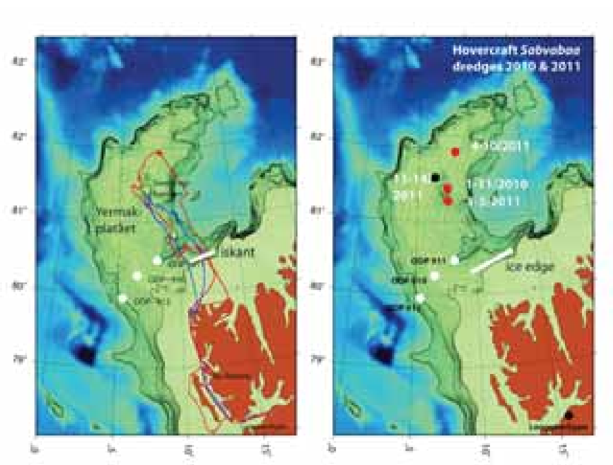

Figure 1-7. Drift track for 2011 and locations of the successful dredges.

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.

The 2011 summer saw three trips to the ice between June and August (Figure 1-7). Prof. Kristoffersen has now spent a full year aboard the craft, with more than 1700 nm of travel on ice; this is three times the distance from the Svalbard ice-edge to the North Pole. The first trip tested the latest attempt to allow active steering on snow and ice with hydraulically activated rudders fore and aft. It was only partially successful, and the decision was made to cease further efforts and accept the effects of maintaining course in cross winds. Two long trips for the Norwegian Petroleum Directorate (617 and 841 n.m.) saw 14 dredge hauls of which 10 were successful (Figure 1-8), a number of seismic lines with CHIRP, echosounder, and airgun seismics, and operation of both seismic and echo-sounding buoys. The data are available on the **www.polarhovercraft.no** website. The dredged basalts are being investigated at the Centre for Geobiology, University of Bergen and the continental rocks by Dr. Yoshihide Ohta (Natural History Museum, University of Oslo). At the start of the 2011 season, senior engineer Ole Meyer, University of Bergen, upgraded and integrated the software and electronics of all the data logging systems onboard the hovercraft. Gaute Hope of the University of Bergen, the student crew member, completed procedures for downloading ice maps and weather information, as well as email capability via Iridium. For his master's thesis, Hope is developing a micro-earthquake array for future deployment from the craft. The hovercraft encountered its first minor hull damage, which was readily repaired at the end of season. We have been invited by the Alfred Wegener Institute (AWI) to join the 2014 cruise of the R/V *Polarstern* in the Central Arctic.

Figure 1-8. Hovercraft dredging operation. The hydraulically powered take-up reel holds lengths of 1000 m of kevlar aramid fiber line with 2 ton breaking strength. All the strain is taken by the hydraulically powered capstan at the ice edge. Note the lightweight dredge with basalt rocks inside. Lines into the water beyond are to an echo-sounder and CHIRP transducers, as well as hydrophones for concurrent air-gun seismic work.

NOAA ROV

The new NOAA cooperative agreement includes a much closer and more formalized collaboration with

Figure 1-9. New room constructed in the high bay for ROV storage.

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 1-9).

The NOAA ROV system comprises two vehicle systems—an ROV (Figure 1-10) and a Camera Sled (Figure 1-11). The ROV, which is currently being upgraded by OER here at the Center, is connected

Figure 1-10. New 6000 m ROV being developed by OER at the JHC.

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.

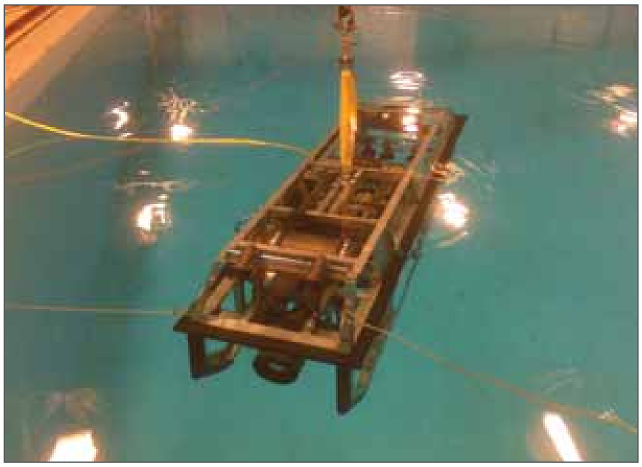

Figure 1-11. Camera sled for ROV being developed by OER at JHC

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.

June 1, 2011
To: Larry Mayer
Andy McLeod
Andy Armstrong
Paul Lavoie

From: Dave Lovalvo/NOAA Office of Ocean Exploration and Research

Subject: Completion of NOAA Camera Sled "Seirios"

Dear All,

As you may know, we recently completed sea trials for our new Camera Sled "*Seirios*," which was built and tested this past winter at the *Jere A. Chase Ocean Engineering Laboratory at UNH*. NOAA OER recognizes the major contribution UNH has made to these efforts through their generous support in both facilities development and onsite expertise. I wanted to personally thank everyone at UNH for all of your efforts and hope that the accomplishments we have all achieved together are shared and appreciated by all who participated so professionally. I know I speak for all of OER when I say we look forward to our continuing partnership at UNH.

Sincerely,

Dave Lovalvo
NOAA Office of Ocean Exploration and Research

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 of Standard 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 due for renewal in 2011. 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 began, under the leadership of Semme Dijkstra, a re-evaluation of the entire ocean mapping curriculum.

A curriculum committee was established with the goal of creating a new curriculum that would:

- 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.

A new curriculum was presented to the FIG/IHO/ICA education board by Semme Dijkstra and Capt. Armstrong for review. We are most pleased to report that the FIG/IHO/ICA education board accepted the new curriculum and lauded the UNH submission as "outstanding." Thus, the Center will maintain an IHO Category A Certification until at least 2021 and continue to be one of only two Category A programs available in North America. The new curriculum (Appendix A) has been submitted to the College of Engineering and Physical Sciences curriculum committee. If approved, the next stage will be approval by the graduate school. We are optimistic that the curriculum will find approval before the next fall term. In the mean time, many aspects of the new curriculum have already been implemented using the existing course structure.

2011 incoming students.

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 Department 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 Department. In 2008, in recognition of the importance of our educational program, we created the position of full-time instructor in hydrographic science. This position has been filled by Semme Dijkstra, who led the effort to revamp our curriculum and renew our FIG/IHO Category A certification.

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
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 taught in Seattle and Norfolk in association with the NOAA hydrographic training and received excellent reviews.

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 four months (through the tremendous cooperation of the UNH Graduate School and the Foreign Students Office), seven students were selected, admitted, received visas and began their studies. This first class of seven students graduated (receiving a "Certificate in Ocean Mapping") in 2005, the second class of five 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 in 2009; and six more 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). 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. 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.

Extended Training

With our fundamental education programs in place, we are expanding our efforts to design programs that can serve undergraduates, as well as government and industry employees. We are working with the NOAA Ocean Exploration program to formalize an intern program that will allow undergraduates to participate in Ocean Exploration cruises, 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. 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 Interagency Working Group for Integrated Ocean and Coastal Mapping (IWG-IOCM).

Hydrographic Field Course

The summer of 2011 Hydrographic Field Course brought the R/V *Coastal Surveyor*, R/V *Cocheco*, 15 JHC/CCOM students, and several technical staff under the supervision of Andy Armstrong and Semme Dijkstra to Boon Island in the waters of Maine. At the request of the government of Maine the survey was conducted with the purpose of evaluating the bottom for placement of windmills south of the island. A secondary goal was to obtain an update on the location and state of the M/V *Empire Knight* wreck located within the survey area.

The survey revealed that the location of the charted wreck differs from the actual position by approximately 270 meters so an AWOIS report was generated. In addition, it was observed that four moored lighted buoys indicated in the chart were not present during the survey. A comparison with Chart 13286 was performed and the observed depths were generally greater than the charted depths, but some of the shoals were significantly shallower. Finally, the charted contours do not align well in places with the automatically generated contours from the dense MBES data.

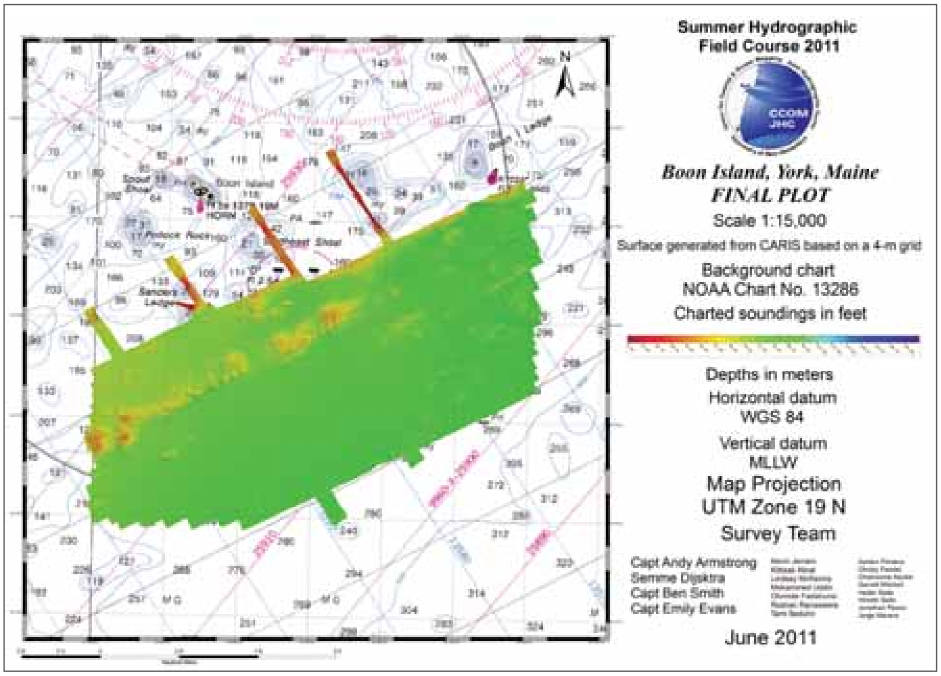

Figure 2-1. Product of the Hydrographic Field Course.

The remoteness of the site provided numerous challenges but presented a realistic work environment for the students. The product of the Hydrographic Field Course, displayed below (Figure 2-1), will, if deemed suitable, be used to update NOAA charts.

We have 34 full-time students currently enrolled in the Ocean Mapping program, (see listing below) including six GEBCO students, two NOAA Corps officers and a NOAA physical scientist. We have produced five Ph.D. students: Luciano Fonseca (2001), Anthony Hewitt (2002), Matt Plumlee (2004), Randy Cutter (2005), and Dan Pineo (2010). This past year, we graduated six new master's students (see listing below) and six Certificate students, bringing the total number of master's degrees completed at the Center to 37 and the total number of Certificates in Ocean Mapping to 40.

STUDENT	PROGRAM	ADVISOR
Anastasia Abramova	MS ESci (Rec'd 2011)	Monahan
Jorge Alvera	MS ESci (Rec'd 2011)	Armstrong
Chukwuma Azuike	MS OE	Armstrong
Tami Beduhn (NOAA)	MS ESci (Rec'd 2011)	Armstrong
Anna Berry	Certificate OE	Armstrong
Sean Denney	OE	Armstrong
Christopher Englert	MS ESci	Mayer
Olumide Fadahunsi	Cert OE	Armstrong
Christina Fandel	MS ESci	Lippmann
Ashton Flinders	MS OE	Mayer
Xiao Guo	MS OE	Parrish
Kevin Jerram	MS OE	Weber
Nikki Kuenzel	MS ESci (Rec'd 2011)	Gardner/Mayer
Christina Lacerda	MS. ESci	Monahan
Carlo Lanzoni	MS OE (Rec'd 2011)	Weber/Irish
Meghan Luke	MS ESci	Gardner
Mashkoor Malik	Ph.D. NRESS (Rec'd 2011)	Mayer/Calder
Giuseppe Masetti	MS OE	Calder
Lindsay McKenna	MS Esci	Lippmann/Ward
Dandan Miao	MS OE	Calder
Garrett Mitchell	MS Esci	Gardner
Kittisak Nilrat	MS Esci	Armstrong
Rachot Osiri	MS Esci (Rec'd 2011)	Armstrong
David Pilar	MS CS	Ware
Glen Rice (NOAA)	Ph.D. OE	Armstrong/Calder
Maddie Schroth-Miller	MS Math	Weber
Derek Sowers	Ph.D. NRESS	Mayer
Rohit Venugopal	MS CS	Calder
Briana Welton (NOAA)	MS ESci	Armstrong
Matt Wilson (NOAA)	MS ESci	Armstrong
Monica Wolfson	Ph.D. NRESS	Boettcher
Fang Yao	MS Esci	Parrish

GEBCO Students: (2010-2011)

STUDENT	INSTITUTION	COUNTRY
Mohammad Chowdhury	University of Chittagong	Bangladesh
Prasadh Gunasinghage	Sabaragamuva University	Sri Lanka
Hiroki Minami	Japanese Coast Guard	Japan
Thanh Nguyen	Academy of Science & Technology	Vietnam
Hassan Norhizam	Royal Malaysian Navy	Malaysia
Saw Thein	Myanmar Maritime Univeristy	Myanmar

Status of Research: January–December 2011

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 2011 efforts were conducted under these thematic headings, our current research efforts will be described in the context of these seven themes.

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

Our 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, a state-of-the-art sonar (and lidar) calibration facility that allows us to better understand the performance of systems and 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 systems for both bathymetry and 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 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.

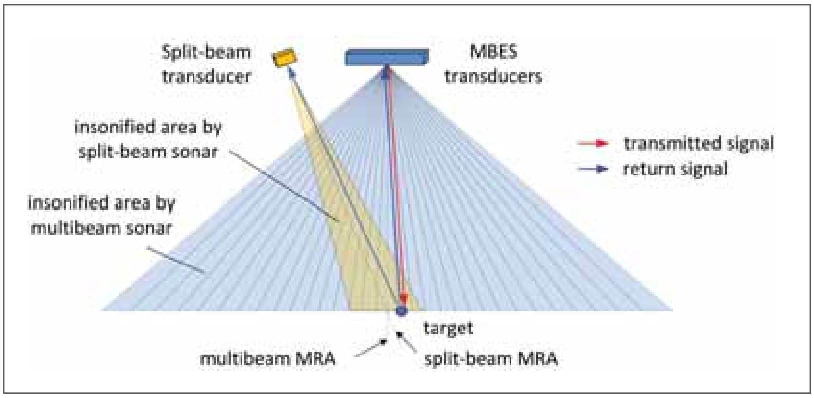

Figure 3-1. Calibration set-up geometry.

Under the supervision of Tom Weber, Carlo Lanzoni was a prime user of the calibration facility in 2011 as he finished his M.S. thesis work which aimed at developing field-calibration procedures for multibeam echosounders (MBES) using a Simrad EK-60 split-beam echo-sounder and a target calibration sphere. The idea of this approach is that the split-beam echo-sounder 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 approach was tested with a Reson 7125 MBES in our acoustic tank. The split-beam EK-60 sonar was used to determine the athwartship and alongship angular position of the target sphere which, in turn, was used to compute the radiation beam pattern of the MBES. The split-beam transducer, a 200 kHz SIMRAD ES200-7C, was installed on one side of the MBES transducer in a rigid metallic structure. The target sphere was suspended in the water column by a monofilament line at a range of approximately 8 m. The MBES was configured to transmit 256 equiangularly-spaced beams at an operating frequency of 200 kHz; the

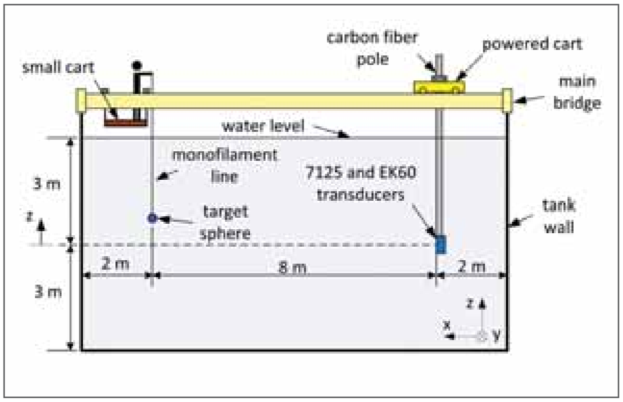

Figure 3-2. Tank set-up.

split-beam system was set to operate passively at the same frequency, triggered by the MBES. Figure 3-1 shows the methodology overview and Figure 3-2 shows the setup of the tank experiment.

Calibration tank data collected in this manner generated beam patterns for the RESON 7125 and demonstrated that this approach is technically viable (Figure 3-3). The results of this work were presented at the 2011 MTS-IEEE Oceans conference in Kona, Hawaii, and were also the subject of Carlo's master's thesis which he defended on 14 December 2011. Efforts are currently underway to bring this methodology into the field.

Figure 3-4. Gavia AUV mounted vertically for calibration of the Geoacoustics Geoswath

GeoSwath Calibration

In support of our ongoing efforts to better understand Phase Measuring Bathymetric Sonars (PMBS) as well as our collaboration with the University of Delaware with respect to use of the Gavia AUV, we brought the Gavia and its GeoSwath+ PMBS to our acoustic tank to better understand the acoustic behavior of the GeoSwath while mounted in the AUV. The motivation for this calibration was two-fold: first to gain experience with acoustic calibration of sidescan sonar systems operating at high (>200kHz) frequency, and second, to allow for collection of calibrated angular response curves at 500kHz where models on which the Geocoder ARA analysis (see seafloor characterization discussion below) has yet to be fully vetted. The Gavia AUV was mounted vertically in the UNH acoustic test tank for the calibration (Figure 3-4). Transmit source level, receiver gain ramp and combined transmit/receive beam patterns were measured. The combined beam patterns were measured in the near-field using several tungsten-carbide calibration spheres (Figure 3-5).

Figure 3-5. Six tungsten-carbide target spheres (10-28 mm) used for measuring combined beam patterns in the near-field.

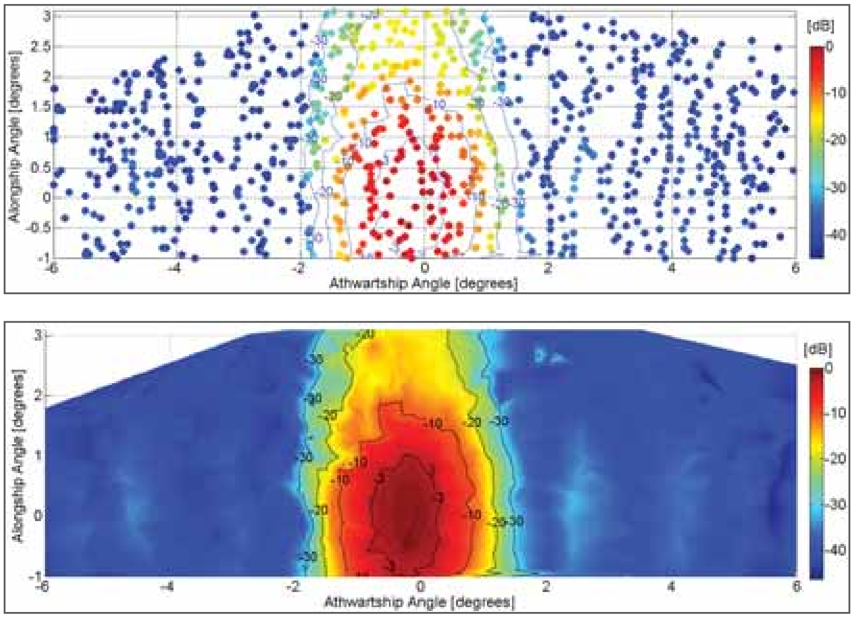

Figure 3-3. Normalized backscatter amplitude from a standard sphere collected with a 200 kHz Reson 7125, representing the combined transmit/receive beam pattern for beam 129 (top). The interpolated version of beam pattern (bottom).

Field Tests Of New Sonar Systems

Along with the Center's tank calibration facilities, the lab was also been involved in the field testing of several new sonar systems in 2011.

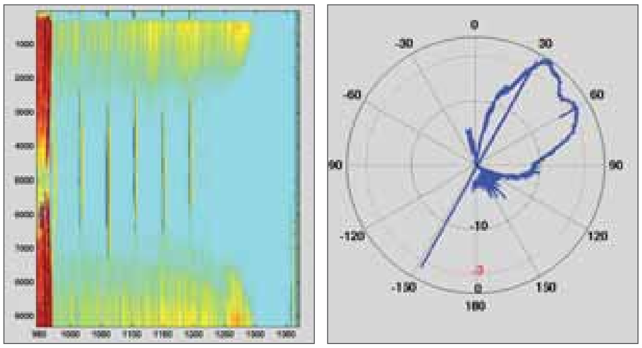

Figure 3-6. Left: acoustic returns from six target spheres appear as vertical lines in the time series of returns generated as the AUV was rotated. The AUV is suspended on the far right, while the red on the far left is the opposite wall at approximately 10 m. Spheres are suspended at 1m increments from 5-9 m. Right: returns from the 9 m sphere were used to generate the preliminary combined transmit/receive beam pattern.

EdgeTech 4600

In April 2011, the Center received the loan of an EdgeTech 4600 PMBS as part of the agreement with our Industrial Associate, EdgeTech. Jonathan Beaudoin took part in the installation, calibration and operation of the sounder with the goal of collecting data to evaluate the bathymetric performance of the 4600.

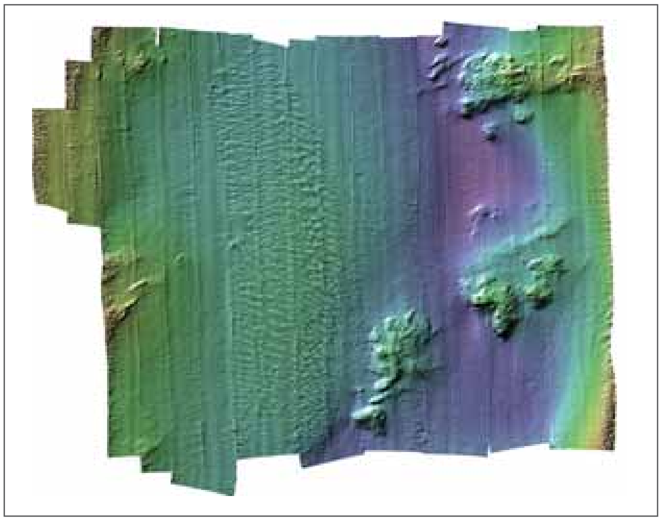

Figure 3-7. Preliminary bathymetric DTM created from the test of an EdgeTech 4600 PMBS.

The 4600 system was used to acquire a data set over the sand wave field at the mouth of the Piscataqua River in Portsmouth Harbor and by adapting UNB-OMG software for the 4600, a preliminary 0.5 m resolution bathymetric map was produced for an area approximately 900m x 750m in water depths reaching 25 m. Line spacing was 50 m with 100% overlap between survey lines (Figure 3-6).

Examining swath profiles for 100 swaths over a flat seafloor allowed for a preliminary estimation of the sounder's bias and uncertainty characteristics (Figure 3-7).

Examining the mean depth and the standard deviation about the mean for the same 100 swaths as above (recall, these are binned soundings) shows small biases that vary with incidence angle and sounding uncertainties in line with IHO Special Order requirements over a +/- 65° angular sector (the innermost black and yellow dashed line that brackets the mean depth indicates allowable uncertainty for IHO Special Order (Figure 3-8).

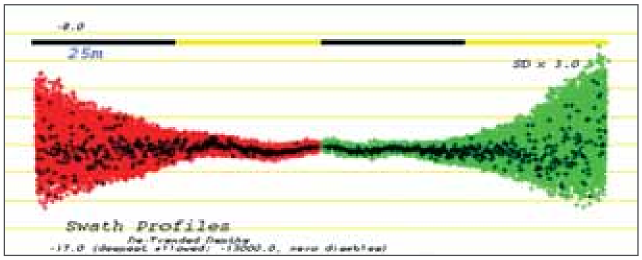

Figure 3-8. Sounding data, after binning into 1000 across-track bins, are shown for 100 swaths; the black crosses are soundings from an individual swath.

Klein HydroChart 5000

Jonathan Beaudoin has been collaborating with Steve Brodet and Janice Eisenberg of the Hydrographic Systems and Technology Programs (HSTP) to investigate the suitability of the Klein HydroChart 5000 (HC5K) for hydrographic mapping. A preliminary project involved re-evaluating the effectiveness of traditional patch test calibration procedures for phase measuring bathymetric sidescan systems (PMBS). Initial results indicate that reconfiguring the imaging geometry and ordering of patch test calibration lines can improve the reliability of operator estimated patch test offsets for such systems; results from this were presented at the U.S. Hydrographic Conference in Tampa Bay, FL (April 27-28, 2011).
A second aspect of work with the HC5K involved

troubleshooting refraction-like artifacts that appeared to be related to surface sound speed issues. Figure 3-10 shows the artifact from three different survey locations with nearly vertically homogeneous water masses but dramatically different sound speeds from area to area. The homogeneity of the water masses in each location rules out traditional refraction artifacts (due to inadequate vertical profiling). The pronounced curl at nadir, combined with the tilted arrays is consistent with a surface sound speed problem. Note that the direction of "curl" of the inner portion of the swath depends on the sound speed. Combined with the fact that the artifact is non-existent in the 1500 m/s case, this suggests that there may be an error in the internal processing related to the designed array sound speed or a mishandling of the surface sound speed probe data feed.

A review of the Klein batch processing software was undertaken by Klein during the summer. An error was found in the software where the wavelength distance between staves was calculated using an assumed surface sound speed of 1500 m/s, as diagnosed by the Center. Klein provided an updated version of the batch processor to the Center and HSTP. Initial results indicated that the sound speed related artifact appeared to have been corrected. However, it was agreed that further processing was required with other data sets to confirm this.

Beaudoin and Val Schmidt have been working with Klein and NOAA to better understand how the uncertainty model, developed by Klein, could be incorporated into the NOAA workflow for the HC5K system. The initial model required many input parameters, such as wind speed, bottom roughness, bottom type, etc. After discussion with Center researchers and others, Klein had simplified the model such that it required only the signal-to-noise ratio as input, with this value being estimated directly from the multi-channel data streams. Results from Klein's internal testing were presented and it was agreed that the model was ready for incorporation into the NOAA workflow. The Center had suggested that all uncertainty model calculations take place within the manufacturer's software and that the uncertainty be provided as an additional output in Klein's binary file format. This approach facilitates rapid deployment of the model since hydrographic processing software vendors need only to read the additional fields and apply these values accordingly in their internal uncertainty models.

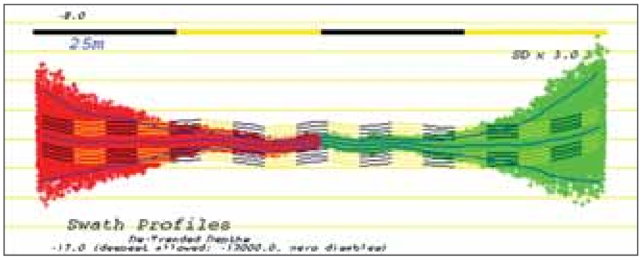

Figure 3-9. The mean depth and the standard deviation about the mean for the same 100 swaths with respect to IHO Special Order requirements.

Finally, alternate methods for patch test calibration of PMBS systems such as the Klein HC5K are being explored. The goal is to find a method that would circumvent the limitations associated with being unable to image bathymetry in the nadir region. A race track pattern was proposed with the hope that it would allow the separation and isolation of heading and pitch misalignment through the fact that separation of a single seafloor target due to yaw misalignment is a function of the distance from which it is imaged. A short field program was conducted on the R/V *Coastal Surveyor* with Klein providing technical support and the Center being responsible for survey design, execution and analysis. A data set was collected in Portsmouth Harbor and will be analyzed soon.

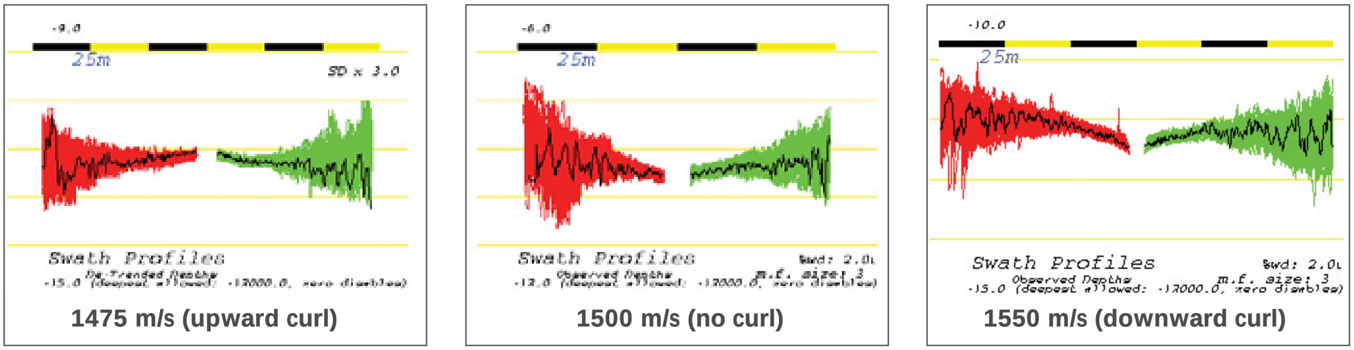

Figure 3-10. Refraction artifact in Klein 5000 in three different settings with homogenous water masses.

Very Shallow Water Surveying – CBASS

Tom Lippmann has focused on mapping bathymetry around harbor entrances or inlets, a region of particular interest to mariners because it is often characterized by rapidly shifting sands 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 within 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, or around rocky shores where submerged outcrops are poorly mapped or uncharted. To address these issues, Tom has developed the Coastal Bathymetry Survey System (CBASS).

The CBASS has been used extensively in rugged marine environments such as the surf zone where breaking waves are present, in very shallow fresh-water bodies around the Great Lakes, and inland rivers near bridge piles. Estimated accuracy of the survey system is 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 erodable bottom is rapidly evolving). It is particularly useful where shallow hazards prevent the use of vessels with larger drafts.

This year, Lippmann expended a significant portion of his effort on improving the capabilities of the CBASS (Figure 3-11). The first notable improvement is development of full waveform capabilities in our 192 kHz single-beam echosounder (SBES). This SBES, designed and built by Bill Boyd of Scripps Institution of Oceanography, will allow for examination of spatial variation in bathymetry coincident with textural classification of seafloor properties in shallow water depths ranging 1-25 m. The second,

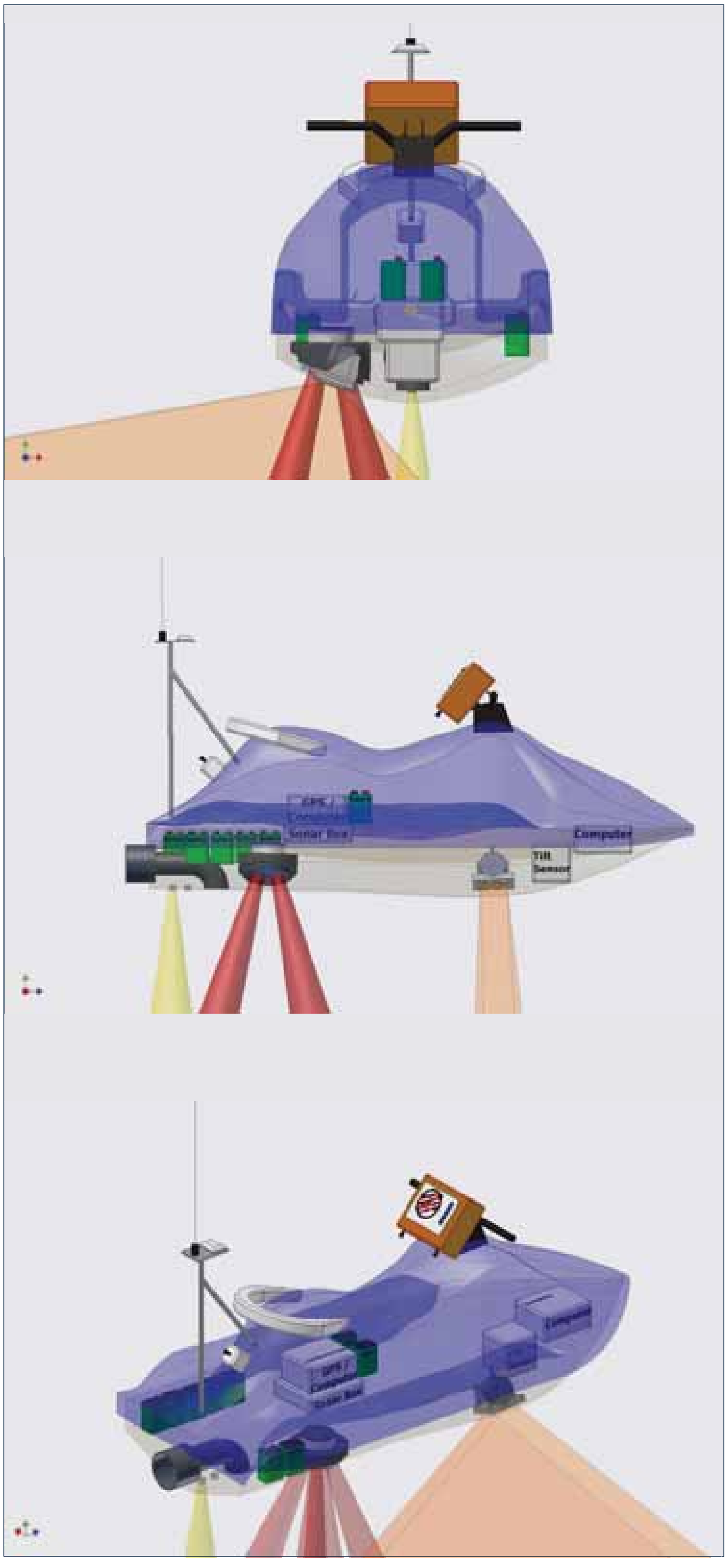

Figure. 3-11. Scaled CAD drawing showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Views from the front, side, and oblique angles are shown for clarity.

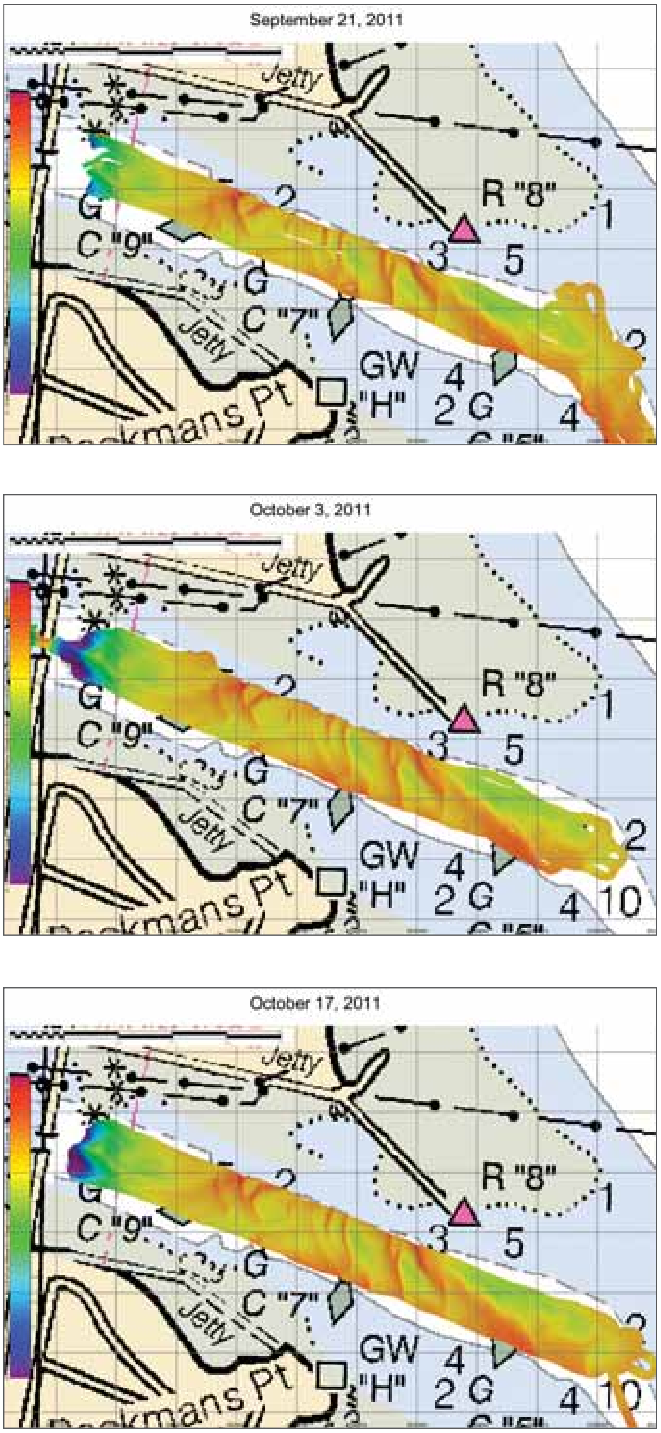

Figure 3-12. Observations of shallow multibeam bathymetry from the Hampton Inlet Experiment in the Fall of 2011. Data are shown from beginning, middle, and end of the experiment, with each survey separated by about two weeks. Clearly present is a spatially complex system of sand waves, dunes, and megaripples that migrate and evolve in time. The extent of the surveyed region is about 1 km along channel and 100 m across channel. CBASS ADCP cross-channel transects were conducted periodically at about 5 locations within the inlet, and down the center of the channel.

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). We are in the process of integrating a new Applanix POS MV 320 SFF into the CBASS. The new multi-beam capabilities will allow for detailed examination of seafloor topographical evolution in very shallow water with typical water depths of 1-25 m. The third improvement is the integration of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) to be used for observation of the vertical structure of mean flow. This work is collaborative 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 near-shore areas will allow for models on seafloor evolution to be tested. The components for the improved CBASS are shown in Figure 3-11, and an example of its research application is discussed in the next section. The ADCP and MBES instruments have been installed and tested, and we expect the POS MV to be fully functional and tested by the end of the spring of 2012.

The efficacy of using the Delta-T for repeat surveys to understand bedform movement was put to test during a 30-day field experiment conducted in Hampton Inlet, NH as part of the thesis work of graduate student Lindsay McKenna under the supervision of Tom Lippmann. In this experiment, the Imagenex Delta-T multibeam echosounder (240 kHz, 120 degree swath width) and Applanix POS MV motion sensing package were installed onboard the R/V Coastal Surveyor. Surveys referenced to the ellipsoid were conducted at mid-to-high tides approximately every two to three days for four weeks, and processed with CARIS HIPS to combine survey tracks and geo-reference the bathymetry. Example survey grids from within the inlet throat are shown in Figure 3-12. In this shallow water environment with a mixture of fine-to-coarse grained sand, the multibeam data were found to be very clean with few artifacts, particularly when overlapping track lines were conducted.

