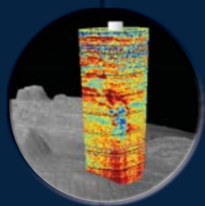

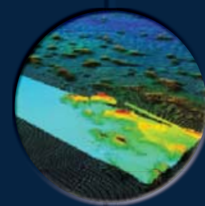


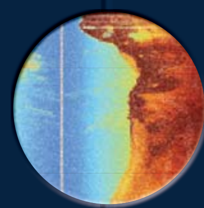


UNH/NOAA Joint Hydrographic Center

Performance and Progress Report

Project Title: Joint Hydrographic Center
Report Period: 01/01/2010 – 12/31/2010

Principal Investigator:
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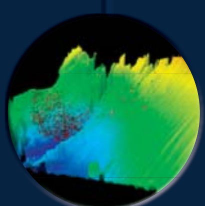
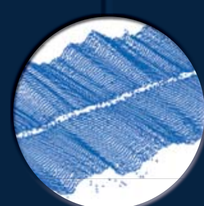
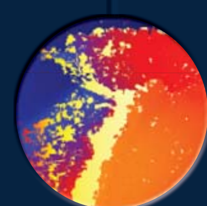
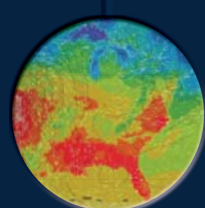
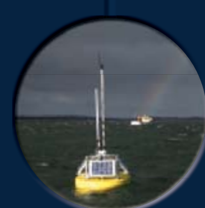
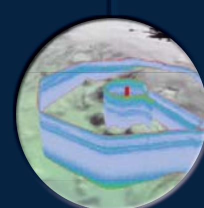