The Imagenex multibeam sonar will be deployed on the CBASS as part of the ONR-sponsored RIVET experiment in New River Inlet, NC in the spring of 2012. This experiment is designed to make repeated large-scale measurements of fine-scale bathymetry coincident with vertical profiles of the mean circulation to study the morphodynamic behavior of a wave and tidally dominated inlet environment.

Sea Acceptance Trials – MAC (Multibeam Advisory Committee)

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 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 has now been formalized with the funding in 2011 of Center researchers Jonathan Beaudoin and Paul Johnson 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 who 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 including the Schmidt Ocean Institute with their new vessel R/V *Falkor* and the Ocean Exploration Trust with its vessel E/V *Nautilus*. The has already entered into 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. SOI has not only expressed a need for assistance during the installation and testing phases, but has also expressed a desire for long-term assistance in maintaining technician skill sets, monitoring of acoustic system health, etc., which is entirely consistent with the program being established under the MAC. The Ocean Exploration Trust has also asked the Center to provide similar guidance and support.

Lidar

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric lidar systems offer the possibility of rapidly collecting bathymetric (and other) data in these very shallow regions but there still remains great uncertainty about the accuracy and resolution of these systems. Additionally, both bathymetric and terrestrial lidar 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 Dr. Shachak Pe'eri and Dr. 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.

Airborne Lidar Bathymetry Simulator

There is a growing need for coastal mapping communities to estimate the accuracy of Airborne lidar Bathymetry (ALB) as a function of the survey system and environmental conditions. Knowledge of the ALB accuracy can be also used to evaluate the quality of products derived from ALB surveying. Shachak Pe'eri has developed a lidar simulator at the Center in order to understand the capabilities of airborne lidar bathymetry (ALB) and extend its capabilities for a range of NOAA-related applications (Figure 3-13). Current efforts are focused on characterizing the beam profile of the laser, measuring and simulating optic losses throughout the simulator hardware, and redesigning the simulator to fit on a portable platform. The next step in his research will be beam empirical measurements of the laser pulse within the water column and also waveform collection and analysis.

The Impact of Sea State Condition on ALB Measurements

In order to fully understand the nature of the waveforms returned from ALB and how this might impact bottom detection and feature resolution, it is essential to understand the impact of sea state on the received waveform. Shachak Pe'eri, working with Torbjorn Karlsson from Lund University in Sweden, and Andreas Axelsson from AHAB, has been investigating this issue. The simulated environmental conditions were defined according to the typical conditions under which successful ALB surveys can be conducted (Beaufort Sea State 2). The theoretical part of the research included simulations using optical system design software, where the ray-path geometry of the laser beam was monitored above and below the water surface (Figure 3-14).

Wave-tank experiments were conducted to support the simulation. A cross section of the laser beam was monitored underwater using a green laser with and without wind-driven waves. The results of the study show that capillary waves and small gravity waves (6 m in wavelength) distort the laser footprint. Large gravity waves stretch the laser footprint but do not distort the laser beam. Because sea-state condition is related to wind at a first-order approximation, it is possible to suggest wind speed thresholds for different ALB survey projects that vary in accuracy requirements. If wind or wave information were collected during an ALB survey, it may be possible to evaluate the change in accuracy of ALB survey due to different sea surface conditions.

The Impact of Sea Floor and Other Environmental Conditions on ALB (and Hyperspectral) Measurements

Just as surface wave conditions can affect the nature of the lidar return, so can the nature of the seafloor substrate. In order to establish a broader understanding of the these factors, Pe'eri and Jim Gardner have collected a number of "ground truth" seafloor samples from regions where ALB data had been collected (New Hampshire/Massachusetts coastal areas, Keku Strait, AK and Buck Island, St. Croix, USVI). At each station, the ground truth measurements included physical measurement using grab sampling, texture evaluation using underwater video imaging, and color evaluation using spectral measurements.

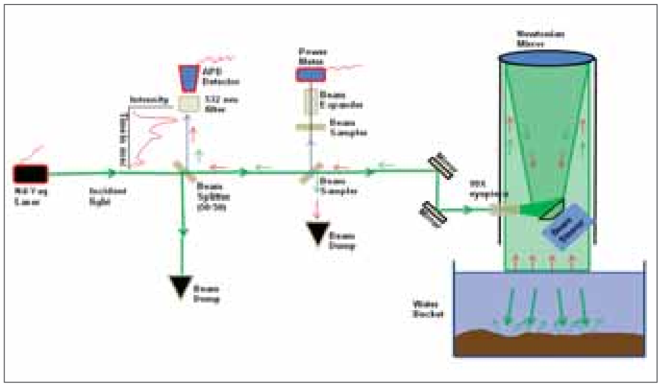

Figure 3-13. Schematic illustration of the original design of the bathymetric lidar simulator.

In situ optical sensors (underwater video imaging and spectral measurements) were made using a small instrument cage that can be deployed manually by a single operator (Figure 3-15). The imagery is captured by an underwater camera mounted on top of the cage looking down. The video imagery is recorded digitally and, by using a black and white frame, the operator can measure features within the frames on a sub-centimeter scale (Figure 3-15). By adding a 25 m fiber optic cable connected to a spectro-radiometer, the bottom reflectance can be measured in addition to the seafloor texture by the underwater camera. We have recently added a pressure gauge to measure depth and thus infer water clarity by differing radiance values at different depths.

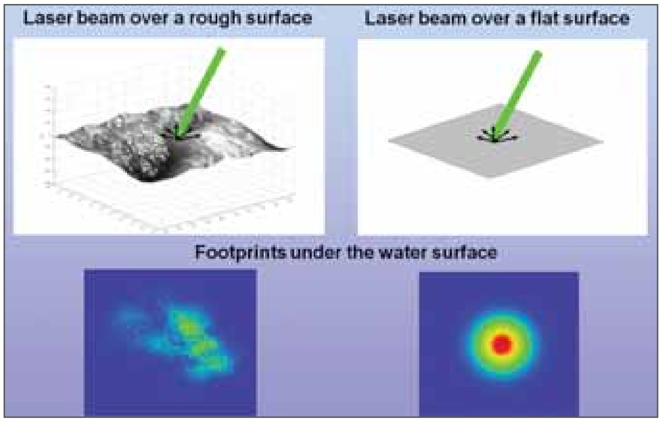

Figure 3-14. Scattering pattern simulations using ZEMAX: (top) water surface conditions, (bottom) scattering plot.

Typical analysis of the seafloor samples includes full grain-size analysis as well as measurements of the spectral response of materials at different azimuth and angles of incidences through the use of a goniometer constructed in the lab (Figure 3-16).

With this device we can measure the bi-directional reflection distribution function (BRDF) of the sample. These BRDFs provide the user with the ability to estimate the spectral change of a given seafloor type for a given morphology and survey configuration. The BRDFs will also aid in threshold estimation for algorithms classifying the seafloor using optic remote sensing datasets.

Figure 3-15. Left: the underwater camera and deployment frame with the fiber optic cable. Right: frame imagery of gravel seafloor at the UNH Coastal Marine Laboratory.

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

Sea surface salinity (SSS) and temperature (SST) are used as a base layer for many important applications, such as global productivity models and fish school locations, and are a key input into sound speed corrections necessary for acoustic surveys. However, these models are assigned with generic boundary conditions. Shachak Pe'eri and Andreas Axelsson from AHAB have been working together to investigate the potential use of ALB surveys to constrain SSS and SST models. Preliminary work has shown that there is a linear correlation between temperature and the amount of energy at 651 nm. This research work is conducted in two stages. The first stage investigated the spectral response of the water from an incident green laser beam at different temperature and salinity conditions. This work was conducted by Nicholas Parriello as part of his senior project under the guidance of Pe'eri. The second stage will be to evaluate historic ALB datasets that contain a red channel (typically between 645 to 651 nm) and relate the datasets to SSS and SST models over the ALB survey areas.

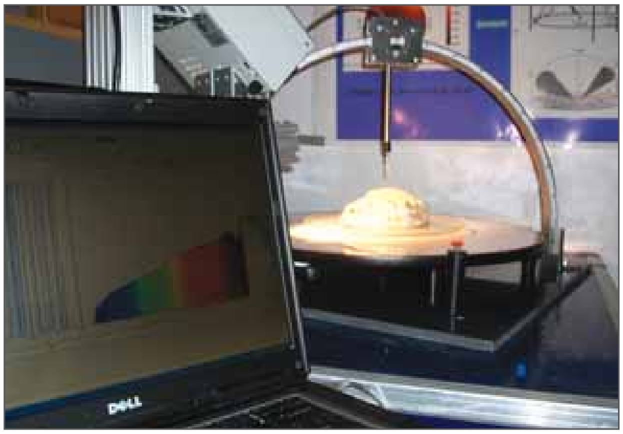

Figure 3-16. The Center's spectral goniometer. The system includes a light source, a spectra-radiometer with a fiber optic cable connected to a goniometer frame.

Coastal Lidar Radiometric Performance Analysis and Calibration

Just as we seek to understand the performance of bathymetric lidar, we also seek to understand the performance and potential of terrestrial lidars that are used in the coastal zone. In late 2010, NOAA/NGS took delivery of a state-of-the-art topographic lidar-mapping system: the Riegl LMS-Q680i Dual System shown in Figure 3-17. The dual scanner design of this system enables very dense data acquisition. Additionally, the system provides full-waveform capture, which is beneficial in wetland vegetation mapping and in supporting various NOAA IOCM research priorities.

Another noteworthy aspect of this system is that it operates at a longer wavelength than topographic lidar systems previously flown by NOAA/NGS. This longer wavelength is more rapidly absorbed offering advantages in eye safety management. However, the enhanced absorption can also lead to a decrease in signal-to-noise ratio (SNR) when operating the lidar system over wet surfaces, a potential concern for shoreline mapping. To look at this issue, NOAA secondee Chris Parrish and Center graduate student Rashot Osiri conducted research aimed at quantifying these by obtaining spectral reflectance measurements for a variety of shorelines under different conditions with a NOAA-owned ASD field spectrometer.

The results of this work are currently being used to define recommended operational parameter settings for NGS's coastal lidar acquisition over various shoreline types. A side benefit of the fieldwork conducted in this project is that it simultaneously enabled radiometric calibration of NGS's Riegl lidar data. In particular, the data were used in Rachot's

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directed research to derive a method for converting from raw lidar intensity data to estimates of surface reflectance. This, in turn, enables the generation of reflectance images from which coastal land cover classification images can produce a product very relevant to both the IOCM and HABITAT MAPPING themes (Figure 3-18).

EAARL Radiometric Calibration and Waveform Processing

The U.S. Geological Survey (USGS) is currently working on upgrades to its Experimental Advanced Airborne Research lidar (EAARL) system to improve measurement of bathymetry in shallow and turbid water environments. To help meet interagency coastal mapping and characterization objectives with this new system, Chris Parrish is working with colleagues from NOAA NCCOS, JHC/CCOM, and USGS to develop new algorithms and procedures for radiometrically calibrating data from the new EAARL-B system.

A primary goal of this work is to enable the generation of seafloor reflectance images that will support NOAA NCCOS and the Office of National Marine Sanctuaries (ONMS) in producing benthic habitat maps. In turn, these habitat maps help policy-makers and scientists make informed decisions related to protection of the nation's fragile shallow-water coastal areas.

The basic principle underlying the work is that amplitude values extracted from EAARL waveforms are related to seafloor reflectance (albedo) in a way that can be mathematically modeled. Progress on this work to date has included establishing an EAARL Airborne Lidar Processing (ALPS) workstation at JHC/CCOM and developing code for extracting and processing waveforms from the current-generation EAARL sensor. In addition, Parrish is working with John Brock and Wayne Wright of USGS, Amar Nayegandhi of Dewberry Davis, Tim Battista of NOAA NCCOS, and Shackak Pe'eri of JHC/CCOM on plans for airborne and field data acquisition in the U.S. Virgin Islands (USVI) in Spring 2012.

Sound Speed Sensors

One of the fundamental requirements of making 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 the largest contributor to uncertainty in our bathymetric measurements. Thus the Center has invested much research into exploring new and better ways to make sound speed measurements or to predict the variability in the sound speed field when no measurements or not enough measurements are available (see the PROCESSING theme).

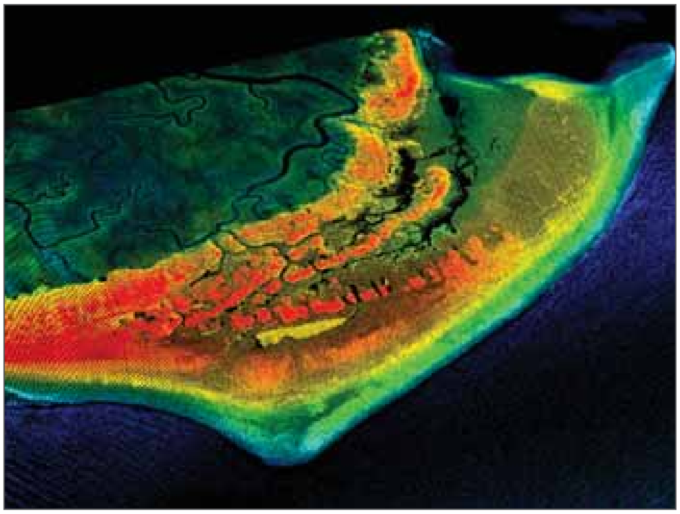


Figure 3-17. The NOAA/NGS' Riegl LMS-Q690i Dual system (left) and data acquired over the Virginia Coast Reserve in a shoreline test project (right).

Oceanscience Underway CTD/Underway Sound Velocity Sensor Testing

Jonathan Beaudoin has been working with new industrial associate Oceanscience to evaluate their Underway CTD/SV (UCTD/USV) system on the stern of the R/V *Coastal Surveyor*. The system was installed on the *Coastal Surveyor* in May 2011 with training on the system provided for faculty and students. Preliminary temperature results are shown Figure 3-19, note that the break at ~22 min is associated with a turn. These initial tests were vital in confirming whether or not the UCTD could be used in shallow estuarine environments as they were initially designed for use in the deep ocean and required customized drop rate retardants to reduce the likelihood of impact in shallow environments.

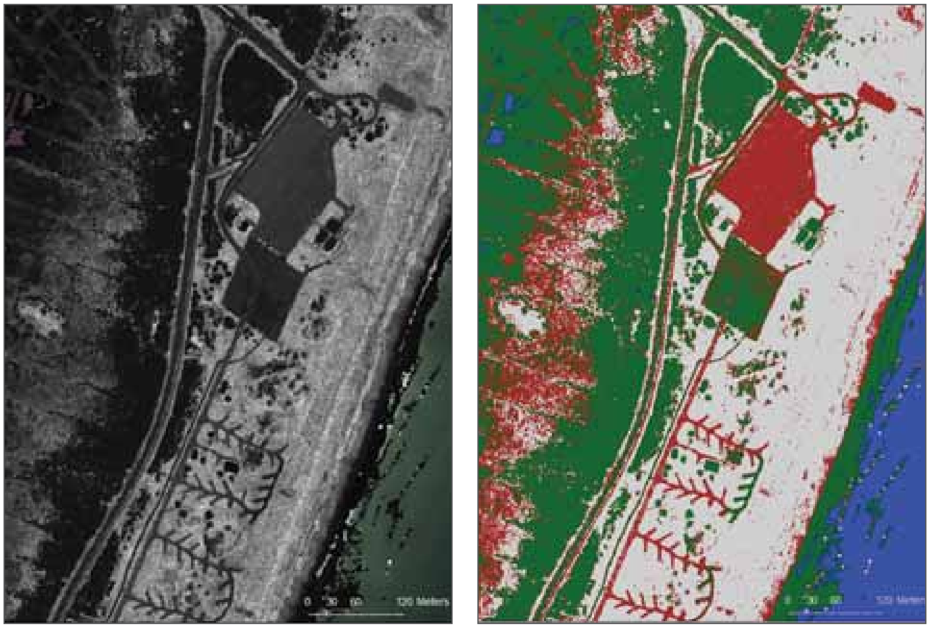


Figure 3-18. Reflectance image generated by applying radiometric calibration procedure to NGS Riegl lidar intensity data (left), and coastal land cover classification image produced from the reflectance image (right).

Additional testing was done to establish acquisition procedures for cross channel sampling as this particular mode of operation is much more challenging due to the complex channel morphology, strong currents (which can vary across the channel) and occasional maritime traffic.

Rolls Royce MVP30

Industrial Associate Rolls Royce provided an MVP30 for use in the Summer Hydro course in June of 2011. Beaudoin also used the opportunity to fit a few sampling campaigns amongst the student training sessions and measured across channel sections repeatedly on two separate occasions. The first section, near the mouth of Great Bay (near the General Sullivan bridge), was sampled 17 times over 4.5 hours with ~20 profiles per section on 16 June starting near high tide with slack water following ~1 hour later.

A second cross-channel section was sampled near the mouth of the Piscataqua River on 21 June with the section being run 24 times with 10-15 casts per run. Results are shown in Figure 3-20. Early analysis indicates that there is significant across channel variability at low tide and nearing high tide but that variability is at a minimum at slack water following low tide.

Oceanographic observations such as these allow for the identification of ideal multibeam survey windows during which water mass variability, and its impact on sounding uncertainty, is at a minimum.

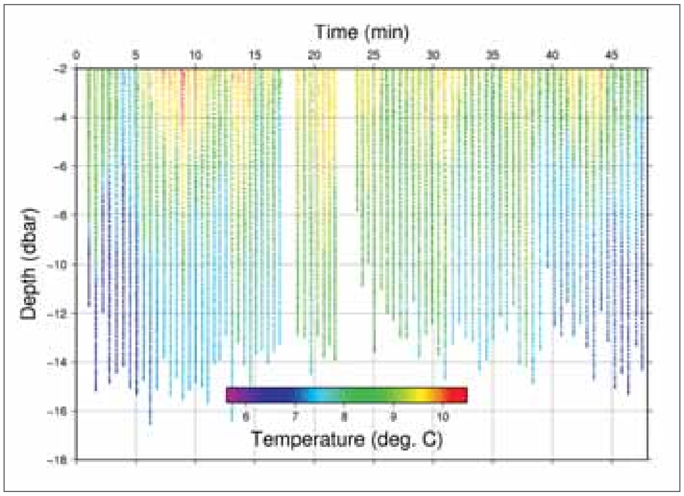


Figure 3-19. Underway CTD measurements made with Oceanscience UCTD.

Further sampling with the UCTD and analysis of the datasets from both the MVP and UCTD will determine optimal pre-analysis methods and survey strategies in the Piscataqua and Great Bay estuary during the 2012 field season. The goal of this work is to explore oceanographic pre-analysis sampling techniques using underway profilers and analysis methods so that these types of observations can be used to direct survey practice to take advantage of windows of opportunity during which water column conditions are conducive to multibeam echo sounding. This work helps to document and understand the oceanographic variability in Portsmouth Harbor, the site of many Center experiments.

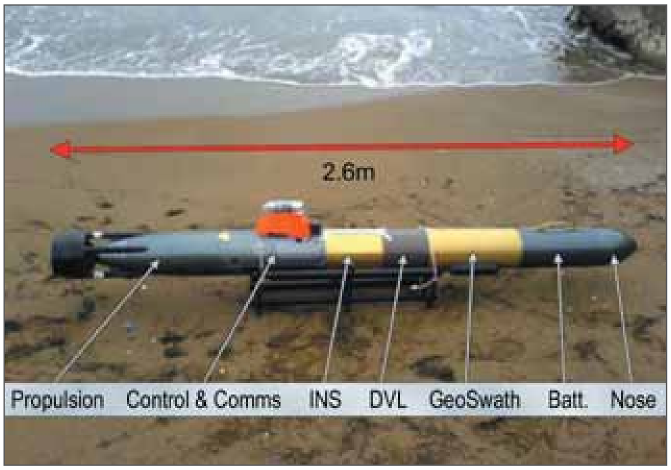


Figure 3-21. Gavia AUV with GeoSwath Phase Measuring Bathymetric Sonar.

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 the use of his Fetch 3 vehicle. We purchased, calibrated, and integrated a small multibeam sonar (Imagenix Delta-T) into this AUV and, throughout 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 (Figure 3-21). 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 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.

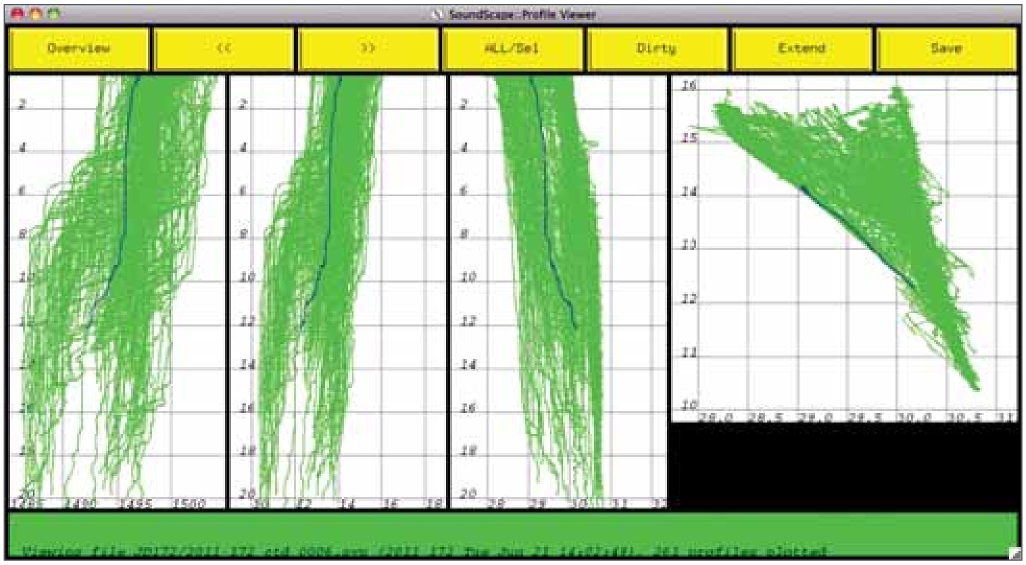


Figure 3-20. Sound speed, temperature and salinity vertical profiles in the three leftmost panels and a T/S plot in the rightmost panel.

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. He 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.

Early in 2011, the Gavia was returned to the manufacturer (Teledyne/Gavia) in Iceland for post-warranty repairs and upgrades. The vehicle's INS firmware was upgraded allowing proper field calibrations and the vehicle's maximum depth rating was increased from 200 m to 500 m. Additionally, two new modules were deployed on the AUV. The first is a 7-24kHz sub-bottom profiler that is manufactured by Teledyne Benthos and was integrated by Teledyne Gavia. While basic operation of the system was satisfactory, improper logging of time and position, as well as corruption of the system under a power failure required further development. A follow-on sea acceptance test will occur in the summer of 2012 to finalize the event.

Figure 3-21. Iceberg chosen for survey with the Canadian Icebreaker *Amundsen* in the distance. The near side is approximately 300 m in length.

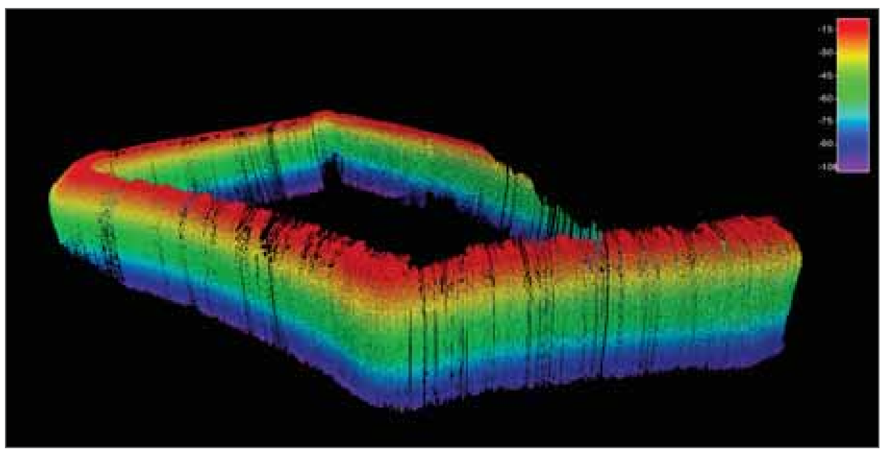


Figure 3-22. Peripheral EM3002 survey data of an iceberg colored by depth.

The second AUV module undergoing development is a magnetometer module. Funded through the Department of Defense's "Environmental Security Technology Certification Program," the magnetometer module is being co-developed by the University of Delaware and Geometrics Inc.

In the summer of 2011, Schmidt was invited to participate in an effort funded by the Canadian Ice Service to map the underside of an iceberg. The goal of the Canadian Ice Service was to measure the underwater volume and surface roughness of an iceberg early in the summer and again late in the season to provide constraints to their modeling efforts. Funding for the effort was not announced until May allowing for only a proof-of-concept effort.

The Gavia's swath mapping system was adjusted to operate while inverted to allow measurement of the iceberg's underside. In addition we enlisted assistance from the University of New Brunswick's mapping team to conduct mapping of the iceberg periphery with a modified EM3002 installation aboard a small boat. Methods were developed to compensate for the drift of the iceberg, as well as mapping a potentially highly variable terrain in an incremental fashion. Recovery procedures involving operating on a thin tether were also developed in the event a mission should go awry.

With limited time available to meet mission objectives (less than 12 hours), the best available iceberg for survey in the allotted time (Figure 3-21) was considerably larger than anticipated. Reaching more than 104 meters in depth, the iceberg was too deep for the AUV to reach and maintain depth. Although we were able to test operation with the tether to more than 60 m prior to departure, the system could not operate at the 120+ meters required for this iceberg. After a frustrating eight hours of attempts we were forced to retire with only the peripheral EM3002 survey (Figure 3-22).

Other Sensors – Instrumenting the Harbor

Harbor Tracking Bouys

In support of our AUV effort and to provide the permanent ability to accurately position this (or any other) vehicle, sampler and other device, the Center began a project in 2006 to install a fixed acoustic navigation array in a portion of Portsmouth Harbor, NH. When fully functional, this positioning system may also provide the ability to passively listen to ship traffic in the harbor as well as to monitor changes in the physical oceanography of the harbor. We have called the project the "Harbor Tracking and Observatory Project." The focus of this project has been the construction of a tracking buoy system. The buoys will serve the dual purpose of communicating with the AUV and providing AUV positioning while underwater, using a synchronized timing scheme. The devices are positioned by RTK GPS units (with 2 cm stationary accuracy), contain onboard temperature, conductivity and attitude sensors and utilize WHOI modems for underwater communications and ranging. Data is telemetered from each unit via a WiFi link to shore for data monitoring and processing.

Figure 3-24. Buoy deployed in New Hampshire's Great Bay.

In 2011, Tom Weber supervising Mechanical Engineering undergraduates and interns Matt Normandeau and Evan Leach, upgraded the autonomous tracking buoys in preparation for future deployments (Figure 3-23). This included replacing the wire harnesses, replacing hardware corroded from previous deployments, and powder coating of all exposed aluminum to prevent corrosion. Each component of the buoy is being extensively tested as part of this rebuild which is expected to be completed in January 2012.

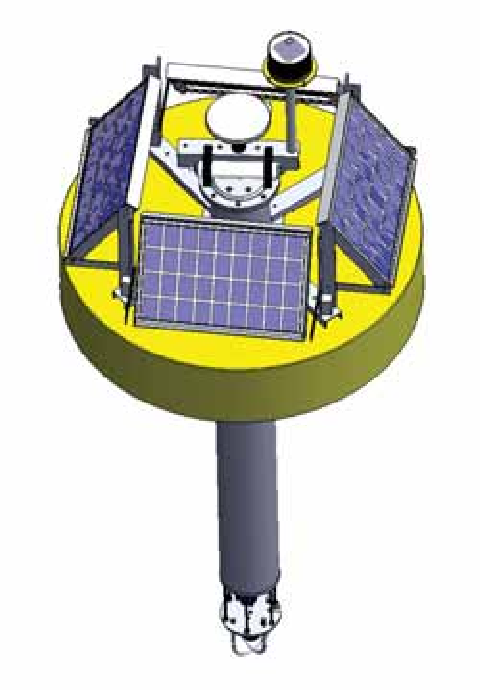


Figure 3-23. Upgraded Harbor Tracking Buoy design.

Harbor Sensor Network

To extend the capabilities of the Tracking Buoys and allow greater access to other platforms and measurements in the harbor, Kurt Schwehr and Andy McLeod are leading the development of a robust RF mesh data transfer and logging system for the New Hampshire coastal and estuarine environments. The network will eventually consist of tide gauges (pressure and radar), weather stations, cameras and Automatic Identification System (AIS) receivers.

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 error 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 developing 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 (10s to 100s of times faster than 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 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, AK; Woods Hole, MA; and Valdez, AK) 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 are now implementing 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 2011 is described below.

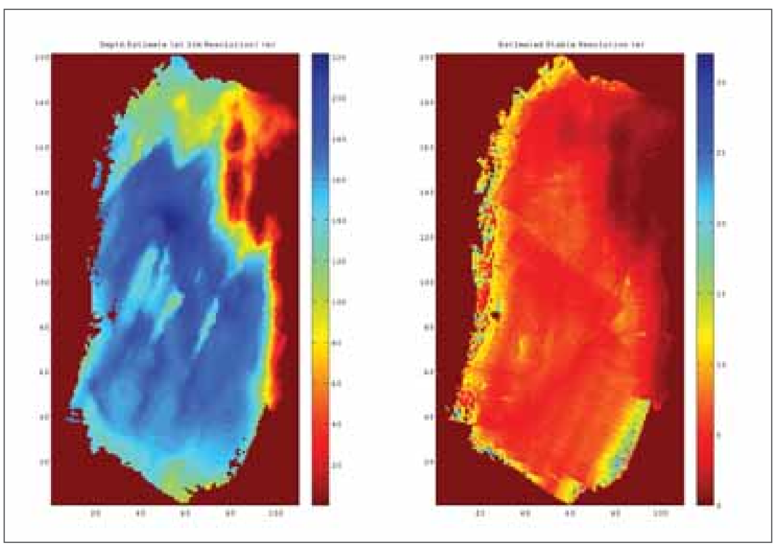


Figure 4-1. First-pass results from the original algorithm. The algorithm computes the resolution appropriate to the data density observed (right) using Rice's rule (resolution is inversely proportional to the square root of density), but also computes a low-resolution estimate of depth (in this case at 32m centers) with CUBE (left). The low-resolution depth estimate can assist in data filtering or, possibly, slope-correction in the second pass.

Multiresolution Grids – CHRT

Calder's efforts with respect to CUBE in 2011 focused on the CHRT (CUBE with Hierarchical Resolution Techniques) algorithm. The goal of the project is to develop a multi-resolution representation of bathymetric surfaces appropriate for the hydrographic (and bathymetric) data processing problem, and to adapt current bathymetric estimation algorithms to this representation using data density estimates as a driver for adaptation of the multi-resolution representation. Previous work on the algorithm had resulted in a workable code base that had generated some preliminary estimates of data density, but which needed to be extended and tested to allow for multi-resolution adaptation and depth estimation. During the past year, Calder's efforts focused on the testing and development of the core algorithms to reliably estimate data density, adapt the multi-resolution representation, and compute depths at variable resolution. He also worked on infrastructural improvements to the core algorithms, the flexibility of the estimator, and the structure of the client-server applications which implement the algorithm.

The algorithm operates in two passes, estimating the operational data density in the first pass and refining the multi-resolution representation, then estimating the depth at variable resolution in the second pass. The CUBE estimator code has been adapted so that it estimates depths at low resolution during the first pass of the algorithm (Figure 4-1), and then at the best-estimated resolution during the second (Figure 4-2). The algorithm appears at first analysis to be operating as expected, and generates the usual CUBE-like auxiliary metrics of uncertainty estimates, hypothesis counts and hypothesis strength estimates. In essence, these figures illustrate the core of the CHRT algorithm, given that we believe the estimates of resolution that the first pass of the algorithm generates.

Qualifying this last statement, however, has been the primary concern of the research in this reporting period. That is, the quality of the high-resolution depth estimation is critically dependent on the accuracy of the resolution estimates generated during the first pass and, therefore, on the data

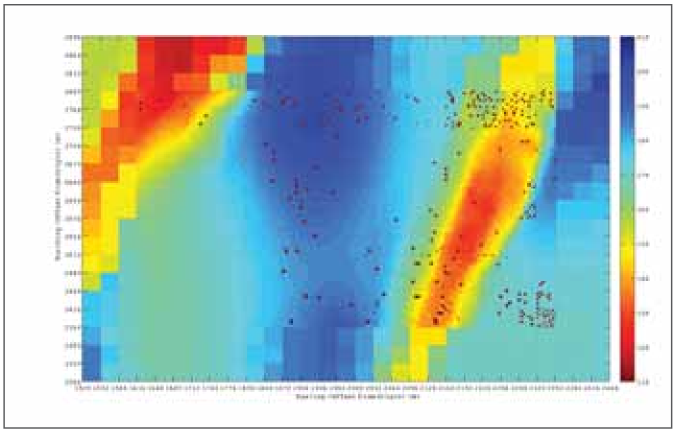


Figure 4-2. High-resolution depth estimates from the second pass of the algorithm overlaid on 32m-spacing low-resolution depth estimates from the first pass of the algorithm. Note the general agreement, but significantly improved resolution, of depths between the two passes.

density estimates. Ultimately, this depends on the estimation of the area of each first-pass low-resolution grid cell (which is used to structure the computation) that is being occupied by the MBES swaths in the region. Further investigation of the estimates of resolution generated by the algorithm showed that they were unacceptably inaccurate in regions of low data density (e.g., the edges of the survey area), or in regions where only part of the low-resolution grid cells were being used (e.g., shoal regions around the shoreline).

The first of these effects was shown to be caused by an aliasing effect. In deep water, it is possible for the spacing between outer beams of the MBES to be such that only a single beam occurs within the low-resolution grid cell leading to inaccurate estimates of the area occupied and, hence, data density and resolution, due to an initial implementation requirement assumption that we treat soundings independently so that no contextual information about the swath is available (this simplifies the code and allows for a wider range of sensors). This can be resolved by agglomerating estimates of area from multiple surrounding cells and then renormalizing to the cell of interest to improve the estimate. This estimate has lower spatial resolution than the original estimate, but a composite product can be constructed if required by merging the results using a prediction of stability (e.g., how quickly the area estimate changes between levels) to blend the two estimates (Figure 4-3).

A second effect occurred when only a small proportion of the low-resolution cell was covered by high-density data: the approximation error in the estimating process dominates the areas computed. This can be resolved by computing a mask for the occupied area at one eighth of the resolution of each cell and then computing the active area in quanta of the sub-cell mask units. (A sub-cell of one-eighth of the original was chosen for efficiency of implementation.) This results in much better estimates of active area in shoal areas, although the estimates are limited in deeper water where the beam-to-beam spacing of the MBES swath results in unoccupied sub-cells.

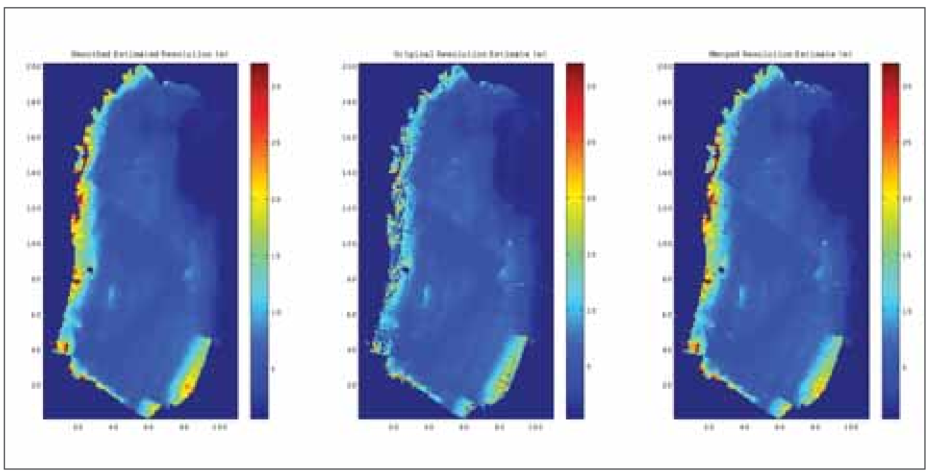


Figure 4-3. Original (middle), agglomerated (left) and merged (right) estimates of resolution at which to compute the high-resolution depth estimates in the second pass. Note the inevitable smoothness of the agglomerated estimates, which suggests that we retain the original estimates where possible, substituting the agglomerated results only where required. The example here uses an estimate of variability of resolution over scale to determine where the estimation is unstable, and therefore where the agglomerated estimates are preferred.

A method was developed to directly compute a simple coverage grid based on the outer extents of each swath, using an off-screen but hardware-accelerated OpenGL rendering context to speed up the estimation. Using super-sampling within each cell and anti-aliasing techniques during rendering to improve the fidelity of the area estimate, the resulting algorithm generates estimates that can be cheaply persisted to disc, and has been observed to execute faster than data can be read from the local hard disc on the test system. It does, however, require that the data be structured in pings (i.e., random point data is no longer allowed). This is a small constraint on the data input stream, and is not expected to be a significant problem in normal practice of the algorithm. The OpenGL-based resolution estimation code is integrated and, currently, being tested.

The second component of Calder's effort in this reporting period is related to infrastructural improvements in the code base. Previous effort had developed a client-server application pair that allowed the user to asynchronously pass commands from a separate client application and have them executed by CHRT on a remote server. This mechanism allows much greater flexibility of implementation, with the ultimate goal being a code-base that demonstrates an appropriate implementation of the algorithm and, therefore, allows for diagnosis of design errors that might cause problems should the algorithm be adopted for use in the field.

A more significant improvement has been to adopt a globally defined grid. That is, instead of the user having to define a priori the bounding box of the area of interest for the data being processed, it is now possible to allow the code to determine the bounding box incrementally as the data is being added. This is possible because of an extremely flexible memory-addressing scheme within the code that allows the algorithm to address essentially arbitrarily large areas (i.e., it can address a grid that would encircle the Earth multiple times). With this facility in place, the algorithm can pre-define the location of the grid with respect to the coordinate frame of the projected coordinate system, and thereafter simply activate tiles of the grid when data is detected within them. The user never has to specify a bounding box, and only areas that are active have resources committed to them. On output, the code is also careful to only read back the portion of the tiles that are active, and attempts to defer committing memory to the tile until absolutely required. The implementation therefore saves memory and significantly simplifies the setup of the algorithm.

Transition of research code like CHRT to practice while ensuring the integrity of the implemented algorithms can be difficult. Discussions are currently underway with our Industrial Associates (in consultation with the appropriate University groups) to see if it would be possible to develop a cooperative arrangement whereby they might contribute some software engineering resources (generally, the time of professional developers) to stabilize and improve the code-base in return for some improved license terms for the code. This should result in an "industrial strength" code-base that could be used for implementation, easing transfers. At an initial meeting of the relevant Industrial Associates, there was agreement in principle on this approach.

Quality Factors for Uncertainty Estimation

Taking advantage of the visit of Xavier Lurton to the lab, Calder has been working with Lurton to adapt the uncertainty estimation modules used for CUBE and CHRT to include the outputs from the Lurton-Augustin Quality Factor algorithm as part of the computation. In addition to software development, this appears to require some modification of the algorithm to address the situation where there are multiple depth detections within a single beam (e.g., in the outer beams of Kongsberg systems), which we are currently pursuing.

Parallel Processing for Hydrographic Data

As data rates rapidly increase, the computational demands for hydrographic processing become ever greater. Many of the computational aspects of hydrographic data processing (including the CHRT algorithm described above) may lend themselves to a parallel-processing approach. Consequently, Calder is supervising graduate student Rohit Venugopal in a master's thesis that focuses on the concept of a parallel-processing system for hydrographic data. The Center owns a seven-blade Dell Poweredge Blade Server (see the IT section) that is ideally suited for testing the algorithms developed under this project. Venugopal has been working on the scheduling algorithms for the parallel processing problem, taking into account classical problems of scheduling fairness, resource starvation and deadlock. In addition, all of the preparatory work is completed on the hardware parts of the project.

Work has progressed so that we now have both an appropriate NDA with CARIS for their hydrographic data processing toolbox, and have also taken delivery of the first version of this code. Venugopal is currently integrating this code into the extant code-base. Calder has also continued to develop the code-base for the CHRT client-server application required to support parallel bathymetric computation, as described above, although the distributed version of the algorithm is still at the design stage.

Improved Processing for Phase-Measuring Bathymetric Sonars

Phase-measuring bathymetric sonars (PMBS) are multi-row sidescan sonars that look at the phase differences of the acoustic signals between the rows to derive a bathymetric solution. They have the potential of offering much wider coverage in shallow water than conventional beam-forming multibeam sonars. NOAA and other mapping agencies recognize this possible 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 the 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 AUV. This has provided us with the opportunity to collect PMBS data and begin to explore the problems associated with PMBS data (as well as AUV-derived data).

Val Schmidt, Tom Weber, Brian Calder, Jonathan Beaudoin, Glen Rice, Larry Mayer, and Yuri Rzhanov have been meeting regularly to begin to outline new approaches to processing these data. As part of this effort, Jonathan Beaudoin has been working with Janice Eisenberg and others at NOAA. In 2011, our experience with PMBS expanded to include work with the Klein HydroChart 5000 and the EdgeTech 4600 (see the SENSORS theme) and also included involvement from Xavier Lurton.

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 the 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, as no filtering is done during data acquisition that might mitigate the volume and complexity of data to contend with.

In 2011, efforts have continued to develop algorithms suitable for handling the large number of outliers inherent in phase-measuring bathymetric sidescan data. In addition to selecting data near the "most-probable" receive angle, Schmidt has experimented with using an estimation of the trend of the seafloor and retention of soundings within some bound of that trend (Figure 4-4). The method works well at rejecting outliers at the far edges of the swath when the signal-to-noise ratio is low and self-noise within the sonar is often tracked rather than the bottom. So far, the method appears to be quite slow and is, therefore, difficult to implement in MATLAB for actual operations. Further research is planned.

In addition, Schmidt has experimented with the processing of densely collected data sets while retaining the full width of the swath. This includes soundings whose nominal uncertainty (and hence noise level) is quite high—far beyond that which would normally be retained for hydrographic purposes. The goal is to identify whether or not a suitable uncertainty model, combined with the CUBE algorithm, could provide a method to include even the most egregiously poor data. The effort thus far has been successful in demonstrating problems with the approach. Two basic problems have come to light. The first is that normal survey methods frequently overlap poor data with poor data. And while there is often a copious amount of data in each grid cell (100s of data points), the noise is not unbiased and identically distributed and cannot be properly averaged out.

Second, in our AUV-based surveys there tends to be greater uncertainty in the soundings from ping to ping than from soundings within a ping. The correlation of uncertainty for soundings within a ping results in uncertainty that is not reduced with the

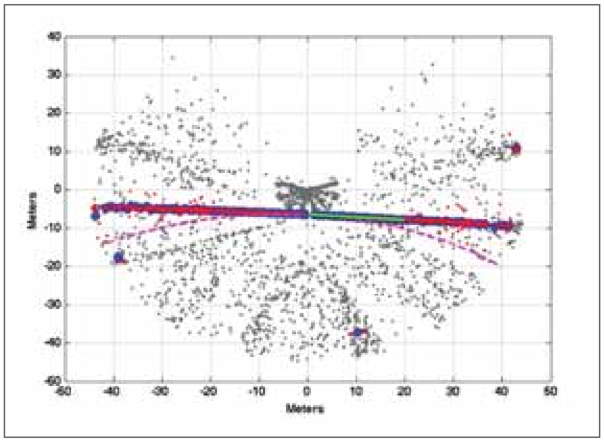


Figure 4-4. Phase-measurement sonar data outlier rejection algorithm showing a single ping of data overlaid with algorithm results (red) and bottom trend (green) and trend rejection boundary (pink).

gridding process. This problem may be unique to phase-measuring bathymetric sidescan systems in that the volume of data in the across-track direction is more than an order of magnitude higher than in the along-track direction. Therefore, small biases common within a ping are not removed in the gridding process.

Schmidt has also explored approaches to utilizing the CUBE algorithm for the gridding of PMBS data. This requires estimates of uncertainty for the depth measurements so, to do this, he has adopted a method proposed by Xavier Lurton to estimate the uncertainty in each receive angle. This method involves fitting a polynomial to the individual receive angle measurement and calculating the r.m.s. residuals about that curve (Figure 4-5). This method is essentially that which is proposed for phase-detections in multibeam echo sounders.

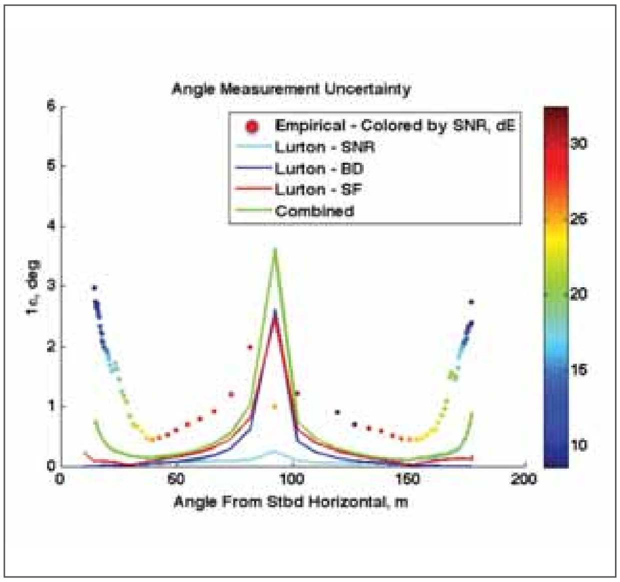


Figure 4-5. Empirical measurement of receive angle uncertainty from the Geoswath, along with theoretical contributions to that uncertainty.

While signal-to-noise-ratio (SNR) is not the only contributing factor for phase measurement uncertainty, it is the largest factor. Moreover, it contributes to the uncertainty in a monotonically increasing way such that it may be used as a convenient proxy for total uncertainty. Therefore a method has been developed to estimate the SNR of each measurement in real time which, when combined with a look-up table, can provide an estimate of measurement uncertainty.

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 high-quality seafloor mapping data and is the largest single source of error within our measurements. With the arrival of Jonathan Beaudoin at the Center, we have dramatically increased our efforts to develop methods to assess the uncertainty in sounding due to the variability in the sound speed profile (SSP) and the way that the profile is.

Sound Speed Uncertainty Modeling

Beaudoin has been following up on earlier work to improve the treatment of sound speed related uncertainties as they pertain to multibeam echo sounding. Initial work focused on numerical simulations in which ray tracing algorithms were exercised for a large number of sound speed casts to better understand the effect of sensor bias and/or noise. Results from the numerical simulations differed markedly from the Hare-Godin-Mayer (HGM) uncertainty model and raised the suspicion that the sound speed portion of the HGM uncertainty model was too simplistic in its treatment of refraction. Follow up work since then has been done with Xavier Lurton, in which a more theoretical approach (based on the analytical derivation of small perturbations of the ray paths characteristics) has been applied to confirm and complement Beaudoin's simulation results. The results are in agreement and such a model appears to be a good candidate to update the sound speed portions of the HGM model (Figure 4-6). This work is ongoing. Beaudoin and Lurton expect to have a fully developed model for both cases, including a coupling of surface sound speed uncertainty, within the next few months.

Streamlining SVP Pre-Processing

The essential real-time sound speed corrections that are applied to multibeam echo sounders are often constrained by the sonar manufacturers' software that limit the number of sound speed measurements that can be input in a given profile. Additionally, sound speed profiles, particularly those taken by or derived from expendable devices (e.g., XSVPs or XBTs), do not often reach the full depth of the regions being mapped. To address these issues, Beaudoin has been working with industrial associate Rolls Royce (formerly ODIM Brooke Ocean) to implement sound speed profile pre-processing algorithms that interface with Kongsberg Maritime (KM) multibeam echo sounders. The algorithms deal with the extension of the cast to a depth of 12,000 m and the reduction of the number of data points to meet KM input criteria that casts contain less than 1,000 data points.

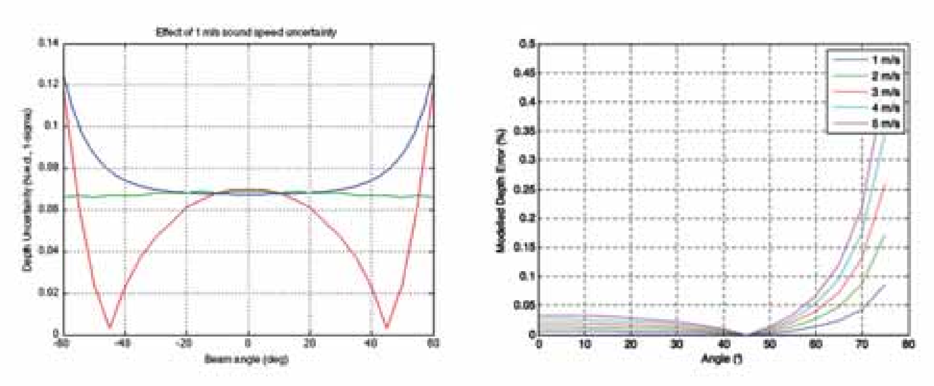


Figure 4-6. Results from numerical simulations on the left (blue is HGM model, red and green are simulation results for case of surface sound speed aided and unaided ray tracing, respectively). The figure on the right shows initial results from Lurton's model for the surface sound speed aided ray trace for varying sound speed sensor biases (note that it only shows half the swath).

The data reduction algorithm is a variant of the Douglas-Peucker (DP) line reduction algorithm, a procedure that is commonly used in computer cartographic applications to reduce the number of points on complex poly-lines such as coastlines. The algorithm allows the specification of the tolerance between the original and thinned profiles in units of meters per second. The algorithm was subjected to an uncertainty analysis using a data set of 2,147 sound speed profiles for soundings at a 60° angle of incidence. The results validate the line reduction algorithm and demonstrate that, at low tolerance levels, the algorithm introduces sounding uncertainty in much the same manner as a noisy sound speed sensor. The cast extension algorithm also consisted of a user-specified sound speed profile to extend casts, followed by a further extension using the Generalized Digital Environmental Model (GDEM) or World Ocean Atlas (WOA) oceanographic temperature and salinity mean climatologies.

As a test case study to assess the potential impact of using the proposed extension strategy, an analysis was performed to estimate the sounding uncertainty associated with differing profiling depths across a 1° band centered on ~36° latitude in the North Atlantic. Archived CTD casts were extracted from the World Ocean Database of 2009 (WOD2009). A ray trace comparison was conducting by comparing the full depth CTD cast to one artificially clipped to the depth of investigation and then extended using the WOA. The results indicate that some areas of the ocean are amenable to shallow sampling despite great depths, whereas others require the majority of the water column to be sampled to maintain accuracy, e.g., the Gulf Stream region. This type of analysis can provide guidance to the surveyor when choosing sound speed instrumentation and optimizing deployment of systems like Moving Vessel Profilers (MVP).

The algorithms were tested in the field during an MVP200 Sea Acceptance Trial (SAT) for IFREMER in Toulon, France. The two day cruise tested the MVP controller software and we were able to successfully integrate the MVP system with the KM EM302 multibeam system onboard such that hands free operation was achieved thanks to the automated pre-processing routines discussed above. The extension and thinning algorithms were evaluated in terms of resulting sounding uncertainty, as summarized above, and were presented at the U.S. Hydro 2011 conference in Tampa Bay, FL (April 27-28, 2011).

SVP Server

Beaudoin has been working to combine many of the tools and concepts described above into a suite of simple sound speed related tools to automate common, and often subjective, tasks involved with the refraction corrections associated with multibeam mapping. A recently developed tool is the SVP Server, an application that subscribes to the ship's

PROCESSING

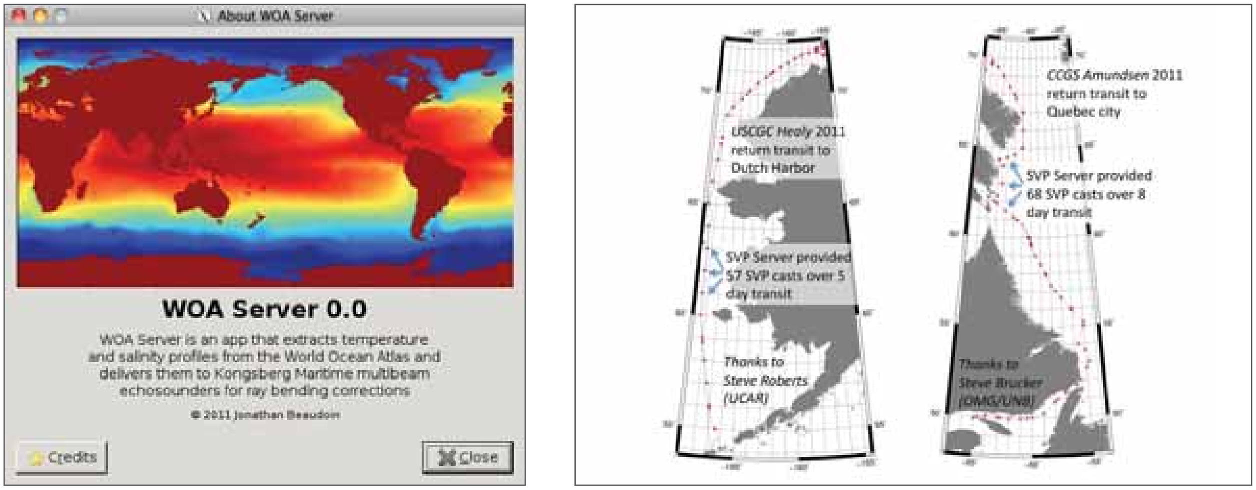


Figure 4-7. Early version of the SVP server and results of locations where sound speed profiles were provided for transits during 2011 USCG HEALY and CCGS AMUNDSEN cruises during which the software was tested (with the WOA2009 data source only).

position datagram from Kongsberg Maritime (KM) multibeam echo sounders and does a lookup for temperature and salinity profiles in either the World Ocean Atlas of 2009 (WOA2009) or the Global Real-Time Ocean Forecast System (Global RTOFS) (Figure 4-7). The temperature and salinity profiles are then formatted for input to KM multibeam echo sounders and broadcast over the vessel network to the KM echo sounder to be used for immediate application in a completely automated fashion without user intervention other than the configuration of the server prior to start up. The cooperation of industrial associate Kongsberg Maritime was instrumental in the early development stages in which the interface was built to communicate with KM multibeam echo sounders. KM provided a license for their Seafloor Information System (SIS) data acquisition software and also provided their hardware simulator software which allowed for the replay of data in a simulation mode so that the SVP Server could be tested in the lab before being trialed at sea.

This application is designed for opportunistic mapping while underway such that mapping data collected in transit has at least a rudimentary refraction correction applied with no operator intervention required at all (a situation common on many vessels that collect data during transits). Expected refinements include the ability to input user sound speed profiles and have them extended using the WOA2009 or RTOFS followed by automatic transmission to the echo sounder.

The WOA2009 grids provide monthly estimates of the mean temperature and salinity based on historic measurements. In areas of dynamic oceanography, the mean conditions captured in WOA2009 may not suffice. For this reason, the SVP Server offers the use of a real-time ocean model: Global RTOFS. The Global RTOFS grids are at a higher spatial resolution (1/12°, 5 nmi) with similar vertical resolution as WOA2009. The model incorporates available *in situ* measurements and satellite based measurements of sea surface temperature (SST) and sea surface height (SSH) and is forced using momentum, radiation and precipitation fluxes from the operational Global Forecast System (GFS). Two-day nowcasts and six-day forecasts are available daily shortly after midnight (GMT) and it is expected that these models can provide better estimates of actual oceanographic conditions as compared to WOA2009, which is time-invariant.

Testing is currently underway to validate both the WOA2009 and Global RTOFS models for refraction correction using ARGO float data. Daily sets of ARGO data are downloaded and their reported positions are used to query both models for the generation of pseudo-casts. The ARGO observations are then compared to the pseudo-casts in a ray tracing simulation in order to ascertain the uncertainty associated with use of either model. Preliminary results show that the WOA2009 provides ray-tracing solutions with 0.75% water depth accuracy (2-sigma) for a beam angle of +/-65° over the top 2000 m of water (note that ARGO floats do not sample below 2000 m depth) and that the Global RTOFS can improve on WOA2009 ray tracing accuracy by approximately 30%.

Hydrographer's Weather Map

Carrying the approach to 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 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 us with some idea of where and when spatial variability in the water column can be problematic. The procedure, which is at the proof of concept stage, 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 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.

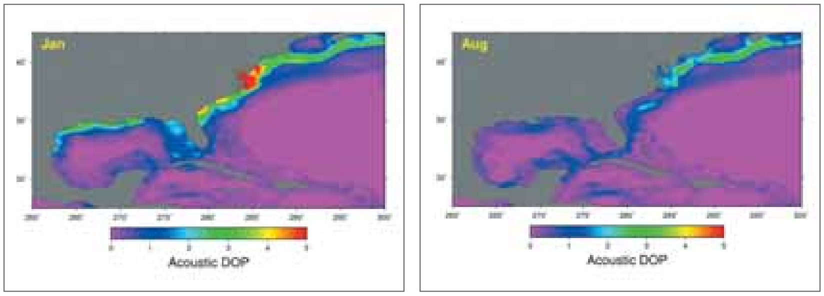


Figure 4-8. Acoustic DOP for the Gulf of Mexico and Gulf Stream region of the eastern United States, again with WOA2001 providing the underlying data set. In this case, the analysis indicates that spatial variability is more problematic in January in the Gulf Coast region of the southern US and along the continental shelf south of Cape Hatteras. Conditions in both regions are much less severe in August.

The World Ocean Atlas (2001) temperature and salinity climatological fields are used for the basis of the calculation (WOA provides data for 33 depth levels). The output is presented as the uncertainty relative to the depth uncertainty that a 1 m/s accurate sound speed sensor would provide. This parameter, called Acoustic Dilution of Precision (DOP), then allows hydrographers to evaluate how variable the water mass is relative to sensor accuracy and to plan mapping operations accordingly (Figure 4-8).

The approach described above can be used to provide guidance in the selection of appropriate sound speed sampling technologies and field procedures (e.g., sampling intervals). The above maps are of limited use, however, as the WOA grids are heavily smoothed both temporally and spatially; the results of the analyses suffer from this and potentially underestimate the true degree of variability in any given region. It is expected that time-varying oceanographic models of higher resolution can provide a higher fidelity representation of front locations and severity. The same spatial variability analysis has been applied to the Chesapeake Bay Ocean Forecast System (CBOFS), a high resolution, time-varying 3D baroclinic model run and maintained by NOAA (Figure 4-9). As the CBOFS model provides forecasts, it is anticipated that the spatial variability analysis can provide the means to work around periods of high spatial variability by identifying windows of opportunity when spatial variability is at a minimum.

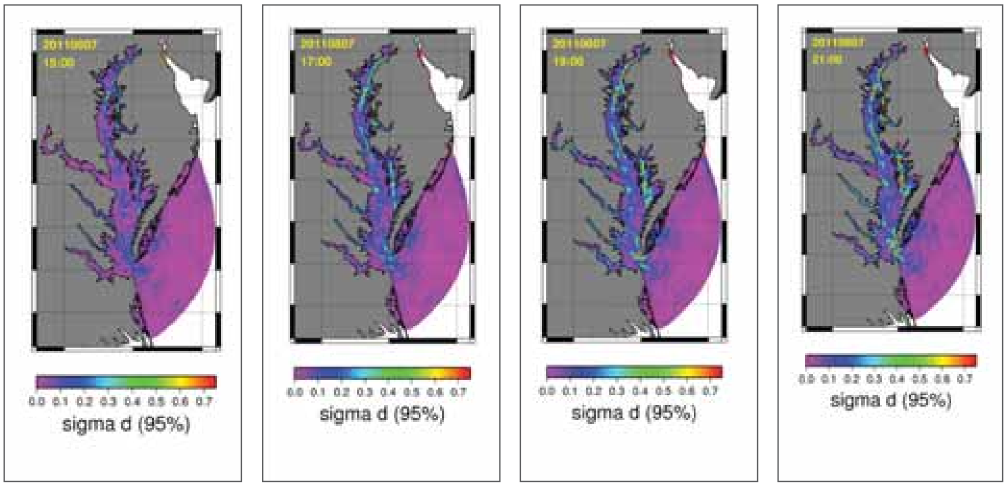


Figure 4-9. Depth uncertainty due to spatial variability over a six-hour period as forecasted for 7 August, 2011. Note the variability in the predicted uncertainty at the mouth of the estuary over the six hours.

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.

In 2011, Chris Parrish began extending the shoreline TPU work to photogrammetric mapping procedures, which remain NGS' primary method of mapping the National Shoreline. The first phase of this work entailed generating a tool for computing propagated uncertainty in X,Y ground coordinates of points, due to uncertainty in camera position and orientation parameters determined from direct georeferencing (e.g., Applanix POS and other integrated GPS/IMU systems) and in measured image coordinates.

The motivation for this tool is that the use of direct georeferencing, where and when appropriate, can potentially lead to great time and cost savings in NGS's Coastal Mapping Program, when compared with the alternative of always requiring full photogrammetric aerotriangulation. However, if direct georeferencing is to be used in production, RSD personnel require a method of assessing the uncertainty of mapped points. Furthermore, this work is highly beneficial in analyzing uncertainty as a function of distance from the GNSS base station, which will assist NGS's Coastal Mapping Board (CMB) in making policy decisions regarding maximum permissible baseline lengths.

Evaluating Chart Adequacy for Navigation

Graduate student (and Nigerian Naval Officer) Chukwama Azuike, under the guidance of Shachak Pe'eri and Lee Alexander is developing an ArcGIS procedure for evaluating the quality and adequacy of a given navigational chart. He will use commercial multi-spectral satellite remote sensing imagery to infer bathymetry and compare that to the available nautical chart. The evaluation will be done on two levels. The first is a stand-alone evaluation in which the adequacy of the chart will be evaluated based on the chart scale, sounding density, IHO charting standards and areas of importance to navigation (e.g., private and commercial traffic, tourism and military) The second level is a comparison to bathymetry produced by the satellite imagery in which, based on the coastal geomorphology from the relative bathymetry, procedures will be developed to delineate physiographic zones that are important for navigation and cross reference them with the areas of importance to navigation. Azuike's study will focus on the nautical charts that cover the territorial waters of Belize and Nigeria.

Procedure Development for Coastline Mapping and Characterization Using Satellite Remote Sensing

In addition to evaluating the chart adequacy in poorly mapped regions, there are also concerns about the adequacy of shoreline delineation. While the techniques being developed by Parrish and collaborators are useful where modern technologies are being applied to delineation, these 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. A spectral analysis using different image bands can be used to define the land/water boundary and characterize the coastal area around the coastline. A first-order uncertainty analysis and comparison of satellite-derived coastlines to charted coastlines will be used to evaluate the adequacy and consistency of the charted coastlines. The satellite-derived coastlines will also be compared to coastlines derived from historical maps to assess changes and change rates between the coastlines. The results of the coastline uncertainty analysis will then used to compute propagated uncertainties in coastline change rate estimates and to gain greater insight into actual changes.

Improved Backscatter Processing

In parallel with our efforts to improve bathymetry processing techniques are several efforts 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. While 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 try 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. project aimed at trying to address 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 will be 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 a 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).

Beginning in January 2012, a Reson 7125 (on loan from the the NOAA Ship *Fairweather*) will be calibrated in the tank, along with a simpler 200 kHz EK60 split-beam echo sounder. The calibration will be done using a standard sphere calibration (the subject of Carlo Lanzoni's master's thesis). In order to test and compare the calibration result for both systems, an extended target for use in the tank is currently being constructed. This work will eventually (spring/summer/fall) transition to field work in Portsmouth Harbor, with the idea of identifying and fully characterizing backscatter reference surfaces that can be used by the Center and others. We will also be exploring mechanisms to identify and treat sea beds with anisotropic scattering strength, and testing our ability to invert backscatter models for sediment parameters in varying conditions.

Restructured GeoCoder

When Luciano Fonseca, the developer of our backscatter processing software GeoCoder, departed several years ago, 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. 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 partners. 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. The framework of this collaboration was presented at the NOAA NOS Field Procedures Workshop, FEMME 2011 and also at U.S. Hydro 2011.

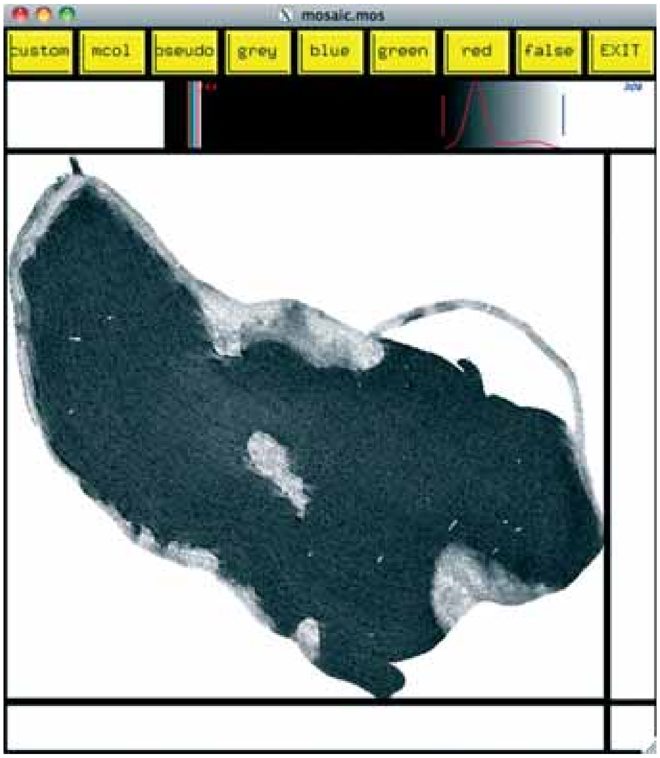


Figure 4-10. R2Sonic backscatter data processed by Jonathan Beaudoin.

R2Sonic 2022/2024

In addition to the lab-wide NEBEX project, we worked on several sonar-specific efforts aimed at improving the backscatter produced by these systems. While these efforts are often focused on system-specific problems, the solutions often result in insights or software tools that are applicable to other systems. A case in point is Jonathan Beaudoin's work with the R2Sonic 2022/2024 sonar that not only helped create an interface to a new sonar, but also served as a pilot project to explore the viability of the plug-in approach described above.

To this end, Beaudoin helped organize, mobilize, and participated in a seafloor backscatter mapping project with an R2Sonic 2024 multibeam echo sounder in February and March of 2011. Surveys were conducted in two freshwater lakes on Vancouver Island, BC, Canada with logistical and field support provided by Mike Brissette of Mosaic Hydrographic Services (Canada) Ltd. Software support for the R2Sonic exists in commercial software, however, there is currently little support for backscatter calibration. As an initial approach, the University of New Brunswick/Ocean Mapping Group (UNB/OMG) SwathEd software suite was upgraded to handle the R2Sonic system in order to do near real-time evaluation of the backscatter performance (Figure 4-10). Prior to the survey, several test files were acquired with another R2Sonic system owned by local surveyor Tom Reis of Substructure Inc., an industrial associate of the Center. These calibration files, acquired in Portsmouth Harbor, proved crucial for initial relative calibration efforts in which frequency, pulse length, source level, receiver static and time-varying gain calibrations were attempted in an uncontrolled setting in the field. The findings from this initial work enabled a rudimentary calibration of the backscatter from the surveys conducted in British Columbia using the OMG/UNB SwathEd framework.

Based on these initial results, a plug-in was created for IVS3D's FMGT and a new GSF sub-record to support the R2Sonic sonar configuration parameters, in cooperation with Shannon Byrne of SAIC, Inc. After internal reviews and testing by SAIC, this updated subversion record (and the associated I/O code) was released in GSF version 3.03 on November 18, 2011.

The results of the relative calibration procedures for the R2Sonic multibeam system area are available to all industrial associates and have been shared with industrial associate Caris. Subsequent follow-up work has been done with Dr. Joern Hatzky of Caris to assist in the incorporation of the Center R2Sonic calibration routine in their implementation of GeoCoder. In addition to this work, Caris has also begun the process of improving their implementation of GeoCoder and has undertaken work to identify the causes of differences in output from the standalone version of GeoCoder and their commercial implementation. Caris approached the Center with the results from their comparisons, as well as the underlying sources of discrepancy, and requested a meeting to review their findings and discuss the best way to share corrections and improvements to GeoCoder. Several ideas came out of the meeting, including that of a community forum to facilitate communication amongst researchers, developers, and users of GeoCoder.

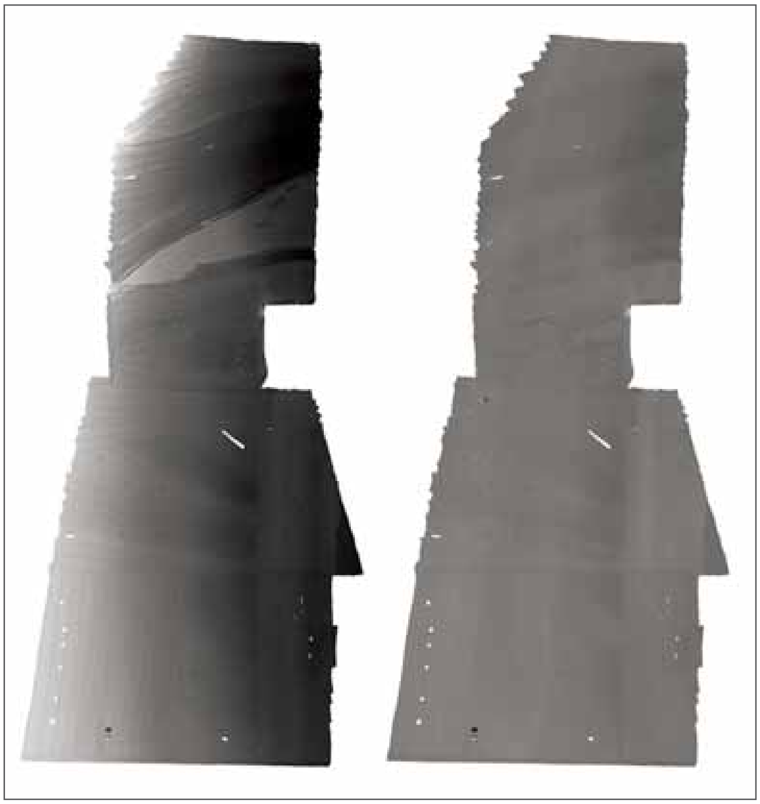


Figure 4-11. Backscatter mosaics of three *Fairweather* survey sheets before (left) and after (right) application of the calibration plug-in correction. The homogeneity of the right image is a much more accurate reflection of the nature of the seafloor in this region.

NOAA Ship *Fairweather* – Reson 7111 Backscatter Processing

In direct support of NOAA's IOCM efforts, Beaudoin was asked to help process data from the *Fairweather's* Reson 7111 since there were difficulties with attempts to complete mosaics using commercial software implementations of the Center's GeoCoder software. Beaudoin added support for the Reson 7111 system to the UNB/OMG research code base and augmented existing relative backscatter calibration code for Reson 7125 systems to deal with the 7111. The data for three survey sheets (H12220, H12222 and H12223) were processed for Nancy Wright of the Olympic Coast National Marine Sanctuary and were meant to direct USGS seafloor grab sampling operations. Initial calibration efforts were limited by poor understanding of the Reson TVG functions at the time of processing. Figure 4-11 shows how the discrepancy between expected transmission losses and the time-varying gain applied in real-time can lead to backscatter artifacts if the applied TVG is unknown. If the real-time TVG is not sufficiently understood, then there is little hope of compensating for this in post-processing.

Reson agreed to provide, under a non-disclosure agreement (NDA) information on how to reconstruct the real-time TVG based on the gain, spreading, and absorption parameters recorded in the data files. The algorithm was implemented as a plug-in for use in IVS3D's FMGT, enabling the Center's IOCM team to meet balanced scorecard deliverables through the use of commercial software (Figure 4-11). These calibration routines are available to all of our industrial associates who sign an appropriate NDA with Reson with respect to Reson's TVG algorithms. An intriguing result of this work is the presence of apparent anisotropy in the backscatter recorded by the 7111. This result will be the focus of further research and will be included as a part of the NEWBEX project.

Data Management

After five years of searching for an appropriate data manager for the Center we are delighted to report that we have filled the position this year with the very capable Paul Johnson who comes to us from the University of Hawaii's Mapping Research Group. Johnson 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.

Metadata and GIS Product Generation

The value and usefulness of data is inextricably linked to the ability of others to discover and work with them. Metadata (data about the data) is a key component to ensuring that full value can be derived from data. To support the creation of metadata, Johnson is developing a series of scripts and tools designed to extract information out of gridded, raw and processed multibeam data and to then turn this information into usable products meant to be incorporated into a database managed through a GIS. The routines are designed to "harvest" information, such as time, date, location, depth, etc., from any multibeam files, which they encounter on disk and can identify and create appropriate metadata. Routines are in place to ensure that all metadata will be migrated to the new ISO 19115 standard.

Extracted information and GIS products include:

1. **Navigation.** The data mining scripts extract position, date, time, heading, and speed from each raw or processed multibeam file they encounter. They then generate a GIS point shapefile holding this information, as well as acquisition system, survey name, and path to file. As an option, the scripts will also subsample this information by a user specified time interval and/or generate a simplified GIS polyline shapefile suitable for the rapid display of navigation if the detailed information is not needed. This method of extraction and presentation allows an interested user to simply click on a navigation point with an ArcGIS query tool and instantly see all of the relevant information associated with that point in the "Identify" results.

2. **Survey Coverage Maps.** Simple polygon shapefiles indicating the areas covered by a particular survey are also generated by the data extraction and content generation scripts. These polygons can be generated by examing the area covered with data values in the final gridded products (SD, xyz, or ESRI grid) or by examing the regions mapped in the raw or processed multibeam files.

3. **File Coverage Maps.** A detailed polygon is generated from each raw or processed file representing the geographic area covered containing bathymetric values from that file. Each polygon is then added to a single "master" polygon shapefile containing the outlines for each file of that cruise. Attached to each polygon is file-specific information for that coverage, including start time, start date, end time, end date, track length, average speed, geographic area covered, number of pings, number of beams, system type, and cruise identification. All of this information can be easily queried through the GIS, and we believe this will be very useful in future searches for files of a specific multibeam system, or geographic area, or which were collected in certain time ranges. With the product generation scripts, it is possible to capture either a very detailed and accurate polygon for the coverage of each file, including gaps within the swath or extraneous clusters of points disconnected from the main swath or to capture a more generalized shape if desired.

4. **Bathymetric and Backscatter Products.** All gridded data products (SD, xyz, and ESRI grid) have their geographic bounds, minimum and maximum depths, and cell sizes catlogued. If desired, the scripts can combine all gridded data products of a similar type (bathymetry or backscatter) into a single gridded synthesis at a grid cell size that is common to all of the data products or at a size that the user specifies. The user also has the option to generate geographically registered backscatter or side illuminated color bathymetry PNGs for export to other mapping packages.

Briana Sullivan has been working with Johnson to create a cruise report-specific metadata extractor. The approach uses Word 2007, XML and XSLT (EXtensible Stylesheet Language) to search a cruise report, appropriately tag portions of it, then generate a template for cruise level metadata. The template is then merged with the metadata pulled directly from data collected and an FGDC formatted XML metadata file is produced.

ArcGIS Data Server

Following the development of the metadata extraction and GIS product generation scripts described above, Johnson began to incorporate the products into an ArcGIS server installed at the Center. Johnson worked with ESRI to evaluate their new beta release of a nautical solutions package and with this evaluation we received access to the 10.1 beta release of the ArcGIS server which proved to be much more stable than earlier releases.

The ArcGIS server allows us to publish data available at the Center so that it is discoverable through ArcGIS Online, a search portal available to all GIS users with internet access. This makes adding data in ArcMap as simple as clicking on the "Add Data from ArcGIS Online" menu option, making our data much more easily accessible and useful. Data search, download, and visualization are also available through a combination of ESRI services run in parallel to the Center's server. Users (including those who do not use ArcGIS) can visit **http://arcgis.com** and under enter "datasets" in the "Find maps, applications, and more…" search box. Figure 4-12 shows the result of searching for bathymetry on the site. Included in the list are some of the Center's available datasets and maps that are currently being served off of the GIS server here. Clicking on the Mariana Islands Region link within the search results brings the web page (shown on the right) which displays the details of the metadata for that file, including material on the Law of the Sea program, information on the grids available, access and use constraints, etc.

A user can then click on the "Open" button on the informational page, select "Open in ArcGIS Explorer Online" and the data will be opened in a web based GIS which is freely available for all (Figure 4-13). Using this interface, users can zoom and pan, add other datasets, perform queries on the data, measure lengths or areas of features, and determine the geographic locations of features.

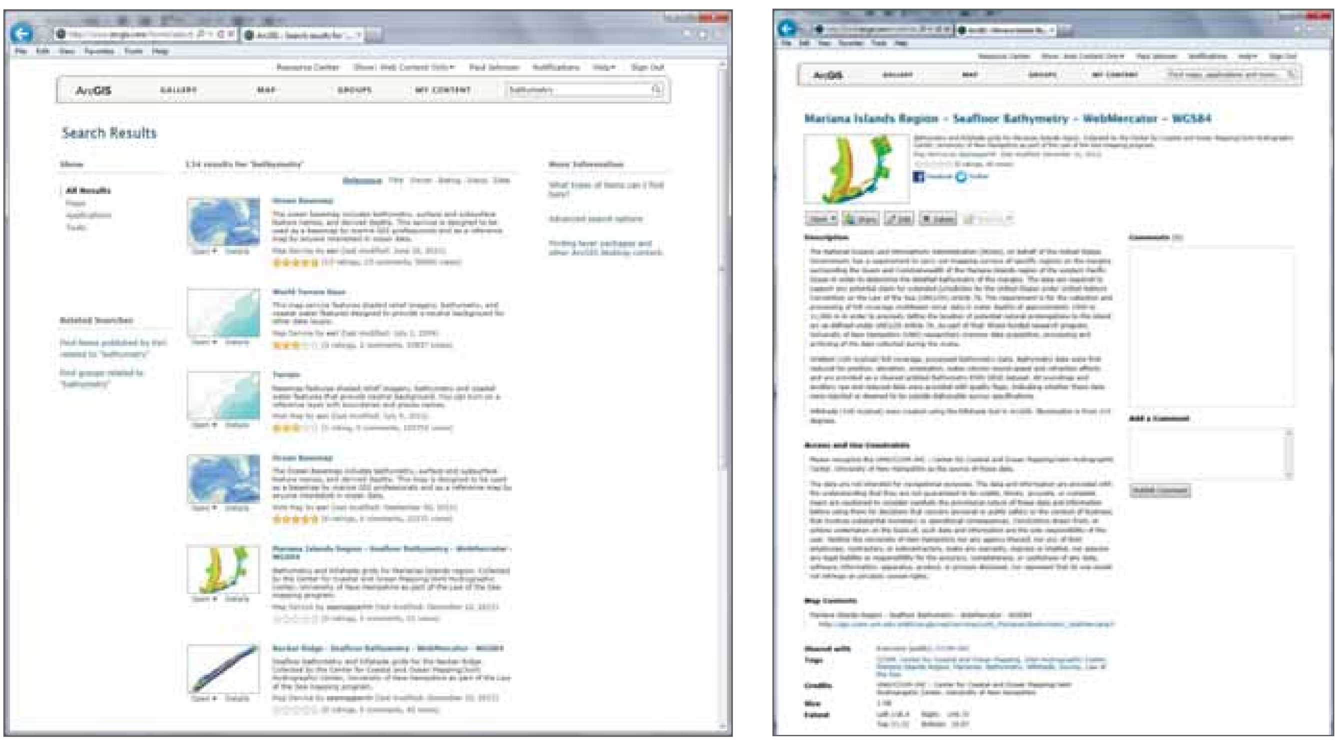
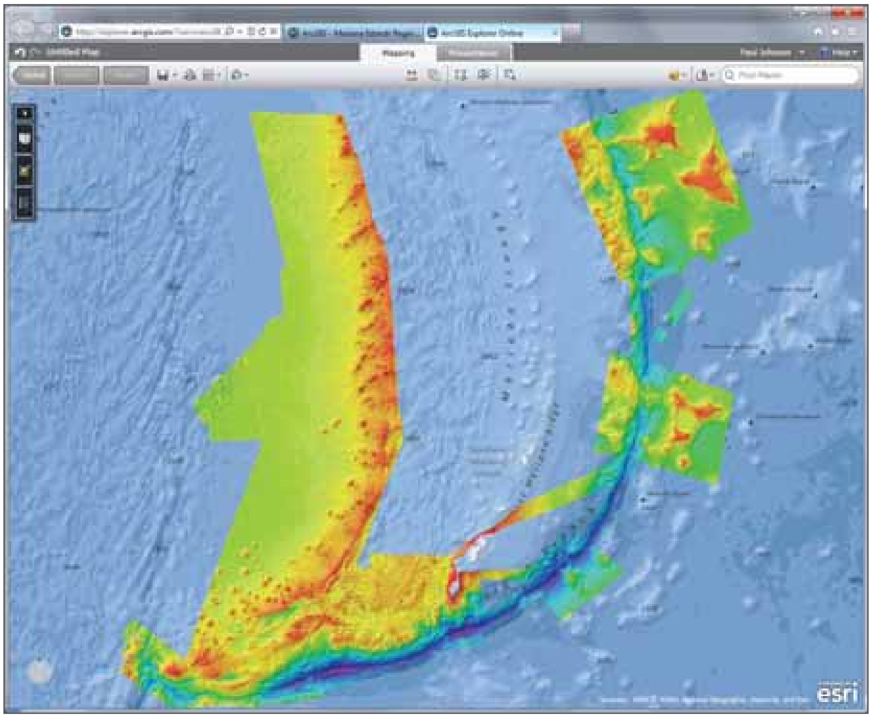


Figure 4-12. ArcGis page serving JHC data.

While not as visual as the features listed above, all of the available services offered by the Center GIS server can also be accessed through a web-based text portal. By going to **http://tinyurl.com/7rshnhp** (this URL has been shortened to make it easier to use), a list of the available resource for the Marianas bathymetry dataset can be seen. From this page, users can open data in their GIS or as a KML within Google Earth, examine available outputs from the server, or pull data across using other protocols such as WMS.



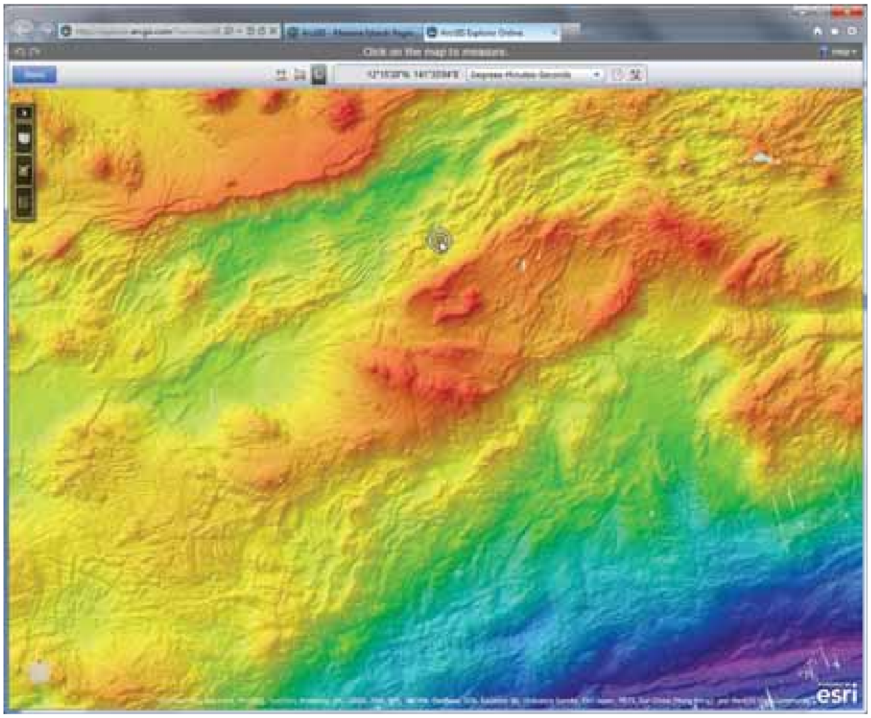


Figure 4-13 JHC data being served through the ArcGIS cloud.

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 that we derive from the sensors we work with (sonars and lidar). As we perfect these techniques (which are currently far from perfected) we are working more closely with biologists and fisheries scientists to see how the data we can 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, 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 are not (e.g., local slope) and, for others, many questions remain about how and where the corrections are applied. As described in the Backscatter Processing section, 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 (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

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 ARA (Angular Response Analysis) software package—also developed by Fonseca—that is designed 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.

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 now 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 and collaboration with our industrial associates will allow the development of new capabilities for GeoCoder through the creation of plug-in modules (see 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 in Greece, on the analysis of relative importance of

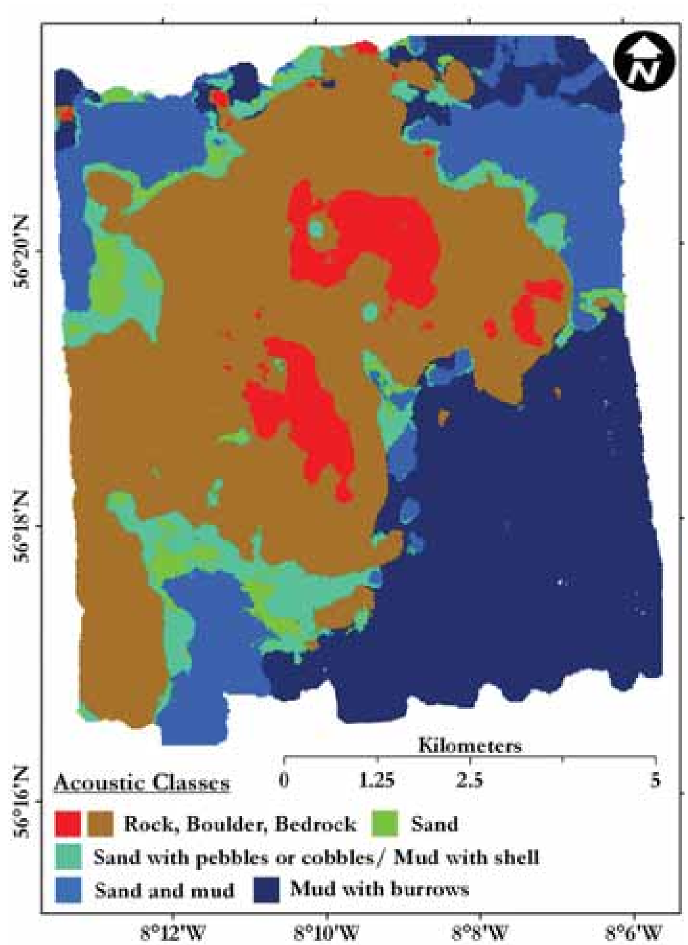


Figure 5-1. Typical result of unsupervised classification of the Stanton Banks backscatter.

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 to 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 sea bottom model and corrects for the grazing angle accordingly. Steep slopes obviously change the correction values and can have a 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. The DEM can be built with a variety of resolutions, however, and 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. We have built more than 12 mosaics with different sets of corrections applied, for a variety of DEMs. For a backscatter mosaic resolution of 1 m, the resolution of the DEMs was varied from 5 m to 50 m and the resulting mosaics were 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.

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

As part of our IOCM activities (see the IOCM theme), we are exploring means of extracting multiple data sets from a single sonar survey/system. To this end, Tom Weber and biologist Jodi Pirtle have been working with the Simrad ME70 MBES (developed for mid-water fisheries applications) on the NOAA Ship *Oscar Dyson* to see if it can also be used to generate seafloor characterization maps in the Gulf of Alaska (GOA). During the past year, this work was conducted opportunistically during the Alaska Fisheries Science Center (RACE Division) summer GOA walleye pollock survey (Figure 5-2), as well as for ME70 data collected on earlier *Dyson* cruises in 2010.

The *Dyson* conducted three summer cruises, with participation from Pirtle on two of the three legs. In addition to bathymetric mapping, the ME70 was used to collect absolute seafloor scattering strength with the primary goal of estimating the amount of untrawlable habitat (ultimately for the purposes of evaluating the associated biomass of fishes and invertebrates) and to identify regions likely to contain deep sea coral and sponge ecosystems, (DCSEs), areas vulnerable to anthropogenic activities. The assessment of untrawlable habitat is based on work performed (and nearing completion) over the last few years on a project funded by the North Pacific Research Board.

A total of 37 previously sampled camera locations were included in the 2011 *Oscar Dyson* trackline and fine-scale ME70 surveys. Fine-scale ME70 surveys also targeted localized areas having no ground truth seafloor data, but which are suspected of being untrawlable (e.g., high relief, DCSEs) or characterized by some other unique habitat features (e.g., canyon, bank) based on historical information from AFSC groundfish surveys. Fine-scale surveys were conducted at 21 locations. To characterize the seafloor for comparison with ME70 data, single (Drop) (n = 44) or stereo camera (SDC) (n = 3) deployments

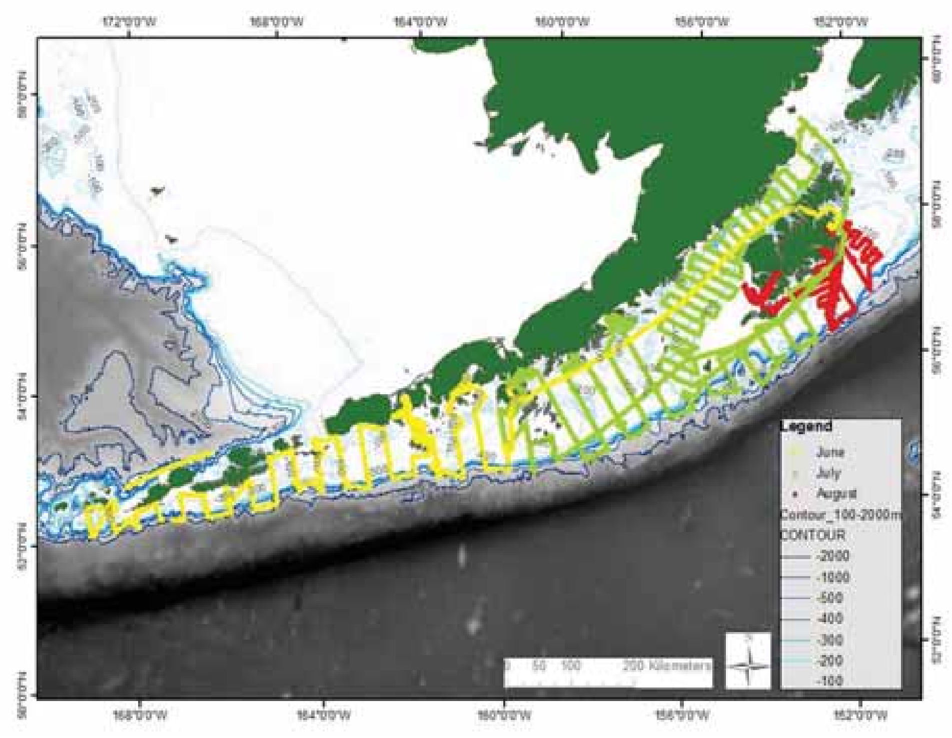


Figure 5-2. *Oscar Dyson* 2011 GOA ME70 footprint displayed by survey segment, including June (yellow), July (green), and August (red).

were conducted at stations in the fine-scale survey areas. Camera deployments at fine-scale survey locations identified trawlable seafloor at 26 camera stations and untrawlable seafloor (e.g., boulders, rock ridge) at 18 camera stations, including areas of Albatross Bank on the south Kodiak Shelf with rock ridge, boulders, corals and sponges, and associated rockfishes (*Sebastes spp.*) (Figure 5-3).

Figure 5-3. Stereo Drop Camera (SDC) image collected on August 12, 2011 on Albatross Bank with Sebastes spp. associating with untrawlable habitat composed of rock ridge, boulders, corals, and sponges.

To estimate the amount of trawlable and untrawlable seafloor within the survey area, the oblique (45 degrees) incidence seafloor backscatter data from the ME70 was matched with the spatial location of previously conducted AFSC bottom trawl survey tows from 1996-2011. Backscatter values were extracted for the area that the net contacted the seafloor, taking into account the length of the wire out from the ship and the width of the net. Tows had been previously classified as good, failed, or marginally successful by the AFSC based on the level of gear damage sustained from contact with the seafloor. Tows that were classified as marginal or failed due to gear damage only were used in this analysis. The ME70 mapping data from the ship trackline and fine-scale surveys corresponded with the location of 351 tows, including 325 good tows, 12 marginally successful tows, and 14 failed tows. Preliminary analysis shows separation in the distribution of backscatter values and corresponding seafloor types for the three tow performance categories (Figure 5-4).

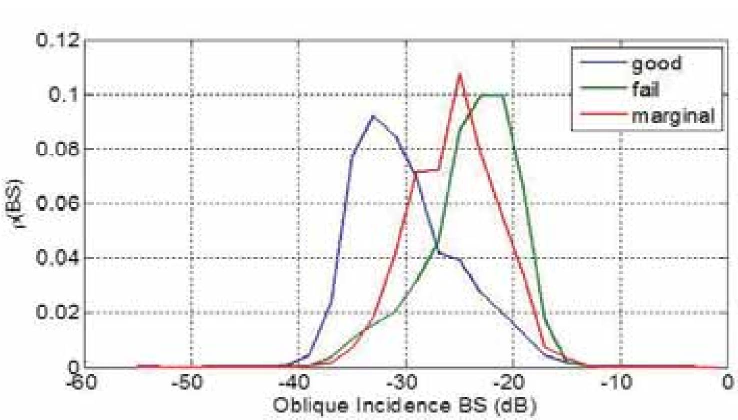


Figure 5-4. Histograms describing the distribution of oblique incidence backscatter values (45 degrees) at locations in the GOA previously towed (1996-2011) by the AFSC bottom trawl survey and classified as good, failed, or marginal.

A progress report was generated for NOAA AFSC on October 31, 2011. In 2012, we will continue data analysis and model implementation to estimate seafloor trawlability from ME70 acoustic data for areas of the GOA. Following that, we will characterize groundfish habitat and associated fish and invertebrate communities in the 2011 survey area and develop habitat maps.

Seafloor Characterization and Habitat Studies—Jeffreys Ledge

A focal area for our habitat mapping studies is Jeffreys Ledge off New Hampshire. This region, which is a critically important fishing area, is partially closed to fisheries and has been the subject of several mapping and ground truthing studies. Larry Ward is leading the effort on Jeffreys Ledge, synthesizing the bathymetric, sedimentologic, videographic, and subbottom seismic data that were collected during field campaigns. In addition, a portion of the bottom sediment and videographic data has been requested to help with fisheries management issues. Therefore, a considerable effort is being given to prepare the data for that purpose. Further effort is focused on developing a clearer understanding of the physical and geological characteristics of Jeffreys Ledge and their relationship to the western Gulf of Maine. We expect these syntheses to be completed by the end of 2012.

Lidar, Hyperspectral and Optical Approaches to Habitat Characterization

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

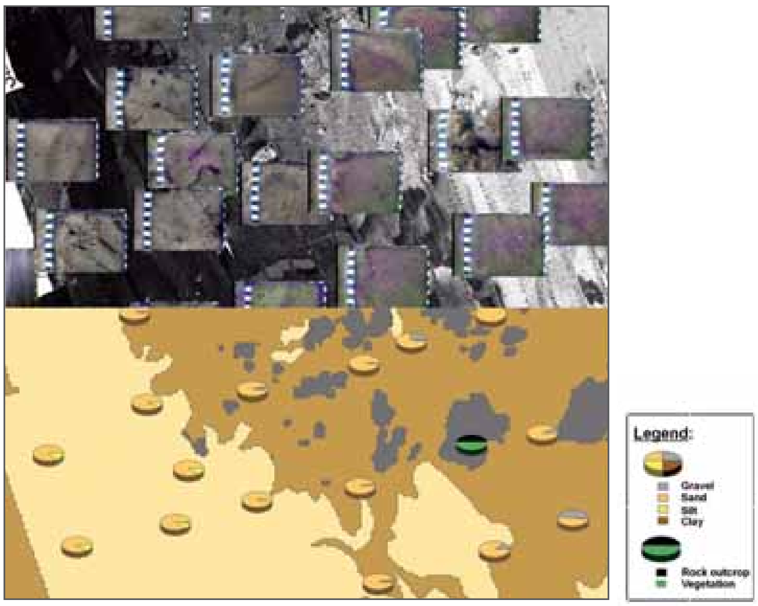


Figure 5-5. Seafloor characterization southeast of the mouth of the Merrimac River in Massachusetts. The lower image shows the grain-size results and the upper image shows the texture observed by underwater camera.

Resolving Grain-Size Analysis Using ALB Waveforms

Following on our studies of the influence of substrate on lidar detection (see the SENSORS Theme), it was noticed that the lack of detection appeared to be highly correlated to the grain-size of the seafloor. After identifying this phenomenon, Shachak Pe'eri and Jim Gardner (in collaboration with researchers from the USGS in Woods Hole) are looking in more detail at this phenomenon. They have collected ground truth samples around the Merrimac River. They are in the process of conducting grain-size reflectance measurements with the goniometer described earlier (Figure 5-5). These results will assist in controlling ALB classifiers and aid in compiling seafloor classification results between ALB and acoustics.

Coral Mapping Using Hyperspectral and Lidar Signature

Modern coastal mapping systems are now also including hyperspectral scanners. In 2010, a collaboration project focused on Buck Island in the U.S. Virgin Islands began between the Center and NOAA's biogeography group (Tim Batista, CCMA), Fugro LADS (James Guilford), and NPS (Ian Lundgren). The study's goals are to evaluate the potential products for mapping a coral habitat base on ALB/HSI data, and to create an ALB/HSI procedure for generating products consistent with existing schema defined by NOAA groups for monitoring the habitat of interest (not only corals). A spectral ground truth collection was conducted in November 2010 around Buck Island, St. Croix using the NPS's R/V *Osprey*.

The ground truth dataset included 37 stations (some of the stations were redundant for QA purposes). Texture (video/frame image) measurements and color (spectral) measurements were collected at each site. The spectral response, bi-directional reflection distribution function (BRDF) plots and the water conditions at the time of the ground truth survey (diffuse attenuation) were calculated based on the spectral measurements and bathymetry from the ALB system.

An aerial survey was conducted in February 2011 using a LADS MKII ALB system and a Hyspex HSI scanner. Pe'eri has calculated the water conditions at the time of aerial survey and plans to develop a classification scheme using a combination of the HSI and ALB.

Classification of Seabed Coverage from Optical Imagery

We are also exploring approaches for quantitatively analyzing seafloor imagery collected with optical systems (video or photographic). Yuri Rzhanov has applied color-based classification approaches to image classification in situations where the height above the bottom is well known. When height above bottom can be well-constrained, color-based

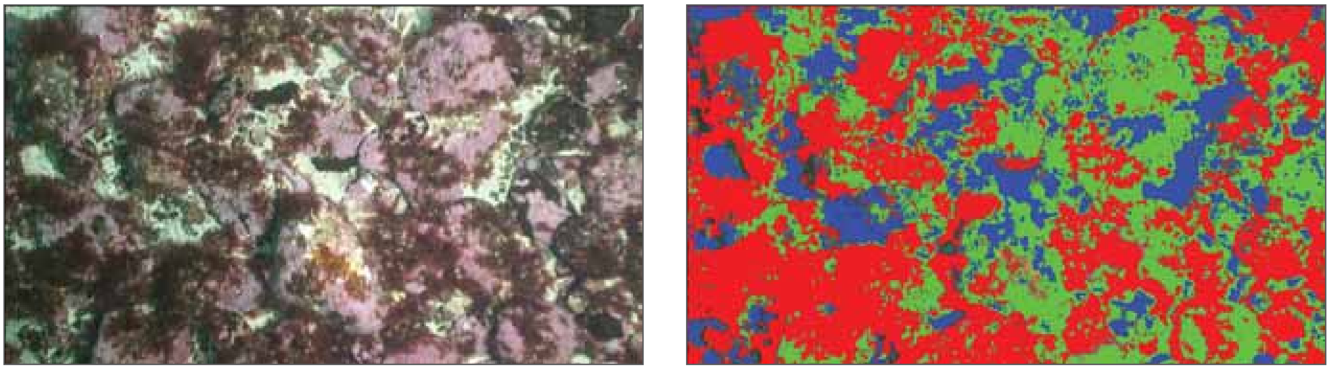


Figure 5-6. Original seafloor image on left and classified image with three classes: red algae (red), lithotamnium (green), and sand (blue) on right.

techniques can provide classification at the pixel level. If height above bottom varies, color imbalance due to wavelength-dependent absorption degrades the image and the ability to classify pixels. Automatic classification of imagery obtained near Havsul, off the Norwegian coast, has demonstrated very encouraging results using this approach (Figure 5-6).

Stereofish – Application for Dense Underwater Scene Reconstruction

Another aspect of our mid-water and habitat work is Rzhanov's collaboration with the NOAA Southwest Fisheries Center. His efforts have focused on imagery acquired by SWFC staff with their Videre stereo rig and are aimed at developing image processing techniques that can be applied to identifying fish species in stereo optical images. The problem being addressed is that variations in the medium (i.e., refraction due to water mass properties, or the presence of suspended particles) make the critical calculation of image disparity needed to produce stereo very difficult. Rzahnov is using windows of several sizes for normalized cross-correlation that allows finding conjugate pixels to provide a rough estimate of horizontal disparity for majority of pixels in overlapping areas of a stereo pair. (Horizontal disparity for rectified stereo pair of images is a distance between locations of two pixels in different images pointing to the same location in a 3D space.) The images are then "over-segmented." Detected boundaries between the segments reflect actual boundaries between different objects in the scene (Figure 5-7).

Hence, every segment can be considered to represent a smooth continuous opaque patch. Such a patch should have only a narrow range of disparities. Building a histogram of disparity values for a patch allows for the detection of outliers, which are removed and replaced by values obtained by interpolation. With the disparities resolved, sub-pixel disparity is estimated and a dense depth field is calculated by triangulation in 3D space (Figure 5-8).

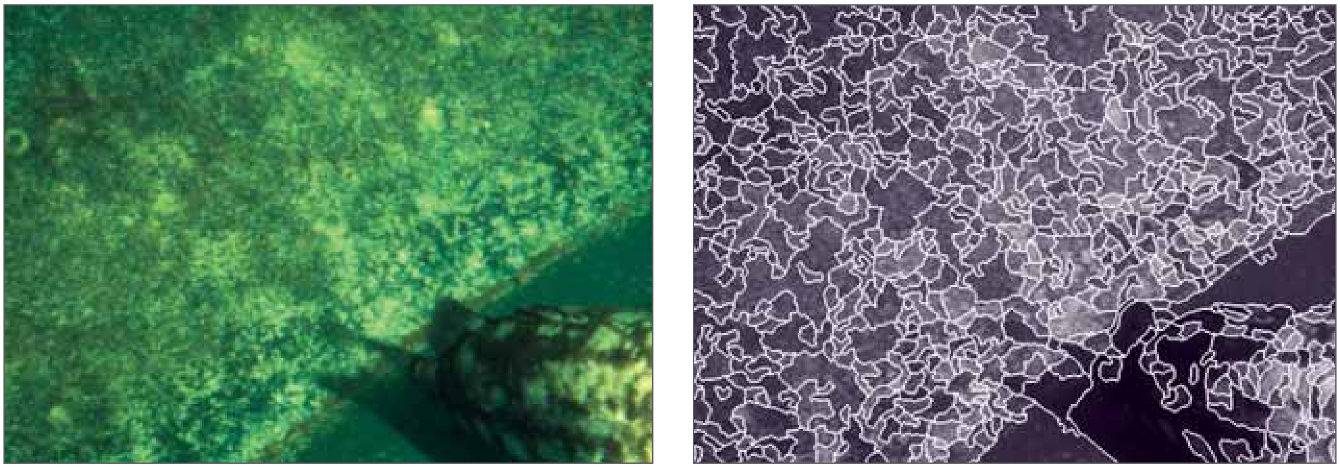


Figure 5-7. Original image and corresponding segmented image.

The next stage will involve the detection of oblong 3D shapes separated from the background and then will be interpreted as fish body. Shape and associated texture are important cues in species recognition.

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 last year's Deepwater Horizon crisis (see last year's annual report for a full description of our activities related to Deepwater Horizon).

Analysis of Acoustic Observations of Oil in the Water Column

Subsurface oil was mapped acoustically by the NOAA Ship *Thomas Jefferson* during the DWH-Macondo oil spill, as shown in Figure 5-9 (see the 2010 JHC Annual Report for a full description). As a continuation of our efforts related to Deepwater Horizon, an analysis of these data was conducted in order to develop and test a methodology for estimating the oil concentration and flow rate based on

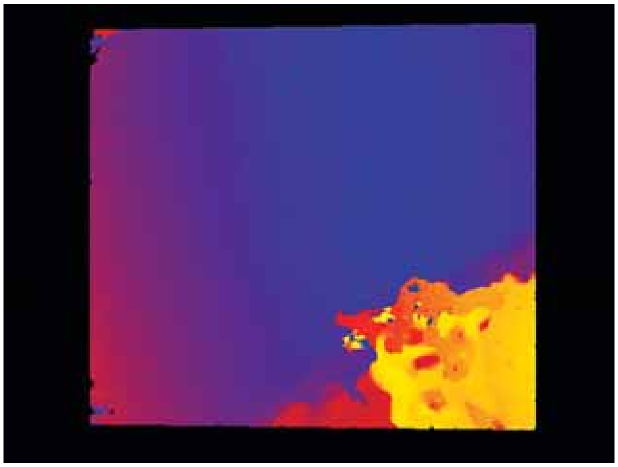


Figure 5-8. Colorcoded depth field.

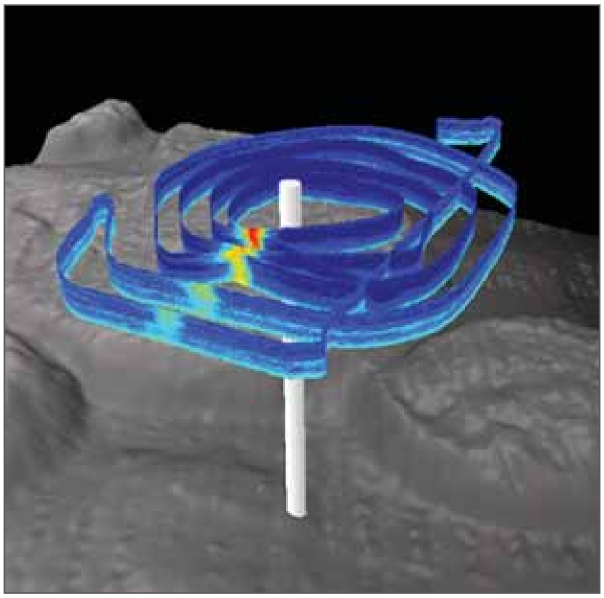


Figure 5-9. Acoustic observations of the oil made with a calibrated 200 kHz echo sounder onboard the NOAA Ship *Thomas Jefferson* during the DWH-Macondo oil spill.

high frequency acoustic measurements. Although the uncertainty in the result is high due to lack of absolute knowledge of the properties of the oil droplets (e.g., their size distribution), the flow rate estimate is remarkably consistent with those made at the wellhead by other means. The results of this analysis demonstrate a methodology for acoustically assessing oil in the water column that can be used to help quantitatively assess the fate of spilled oil for future incidents. One of the highlights of this project is the collaborative effort between the Center, NOAA NMFS, and NOAA OCS, all of whom played important roles in the DWH response and in this subsequent analysis. Should the need to respond to a similar response arise, this NOAA/Academic team will be well poised to contribute with specific (and documented) methodologies. A manuscript describing these efforts has been published in the Proceedings of the National Academy of Science.

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 capability (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 (the *Okeanos Explorer* equipped with an EM302 was deployed in Indonesia) so instead 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.

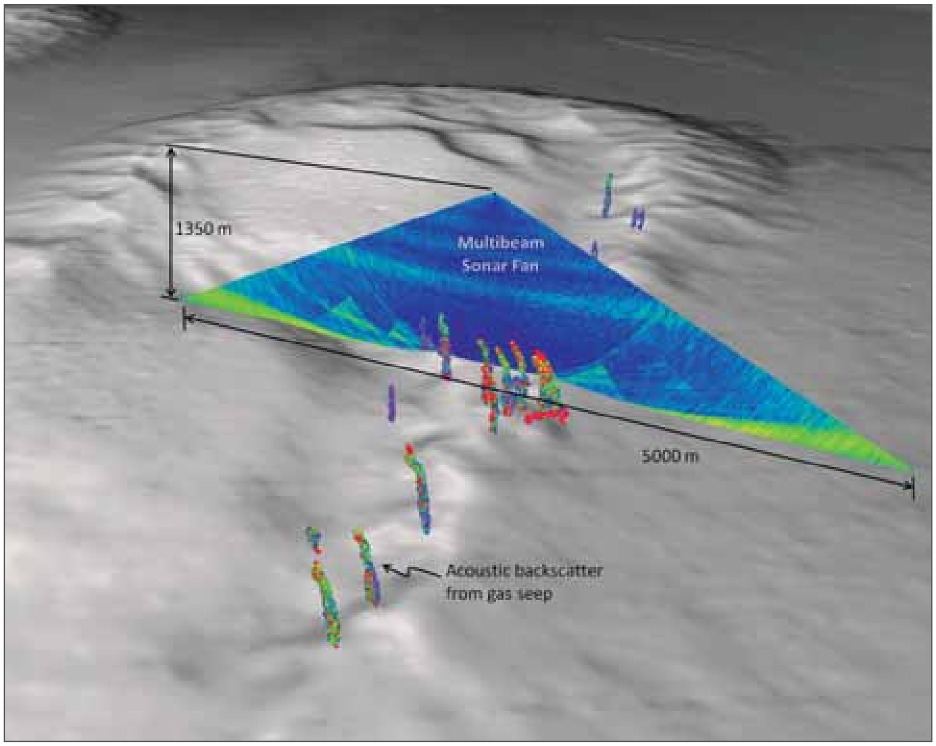


Figure 5-10. Seeps imaged with the EM302 on the *Okeanos Explorer* on the Dauphin Dome in the northern Gulf of Mexico. The blue dots indicate locations of seeps.

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 EM302 water column mapping capability for detecting and characterizing methane gas seeps, including comparison against data collected with a Simrad 18 kHz EK60 split-beam echo sounder (a known performer 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 km^2 of the northern Gulf of Mexico making 573 seep observations (some of which were repeat observations of the same seep). 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 5-10). 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: **http://www.noaanews.noaa.gov/stories2011/20110915_okeanosexplorer.html**.

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

Traditionally, the abundance of juvenile bluefish tuna (part of a very 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 400 kHz Reson 7125 multibeam sonar backscatter data collected from schools of juvenile tuna in 2009. This not only includes analysis of the data for school morphology (e.g., Figure 5-11), but also includes analysis and development of techniques for counting fish with MBES based on the normalized second moment of acoustic backscatter intensity. This is a technique previously developed for single beam systems in the early 1990s but is better suited to MBES because the results are greatly improved with high resolution systems. If successful, this technique may be useful for estimating fish density with MBES for a number of different species and would represent a significant technical advancement for mid-water mapping using MBES.

In concert with the acoustic techniques, Yuri Rzhanov is working on ways to detect bluefin tuna schools in 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. To accomplish this, photographs need to be taken almost vertically and without sun glint obscuring part of the image. Even if the camera is mounted vertically with respect to the airframe, its optical axis is not guaranteed to be coincident with the gravity vector. Hence the acquisition system requires a tilt sensor rigidly attached to the camera. GPS and altitude sensors are also needed for correct geo-locating acquired images.

Rzhanov has determined requirements for the optimal acquisition system, given constraints on the required accuracy of measurements and equipment that cannot be modified (namely, the plane). Some of these requirements are being implemented—a good still color photo camera has been purchased that provides 10 MPixel images with dynamic range at least 14 bits per pixel per channel. Also it is likely that a MicroStrain device will be purchased that combines properties of a tilt sensor with that of a GPS, and eliminates the necessity to have (and control) an additional unit on-board. However the pilot still requires that the camera remains fixed rigidly to the plane. Once this issue is resolved, it will be possible to develop an application running on a Windows laptop that will constantly log pose (location and attitude) of the plane, acquire a sequence of images from the camera (upon triggering by a pilot), and store these images on a hard drive, logging the acquisition time. All data can then be easily synchronized because all events will be tagged by a single computer and clock.

In the meantime, Rzhanov is developing software to analyze the imagery data. He has developed a Windows application called "TunaClock" that displays a digital clock with accuracy of 0.01 sec. and allows for the synchronization of computer and camera clocks with an error not exceeding 0.02 sec.

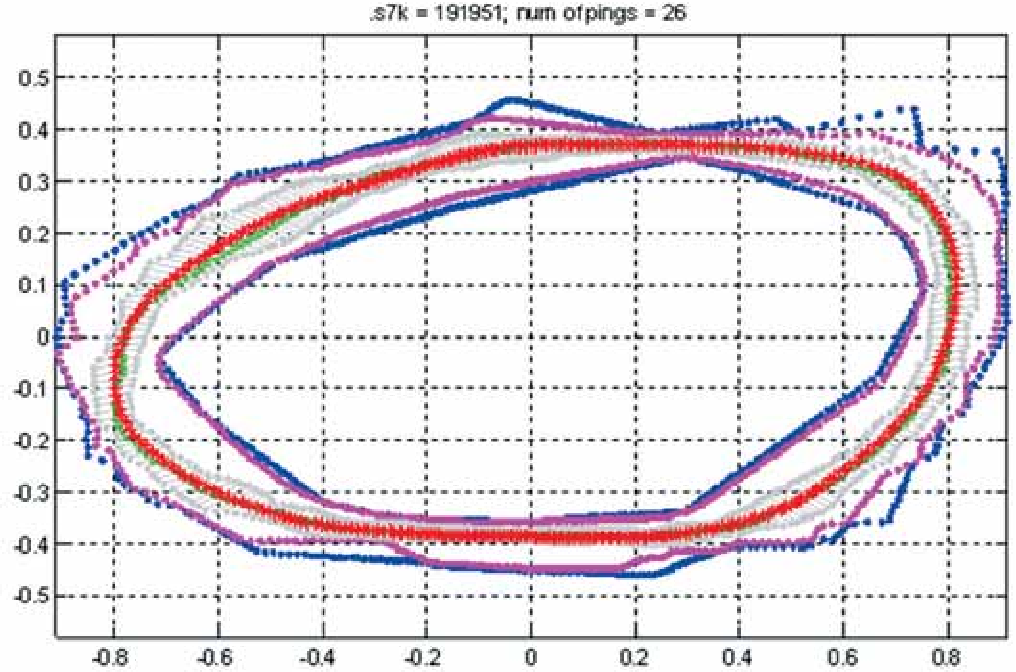


Figure 5-11. The normalized school shape in a vertical slice for a school of juvenile Atlantic bluefin tuna, based on data collected with a Reson 7125 MBES.

The low contrast typical of the raw imagery makes automated processing (counting and size estimates of individual organisms) very difficult (Figure 5-12). A processing scheme consisting of ortho-rectification, blue shift compensation, rescaling and thresholding has been developed that allows targets of pre-selected size to be automatically identified. The result of this processing is shown in Figure 5-13 where outlines of the detected blobs are colored in successive shades of gray for ease of identification.

Figure 5-12. Raw imagery of tuna school.

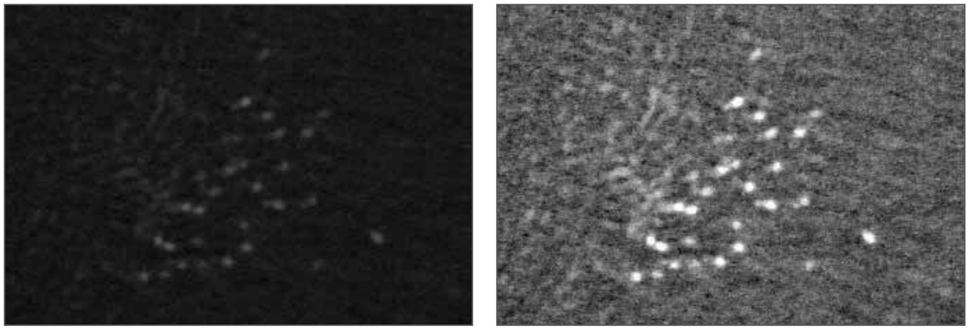


Figure 5-13. Enhanced and rescaled images.

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 supports 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. Our plan is to bring 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 be trained 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 2011 our IOCM efforts focused on collaborations with the Office of Coast Survey, Office of Ocean Exploration and Research, NMFS and with NOS's Marine Modeling and Development Office.

IOCM Activities on the *Oscar Dyson*

Exemplifying the best of the IOCM concept and supporting NOAA milestones for the IOCM center to reprocess 100 square nautical miles of during the 2011 fiscal year has been our efforts on the NOAA fisheries vessel *Oscar Dyson*. The significance of this work is not so much the reprocessing of data but rather the workflows that have been developed and documented as a result of this work. These workflows set the stage for the potential extraction of bathymetric and habitat products from data sets collected for other purposes.

The Simrad ME70 multibeam echo sounder (MBES) installed on the NOAA Ship *Oscar Dyson* was originally designed for mapping pelagic fish schools but, using software developed at JHC/CCOM over the last few years (in collaboration with NOAA Fisheries), is now routinely used for seabed mapping purposes. For example, data that was collected during an acoustic-trawl survey for walleye pollock conducted by the Alaska Fisheries Science Center has been opportunistically processed for seabed characterization in support of essential fish habitat (EFH) (see the HABITAT Theme) and, as will be discussed below, in support of safety of navigation leading the discovery of a previously uncharted Danger to Navigation.

The third quarter deliverable was for 50 square nautical miles of bathymetry from a fisheries ME70 multibeam aboard the NOAA Ship *Oscar Dyson* to be reprocessed for charting use (Figure 6-1). This was a collaborative effort between Rice, Tom Weber, Jon Beaudion, and Jodi Pirtle. Tom Weber's MATLAB code for extracting soundings from the ME70 RAW files was a primary step toward collecting bathymetry with this multibeam. This code was updated by Tom Weber to include uncertainty estimates and write them in a GSF file that could easily be read into different hydrographic software packages.

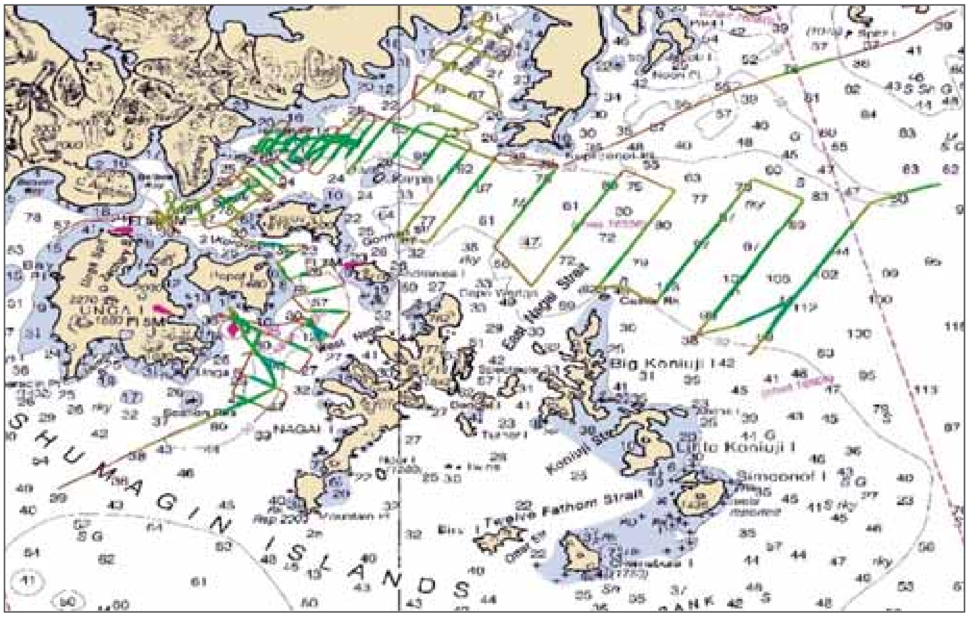


Figure 6-1. *Dyson* data from 2010 that was processed for the extraction of bathymetry.

Instrument vessel offsets were difficult to define. The original surveys conducted by the shipyard were not well documented, and an offset to the waterline was not included. Through detective work from a group at the Alaska Fisheries Science center and a lot of emails, offsets between the multibeam and the vessel motion sensor was established within acceptable limits. Vessel drawings did not allow for a proper reference to the static waterline from the draft marks. Instead we referenced a time series of the vessel's vertical position to the ellipsoid and compared it to a concurrent time series from a local tide gauge, also referenced to the ellipsoid. The difference between the two time series, averaged over the period, was used as an estimate of the vessel's waterline.
A cross correlation between the two time series (over a predefined time frame) was also added to the code to act as a rough tide model for when the gauge and vessel were separated by significant distances. This code was used by NOAA Ship *Hassler* to uncover a discrepancy in their waterline that had not been defined until that time. Preliminary comparison of *Oscar Dyson* ME70 data to a relatively shallow hydrographic reference surface indicated that these offsets were properly applied.

As the *Oscar Dyson* does not routinely collect CTD or XBT casts, Jonathan Beaudoin provided approximate refraction corrections using a set of sound speed profiles generated through a combination of surface thermosalinograph measurements and modeled mean temperature and salinity profiles from the World Ocean Atlas (WOA) of 2001 quarter degree monthly grids. This involved a unique chain of pre-processing stages that combined high temporal resolution (1Hz) surface sound speed measurements with low spatial and temporal resolution oceanographic pseudo-profiles from a gridded oceanographic model. He also provided pre-analysis to direct sound speed profiling sampling procedures for the *Dyson's* 2011 field season during which additional seabed mapping data was opportunistically acquired for charting purposes (see the PROCESSING Theme discussions) and has been working with Lt. Mark Blankenship to establish IOCM bathymetry standards, particularly with respect to best practice for sound speed sampling. Tide corrections were handled using NOAA Pydro software and a TCARI grid that was created for other NOAA surveys in the same area. The workflow, survey information, and 100 square nautical miles of bathymetric data was documented, organized and submitted to the Atlantic Hydrographic Branch. Subsequent work with this data uncovered a bug in the sounding detection that scaled with depth. This bug has since been fixed, but further analysis is pending to further ground truth the depths reported through the described process.

To date, more than 100 sq. miles of bathymetric data (along with uncertainty and calibrated backscatter) derived from the ME70 fisheries sonar has been submitted for charting (e.g., Figure 6-2). One of the most exciting aspects of this effort was the discovery of a previously uncharted shoal during the *Dyson's* ME70 work in the 2011 season. Thus from a single fisheries sonar and a fisheries cruise dedicated to acoustic-trawl surveys of walleye pollock, seafloor habitat data, bathymetric data for charting and a specific Danger to Navigation were all derived. We have indeed mapped once, and used many times. Several other NOAA fisheries vessels are now interested in collecting bathymetry with their ME70s, and some work has begun to formalize the sounding extraction portion of the workflow. OMAO is looking into making this process standard aboard NOAA vessels with ME70s as part of the NOAA R2R program.

Backscatter from Hydrographic Vessels

Center efforts to generate high-quality backscatter data in direct support of IOCM efforts (from NOAA vessels *Oscar Dyson* and *Fairweather*) 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). With respect to the NOAA IOCM deliverables, 100 square nautical miles of backscatter for part of the Olympic Coast National Marine Sanctuary survey conducted by NOAA Ship *Fairweather* was reprocessed and provided to both the Sanctuary and to NGDC to meet the NOAA milestones. As a result of lessons learned from this effort, Glen Rice 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. These will be presented at the 2012 NOAA Field Procedures Workshop. Glen also used the lessons learned from tank calibrations of the Reson 7125 sonar (Sam Greenaway's thesis work) to create a preliminary version of a backscatter saturation monitor that will help field teams ensure they collect backscatter data that remains within calibration parameters.

Collaborations with OER

In 2011, the Center continued to provide support for NOAA OER employees Meme Lobecker, Mashkoor Malik and Adam Skarke in their work with the *Okeanos Explorer* and the Ocean Exploration program. At mid-year, Malik moved full-time to Silver Spring but was replaced by Adam Skarke. Lobecker was the Expedition Coordinator for three *Okeanos Explorer* expeditions in 2011 and served as Mapping

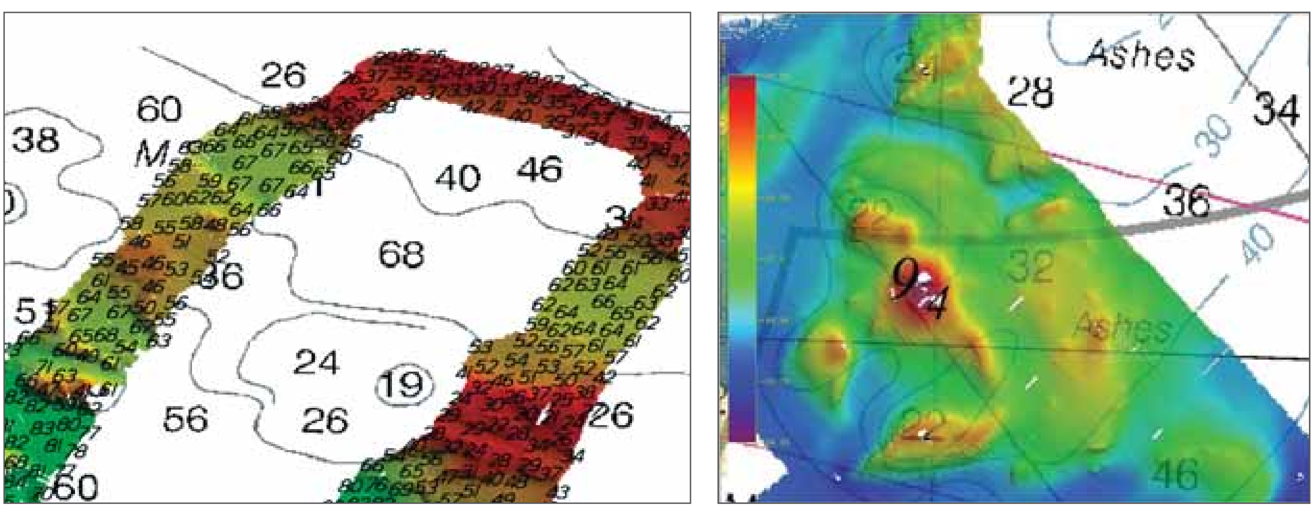


Figure 6-2. An example of data collected with the Simrad ME70 MBES on the NOAA Ship *Oscar Dyson* (left) in support of safety of navigation. ME70 data (color, small font) are overlaid on existing chart data (all depths in fathoms). Danger to Navigation (right) mapped using the Simrad ME70 during a cruise on the NOAA Ship *Oscar Dyson*, mapped by Glen Rice and Jodi Pirtle.

Team Lead for a fourth expedition over the Mid-Cayman Rise. In total, the mapping team collected 180,000 km2 of EM 302 sonar data, all of which were stored, processed, and documented at the UNH IOCM Center, and were made publically available in raw and processed formats in the National Geophysical Data Center online archives within three months of data acquisition. Additionally, all data were processed in near real time and updated daily mapping coverage was publically provided through the *Okeanos Explorer* Digital Atlas at **http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm**.

This year, draped bottom backscatter data was added to the standard suite of field processed data products to aid in the exploration field decision-making process. This processing was completed using QPS Fledermaus FMGT, and was enabled through the ineraction of OER scientists with JHC researchers (Figure 6-3).

The data collected throughout the field season will not only be used as the basis for further exploration, but will also be integrated into marine resource management within the U.S. This year, data partnerships between OER and the IOCM were strengthened with several federal agencies and NOAA line offices through data collection efforts during expeditions throughout the field season. Roughly 1/3 of the federal waters in the Channel Islands National Marine Sanctuary (NMS) were mapped, as well as extensive areas just outside sanctuary bounds. Three seamounts, San Juan, Hancock, and 109, were mapped in support of sanctuaries and NOAA's Southwest Fisheries Science Center management efforts. Sur Ridge and a substantial pockmark field filling the southern portion of the sanctuary were mapped within the Monterey Bay NMS. Cruise EX1105 in the Gulf of Mexico aimed to further our understanding of the EM 302's capability to detect water column features such as seeps (see the Water Column Mapping discussion), and represented a very close collaboration between Center researchers, OER and BOEM. During EX1106, extensive data was collected over several Mid-Atlantic Canyons, again in partnership with BOEM and the NOAA Office of National Marine Sanctuaries. During EX1104, scientists from the NASA Jet Propulsion Laboratory and the National Science Foundation were actively involved with exploration control from shore, and major research expeditions are planned to return to the Mid-Cayman Rise in 2012 and beyond. As in previous years, data collection efforts by the *Okeanos Explorer* benefited several NOAA management offices, including Papahanaumokukea Marine National Monument, NOAA Fisheries Service, the Cordell Bank NMS, the Olympic Coast NMS, and the Gulf of the Farallones NMS.

The Center's telepresence console was utilized during the EX1105 water column expedition in the Gulf of Mexico and related follow-up media events. Through this medium, Center scientists provided technological and scientific support to shipboard scientist throughout the *Okeanos Explorer* field season.

The Center continued to provide support for the further development of the Ocean Exploration 6000 m ROV system. In 2011, the Center provided a secure work facility, engineering and machining support, and the use of our acoustic test tanks for testing components. This season saw the completion and testing of the *Seiros* camera sled as well as its successful deployment on the *Okeanos Explorer*.

Nearshore Bathymetric Estimation from Lidar-Based Airborne Imagery

In the spirit of IOCM (multiple use for data sets), Tom Lippmann and Yuri Rzhanov are seeking ways to extract bathymetric data from airborne imagery obtained during lidar overflight missions. The techniques can be applied to a wide range of oceanic conditions, from high waves with large, wide surf zones, to small wave with a narrow surf zone, independent of water clarity. The analysis will be done on field data obtained from video overflights using the Digital Airborne Video System (DAVS) developed as part of the research effort and is aimed at the zone from the shoreline to 10 m depth where sonar techniques are least efficient.

This research has four principal objectives. The first is to develop bathymetric inversion methods whereby time series of geo-referenced airborne video images of nearshore wave propagation are used to obtain bathymetric depth retrievals in and near the surf zone. In this part, we propose to incorporate established methods for land-based video systems to airborne platforms, and utilize seamless mosaicing techniques (developed in the third objective) to stabilize the imagery, even for systems with imperfect orientation devices or measurements. The second objective is to link the bathymetric inversion methods developed and tested in objective one with data assimilation techniques developed in the past two years as part of research supported by JABLTCX. These assimilation methods are solely applicable to regions within the surf zone. The combination of the results from objectives one and two will allow bathymetric profiles to be estimated from well outside the surf zone (in nominally 10 m water depths) to the shoreline. The third objective is to develop seamless mosaicing techniques to stabilize and geo-reference airborne video imagery with uncertain orientation. In the methodology, a time series of video images can be registered relative to one another such that accurate time series analysis can be performed, allowing the bathymetric inversion methods in objective one to be implemented and high-resolution mosaics to be created for data assimilation in objective two. The fourth objective is focused on the fabrication of the DAVS and its utilization in the field. Data collected under a variety of environmental conditions will allow algorithms proposed in objectives one, two and three to be developed and tested. The DAVS will allow bathymetric profiles to be estimated in regions where turbid, opaque water precludes the detection of lidar laser pulses reflected off the bottom. This added capability will expand the usefulness of present and future lidar systems by extending the conditions by which the lidar systems can be used to include time periods with high waves and high water turbidity.

Recent field tests utilizing the new DAVS system deployed on 13 January 2011 along the Outer Banks of North Carolina were used to test the methodologies. Image mosaicing techniques developed by Dr. Rzhanov were used to stabilize each overlapping video frame from all three passes to create a consistent image mosaic over an approximately 5 km stretch of coastline near the U.S. Army Corps of Engineer's Field Research Facility (FRF). The mosaicing techniques do not rely on the GPS for stabilization and thus require that the mosaic to ground transformation be accomplished by selecting the mosaic location of known ground control points surveyed at the FRF. Pixel resolution in the mosaic is about 1 m on a side. Ground truth bathymetric surveying was done independently by the FRF with traditional *in situ* survey methods using differential GPS and sonar depth sounding onboard an amphibious watercraft. Data analysis of these data will be complete in early 2012.

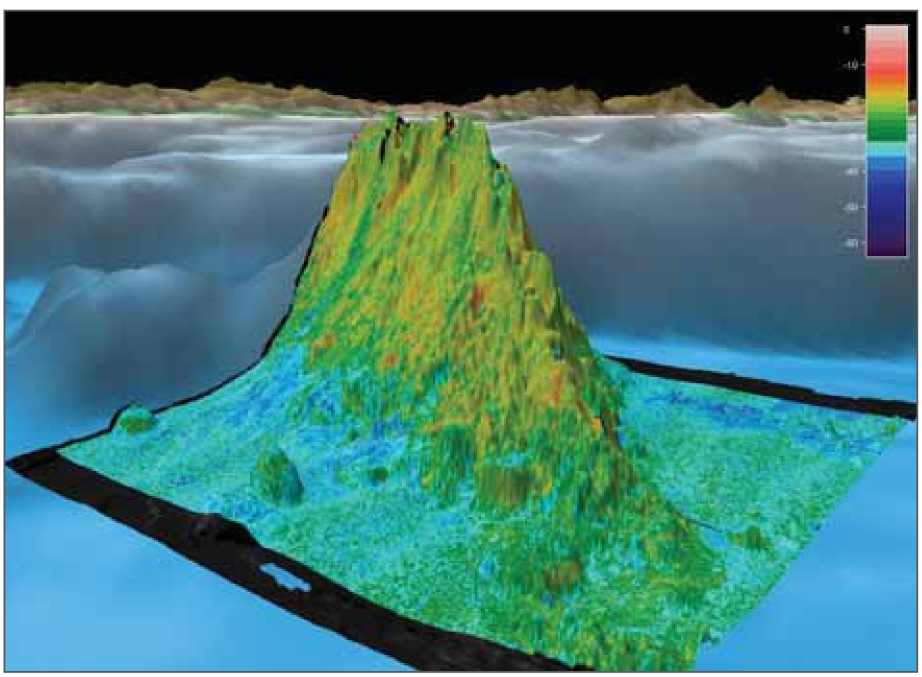


Figure 6-3. San Juan Seamount —backscatter draped on bathymetry from *Okeanos Explorer* Expedition EX1101.

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 to have a very strong focus on the development of innovative approaches to data visualization and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team (Arsenault, Plumlee, Sullivan, Pineo and Schwehr), 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 (see earlier Annual Reports). This year, Ware and a new addition to the team, postdoctoral research associate Tom Butkiewicz, collaborated to develop a new interactive 3D/4D visualization environment specifically designed to help oceanographers and biologists interpret complex data from a variety of sensors and models.

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

Tom Butkiewicz and Colin Ware have been developing 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/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.

Modern ocean flow simulations are generating increasingly complex, multi-layer 3D ocean flow models. However, most oceanographers are still using traditional 2D visualizations to visualize these models one slice at a time. Properly designed 3D visualization tools can be highly effective for revealing the complex, dynamic flow patterns and structures present in these models. However, the transition from visualizing ocean flow patterns in 2D to 3D presents many challenges, including occlusion and depth ambiguity. Further complications arise from the interaction methods required to navigate, explore, and interact with these 3D datasets. 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 naviga-

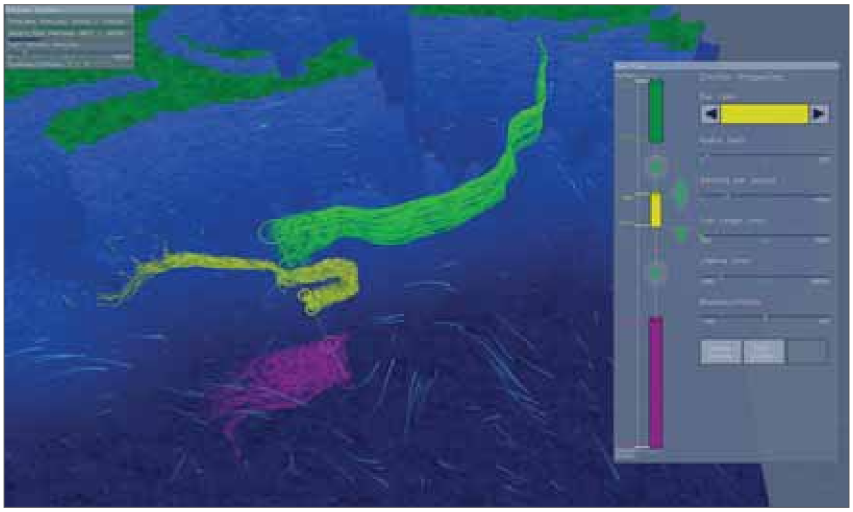


Figure 7-1. A screenshot from the 3D flow visualization. Here a dye-pole has been added off the coast of Nova Scotia. Using the dye-pole editor associated with it, the user has configured three custom dye-emitters at different regions along the pole. Each releases different colored dye particles into the model, which are carried away by the currents at the particular depths. You can see that the flow directions and velocities vary significantly at the three different depths. It looks even better with stereo glasses!

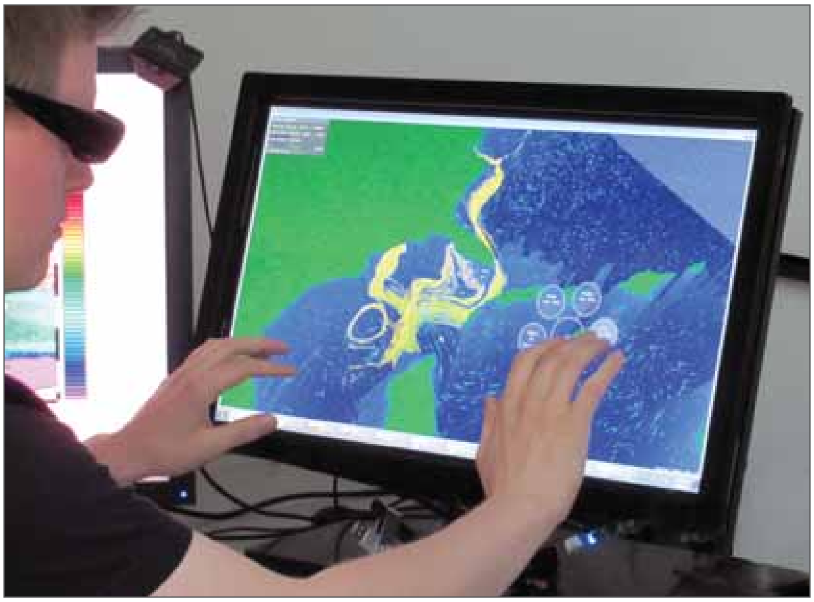


Figure 7-2. Our setup, shown here, was designed to be as unencumbering as possible to preserve its practical usability in an office environment or aboard a research vessel. The only requirement for the user is to wear active shutter glasses for stereoscopic rendering.

tion and manipulation within the 3D environment. Exploratory visual analysis is facilitated through the use of a highly-interactive toolset which leverages a smart particle system.

Illustrative dye particles can be introduced into specific areas of interest through the use of dye-pots and dye-poles. As shown in Figure 7-1, multiple custom dye particle emitters can be configured along each dye pole to reveal the often quite different flow patterns found at different depths in any particular location.

Particles can be given density values that influence their vertical movements based on buoyancy. Beyond just flow direction and velocity, the models we work with often contain additional information such as salinity and temperature, and we are working on using these values to simulate more complex behaviors, such as diffusion, thermoclines, and changes in temperature over time.

To support these efforts, many new techniques are being designed and evaluated, including our unique hardware setup with the display/interaction device being an experimental combination of 3D LCD monitor and multi-touch overlay, and repurposing a cheap off-the-shelf Microsoft Kinect device to perform tracking and other functions that have traditionally been very difficult and cumbersome to the user, or prohibitively expensive (Figure 7-2). Butkiewicz has developed novel algorithms to use the Kinect for head tracking, hand/arm capturing/modeling, and touch-screen enhancement (e.g., differentiation of left and right hand touches). A paper has been written describing these new algorithms and why they are superior to existing methods; it is currently submitted for publication to the Advanced Visual Interfaces conference.

Our visualization environment is 3D, but a multi-touch screen is inherently a 2D input device. To enable it as an effective interface, Butkiewicz has been developing new multi-touch gestures that allow users to quickly select, reposition, and manipulate objects in 3D with a single hand.

The new visualization environment is remarkably efficient in providing the user a clear indication of full multi-level 3D flow from point source at any

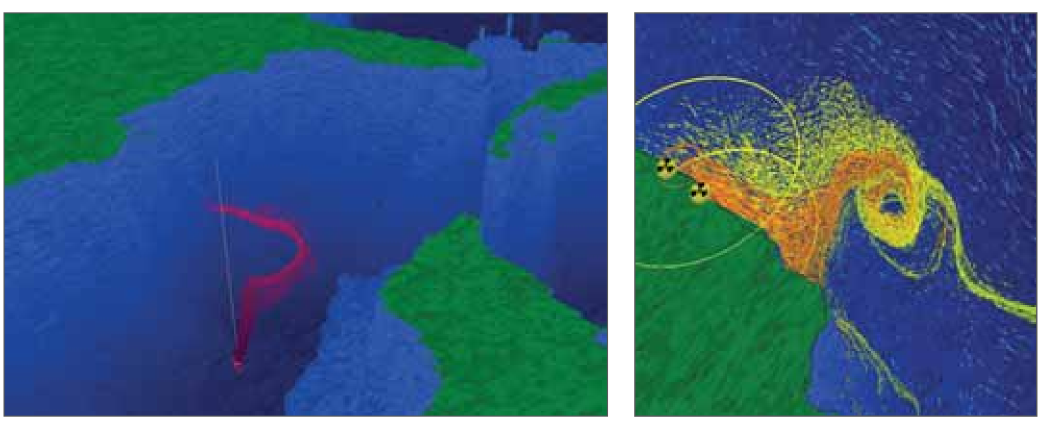


Figure 7-3. An example of buoyant particles being released near the seabed to simulate an oil plume in the Gulf of Mexico (left) and an example of particles being released into a special, daily-updated, high-resolution Navy Coastal Ocean Model (NCOM) centered around the damaged Fukushima nuclear reactors (right). Particles released near the reactors are first carried south by coastal currents, then out into the Pacific Ocean via the Kuroshio current.

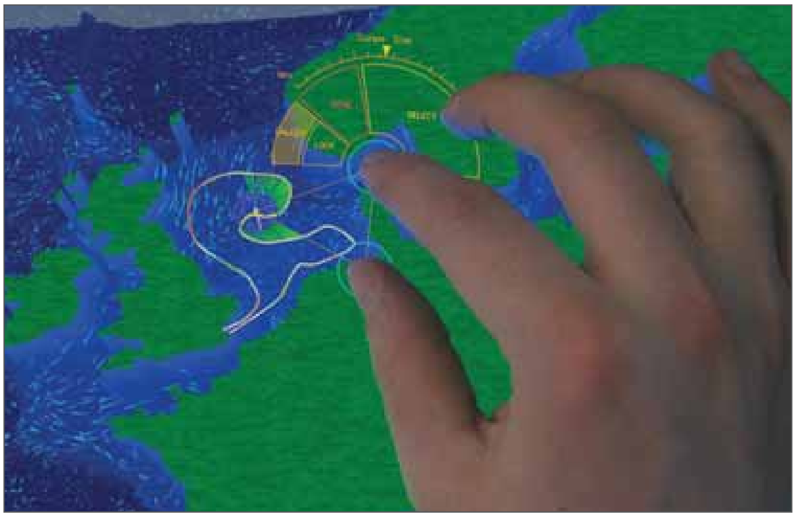


Figure 7-4. A screenshot of the refined pantograph gesture being used to select and manipulate waypoints defining a proposed AUV navigational path. The green lines connect the edges of the cursor to nearby waypoints, adding stereoscopic detail to assist in perception of the cursor's relative position.

depth and would have been tremendously useful for incidents like the Deepwater Horizon spill or the Fukushima reactor disaster (Figure 7-3). Additionally, the tool provides an ideal environment for planning AUV or glider missions in full 3D (Figure 7-4). Simple hand gestures, e.g., the rotation of the hand controls the size of a volumetric cursor, allow the user to select everything from single waypoints to large sections of the path. When plotting proposed navigational courses, the software automatically considers the surrounding flow patterns and evaluates how the flow vectors will affect the vehicle's energy usage. If the flow matches the desired travel direction, less energy will be needed, and these areas of the pathline are colored green to indicate this. Sections of the pathline that go against the flow will require extra energy and are colored red to indicate this. This feature will be further utilized by assisting the user in figuring out the best time to launch a mission, best orientation of grid patterns, etc. based on the best operational flow models that are available.

To extend gesture recognition one step further, Butkiewicz has explored the use of an inexpensive Kinect device to recognize hand and head movements. Using this technique, users can, in essence, "reach into the screen" and manipulate data by hand. It is possible that this could be a much faster method of editing large point clouds than traditional mouse/keyboard interfaces. The team is working with Brian Calder to see if this is a more efficient means of editing and cleaning hydrographic data when such interaction is required (Figure 7-5).

Enhanced Flow Visualization Glyphs

Understanding wind patterns is an essential part of many marine activities and most wind visualizations show wind speed and direction using a glyph called a wind barb. Unfortunately, wind barbs are a very poor way of showing wind patterns (Figure 7-6 (top). Research into flow visualization and glyph design has suggested better ways of visualizing flow patterns, but these have not been adopted, perhaps because, as Center graduate student David Pilar and Colin Ware suggest, these methods lack a key property—unlike the wind barb they do not accurately convey the wind speed. With the goal of improving wind displays, they designed two variations on the wind barb and designed a new quantitative glyph. Figure 7-6 (bottom) shows their new design. All of the new designs space glyph elements along equally spaced streamlines. To evaluate these designs they used a North American mesoscale forecast model. They tested the ability of subjects to

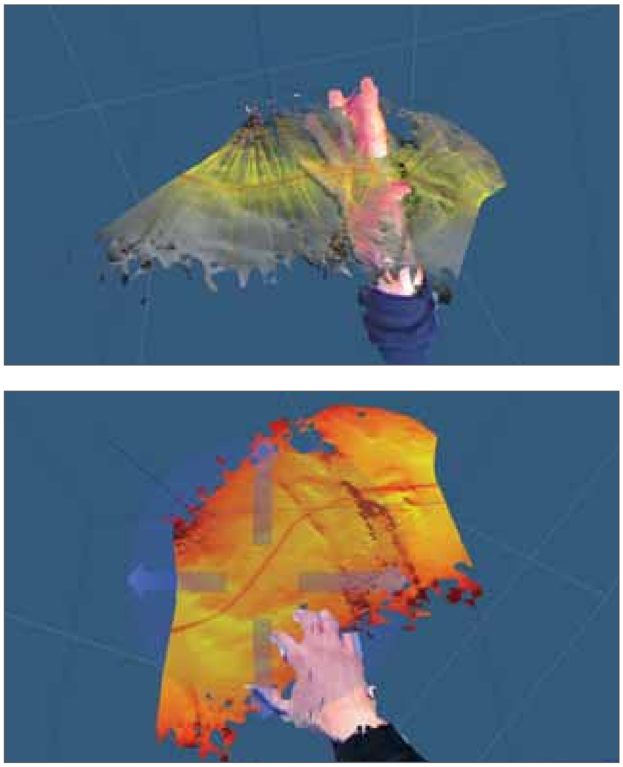


Figure 7-5. Early screenshots showing actual sonar data point clouds and hand models automatically extracted from live Kinect data streams.

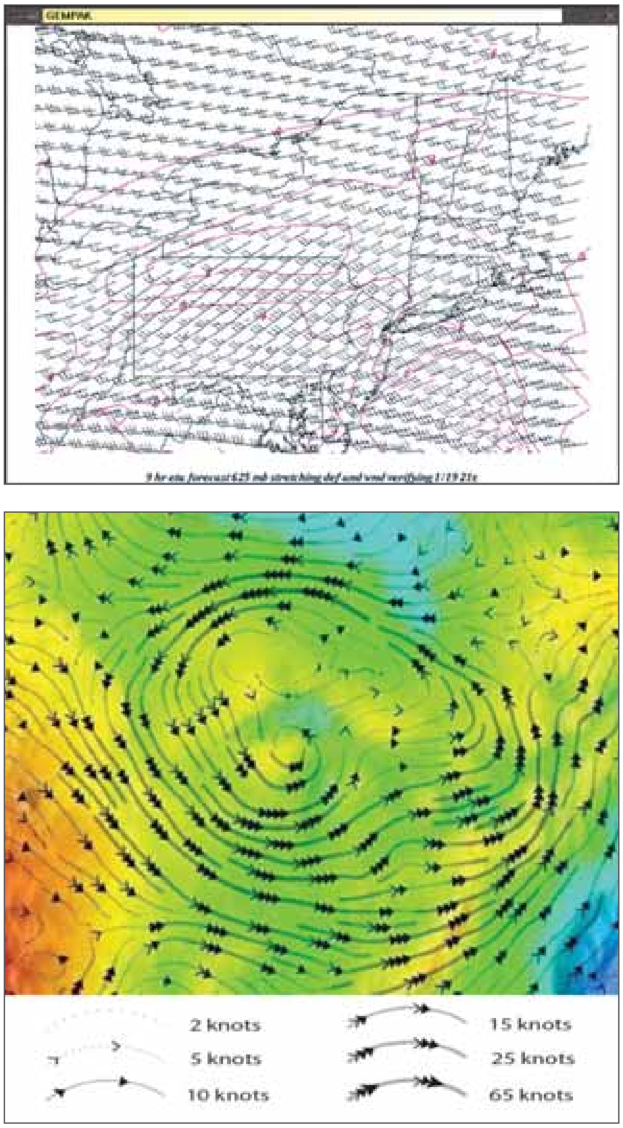


Figure 7-6. A conventional wind barb display (top) and our new display (bottom) with the new symbology.

determine direction and speed using two different densities each of three new designs as well as the classic wind barb. In addition subjects judged how effectively each of the designs represented wind patterns. The results show that their new design is superior to the classic and that the classic barb can be re-designed and substantially improved.

A new effort by graduate student David Pilar is focused on methods for representing wave model forecast data (Figure 7-7). It is based on the wind barb concept in that it uses coded symbols to show wave height. The lines in the figure represent wave orientation and these are orthogonal to the direction of travel.

FlowVis2D

The FlowVis2D software developed by Colin Ware at the Center has been an operational part of the NOAA NowCoast portal for more than a year. It was recently extended to handle the new operational forecast system (OFS) models in Chesapeake Bay, Delaware Bay and Tampa Bay. This was not straight-forward because the model output formats for these estuaries is radically different than it is for the other operational forecast models. Another recent addition that has very quickly gained acceptance is the hill-shading of sea surface height information (Figure 7-8). Ware is also beginning a project with Chris Paternostro's group at NOAA CO-OPS to see if the software can be used to show HF radar data.

Whale Tracking: Mom and Calf

Over the past few years, we have reported on the exciting work of Ware and research scientist Roland 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 WHOI scientists have developed suction-cup-mounted tags that are attached to a whale and 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 geo-referenced 4D displays of the whale's diving and

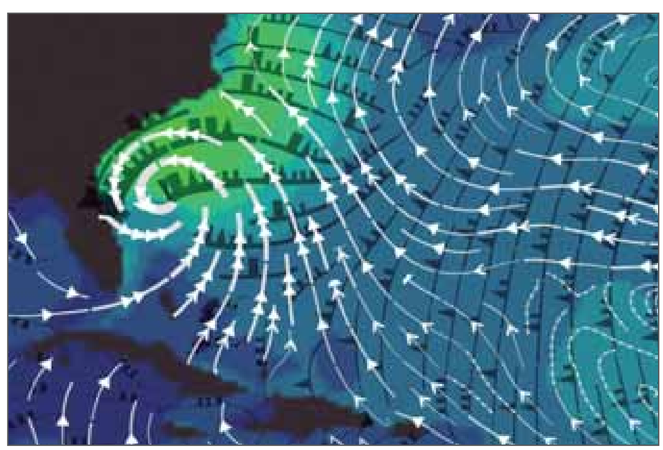


Figure 7-7. A new method for representing wave information. The background shows the significant wave height and direction. Layered over the top is wind speed and direction.

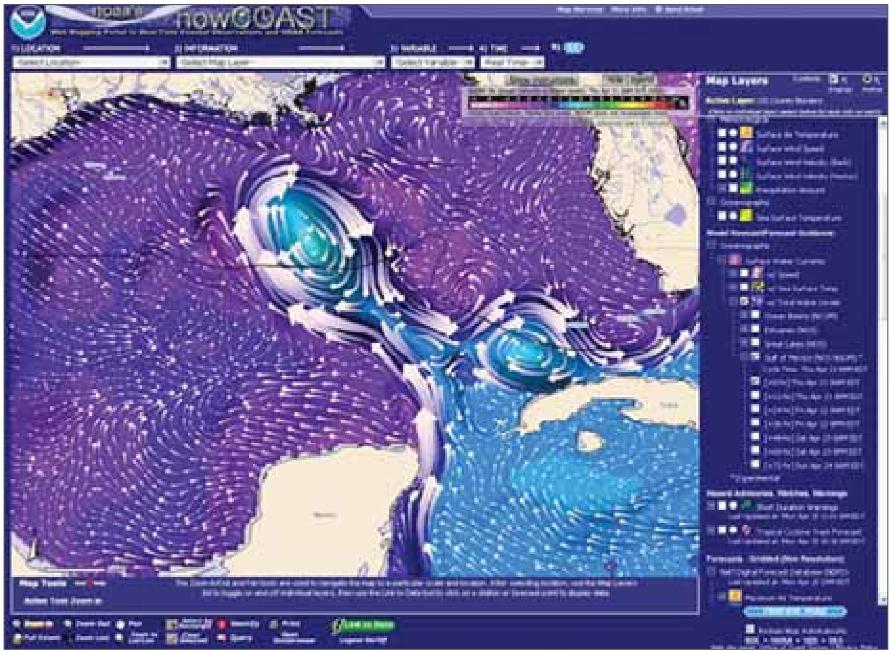


Figure 7-8. FlowVis2D showing shaded sea surface height.

swimming behavior in the context of the bathymetry, 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. 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. (Three papers appeared in 2011with Ware as a co-author in various journals, all relied heavily on TrackPlot analysis). One of the most recent developments has been the ability to show two tracks simultaneously (Figure 7-9). This has been valuable in the analysis of social interactions between animals. In 2010, for the first time, tags were placed on a female humpback and her calf while they were lunge feeding in Antarctica. Both tags stayed attached for more than 20 hours. The calf was just beginning to exhibit feeding behaviors and TrackPlot is being used to help understand the social interactions that occur at this critical stage of development. TrackPlot has now been used for the following species: humpback whales, blue whales, pilot whales, beaked whales, killer whales, spotted dolphins and Florida manatees.

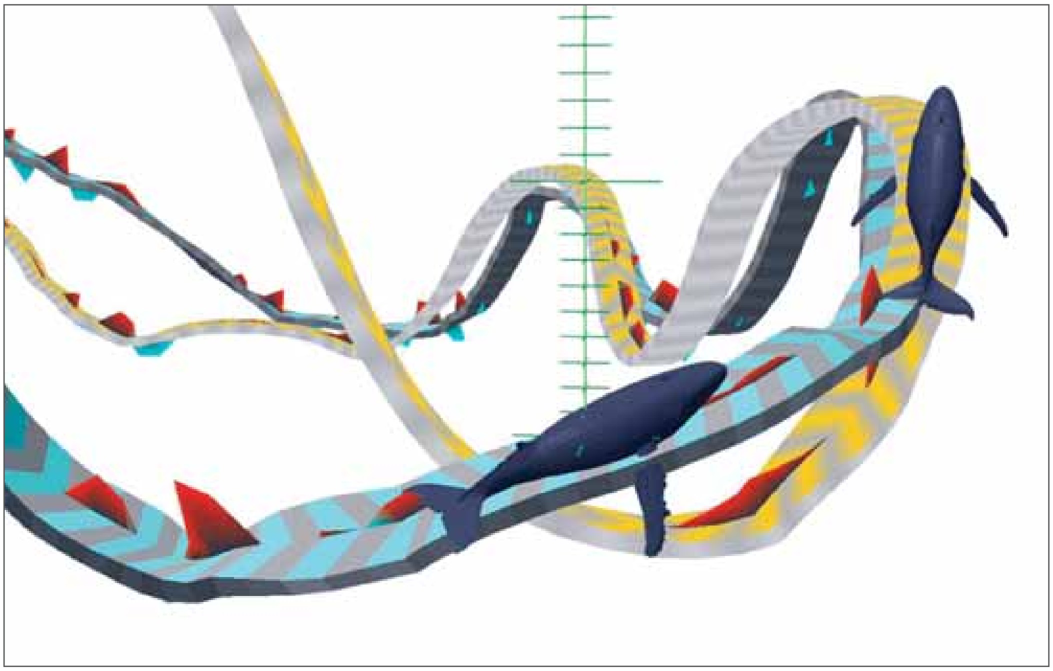


Figure 7-9. Visualization of the tracks of two humpback whales, a mother (orange track) and her calf (blue track).

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 this with imagery from a digitally controlled camera, and mosaic the result onto an ortho-rectified image. This system was developed and first deployed on the R/V *N.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 Patrick Halpin of Duke University with Roland Arsenault as the primary UNH developer. The preliminary results are 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).

Figure 7-10. The geoCamera v2.0 installed outside the Aloft-Con on the USCGC *Healy*.

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 the 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-Con on the forward rail at an approximate height of 30 m above the water line (Figures 7-10 and 7-11).

Scripts written in the Python programming language were developed to control the Axis camera over its VAPIX http-based API. Initial data processing scripts were also developed in Python with the goal to automate the creation of ice maps. Those initial command line scripts were easy to develop but were not very efficient. Processing time was much longer than the collection time for a given data set, unnecessarily prolonging the iterative development process. The slow processing times along with the desire to have interactive control of some key parameters prompted the development of a new processing application written in C++ and featuring a graphical user interface (GUI). This new tool, called geoCamTool, took advantage of available graphics hardware to significantly accelerate the re-projection of images. This allowed interactive tweaking of some parameters using sliders, while instantly seeing the results.

Although data was collected almost continuously, the tools necessary to process that data were not ready until the last quarter of the cruise. The data processing pipeline still leaves quite a bit of room

Figure 7-11. Image taken from the geoCamera at about 2:50GMT on 25 August 2011.

for enhancements and, consequentially, it currently takes roughly as much time to process the data as it takes to collect it. For this reason, only a few select portions of the data have been processed by the end of the cruise. The data to process was chosen to coincide with available synthetic aperture radar (SAR) ice imagery (RadarSat) that was captured when the ship was located within the satellite's field of view (Figure 7-12).

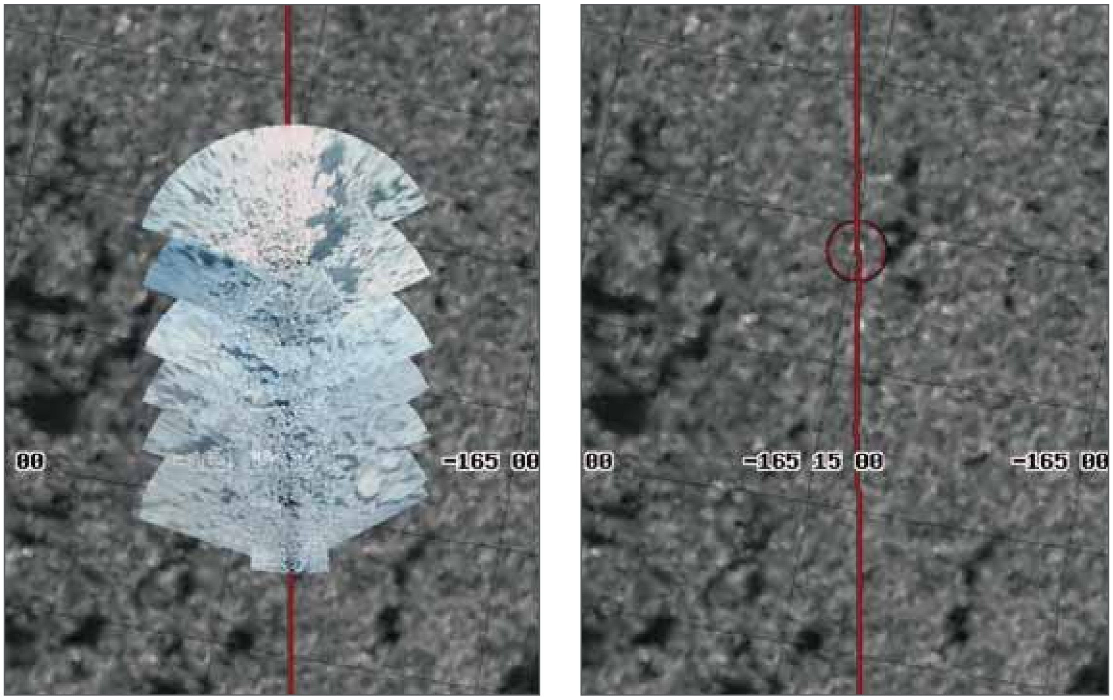


Figure 7-12. Features visible in the SAR image match the ones seen in the geoCamera map generated from data acquired around the time the SAR image was taken.

The georeferenced nature of the geoCamera data allows co-location with our geospatial data, including the real-time mapSever on board the *Healy* (Figure 7-13), providing a powerful tool for exploring ice conditions around the vessel and understanding the impact of ice on the quality of the multibeam sonar data collected.

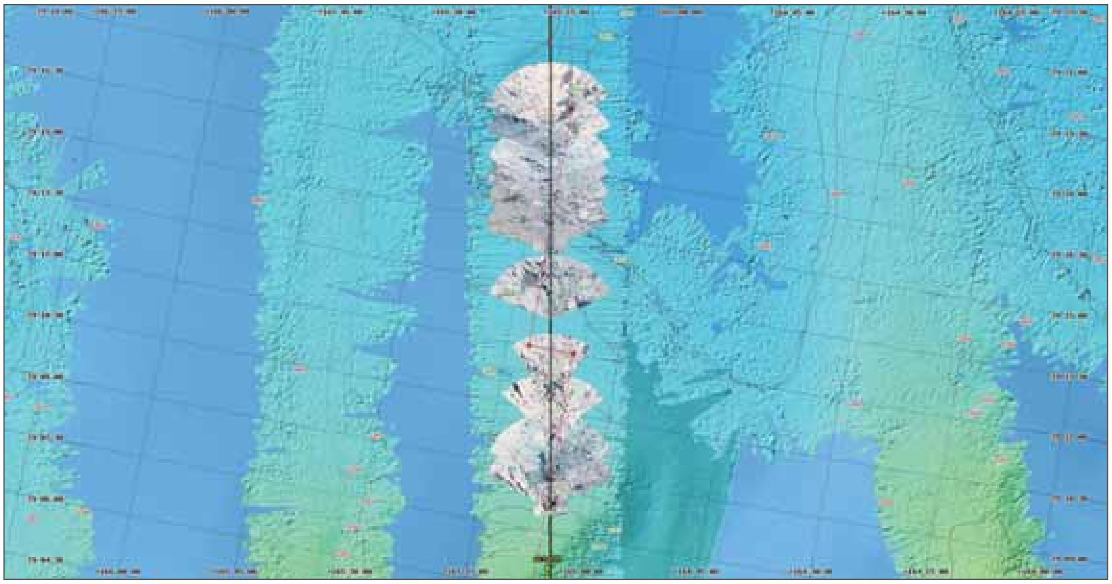


Figure 7-13. Maps produced from the geoCamera were included as a layer in the ship's onboard mapServer.

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. It is intended to provide short-term solutions for the need to see updated electronic charts. In concert with this evolutionary development, we have also embarked on a revolutionary development with researchers in our Visualization Lab to explore 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 the U.S. Coast Guard, the 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/services that have been adopted by IMO, IHO, and IALA to determine their compatibility with the e-Navigation concept of operation. Particular attention will be 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 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 met/hydro information to shipborne maritime users in major U.S. ports and coastal areas via AIS Application-Specific Messages. The initial approach will be to determine a means/process to convert the information content of NOAA NOWCOAST and NOAA PORTS into the AIS Application-Specific Message format recently adopted by the International Maritime Organization (IMO SN.1/Circ.289).

Finally, Alexander is working with Dr. Sanghyun Suh (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 MEBS 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 ENCs are 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 v1.4.0 on 2011-08-10, and is currently working on the next candidate release (v1.5.0). Version 1.4.0 addressed compression in the data formats, while v1.5.0 will address additional layers for QA/QC purposes.

The Bathymetric Attributed Grid (BAG) data file format for high-density gridded data is now in active use in a number of countries, and by a number of different agencies including NOAA, NAVO and the UKHO. It has also been proposed as the basis for the IHO S-102 standard on high density bathymetric datasets, which is currently in its second round of Member Country reviews (typically the stage immediately prior to adoption); a modified version of the standard is currently being considered for compatibility with BAG v1.3.0, with the hope that it will continue to track the BAG library as it evolves.

AIS Related Projects

As part of the Chart of the Future Theme, the Center has been exploring the power of using the Automatic Identification System (AIS) carried by many vessels for a variety of applications including sending binary messages from shore to ships. This effort, led by Kurt Schwehr, is garnering great interest from NOAA CO-OPS/PORTS, USCG, the U.S. Army Corps of Engineers, and the Radio Technical Commission for Maritime Services. Projects include working with Ohmex and Caris on transmission of real-time water levels via AIS, working with SpaceQuest on applications of space-based AIS (S-AIS), developing algorithms to estimate down time in AIS receivers that do not indicate that they have failed, evaluating AIS-Hub, AIS for survey planning, for whale monitoring, vessel tracking, and the establishment of AIS standards.

In 2011, Schwehr continued work on transferring the Center's AIS technology to NOAA and others. Kyle Ward and Barry Gallagher have successfully used Schwehr's NOAAdata software to import a year of NAIS data into a NOAA Oracle Spatial database. Kyle Ward has started using AIS and Schwehr has initiated a process across all of NOAA to consolidate NAIS data logging to one NOAA data center rather than the disjointed efforts currently scattered across NOAA. It is unclear how the process will unfold, but it has caused NOAA to better understand the entire organization's needs and improve collaboration between groups using AIS.

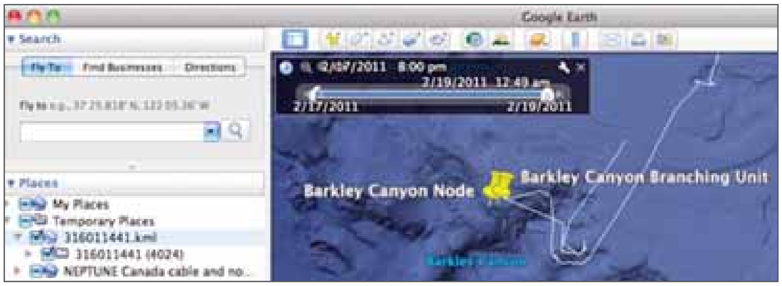


Figure 8-1. Analysis of a fishing vessel going over two Neptune nodes at approximately the time that communication with the nodes was lost.

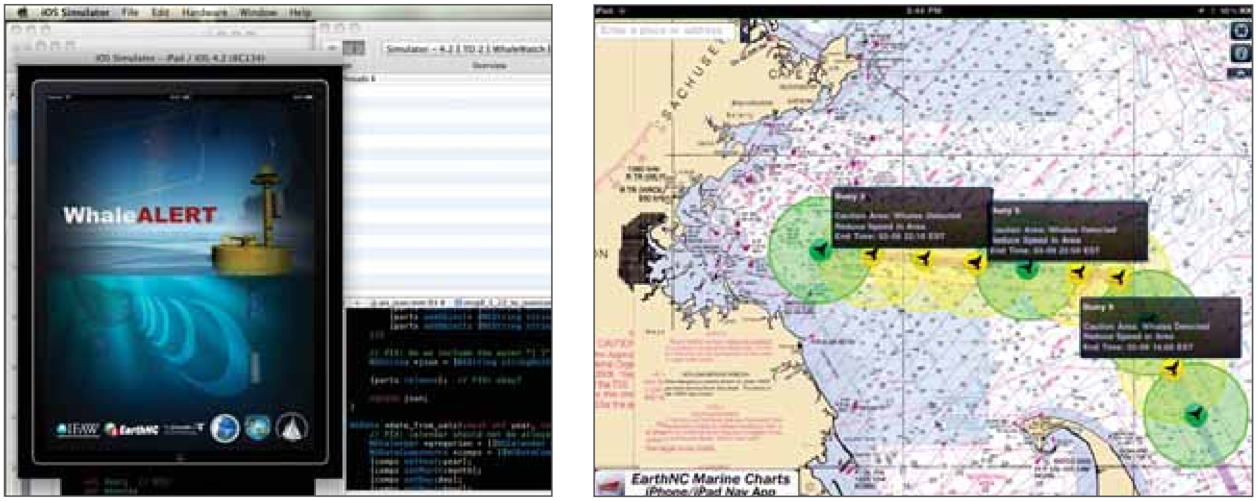


Figure 8-2. iOS development of Whale Alert with EarthNC, TrailBehind, and IFAW (left), Whale Alert iPad application running in the simulator with real data (right).

The power of AIS and the viability of our software was demonstrated in June, when Schwehr assisted the Neptune Canada project by providing initial evidence that a particular trawling vessel had indeed violated Canadian fishing regulations and was most likely responsible for substantial damage to their undersea cabled network in February 2011. Official sources of AIS had difficulty in establishing what happened but Schwehr's NOAAdata software was able to establish the likely disposition of ships around the affected area in 30 minutes (Figure 8-1).

Schwehr is also working on a number of papers on AIS. A "Toils of AIS" paper with Eric S. Raymond (author of "AIS Support in GPSD" and a number of technical books) is almost completed. This paper makes a critical analysis of the design process used for AIS messages and the impacts that process has on software error rates. Software defects in AIS systems have the potential to negatively impact "Safety of Life at Sea."

Right Whale AIS Project

The right whale AIS Project is currently planning to release an iPad application for ship bridges to display the AIS whale notices derived from the Cornell/WHOI whale listening network. There are numerous legal and agency hurdles to overcome but help from the SBNMS and EarthNC have kept the project moving forward (Figure 8-2).

ERMA and Deepwater Horizon Oil Spill

During the Deepwater Horizon incident, Kurt Schwehr worked with the Environmental Response Management Application (ERMA) team creating a vessel tracking layer using the maritime Automatic Identification System (AIS) received through the USCG National AIS network of receivers. Schwehr reconfigured the ERMA feed to cover the Gulf of Mexico. In order to better highlight the response vessels, he used vessel-contracting lists from the USCG and BP. Identifying the vessels was difficult because the lists do not include the unique MMSI identification numbers. Schwehr has used NAIS ship name reports, outside databases (e.g., ITU registrations), and brute-force visual searching of vessel movements to create a master list of response vessels with the required MMSI. This list is now in ERMA and allows the system to present the response vessels separate from the rest of the local AIS traffic.

This is especially important in the very busy Gulf of Mexico environment. Schwehr also completely rewrote his AIS decoding and database updating software to meet the heavy load of presenting all the vessel traffic in real time for such a large and busy waterway. The USCG has designated the JHC/CCOM ERMA NAIS feed as a "Critical Client."

In 2011, the ERMA team was a finalist in the Homeland Security Medal for work done on the Deepwater Horizon oil spill in 2010 and was selected as a finalist for the Samuel J. Heyman Partnership for Public Service to America for Homeland Security. Now Schwehr hopes to step back in his ERMA involvement and transition to the more appropriate NOAA and NOAA contractor support of ERMA's AIS functionality. Based on his AIS experience, however, Schwehr has proposed enabling UNOLS research vessels, NOAA research ships, and USCG vessels to forward their shipboard AIS received messages via satellite in compressed batch mode to ERMA (and hopefully directly into NAIS). Initial work has demonstrated success with the SIO R/V *Revelle* (Ralph Stephen, Tom Bolmer, and Ernie Aaron) and the USCG Ice Breaker *Healy* (Figure 8-3). Attempts with NOAA vessels have brought out cabling and data logging issues on the ships. It will take time to get AIS data, which is only available on the bridge, routed into NOAA ships' networks so that it can be aggregated, compressed, and fit into the satellite data stream at an appropriate priority level so as to not interfere with existing critical uses of shipboard satellite internet.

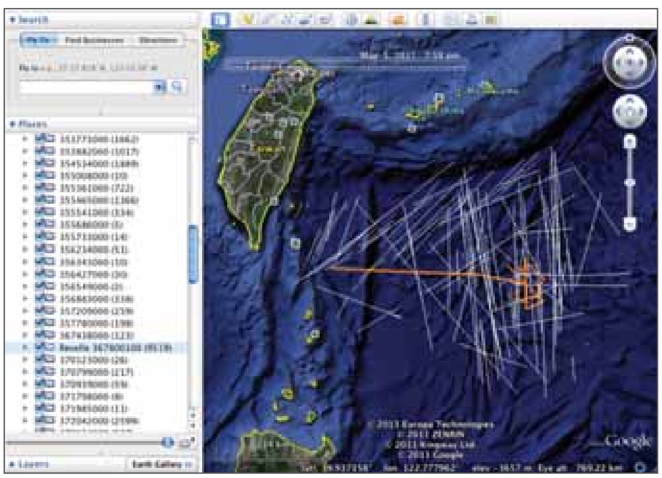


Figure 8-3. AIS data from a WHOI / SIO OBS team sending near realtime data via their HiSeasNet to JHC/CCOM for ERMA proof of concept.

Revolutionary

Within the context of the "revolutionary" effort, Colin Ware, Kurt Schwehr, 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 so we will only highlight 2011 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 of 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 with the click of a mouse, any object identified in the text and see a pictorial representation (in 2D or 3D) of the object in a geospatial context. Conversely, a click on a picture of an object will link directly to the full description of the object as well as other relevant information (Figure 8-4). 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. First, a multirama is a collection of photos of a landmark or a navigation aid taken from multiple vantage points. The multiramas are situated within 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 set up 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.

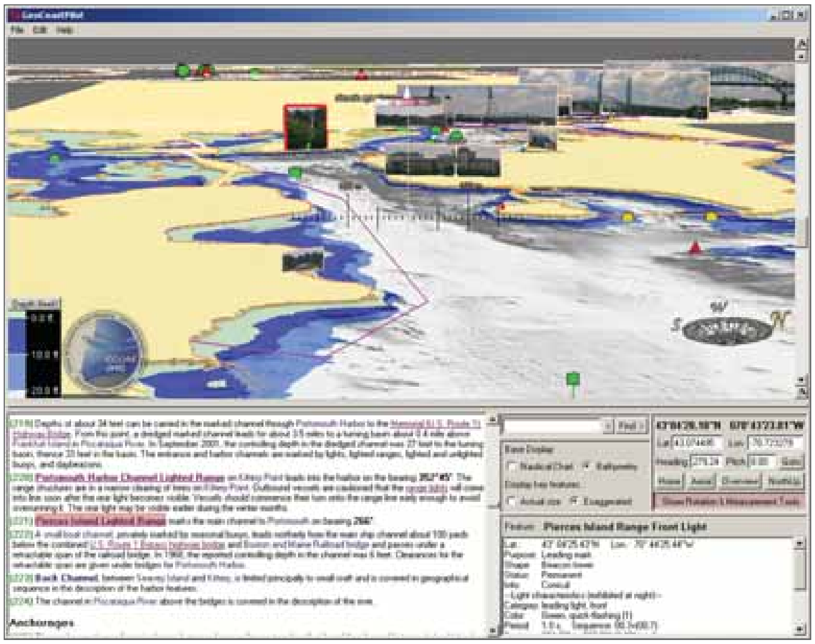


Figure 8-4. Image captured from the GeoCoastPilot showing the approach to abridge in Portsmouth Harbor.

The second capability that GeoCoastPilot introduces is hyperlinks between the NOAA Coast Pilot publication text, S-57 electronic navigational charts (ENCs), multiramas, and the U.S. Code of Federal Regulations (CFR). When the mariner clicks on a photograph in the 3D scene, for example, it highlights the description in the GeoCoastPilot.

GeoCoastPilot now includes the ability to deal with maps at multiple scales (this is necessary to implement a larger and more complex geographic region) as well as providing multirama development tools. Multiramas provide a way of dealing with georeferenced imagery that can have widespread application. Efforts in 2011 focused on creating an efficient system for harvesting and digitally delivering Local Notices to Mariners and porting the GeoCoastPilot on a mobile device.

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 the data and allow programmers to be able to experiment with creative ways to display the data. We propose that using a database system, where changes to aids can be tracked and histories viewed, would be the best solution.

To test the database solution, Briana Sullivan 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 Google Earth, the Google Earth Plug-in and the Google Maps interface (Figure 8-5).

As the view is zoomed or panned, the Navigation Aids list is updated accordingly. When the view is zoomed in, the navigation aids become visible. Hovering over individual icons will reveal their names and other information (Figure 8-6). Future efforts will focus on merging the Local Notice to Mariners with the GeoCoast Pilot and delivering this product on a spatially aware hand-held device.

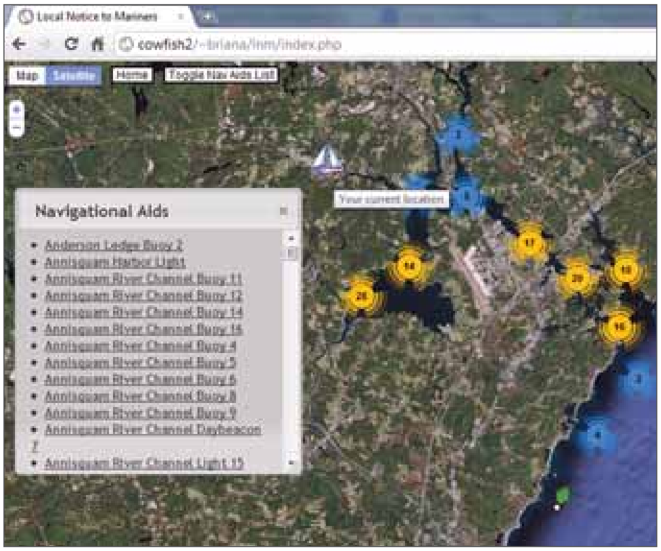


Figure 8-5. Navigation aids within the viewing area are shown in clusters (represented as circles) to further reduce the clutter on screen. A full list of names is shown in the Navigational Aids window (the sailboat icon shows the current position of the user).

The Spatially Aware Hand-Held Chart

Charts are basic tools of the mariner and the task of matching chart features to objects in the world is fundamental to navigation in confined waterways. This task is also known to be cognitively difficult, which means that it must necessarily draw attention from other potentially critical tasks. It seems likely that a spatially aware hand-held navigation aid may substantially reduce the difficulty of the task and free cognitive resources, critical in an emergency. Small touch screen devices, such as tablet PCs or iPhones, can be fed GPS positions together with orientation information. Given this capability it should be possible to present simplified charts in such a way that navigation aids, other ships and shore features can be cross-referenced to objects on the display much more easily than is presently possible with a fixed display or paper product.

The objective of this project has been to design hand held spatially aware navigation aids and carry out human factors studies to evaluate them. Our initial study has been centered around the basic task of relating chart features, such as buoy symbols, to the corresponding objects in the external environment. The study, comparing hand-held spatially aware chart displays with a conventional track-up display, was carried out using a ship simulator environment established in the Center's VisLab.

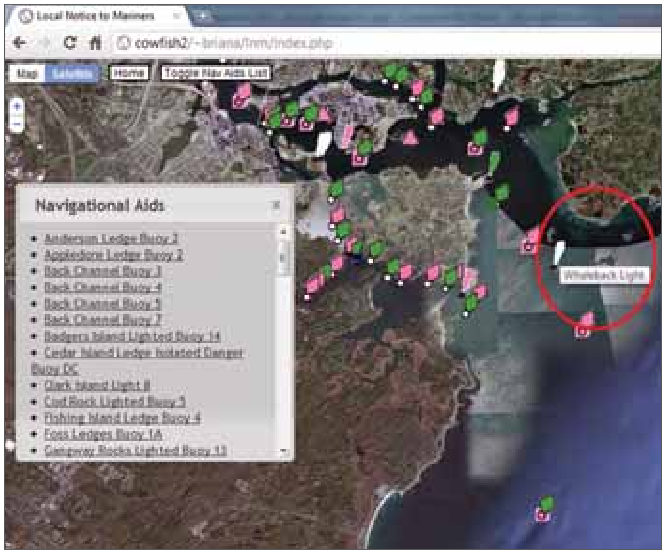


Figure 8-6. Zoomed Navigational Aids window.

Figure 8-7. Mobile version of the GeoCoastPilot showing some S57 chart data in a view with the orientation controlled by the device's orientation.

The Android platform is currently targeted and a Motorola Xoom tablet is being used for development. Progress has been made in managing the large datasets necessary on a platform with limited resources. The orientation of the device is determined using the internal sensors, and work has been done to provide better, more stable orientation information as compared to the solution provided by the Android platform itself. Figure 8-7 shows the current prototype.

To test the value of this approach, two human factors experiments are now complete and have shown significant benefits for the hand-held chart over the more conventional display. Task performance was both faster and more accurate. The "fix far" condition refers to the common situation where a bridge officer must walk some distance between a fixed display and the bridge wing to obtain a view of the environment. In this case the results showed that the attention allocation strategy of the subjects changed dramatically compared to the case where the chart display and the environment were simultaneously in the field of view. The result suggests greater reliance on working memory which is known to be a problem in stressful situations. This suggests that techniques such as this could reduce the effort required for bridge situational awareness.

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 the 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 (nmi) 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. The initial portion of this complex study was carried out in less than six months and a report was submitted to Congress on 31 May 2002. The full report can be found at **http://www.ccom.unh.edu**.

Following up on the recommendations made in the UNH study, Congress funded the Center (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 1.7 million km2 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 the Kingman and Palmyra Atolls, four in the Marinas 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 data are all 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.

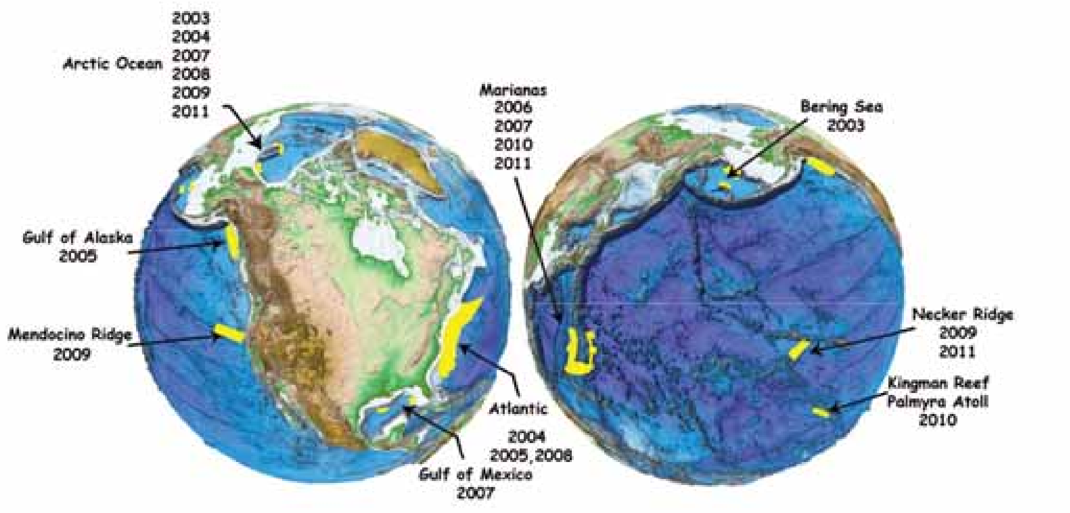


Figure 9-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center to date. More than 1.7 million km2of data has been collected.

2011 Law of the Sea Activities

In 2011, the Center organized and ran two Law of the Sea Cruises—one to the Necker Ridge off Hawaii and the other a two-ship (U.S. and Canadian) operation in the high Arctic. Jim Gardner and Brian Calder were co-chief scientists of the Necker Ridge Cruise and Larry Mayer and Andy Armstrong were co-chief scientists of the Arctic cruise.

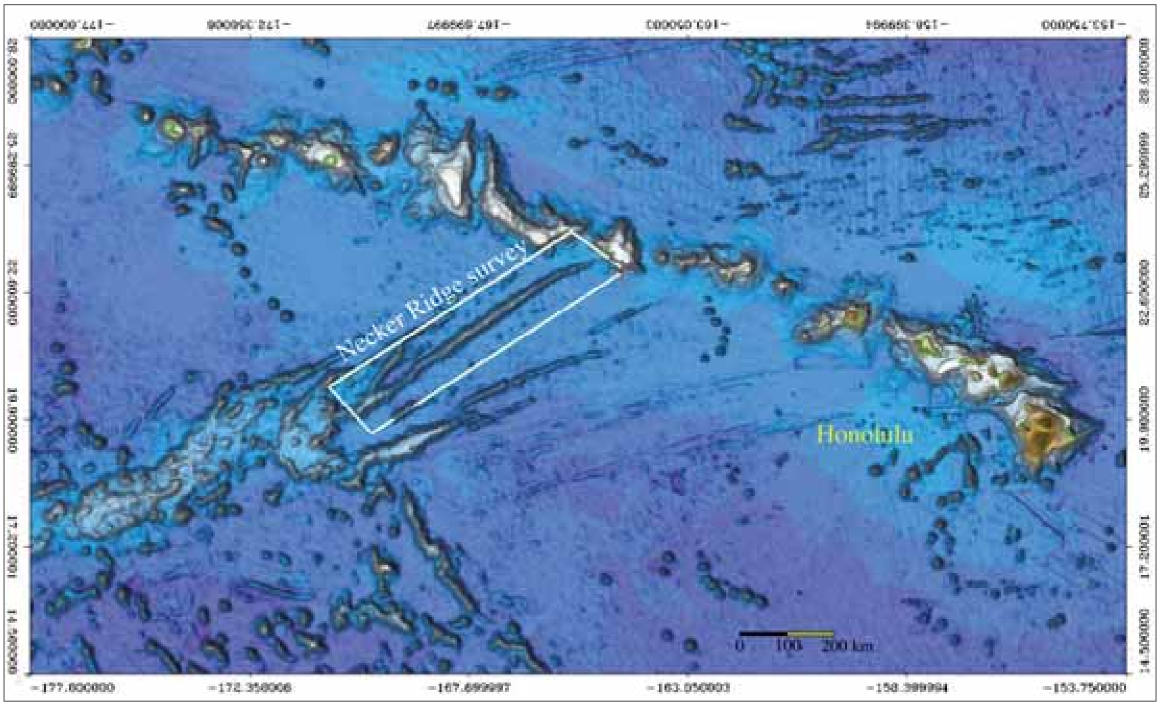


Figure 9-2. Satellite predicted bathymetry (Smith and Sandwell v. 13.1) of Necker Ridge area of the central Pacific.

Necker Ridge Survey

Necker Ridge is an aseismic bathymetric elevation that spans ~700 km from the Mid-Pacific Mountains on the southwest to the Hawaiian Ridge on the northeast. The summit of the ridge varies in water depths from ~1800 to ~3500 m and the ridge rises 2500 to 3000 m above the adjacent abyssal seafloor (Figure 9-2). Three large, generally flat-topped plateaus of Necker Ridge are shallower than ~1850 m; one occurs as a 150-km long section in the south area and the other two are located on a 170-km long section in the northeast. The southern flank of the ridge is steeper (~20°) than the northern flank (~10°). The ridge trends N55E to 22.77°N/166.13°W where the northern-most 165 km has a trend of N65E. There is a pronounced N31E cross grain of summit ridges that occurs in the central deeper region.

One of the principle objectives of the 2011 cruise was to thoroughly map the northeast end of Necker Ridge in the immediate vicinity of the Hawaiian Ridge to determine whether Necker Ridge actually is joined to the Hawaiian Ridge. The survey was conducted aboard the University of Hawaii's R/V *Kilo Moana*. The ship is equipped with a Kongsberg Simrad EM122, the latest generation of their deep-water mulitbeam echo sounder (MBES). The anticipated range of water depths for the Necker Ridge survey was less than 500 m to greater than 5000 m so a 12-kHz MBES was required for mapping efficiency. The cruise initially concentrated on the northern region of Necker Ridge, the results of which are shown in Figure 9-3.

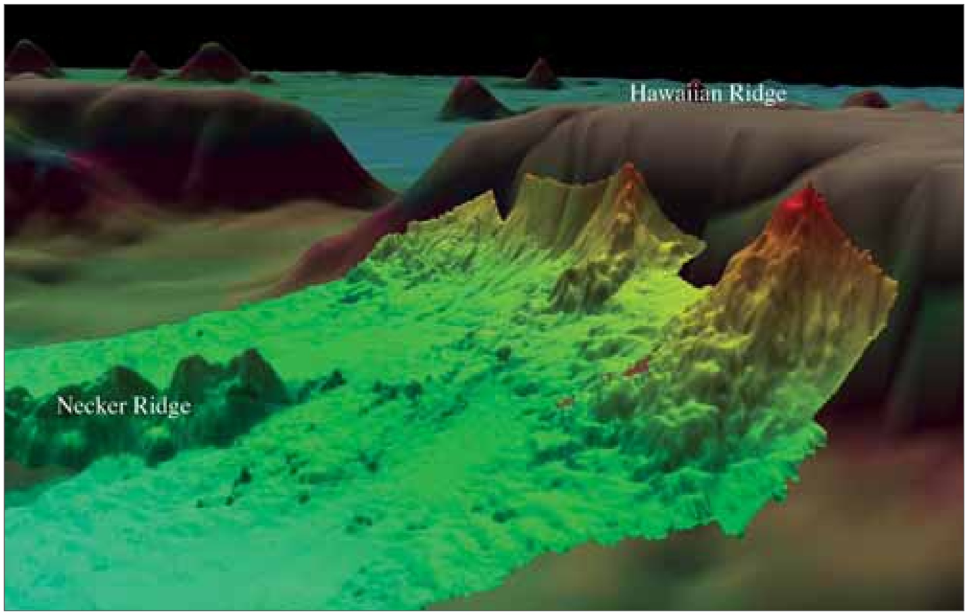


Figure 9-3. Oblique view of the NE region of Necker Ridge in the vicinity of the Hawaiian Ridge. Vertical exaggeration 6x, looking N.

Once the northern area was thoroughly mapped, the *Kilo Moana* commenced a series of long NE-SW lines to map the full extent of Necker Ridge to the Mid-Pacific Mountains to the southwest. The main structure of the ridge is constructed of stacked volcanic flows that rise more than 2000 m above the abyssal seafloor. The flows appear as individual lobate features, one above the other with individual flow thicknesses of 100 to 200 m. The ridge summit is generally ragged (Figure 9-4) but three relatively flat plateaus occur (Figure 9-5), two in the northern half of the ridge and one in the far south. The plateaus represent erosion episodes sometime in the history of the ridge when the summit was at sea level. The most surprising observation is that the three plateaus are found at different water depths, which indicates the ridge has not subsided as a single feature but is segmented into sections, each of which has subsided at a different rate or at a different time. In addition, nearby guyots and plateaus in the Mid-Pacific Mountains to the southwest and Horizon Guyot, 100 km to the southeast, all have different summit water depths. This suggests that the tectonic history of this small area of the Pacific Plate is much more complicated than previously thought.

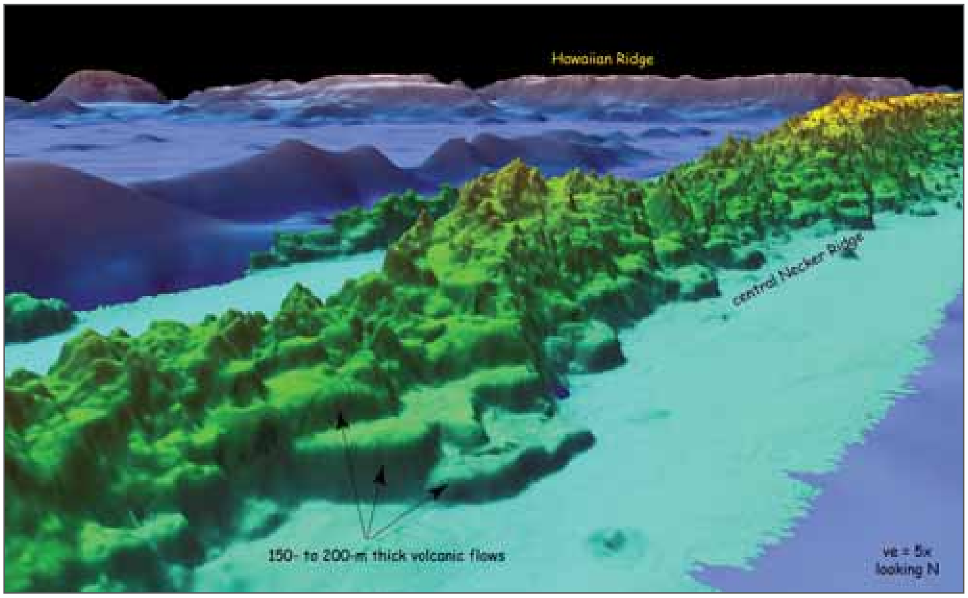


Figure 9-4. Oblique view of the central region of Necker Ridge showing the typical stacked construction of volcanic flows. Vertical exaggeration 5x, looking N.

HEALY-1102

HEALY-1102 was the fourth in a series of two-ship, joint Canadian/U.S. ECS mapping programs carried out by the U.S. Coast Guard Ice Breaker *Healy* and the Canadian Coast Guard Icebreaker *Louis S. St. Laurent* (*LSSL*). The primary objective was to take advantage of the presence of the two very capable icebreakers to collect seismic and bathymetric data in support of delineating the extended continental shelf for both Canada and the United States in regions where

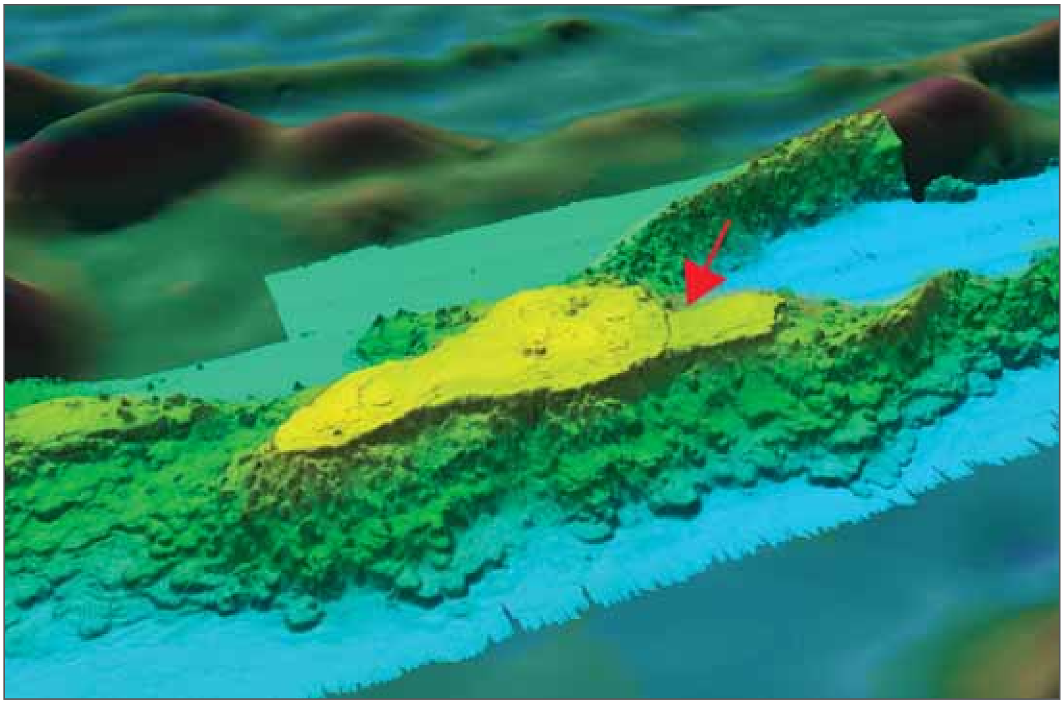


Figure 9-5. Oblique view of the southern plateau of Necker Ridge. Water depths of the plateau are generally ~2100 m with ~150 m of relief. A 300 m step down (red arrow) occurs on the northern region of the plateau. Vertical exaggeration is 5x, looking N.

a single vessel would have difficulty due to ice. In the context of the Law of the Sea, the seismic data is needed to establish the sediment thickness in order to define the "Gardiner Line" (a line denoting points where the sediment thickness is 1% of the distance back to the foot of the slope). The logistical difficulties of collecting seismic data in ice-covered regions make it much more likely that the data can be collected successfully if two icebreakers participate, one in the lead to break a path for the second following with the towed seismic acquisition system. In the context of the Law of the Sea, the multibeam bathymetry is used to establish the position of the foot of the slope and the location of the 2500 m depth contour, each a critical component of the establishment of an extended continental shelf. In addition to the collection of seismic and bathymetric data, gravity data was also collected by both vessels. Each vessel also carried out ancillary projects including meteorological, oceanographic (including ocean acidification studies), wildlife and ice studies; the *LSSL* carried a large Autonomous Underwater Vehicle (AUV) to test the feasibility of using AUVs deployed from icebreakers in ice-covered Arctic waters for seafloor mapping, and the *Healy* was equipped to sample the seafloor with dredges should the opportunity arise. Researchers on the *Healy* also hoped to explore the feasibility of using a small autonomous airplane (UAV) to map ice and wildlife around the vessel, but were denied permission by the USCG and thus the program was moved to the *LSSL*.

The *LSSL* departed Kugluktuk, NWT on 18 August while the Healy departed Barrow, Alaska on 16 August, hoping to rendezvous on the northern Chukchi Cap on 23 August. While waiting for the *LSSL*, the *Healy* proceeded to a region approximately 200 nm WNW of Barrow to continue mapping the margin off the north slope of Alaska in order to delineate the foot of the slope. Survey work in this area was completed on 21 August when it was necessary to depart in order to meet the *LSSL* at the rendezvous point; a total of approximately 25,000 km^2 (7500 nm^2) of multibeam sonar data collected in this area Figure 9-6.

The vessels rendezvoused at approximately 78° 36'N, on 23 August and 250,000 gallons of fuel were transferred to the *LSSL*. On 24 August, the *Healy* took the lead and a remarkable, almost continuous, 750nm seismic line was collected across the top of Chukchi Cap, west of Nautilus Basin, over Alpha-

Mendeleev Ridge, across Makarov Basin and partially up the Lomonosov Ridge. Multibeam sonar data was also collected continuously along the 750 nm line (Figure 9-7). Ice conditions on the Lomonosov Ridge were such that it was impossible to collect seismic data so at this point the *LSSL* and the *Healy* changed positions and the *LSSL* began to lead the *Healy* to optimize multibeam sonar data collection. During the collection of multibeam sonar data on the Lomonsov Ridge, the *Healy* reached its furthest north point—88° 27.4626′ N, 159° 22.05′ E.

Moving south from the Lomonosov Ridge multibeam sonar surveying focused on mapping the foot of the slope in the area of Marvin Spur. Heavy multiyear ice made mapping difficult but, with *LSSL* in the lead, useful data were collected. On 3 September, the *LSSL* separated from the Healy to deploy an AUV equipped with multibeam and single beam sonars, while the *Healy* continued collecting multibeam sonar data on its own until 6 September. The quality of these data was of greatly reduced due to the heavy ice conditions.

Upon completion of AUV operations, the vessels joined up again and proceeded with the *LSSL* in the lead, optimizing multibeam sonar data collection while mapping the foot of the slope around the eastern side of the Makarov Basin (Figure 9-7). The survey of the foot of the slope around Makarov Basin was followed by a long transit to the southeast across Alpha/Mendeleev Ridge and into Stefansson Basin. Subbottom profiler and multibeam sonar data revealed that for several hundred kilometers, the crest of the ridge had a chaotic, 30-50m relief that resulted in complex hyperbolic echoes on the Knudsen profiler.

The transit continued until 12 September when the vessels reached of Sever Spur, a prime target for Canadian ECS mapping. The *LSSL* deployed seismic gear at the approaches to Sever Spur and was able to collect seismic data for 18 hours before ice conditions required recovery of the seismic system. The vessels swapped positions again and proceeded to the east until approximately 80° 09′N, 119° 10′W when ice conditions prevented both vessels from progressing further east. At this point the survey was turned southwest to once again examine the transition from Sever Spur into the Stefansson Basin (Figure 9-7). On 16 of September, the *LSSL* separated from the Healy to launch its AUV while the *Healy* continued to map Sever Spur on its own. The vessels rejoined on 19 September and began a transit into

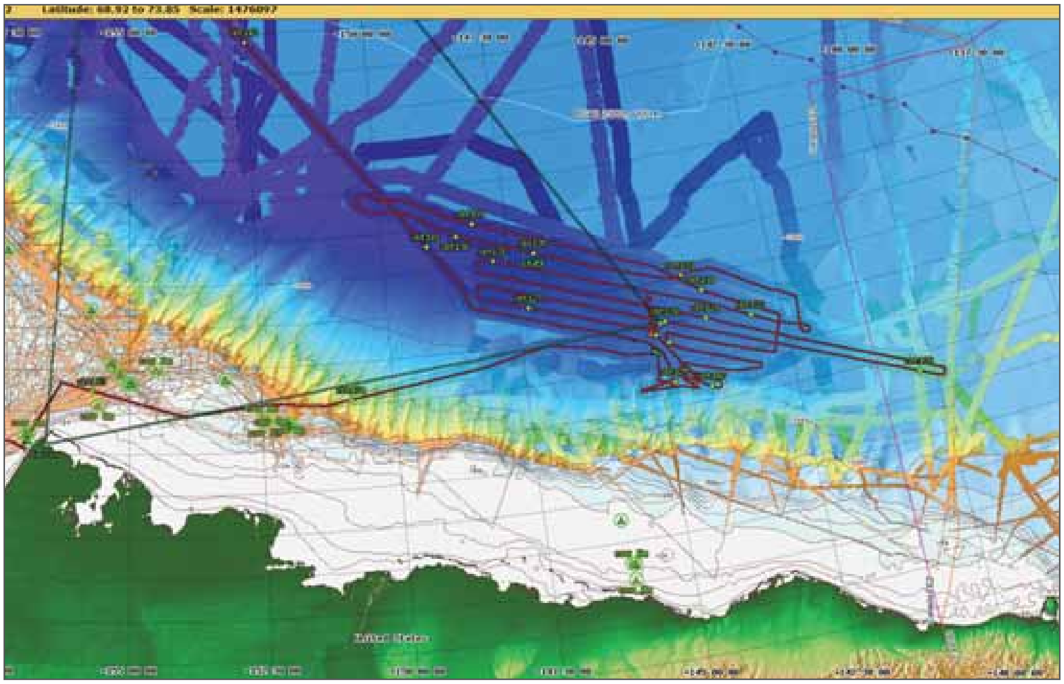


Figure 9-6. North Slope FOS survey 17-21 August 2011.

Canada Basin hoping to again collect seismic data. During the deployment of the seismic gear, the *LSSL* noted a strange noise coming from one of their shafts. Investigation by a small ROV revealed that the main propeller had moved on the shaft and was loose. The *LSSL* received word to proceed directly to the Northwest Passage and requested that the *Healy* accompany her for some of the way through the ice. This brought to a close the joint science operations of the program. Despite this slightly premature ending to the joint program, all of the objectives originally outlined were more than met.

The *Healy* returned to Dutch Harbor on 28 September bringing HEALY-1102 to an official end. The total track covered on HEALY-1102 was 11,447 km (6181 nm) with 9188 km (4,961 nm) of multibeam sonar data and 875 km (472 nm) of seismic data collected in support of ECS purposes. These data were collected in average ice conditions of 9/10th ice cover and at an average speed of 3.5 knots in the ice. ECS multibeam data collection covered an area of approximately 58,000 km^2 (16,960 nm^2) adding approximately 20% to the U.S. Arctic multibeam sonar data holdings.

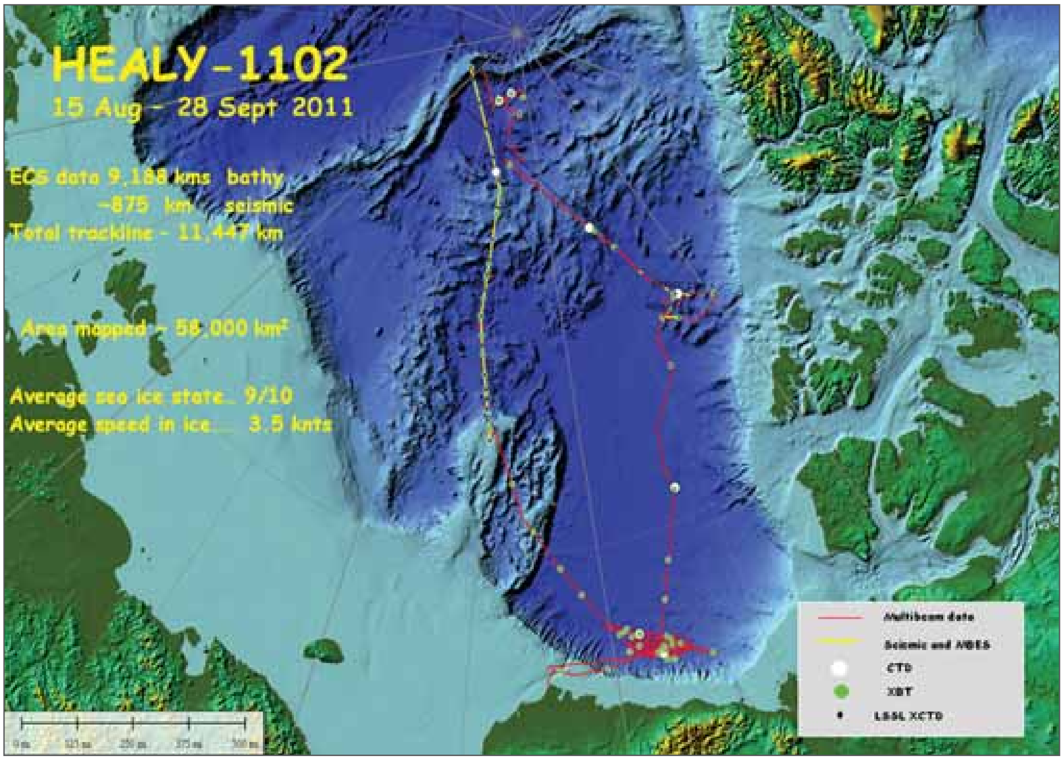


Figure 9-7. Trackline for HEALY-1102. Cross-hatched lines represent seismic data collection lines. Multibeam sonar data was collected on all lines.

Other Law of the Sea Related Activities

In addition to sea-going activities, the Center has also played an important role in managing and archiving the Law of the Sea data that we have collected. Gardner, Mayer and Andy Armstrong have spent much time analyzing ECS data, participating in the ECS Task Force, Working Group, Integrated Regional Team and other meetings related to Law of the Sea. 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. The Center has hosted a number of IRT and other ECS related meetings.

Outreach

In addition to our research efforts, we recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those who ultimately 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 joined our staff this year). Tara has met with Erica Mantz and Beth Potier from UNH Media Relations to coordinate Center-related press releases and media events and has begun working with NOAA media personnel in preparing releases featuring Center faculty.

Tara is also the UNH representative for the Consortium for Ocean Leadership network SCAMPI (Science Communicators and Marine Public Information Officers) which was established in 1988 as a network of ocean science communicators sharing best practices and opportunities for collaboration. Its members are made up of communications, public information, and media-relations professionals from leading ocean research and education institutions, agencies, and non-governmental organizations. They hold a monthly conference call and have a biennial meeting, during which they share news from their institutions and discuss any issues or new developments that concern the science communications field, such as new social media tools, dealings with film and media groups, or outreach opportunities that may exist.

We have hosted a number of community groups (high-school students, marine docents, etc.) and our activities have been featured in many international, national, and local media outlets including, *Nature*, The Associated Press, BBC, *The Toronto Star*, *Popular Mechanics*, and *The Boston Globe*. Some of the highlights are:

2011-12-30	Scientists Find Sea Floor 'Bridges' Across the Mariana Trench - The Deepest Place on Earth	*Daily Mail*
2011-12-22	U.S.-Canada Arctic Ocean Survey Partnership Saved Costs, Increased Data	*Alaska Native News*
2011-12-17	U.S.-Canada Arctic Ocean Survey Partnership Saved Costs, Increased Data	*Lake County News*
2011-12-16	U.S.-Canada Arctic Ocean Survey Partnership Saved Costs, Increased Data	*NOAA News*
2011-12-07	Oceans' Deepest Depth Re-measured	BBC
2011-12-07	Scientists Map Mariana Trench, Deepest Known Section of Ocean in the World	*The Telegraph UK*
2011-12-07	Scientists Map Earth's Deepest Point, Challenger Deep - Before Four Rival Manned Missions Race to the Bottom	*Daily Mail*
2011-12-07	Volcanic Bridges Across the Abyss	AGU Blogosphere
2011-11-10	New Report Offers Broad Approach to Assessing Impacts of Ecological Damage From Deepwater Horizon Oil Spill	National-Academies.org
2011-10-15	The Curious Get to 'Know the Coast' on Saturday	Seacoast Online
2011-10-13	Scientific Challenges in the Arctic: Open Water	*Nature*


Figure 10-1. Middle school children building and testing small ROVs as part of the SeaPerch program.

2011-09-26	Get to Know the Coast at UNH Marine Labs Oct. 15, 2011	UNH Media Relations
2011-09-16	Multibeam Sonar to Detect and Map Deep-Sea Gaseous Seeps	*Hydro International*
2011-09-15	NOAA and Partners Demonstrate Success of Multibeam Sonar to Detect and Map Deep-Sea Gas Seeps	*NOAA News*
2011-09-07	Science at the Top of the World	*UNH Campus Journal*
2011-08-24	Peaceful Competition on Arctic Ice	*Toronto Star*
2011-08-18	Interview with Larry Mayer Aboard the USCGC *Healy* to Air on NatGeo in Spring of 2013	Military.com
2011-07-11	Cartographier un Iceberg: Une Première	*La Tribune*
2011-06-22	Jim Gardner of JHC/CCOM Honored with Prestigious Medal	*UNH Campus Journal*
2011-06-14	Who Owns the North Pole?	*Popular Mechanics*
2011-05-16	Hydrographers Stepping Up to the Challenge	*Hydro International*
2011-05-11	UNH Developers Share Honors for Oil Spill Response Tool	*UNH Campus Journal*
2011-04-01	Sub-Bottom Profiling Using an AUV	*Ocean Byte*
2011-03-06	UNH Professor Leading Study Panel on Largest US Oil Spill	*Boston Globe*
2011-03-28	Earth Matters: Seismic Activity Deemed Normal	*Seacoast Online*
2011-03-28	Margaret Boettcher's podcast - The Earthquake in Japan, Plate Tectonics, and Earthquakes in New England	WOKQ
2011-02-17	UNH Oceanographer Tapped to Lead National Oil Spill Committee	*Foster's Daily Democrat*
2011-02-07	UNH Professor Tapped to Lead Oil Spill Committee	Associated Press
2011-02-05	UNH Oceanographer to Lead National Oil Spill Committee	*Seacoast Online*
2011-02-04	Profile: Center for Coastal and Ocean Mapping/Joint Hydrographic Center	*Sea Technology*

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 were visits from students from Portsmouth and Spaulding High Schools, the participants in the Nor'easter Bowl of the National Ocean Sciences Bowl, and a group of UNH Alumni.

We also hosted a group of middle schools who participated in the SeaPerch Program where students learn to construct small Remotely Operated Vehicles (ROVs) and then put them through their paces in our test tanks (Figure 10-1). We hosted four Oyster River Middle School teams (with 20 students in each team) in November, and it was a fantastic experience for everyone. Four more teams of 20 students are on the schedule from Oyster River Middle School for February, and we are in the process of working with Barrington Middle School to find a date for their challenge.

Hosting these types of events here at the Center rather than at a hotel or community pool offers the students the opportunity to see how relevant their ROV building projects are in the real world, and will hopefully inspire them to follow ocean engineering or scientific career paths. The participants created a wonderful video about the SeaPerch project, viewable at **http://vimeo.com/33591745**.

Figure 10-2. Participants in Know the Coast Day view real-time high definition broadcast from a deep sea ROV in the Mediterranean Ocean.

Through the year, Center scientists participated in outreach activities outside of the Center. Larry Mayer gave numerous public lectures about Center activities, including one at the Seacoast Science Center and Jodi Pirtle offered presentations about her work to students in grades 5-12 in Cordova, Alaska as a guest of the Prince William Sound Science Center and the Chugachmiut Heritage Foundation for Visiting Scholars.

Figure 10-3. Participants in Know the Coast Day generate waves.

On October 15, the Center outreach staff organized Center participants in the 2nd Annual Know the Coast Day. Held at the Chase Ocean Engineering Laboratory, the Coastal Marine Research Facility, and the Jackson Estuarine Laboratory, hundreds of visitors got a chance to see and experience some of the exciting marine research happening in the Seacoast region. At the Center, visitors could test out their skills driving a SeaPerch ROV, build models with LEGOs to float in our wave tank, and learn about research buoys, ROVs and ocean acoustics. Due to fortunate timing, our Telepresence Console was buzzing with activity as the E/V *Nautilus's* ROV *Hercules* dove in the Gorringe Bank in the Atlantic Ocean off the coast of Portugal (Figure 10-2). We had seminar talks throughout the day that highlighted the work the Center was doing on the Deepwater Horizon oil spill, visualizing whale behavior, ocean renewable energy, environmental management systems (ERMA, the Environmental Response Management Application) and Law of the Sea.

Website Upgrades and Other Activities

Colleen Mitchell and Les Peabody have taken the lead 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. New content is also being developed for the website with the assistance of science writer David Sims, including a new Education section and a FAQ. The new website is scheduled for release in 2012.

We are also producing a newsletter, *The Anchor* (Figure 10-4), to provide updates of Center activities for Center staff and other interested parties and are

Figure 10-4. The August 2011 edition of *The Anchor*.

continually updating handout and conference materials (Figure 10-5). This year, the Center exhibited at the U.S. Hydrographic Conference in Norfolk and the American Geophysical Union annual meeting in San Francisco.

Our seminar series is advertised with a beautiful set of individually created flyers (28 were created for our 2011 seminar series). Once the seminar flyers are created, they are reformatted in landscape for kiosk slides, then further expanded, at a 16:9 aspect ratio,

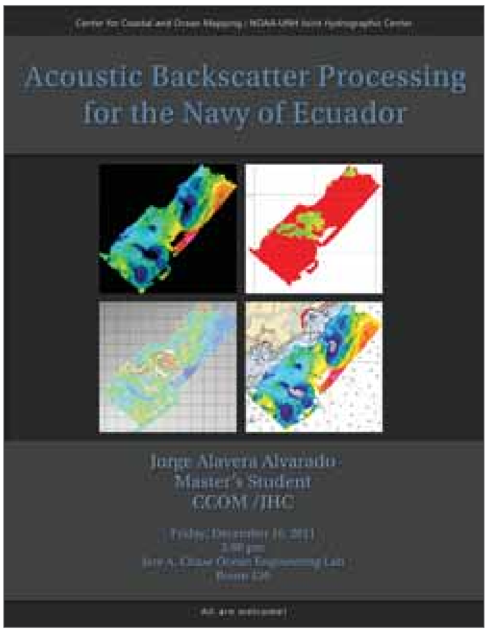
Figure 10-5. Pop-up displays used at conferences.

as title cards for the videos which Will Fessenden edits and posts on the Center's Vimeo site (Figure 10-6). The flyers (Figure 10-7) are posted on the Center's Facebook page and will be presented on the new website.

Each seminar is recorded, edited and uploaded to Vimeo. Many of our seminars are also Webcast allowing NOAA employees and our industrial associates around the world to listen and participate in the seminars. Our Vimeo account, **http://vimeo.com/ccomjhc**, currently has 23 JHC/CCOM seminars. The "Featured Video" on the homepage of the new website will draw from this. The video is also linked from each seminar's page on the website.

Figure 10-6. The Center's Vimeo site.

The Center's Flickr photostream continues to grow with the continual addition of more photos. We currently have 1,138 photos on the site and a backlog of photos to be uploaded. In October, our Facebook page was migrated to an official Organization Page. This allows posts from the Center rather than individuals and we have a custom URL, **http://www.facebook.com/CCOMJHC**. We are able to link up with other organizations now which means we get a feed from such entities as various UNH departments, NOAA offices, Lamont Doherty, CSHEL, the NOAA Ships *Fairweather* and *Thomas Jefferson*, etc. When their posts are pertinent to our work, it is easy to repost them. For the most part, our Facebook page is a means of posting seminar announcements, publications, event announcements and occasionally photos. Although much of this information is repeated from our website, the Facebook page reaches a different audience, extending our outreach effort. Our intention is to create a page that is informative to center employees, NOAA staff, and other visitors, and is interesting to potential students.



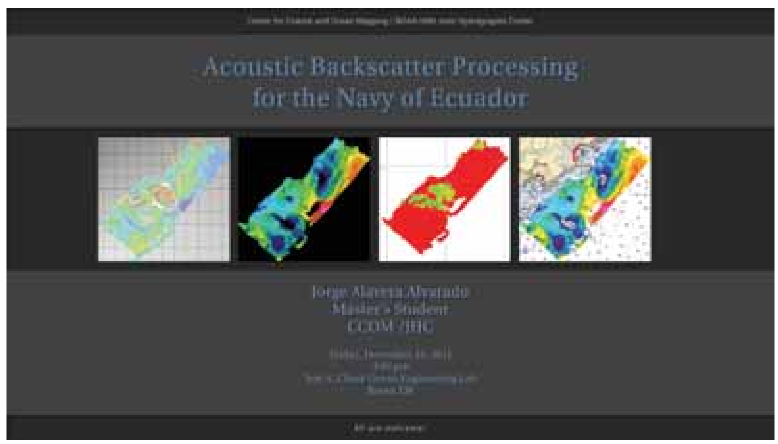


Figure 10-7. Example seminar flyer (right) and title card for seminar video (left).

Partnerships and Ancillary Programs

One of the goals of the JHC 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 postdoctoral 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. New to the program this year are:

- AML Oceanographic
- Ocean Imaging Consultants
- Ocean Science Group Ltd.
- Survice Engineering Company
- YSI, Inc.

Other Industrial Associates:

- Airborne Hydrography AB
- Atlas Hydrographic-GmBH
- ATLIS Informatie Systemen BV
- C&C Technologies Inc.
- CARIS, Inc.
- Chesapeake Technologies
- EdgeTech
- Electronic Navigation Ltd.
- Environmental Systems Research Institute, Inc.
- Fugro LADS Inc.
- Fugro Pelagos, Inc.
- GeoAcoustics, Ltd.
- Geocap AS
- HYPACK, Inc.
- ICAN, Inc.
- IFREMER
- Instituto Hidrografico
- Interactive Visualization Systems, Inc.
- IXSEA Inc.
- Knudsen Engineering Limited
- Kongsberg Underwater Technology, Inc.
- L-3 Communications Klein Associates
- Marport Canada Inc. (pending)
- Ocean Imaging Consultants, Inc.
- Odom Hydrographic Systems, Inc.
- Ohmex
- QinetiQ
- Quality Positioning Services B.V.
- Quester Tangent
- RESON, Inc.
- Rolls-Royce Canada Limited (pending)
- Science Applications International Corporation
- Seismic Micro Technology
- Substructure
- Teledyne Benthos, Inc.
- Tenix
- Triton Elics International, 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 the Blodgett Foundation and the Tyco Endowment. Funding beyond this grant this past year is on the order of $1.27M from a total commitment from other sources of approximately $2.67M (see Appendix C).

Appendix A: Graduate Degrees in Ocean Mapping

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

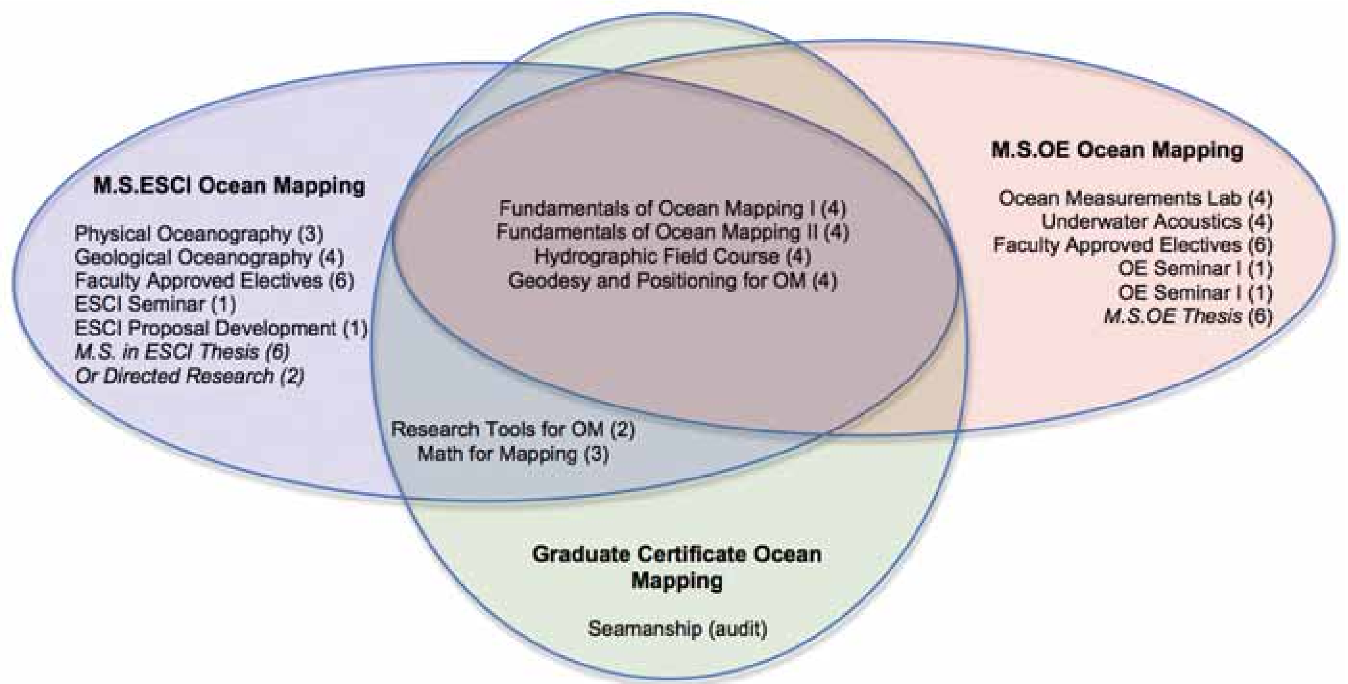


Figure 11-1. Curricula for Master's Degrees and Certificates in Ocean Mapping at UNH JHC/CCOM.

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		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

Large Scale Observation of Fine-scale Seabed Morphology and Flow Structure in Tidally Modulated Inlets (ONR DRI experiments), 1 January-31 December, R/V *Coastal Bathymetry Survey System*, Make field (MBES) observations of fine-scale seabed evolution within an inlet environment coincident with observations of the vertical structure of mean and tidal flows. (Lippmann)

CBASS Data Acquisition System, 1 January-31 December, R/V *Coastal Bathymetry Survey System*, Integrate MBES (Delta-T), new INS, and ADCP into the CBASS for making shallow water observations of fine-scale seafloor topography and mean currents. (Lippmann, Hunt, McKenna)

African Partnership Station, 1 January-31 December, R/V *Anzone* (Ghana Navy vessel), Prepared and re-deployed directional wave-rider buoy on the Ghana shelf in October 2011. (Lippmann)

Long Term Video Observations of Nearshore Processes, 9-16 January, Shore Based out of USACE Field Research Facility in Duck, NC, Repair fiber optic cable break; maintenance of field camera on 60 foot tower. (Lippmann, Hunt)

Nearshore Bathymetric Estimation from LIDAR-based Airborne Imagery, 1 February-31 March, Cessna 172 and 182 Aircraft, Develop imaging techniques for shallow water bathymetric inversion; develop airborne video system with applications in shallow water mapping; make new observations of airborne imagery and obtain estimates of shallow water bathymetry in Duck, North Carolina. (Lippmann)

NOAA/NGS 1550nm Lidar Radiometric Performance Analysis for Coastal Applications: Field Campaign, 4 February-26 May, Acquired ASD reflectance spectra for various shorelines and coastal land cover types and conditions (e.g., dry, wet, snow/ice-covered) for assessing radiometric performance of 1550nm lidar for coastal applications and determining recommended operational parameter settings for NOAA/NGS. (Parrish, Osiri)

R2Sonic Backscatter Trials, 23 February–6 March, R/V *Alumiduck*, Acquisition of backscatter data set with R2Sonic 2024 as a test data set for investigation of R2Sonic system capabilities and augmentation of seafloor characterization routines in support of R2Sonic sensors in Ocean Mapping Group software framework in preparation for inclusion of calibration routines in Geocoder code base in Victoria, BC, Canada. (Beaudoin)

EX1101 Mapping Shakedown Cruise/Sanctuaries Mapping, 16 March-1 April, NOAA Ship *Okeanos Explorer*, Expedition Coordinator / Mapping Team Lead. (Lobecker)

IFREMER MVP200 Sea Acceptance Trial, 19-26 March, R/V *Le Suroit*, Evaluate moving vessel profiler (MVP) controller software upgrades to automate SVP cast pre-processing for integration with Kongsberg Maritime multibeam echosounders. (Beaudoin)

Flow Structure Sediment Transport in and Around Bathymetric Pockmarks, 1 May-30 September, R/V *Cocheco*, Surveyed (SBES) two pockmarks near Belfast, ME; coincidently deployed 2 ADCP moorings in each pockmark; conducted shipboard CTD and ADCP surveys from the vessel around the pockmark. (Lippmann, Fandel)

EdgeTech 4600 Training, Calibration and Testing, 23-27 May, R/V Coastal Surveyor, Install and calibrate EdgeTech 4600 bathymetric sidescan in preparation for use over summer 2011 and inclusion of support for data format in UNB Ocean Mapping Group software suite for sonar evaluation testing. (Beaudoin)

2011 Summer Hydro Camp, 30 May-1 July, R/V *Cocheco* and R/V *Coastal Surveyor* ,Education; Reporting on graduate student research/getting hands-on exposure to field work. (Dijkstra, Sims)

Sediment Transport in the Great Bay Estuary, 1 June-30 September, shore-based deployment of fixed instruments jetted into the seabed, Support field observations from a rotary side-scan sonar, single point acoustic doppler velocimeter, and fine-scale profiling ADCP (Nortek Vectrino.) (Lippmann)

Pollock Assessment, 6 June-29 July, NOAA Ship *Oscar Dyson*, Collect chart quality data from a fisheries multibeam. (Rice)

EX1103 Leg 1 Galapagos Rift Expedition (GALREX), 8 June-2 July, NOAA Ship *Okeanos Explorer*, Expedition Coordinator / Mapping Team Lead. (Lobecker)

Map Essential Fish Habitat in the Gulf of Alaska, 10 June-12 August, NOAA Ship *Oscar Dyson*, Conduct surveys using the Simrad ME70 MBES to characterize groundfish habitat on the Gulf of Alaska continental shelf and upper slope. Collect video imagery of survey areas to ground truth seafloor type and associated fish and invertebrate communities. Develop alternative stock assessment methods for groundfish associated with seafloor habitats that are adversely affected and/or not accessible by bottom trawl gear. (Pirtle)

Pockmarks, 27 June, R/V *Cocheco*, Test deployment of SBES and ADCP for shipboard observations. (Lippmann, Fandel, Hunt)

Iceberg Mapping Field Testing, 5-10 July, Testing of systems and methods for AUV under-iceberg mapping at Lake Massawippi, Quebec. (Schmidt)

Optic In Situ Measurements: Resolving Grain-size Analysis Using ALB Waveforms. 14 July-11 August, R/V *Cocheco*, Collection of bottom samples, underwater video imagery, and spectral measurements in Portsmouth Harbor and offshore Gerrish Island, ME. (Pe'eri)

Iceberg Mapping, 17 July-2 August, Canadian Coastguard Icebreaker *Amundsen*, Proof-of-concept mapping of moving iceberg. (Schmidt)

Pockmark Experiment, Belfast, ME, 25-30 July, R/V *Cocheco*, Deploy, recover, service and redeploy two bottom mounted ADCP systems. (Irish)

KM1121 (Necker Ridge) central Pacific Ocean, 30 July-9 August, R/V *Kilo Moana*, Bathymetric mapping of the entire Necker Ridge from the Mid-Pacific Mountains to the Hawaiian Ridge. (Gardner, Calder, Sullivan, Sade, Johnson)

EX1104 Mid-Cayman Rise Expedition, 2-18 August, NOAA Ship *Okeanos Explorer*, Mapping Team Lead. (Lobecker)

HLY1102, 16 August-27 September, USCGC Healy, Mapping and other Law of the Sea activities in the high Arctic; develop geoCamera system (and teach Python on the side); multibeam data processing. (Mayer, Armstrong, Arsenault, Calder, Miao, Alavera, Mitchell, Fandel, Beduhn)

Eelgrass and Macro-algae Mapping in Great Bay Estuary (GBE). 17 August, R/V *Limulus*, Collection and analysis of spectral measurements and underwater video imagery of eelgrass in Great Bay Estuary, NH. (Pe'eri)

EX1105 -- Gulf of Mexico, 22 August-10 September, NOAA Ship *Okeanos Explorer*, Mid-water mapping of bubble gas plumes in salt dome province of the Gulf of Mexico with EM302 multibeam echosounder and EK60 split-beam echosounder. (Weber, Beaudoin, Jerram)

Okeanos Explorer Seep Mapping Cruise, 22 August-9 December, NOAA Ship *Okeanos Explorer*, Map Seeps. (Rice)

Resolving Grain-size Analysis Using ALB Waveforms, 7 September, Ocean Optics USB2000 spectro-radiometers, Mapping different coastal environment using a camera, terrestrial laser scanner, and RTK GPS at Plum Island and southern coast of Merrimack River, MA. (Pe'eri)

ESCI/OE 870 (Introduction to Ocean Mapping), 11 September, R/V *Gulf Challenger*, Collection and analysis of bottom samples and underwater video in Portsmouth Harbor and offshore Gerrish Island, ME. (Pe'eri)

EX1106, 15-28 September, NOAA Ship *Okeanos Explorer*, Transit Mid-Atlantic Canyons; Expedition Coordinator/ Mapping Team Lead and Trainee. (Lobecker, Skarke)

Large Scale Observation of Fine-scale Seabed Morphology and Flow Structure in Tidally Modulated Inlets (JHC/ CCOM experiments), 16 September-17 October, R/V *Coastal Surveyor* and *CBASS*, Make repeated field (MBES) observations of fine-scale seabed evolution within Hampton Inlet, NH, coincident with observations of the vertical structure of mean and tidal flows; just offshore using an Imaginex Delta-T to map bedform migration over time. (Lippmann, McKenna, Hunt)

Hampton Harbor Experiment, 16 September-18 October, R/V *Cocheco*, Deploy two ADCPs at start and recover two ADCPs at end of experiment. (Irish)

Circulation in Flathead Lake, MT, 13-19 October, R/V *Jessie B*. (Univ. of Montana Research Vessel on Flathead Lake), Conduct CTD casts throughout Flathead Lake; conduct near surface drifter experiments in various parts of the lake. (Lippmann)

Magnetometer Module Development and Field Testing, 23-26 October, U.S. Naval Academy, Field testing of new magnetometer module. (Schmidt)

Flow Structure at the General Sullivan Bridge, 27-28 October, R/V *CBASS*, Conduct ADCP profiles surveys across the channel spanning an entire tidal cycle (over 2 days) as part of OE collaborations on DOE project. (Lippmann)

Flow Structure in the Great Bay Estuary, 31 October, R/V *CBASS*, Conduct cross-channel ADCP surveys over 1/2 tidal cycle in the Great Bay. (Lippmann)

NEWBEX Reconnaissance, 2 November, R/V *Orion*, Acquisition of reconnaissance data set for backscatter "patch test" sites with R2Sonic 2024 multibeam echosounder. (Beaudoin)

Klein HydroChart 5000 Calibration, 7-9 November, R/V *Coastal Surveyor*, Data acquisition in support of new patch test procedures designed to overcome system imaging constraints associated with phase measuring bathymetric sidescans. (Beaudoin)

Magnetometer Module Development and Field Testing, 12-16 December, Field testing of new magnetometer module in Lewes, DE. (Schmidt)

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	30,000	11 months
Collaborative Research: Optimizing Multibeam Data Aquisition, Operations and Quality for the US Academic Research Fleet	Beaudoin, J. Johnson, P.	National Science Foundation	232,374	697,168	3 years
Mapping Seafloor Uncertainty	Calder, B.	Office of Naval Research	-	96,593	4.5 years
Large Scale Observation of Fine Scale Seabed Morphology and Flow Structure of Tidally Modulated Inlets	Lippmann, T.	Office of Naval Research	192,014	327,107	2 years
Africa Partnership Station	Lippmann, T.	Office of Naval Research	-	91,476	2.5 years
GEBCO 8th Year	Mayer, L.	General Bathymetric Chart of the Oceans	555,000	555,000	1 year
Indian Ocean Project	Mayer, L.	General Bathymetric Chart of the Oceans	197,196	197,196	1 year
Tyco Endowment Interest from Perpetuity	Mayer, L.	Tyco	46,885	-	Perpetuity
Seafloor Video Mosaic Research	Rzhanov, Y.	U.S. Geological Survey	-	20,000	2 years
StereoFish	Rzhanov, Y.	U.S. DOC NOAA	-	54,000	2.5 years
Investigation of Motion Cues for Linking Elements of Complex Visual Displays	Ware, C.	Oculus Info., Inc.	13,000	13,000	3 months
HCC Small Interactive Casual Networks	Ware. C.	National Science Foundation	-	147,931	3 years
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	-	180,720	3 years
Fault Thermal Structure and Stress Transfer Modeling to Assess Seismic Hazard Along Segmented Ocean Transforms Faults	Wolfson. M.	Exxon Mobil	-	7,500	-
TOTAL			1,266,469	2,477,384	

Appendix D: Publications

Journal Articles

Beaudoin, J., Sade A., Schulze B., and Hall J.K., "Dead Sea Multi-beam Echo Sounder Survey," *Hydro International*, Volume 15, pp.21-23.

Canning, C., Crain D., Eaton Jr. T.S., Nuesslya, K., Friedlaender, A.S., Hurst, T, Parks, S., Ware, C., Wiley, D.N., and Weinrich, M.T., "Population-level Lateralized Feeding Behaviour in North Atlantic Humpback Whales (Megaptera novaeangliae,)" *Animal Behavior*, Volume 82, pp. 901-909.

Kessler, J., Valentine, D., Redmond, M., Du, M., Chan, E., Mendes, S., Quiroz, E., Villanueva, C., Shusta, S., Werra, L., et al. (Weber, T.C.), "A Persistent Oxygen Anomaly Reveals the Fate of Spilled Methane in the Deep Gulf of Mexico," *Science*, Volume 331, pp. 312-315.

Masetti, G., and Orsini, F., "Il Regime Giuridico Relativo ai Relitti Delle Navi da Guerra," Informazioni delle Defesa, Volume 5.

Masetti, G., Sacile, R., and Trucco, A., "Remote Characterization of Seafloor Adjacent to Shipwrecks Using Mosaicking and Analysis of Backscatter Response," *Italian Journal of Remote Sensing*, Volume 43, pp.77-92.

Monfort, C., and Lippmann T.C., "Assimilation of Airborne Imagery with a Wave Model for Bathymetric Estimation," *Journal of Coastal Research*, Special Issue: Applied Lidar Techniques, Volume 62, pp.40-49.

Parrish, C.E., Jeong, I, Nowak, R.D., and Smith, R.B., "Empirical Comparison of Full-waveform Lidar Algorithms: Range Extraction and Discrimination Performance," *Photogrammetric Engineering and Remote Sensing*, Volume 77, pp.825-838.

Pe'eri, S., Gardner, J.V., Ward, L G., and Morrison, R.J., "The Seafloor: A Key Factor in Lidar in Bottom Detection," *IEEE Transactions on Geoscience and Remote Sensing*, Volume 49, Issue 3, pp.1150-1157.

Pe'eri, S., and Long, B., "Lidar Technology Applied in Coastal Studies and Management," *Journal of Coastal Research*, Volume S162, pp. 1-5.

Pe'eri, S., Morgan, L.V., Philpot, W.D., and Armstrong, A.A., "Shoreline Mapping Resolved from Airborne Lidar Bathymetry (ALB) Waveforms," *Journal of Coastal Research*, Special Issue: Applied Lidar Techniques, Volume 62, pp.75-85.

Rzhanov, Y., "Photo-Mosaicking of Images of Pipe Inner Surface," *Signal, Image and Video Processing*, Volume 5, pp.1-7.

Rzhanov, Y., Fonseca, L., and Mayer, L.A., "Construction of Seafloor Thematic Maps from Multibeam Acoustic Backscatter Angular Response Data," *Computers and Geosciences Journal*, Volume 37. Available online Sept. 2011.

Skarke, A., and Trembanis, A., "Parameterization of Bedform Morphology and Defect Density with Fingerprint Analysis Techniques," *Continental Shelf Research*, Volume 31, pp.1688-1700.

Uddin, W., Gutelius, B., and Parrish, C.E., "Airborne Laser Survey Specifications and Quality Management Protocols for Airport Obstruction Surveys," *Transportation Research Record*, Volume 2214, pp.117-125.

Ward, R., and Alexander, L., "The IHO's Involvement in e-Navigation," *IALA Bulletin*, Volume 2011, No. 1, pp. 26-27.

Ware, C., and Pineo, D., "Data Visualization Optimization via a Computational Model of Human Perception," *ACM Transactions on Visualization and Computer Graphics*, Volume 17, pp. 292-300.

Ware, C., Wiley, D.N., Bocconcelli, A., Cholewaik, D., Friedlaender, A.S., Thompson, M.A., and Weinrich, M.T., "Underwater Components of Humpback Whale Bubble-net Feeding," *Animal Behavior*, Volume 148, pp. 575-602.

Weber, T.C., De Robertis, A., Greenaway, S.F., Smith, S.M., Mayer, L.A., and Rice, G.A., "Estimating Oil Concentration and Flow Rate with Calibrated Vessel-mounted Acoustic Echo Sounders," *PNAS (Proceedings of the National Academy of Sciences of the United States of America)*, Volume 108.

Weber, T.C., Lyons, A.P., and Bradley, D.L., "Consistency in Statistical Moments as a Test for Bubble Cloud Clustering," *Journal of the Acoustical Society of America*, Volume 130, pp. 3396-3405.

White, S.A., Parrish, C.E., Calder, B.R, Pe'eri, S., and Rzhanov, Y., "Lidar-derived National Shoreline: Empirical and Stochastic Uncertainty Analyses," *Journal of Coastal Research*, Volume 62, pp.62-74.

Book

The Electronic Chart: Fundamentals, Functions and other Essentials, A Textbook for ECDIS Use and Training, Hecht, H, Berking, B., Jonas, M., and Alexander, L., 2011, Third Edition, Geomares Publishing, Lemmer, The Netherlands.

Conference Proceedings

Adams, T., Beets, P., and Parrish, C.E., Another Dimension from Lidar – Obtaining Foliage Density from Full Waveform Data, SilviLaser, Hobart, Tasmania, Australia, 16-20 October.

Alexander, L., e-Navigation and Pilotage: Challenges and Opportunities, 2011 Canadian Maritime Pilots Association Congress, Halifax, Nova Scotia, Canada, 5-8 July.

Alexander, L., IALA's Vision of e-Navigation, 2011 Canadian Maritime Pilots Association Congress, Halifax, Nova Scotia, Canada, 5-8 July.

Alexander, L., Providing Meteorological and Hydrographic Information via AIS Application-Specific Messages: Challenges and Opportunities, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Beaudoin, J., Smyth, S., Furlong, A., Floc'h, H., and Lurton, X., Streamlining Sound Speed Profile Pre-processing: Case Studies and Field Trials, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Beduhn, T. and Dijkstra, S.J., On the Horizon: Better Bottom Detection for Areas of Sub-aquatic Vegetation, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Burns, W., Johnson, G., Gonin, I., and Alexander, L., Testing of AIS Application-Specific Messages to Improve U.S. Coast Guard VTS Operations, e-Navigation Underway Conference, Copenhagen, Denmark, 31 January-2 February.

Butkiewicz, T., and Ware, C., Multi-touch 3D Exploratory Analysis of Ocean Flow Models, OCEANS MTS/IEEE 2011, Kona, HI, 19-22 September .

Calder, B.R., and Rice, G.A., Design and Implementation of an Extensible Variable Resolution Bathymetric Estimator, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Lanzoni, C., and Weber, T.C., A Method for Field Calibration of a Multibeam Echo Sounder, Oceans MTS/IEEE 2011, Kona, HI, 19-22 September.

Masetti, G., Trucco, A., and Sacile, R., Correzioni Geometriche e Radiometriche Applicabili a Valori di Backscatter Raccolti con Sistemi MBES Kongsberg EM 3002, 15th CONFERENZA NAZIONALE ASITA 2011, Reggia di Colorno, Italy, 15-18 November.

Rice, G.A., and Riley, J., Measuring the Water Level Datum Relative to the Ellipsoid During Hydrographic Survey, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Wilson, M., Miller J. J., Self Miller V., Mortimer K., and Wyllie K., Improved Raster Navigation Products from High Resolution Source Data, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Abstracts

Ackerman, S, Pe'eri, S., Bernhardt, W., Andrews, B., and Gardner J.V., Fine-scale Sediment Distribution at the Mouth of the Merrimack River, Coastal Geotools 2011, Myrtle Beach, SC, 21-24 March.

Bell, K.L., Ballard, R.D., Coleman, D.F., Roman, C., Brennan, M.L., Turanli, T., Duman, M., Carey, S., Nomikou, P., Marani, M., et al., New Frontiers in Ocean Exploration: The 2011 E/V *Nautilus* Field Season, 2011 American Geophysical Union Fall Meeting, San Francisco, CA, 5-9 December.

Brumley, K, Miller, E.L., Mayer, L.A., Wooden, J.L., and Dumitru, T.A., Petrography and U-Pb Zircon Geochronology of Caledonian Age Orthogneisses Dredged from the Chukchi Borderland, Arctic Ocean, 2011 American Geophysical Union Fall Meeting, San Francisco, CA, 5-9 December.

De Robertis, A., Weber, T.C., Mayer, L.A., and Wilson, C., Acoustic Observations of the Deep Scattering Layer During the Deepwater Horizon Oil Spill, 161st Meeting of the Acoustical Society of America, Seattle, WA, 23-27 May.

Gardner, J.V., and Armstrong, A.A., From Seafloor Mapping to Geological Processes: New Insights in Marine Geomorphic Features Using High-resolution Acoustic Imaging Techniques, 2011 American Geophysical Union Fall Meeting, San Francisco, CA, Dec. 5-9.

Gardner, J.V., and Armstrong, A.A., Western Pacific Bathymetry Mapping for U.S. Law of the Sea, U.S. Hydrographic Conference, Tampa, FL, 25-28 April.

Jones, D., Weber, T.C., Rooper, C., Butler, J., Wilson, C., and De Robertis, A., Assessing Rockfish Abundance in Complex Habitats Using Acoustics and Cameras, 161st Meeting of the Acoustical Society of America, Seattle, WA, 23-27 May.

Lippmann, T.C., and Rzhanov, Y., Digital Airborne Vide System for Unbiased Image Matching with Shallow Water Applications, 12th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, Baltimore, MD, 21-22 June.

Pe'eri, S., Ackerman, S., Guilford, J., Gardner, J.V., and Morris, A., Ground Truth Operation for Seafloor Characterization, Coastal Geotools 2011, Myrtle Beach, SC, 21-24 March.

Pe'eri, S., Guilford, J., Lundgren, I., and Battista, T., Buck Island, St. Croix - Seafloor Characterization Using Optic Remote Sensing, 12th Annual JALBTCX Airborne Coastal Mapping & Charting Technical Workshop, Baltimore, MD, 21-22 June.

Rzhanov, Y., Cutter, Jr., R.G., Matal, Y., and Kastner, R., Detection, Measurement and Recognition of Fish Species Underwater, Mesh Atlantic Video Survey Techniques Workshop, Faro, Algarve, Portugal, 20-22 June.

Rzhanov, Y., Pe'eri, S., and Gardner, J.V., Airborne Hyperspectral Co-registration Independent from Attitude and Positioning Sensors, Coastal GeoTools 2011, Myrtle Beach, SC, 21-24 March.

Rzhanov, Y., Pe'eri, S., Guilford, J., and Gardner, J.V., Seafloor Characterization Using Airborne Hyperspectral Co-registration Procedures Independent from Attitude and Positioning Sensors, Coastal Geotools 2011, Myrtle Beach, SC, 21-24 March.

Šaškov, A., and Rzhanov, Y., Video Mozaikos Metodo Panaudojimas Povandeniniams Tyrimams, National Lithuanian 5th Conference "Juros ir krantu tyrimai - 2011" (Sea and shore researches - 2011), Palanga, Lithuania, 12-15 May.

Schroth-Miller, M., and Weber, T.C., Assessing Juvenile Atlantic Bluefin Tuna Schools in the Northwest Atlantic Using Sonar Data and Aerial Imagery, 161st Meeting of the Acoustical Society of America, Seattle, WA, 23-27 May.

Schroth-Miller, M., and Weber, T.C., Estimating Atlantic Bluefin Tuna Number Density Using the Second Moment of Intensity, Acoustical Society of America, San Diego, CA. 31 October-4 November.

Weber, T.C., Beaudoin, J., Shedd, B., Malik, M.A., Jerram, K., Rice, G.A., and Mayer, L.A., Detecting and Mapping Gas Seeps with a Deepwater Multibeam Echosounder, Subsea and Arctic Leak Detection Symposium, Houston, TX, 8-9 November.

Weber, T.C., Schroth-Miller, M., Lutcavage, M., Pe'eri, S., and Rzhanov, Y., Mid-frequency Backscatter from Spatially Organized Fish Schools, 162nd Meeting of the Acoustical Society of America, San Diego, CA, 31 October-4 November.

Ware, C., Friedlaender, A.S., Tyson, R.B., and Nowacek, D.P., Using Multi-sensor Suction Cup Tags to Quantify the Kinematics of Lunge Feeding in Humpback Whales (Megaptera Novaeangliae) in the Water Around the West Antarctic Peninsula, Fourth International Science Symposium on Bio-logging, Hobart, Tasmania, Australia, 14-18 March.

Conference Presentations and Talks

Alexander, L., "Canadian Coast Guard's Vision and Plans for Implementing e-Navigation," 2011 Regional e-Navigation Conference, Busan, South Korea, 16-18 February.
Alexander, L., "Development and Use of Bathymetric River Information Overlays," Smart Rivers 2011 Conference, New Orleans, LA, 13-15 September.

Alexander, L., "ECDIS Issues and Awareness: The Good, Bad, and Ugly," Florida Maritime Pilots Association Conference, Duck Key, FL, 14-16 November.

Alexander, L., "ECDIS Issues and Awareness: The Good, Bad, and Ugly," eNavigation 2011 Conference, Seattle, WA, 29-30 November.

Alexander, L., "e-Navigation: Frequently Asked Questions -- Looking for Good Answers," Port of Montreal/ Shipping Federation of Canada, Montreal, Quebec, Canada, 9 February.

Alexander, L., "Production and Use of Bathymetric River Information Overlays (RIOs)," Technical Workshop, 2011 U.S. Hydrographic Conference, Tampa, FL, 25 April.

Alexander, L., "Production and Use of Bathymetric River Information Overlays (RIOs)," Inland ENC Harmonization Group (IEHG), Chongqing, Chongqing, China, 17 October.

Alexander, L., "Role and Involvement of IALA in Implementing e-Navigation," 2011 Regional e-Navigation Conference, Busan, South Korea, 16-18 February.

Alexander, L., "S-100 Standard and Geospatial Information Registry," Inland ENC Harmonization Group (IEHG), Chongqing, Chongqing, China, 17 October.

Beaudoin, J., "Sound Speed Error Wedges," NOAA Field Procedures Workshop, Norfolk, VA, 24-28 January.

Beaudoin, J., "Geocoder Update," NOAA Field Procedures Workshop, Norfolk, VA, 24-28 January.

Beaudoin, J., "Oceanographic Pre-analysis: High Density Oceanographic Sampling Campaigns in Support of Hydrography," JHC/CCOM, Durham NH, 11 February.

Calder, B.R., "Multipurpose Sonar Mapping & Integrated Ocean and Coastal Mapping," BOEMRE Atlantic Wind Energy Workshop, Herndon, VA, 12-14 July. [Invited, Panel]

Calder, B.R., "Ocean Mapping with Multibeam Echosounders," University of Connecticut COSEE-TEK Ocean Technology Panel, Groton, CT, 11 November. [Invited]

Fandel, C., "The Formation and Maintenance of Pockmarks in Belfast, ME," Healy Science Party and USCG, Barrow, AK, 26 September.

Lippmann, T., "Very Shallow Water Mapping and the Seamless Coast," NOAA Site Review, Durham, NH, 26 July.

Lobecker, M., Baker, E., Walker, S., White, S., Embley, R., Resing, J., "OS22A-08 GALREX 2011: Extensive Hydrothermal Venting Discovered Along the Eastern Galápagos Rift," Fall Meeting, American Geophysical Union, San Francisco, CA, 5-9 December.

Lutcavage, M., Weber, T., Galuardi B., Heller, M., Pe'eri, S., and Rzhanov, Y., "Combining Aerial and Acoustic Methods to Develop Fishery Independent Approaches for Assessment of Atlantic Bluefin Tuna in the NW Atlantic," SCRS meeting, Barcelona, Spain, 2-4 March.

Malik, M., "Towards Estimation of Uncertainty in the Measurement of the Seafloor Acoustic Backscatter," JHC/CCOM Seminar Series, Durham, NH, 4 February.

Mayer, L.A., "Adventures in Arctic Mapping," Dinner Lecture, UNH Foundation, Durham, NH, 9 November.

Mayer, L.A., "Arctic Marine Research: The Perspective of a U.S. Practitioner," International Conference on Arctic Marine Science, International Law and Climate Protection, hosted by the German Federal Foreign Office and Ministry of Foreign Affairs of Finland, Berlin, Germany, 17 March. [Invited Talk]

Mayer, L.A., “Battle for the Arctic?” Keynote Speaker – Heritage Dinner, Seacoast Science Center, Rye, NH, 10 February.

Mayer, L.A., “The Continental Shelf and Sea Level Change,” International Conference on Maritime Boundary Diplomacy, Bali, Indonesia, 23 June. [Invited Talk]

Mayer, L.A., “Hydrographic Science and the Deepwater Horizon,” Keynote Address, U.S. Hydrographic Conference, Tampa, FL, 26 April.

Mayer, L.A., “Law of the Sea and Mapping the Extended Continental Shelf in the Arctic,” Roger Williams Law School, Bristol, RI, 11 October. [Invited Lecture]

Mayer, L.A., “Mapping in the Gulf of Mexico After the Deepwater Horizon Spill,” Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia, 7 April. [Invited Lecture]

Mayer, L.A., “New Approaches to Seafloor Mapping: From D-Day to Deepwater Horizon,” Keynote Public Lecture, Oceans Week, Halifax, Nova Scotia, Canada, 1 June.

Mayer, L.A., “Ocean Mapping: A Fundamental Tool for Ocean Exploration,” BPPT (Agency for Assessment and Advancement of Technology), Jakarta, Indonesia, 8 April. [Invited Lecture]

Mayer, L.A., “Ocean Mapping and the Deepwater Horizon Spill,” URI Graduate School of Oceanography Lecture Series, Narragansett, RI, 14 October. [Invited Lecture]

Mayer, L.A., “Ocean Mapping and the Deepwater Horizon Oil Spill,” U.S./Japan Natural Resources Subcommittee on Seafloor Mapping, Boulder, CO, 1 December. [Invited Lecture]

Mayer, L.A., “Status of U.S. Arctic Mapping Activities,” Arctic-Antarctic Mapping, Stockholm, Sweden, 3 May. [Invited]

Mayer, L.A., “Status of U.S. Arctic Mapping Activities,” Navigation, Hydrography and Oceanography: Priorities of Development and Innovations of Maritime Activities, “NHO-2011,” St. Petersburg, Russia, 18 May. [Invited]

Mayer, L.A., “Status of U.S. Bathymetric Mapping in the Arctic,” A-5 Arctic Summit, Copenhagen, Denmark, 16 November. [Invited Lecture]

Mitchell, G., Thesis Research and Prior Experiences with ROVs and AUVs, Oyster River Middle School, Durham, NH, 15 November.

Monahan, D., “All Bathymetry is Predicted Bathymetry: Ponderings and Prognostications after 40 ± 5 at 95% Confidence Years of Being a Bathymetrist,” JHC/CCOM, Durham, NH, 11 April.

Monahan, D., “Who Owns the Sea? - How UNH Scientists are Helping to Resolve ‘Law of the Sea’ Conflicts About Jurisdiction over the Continental Shelf Using Underwater Mapping,” Know the Coast Day, Marine Programs, UNH, Durham, NH, 15 October.

Monahan, D., “The United Nations Convention on the Law of the Sea (UNCLOS) and Its Implications for Geomatics,” GGE, University of New Brunswick, Fredericton, New Brunswick, Canada, 15 November.
Parrish, C.E., and Osiri, R., “Lidar Wavelength Considerations and Radiometric Performance Analysis for Coastal Applications,” 2011 American Geophysical Union Fall Meeting, San Francisco, CA, 5-9 December. [Invited]

Pirtle, J., "Adventures in Fisheries Habitat Research: The Secret Lives of Rockfishes and King Crab," Prince William Sound Science Center and Chugachmiut Heritage Foundation, Cordova, AK, 12 April.

Pirtle, J., "Habitat Structure Influences Survival and Predator-Prey Interactions of Early Juvenile Red King Crab, Paralithodes Camtschaticus," American Academy of Underwater Sciences, Portland, ME, 14 October.

Pirtle, J., "Personal Experience of My Career in Marine Science," Prince William Sound Science Center and Chugachmiut Heritage Foundation, Cordova, AK, 11-13 April.

Pe'eri, S., "Seafloor Characterization Based on Data from Airborne Lidar Bathymetry, Hyperspectral Imagery, and Bottom Sampling," USGS, Woods Hole, MA, 3 October.

Pe'eri, S., "Seafloor Characterization Using Optic Remote Sensing," JHC/CCOM (ESCI/OE 870 Introduction to Ocean Mapping), Durham, NH, 8 February.

Pe'eri, S., Korea Ocean Research and Development Institute (KORDI), Maritime and Ocean Engineering Research Institute (MOERI), Uljin, South Korea, 27 June.

Pe'eri, S., "Optical Remote Sensing Technology for Ocean Mapping Technology," Korea Ocean Research and Development Institute (KORDI), East Sea Branch, Uljin, South Korea, 29 June.

Pe'eri, S., "Optical Remote Sensing Technology for Ocean Mapping Technology," Korea Maritime University (KMU), Busan, South Korea, 30 June.

Pe'eri, S., "Littoral Mapping Using: 1. Airborne Lidar Bathymetry (ALB); 2. Hyperspectral Imaging (HSI)," Ohio State University (OSU), Department of Civil and Environmental Engineering and Geodetic Science, Columbus, OH, 18 February.

Pe'eri, S., "Brown Bag Seminar: Seafloor Characterization Using Optic Remote Sensing," Department of Earth Sciences, UNH, Durham, NH, 3 November.

Rice, G., "Measuring the Water Level Datum Relative to the Ellipsoid During Hydrographic Survey," Center for Coastal and Ocean Mapping, Durham, NH, 4 March.

Rzhanov, Y., "Pipe Inspection: Insider's View," JHC/CCOM, Durham, NH, 28 October.

Schmidt, V., "Challenges of AUV Operations for Ocean Mapping," Unmanned Untethered Submersible Technology, Portsmouth, NH, USA, 22-24 August.

Schmidt, V. "Adventures in Iceberg Mapping," Center for Coastal and Ocean Mapping, Durham, NH, 4 November.

Ward, L., "Importance of Sediment Deposits in Great Bay Estuary, New Hampshire," Southeast Watershed Alliance Symposium, Portsmouth, NH, 11 November.

Ward, L., "Seafloor Characterization Studies in the Western Gulf of Maine: New Hampshire Shelf to Jeffreys Ledge," University of New Hampshire, Department of Earth Sciences, Durham, NH, 27 October.

Theses and Directed Research

Abramova, A., *Comparison and Evaluation of Publicly Available Bathymetry Grids in the Arctic*, Master of Science, University of New Hampshire, Durham, NH (Thesis).

Alavera, J.A., *Acoustic Backscatter Processing for the Navy of Ecuador*, Master of Science, University of New Hampshire, Durham, NH (Directed Research).

Beduhn, T., *A Case Study of Robust Bottom Detection and Eelgrass Mapping in Great Bay, New Hampshire*, Master of Science, University of New Hampshire, Durham, NH (Directed Research).

Kuenzel, N.A., *Quantitative Morphological Analysis of Submarine Canyon-channel Systems on the U.S. Atlantic Continental Margin*, Master of Science, University of New Hampshire, Durham, NH (Thesis).

Lanzoni, C., *Field Calibration Methodology for a Multibeam Echo Sounder Using a Split Beam Sonar System and a Standard Target*, Master of Science, University of New Hampshire, Durham, NH (Thesis).

Osiri, R., *Radiometric Calibration and Evaluation of Lidar Data for Coastal Science Applications*, Master of Science, University of New Hampshire, Durham, NH (Directed Research).

Reports

Alexander, L., "Electronic Chart System-related Findings Pertaining to the Queen of the North Sinking, Final Report," British Columbia Ministry of Attorney General, Vancouver, British Columbia, Canada, 25 pp.

Armstrong, A.A., "U.S. Extended Continental Shelf Cruise to Map Sections of the Mariana Trench and the Eastern and Southern Insular Margins of Guam and the Northern Mariana Islands," Center for Coastal and Ocean Mapping / Joint Hydrographic Center, Durham, NH, 45 pp.

Dijkstra, S.J., and Armstrong. A.A., "IHO/FIG/ICA Category A Course Program Submission," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, Durham, NH, 354 pp.

Gardner, J.V., and Calder, B.R., "U.S. Law of the Sea Cruise to Complete the Mapping of Necker Ridge, Central Pacific Ocean," Center for Coastal and Ocean Mapping (CCOM)/Joint Hydrographic Center (JHC), Durham, NH, 59 pp.

Lippmann, T.C., "Africa Partnership Station," Office of Naval Reasearch (ONR), Durham, NH, 7 pp.

Lippmann, T.C., "Large Scale Observation of Fine-scale Seabed Morphology and Flow Structure in Tidally Modulate Inlets," Office of Naval Reasearch (ONR), Durham, NH, 7 pp.

Mayer, L.A., and Armstrong, A.A., "U.S. Law of the Sea Cruise to Map the Foot of the Slope and 2500-m Isobath of the U.S. Arctic Ocean Margin," Center for Coastal and Ocean Mapping (CCOM)/Joint Hydrographic Center (JHC), Durham, NH, 235 pp.

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

Pirtle, J., Wilson, C., Rooper, C., Weber, T.C., and Heifetz, J., "Essential Fish Habitat Project Status Report," NOAA Alaska Fisheries Science Center, Seattle, WA, 6 pp.

Rice, G.A., Weber, T.C., Beaudoin, J., and Pirtle, J., "Descriptive Report for Project BY1001," NOAA Integrated Ocean and Coastal Mapping Center, Durham, NH.

Schmidt, V.E., "Empirical Uncertainty Estimation for the Klein 5000v2 Sonar," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, Durham, NH.

Posters

Beaudoin, J., Johnson, P., Ferrini, V., "Optimizing Multibeam Data Quality Across the Fleet," RVTEC 2011, New Orleans, LA, 14-18 November.

Gardner, J.V., Armstrong A.A., "The Mariana Trench: A New View Based on Multibeam Echosounding," 2011 American Geophysical Union Fall Meeting, San Francisco, CA, USA, 4-9 December.

Ware, C., Butkiewicz, T., "Exploratory Analysis of Ocean Flow Models with Stereoscopic Multi-touch," IEEE Visualization Conference, Providence, RI, 24-28 October.

Ware, C., Friedlaender, A., Hazen, E., Halpin, P., Stimpert, A., Tyson, R.B., Nowacek, D., "Decisions, Decisions. Direct Measurements of Humpback Whale Feeding in Relation to Vertically Stratified Humpback Whale Feeding in Relation to Vertically Stratified Prey Abundance," 19th Biennial Conference on the Biology of Marine Mammals, Tampa, FL, 28 November-2 December.

Ware, C., Pilar, D., "Building a Better Wind Barb," IEEE Visualization Conference, Providence, RI, 24-28 October.

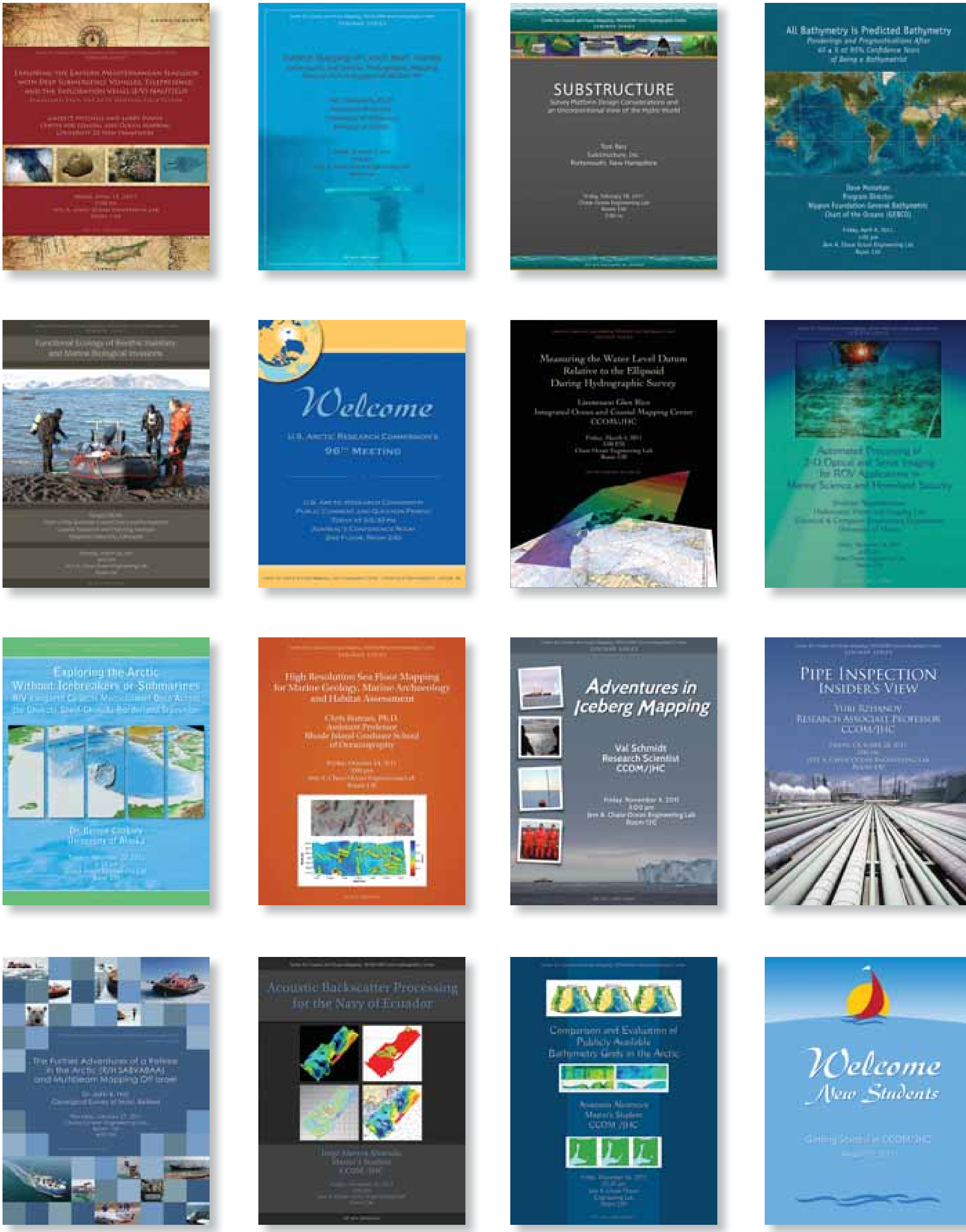
Ware, C., Tyson, R.B., Friedlaender, A.S., Stimpert, A.K., Nowacek, D.P., "Humpback Whale (*Megaptera novae-angliae*) Mother and Calf Foraging Behavior: Insights from Multi-sensor Suction Cup Tags," Fourth International Science Symposium on Bio-logging, Hobart, Tasmania, Australia, 14-18 March.

Ware, C., Tyson, R., Friedlaender, A., Ari, S., Stimpert, A.K., Nowacek, D.P., "In Sync? Humpback Whale (*Megaptera novaeangliae*) Mother and Calf Foraging Behavior in the Western Antarctic Peninsula," 19th Biennial Conference on the Biology of Marine Mammals, Tampa, FL, 28 November-2 December.

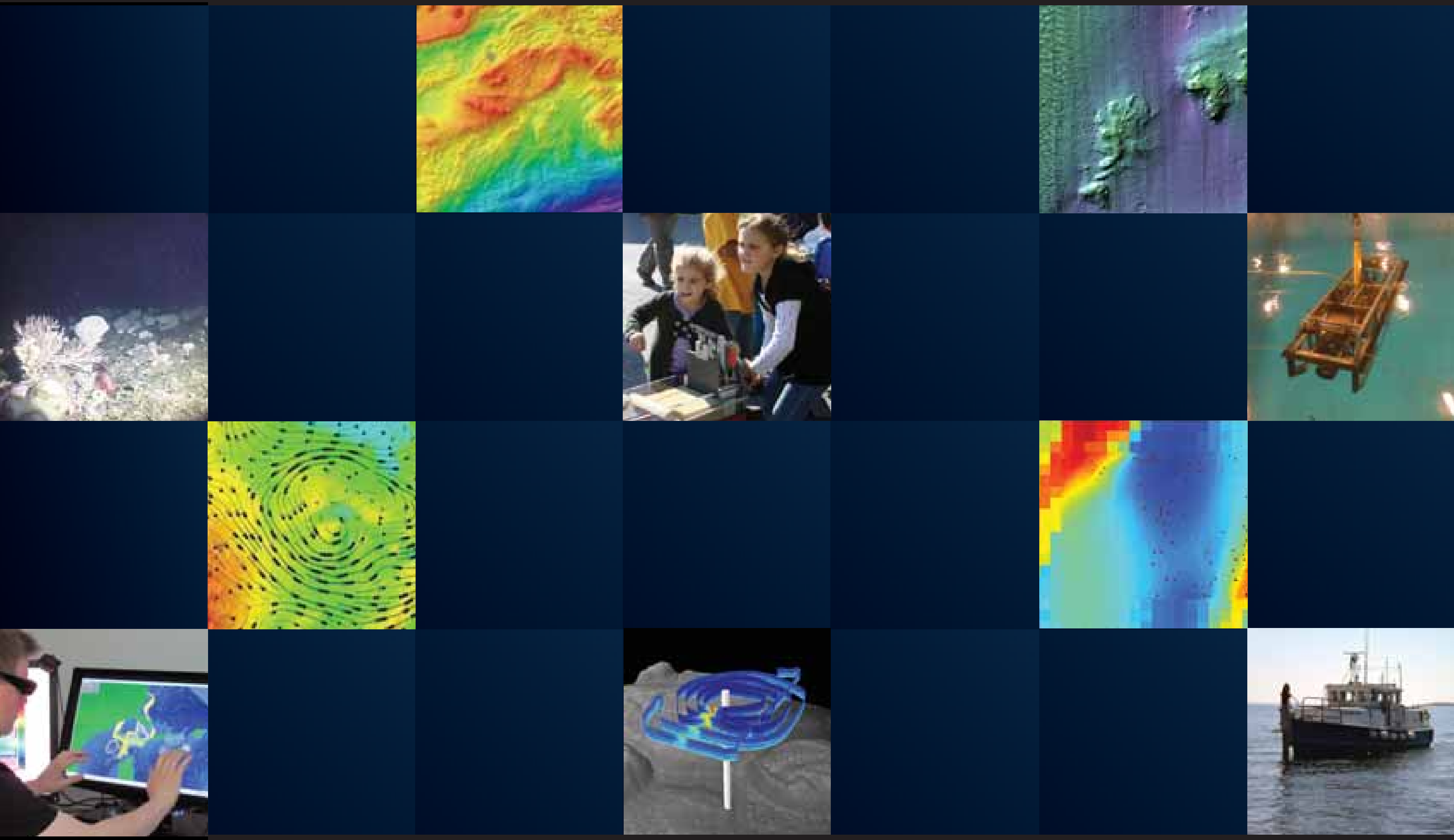
Ware, C., Wiley, D., Friedlaender, A.S., Burgess, W., Nowacek, D., Weinrich, M., Tyson, R.B., Maresh, J. "TrackPlot: Helping to Identify Kinematic Patterns in the Trajectories of Tagged Marine Mammals," 19th Biennial Conference on the Biology of Marine Mammals, Tampa, FL, 28 November-2 December.

Ware, C., and Wright, W., "AARCS Animated Attention Redirection Codes," IEEE Visualization Conference, Providence, RI, 24-28 October.

Wolfson, M., Boettcher, M., McGuire, J., Collins, J., "Absolute Locations of Repeating Mw 5.5 - 6.0 Earthquakes on Discovery Transform Fault, EPR," 2011 American Geophysical Union Fall Meeting, San Francisco, CA, 5-9 December.



Flyers from the 2011 JHC/CCOM Seminar Series and welcome signs.



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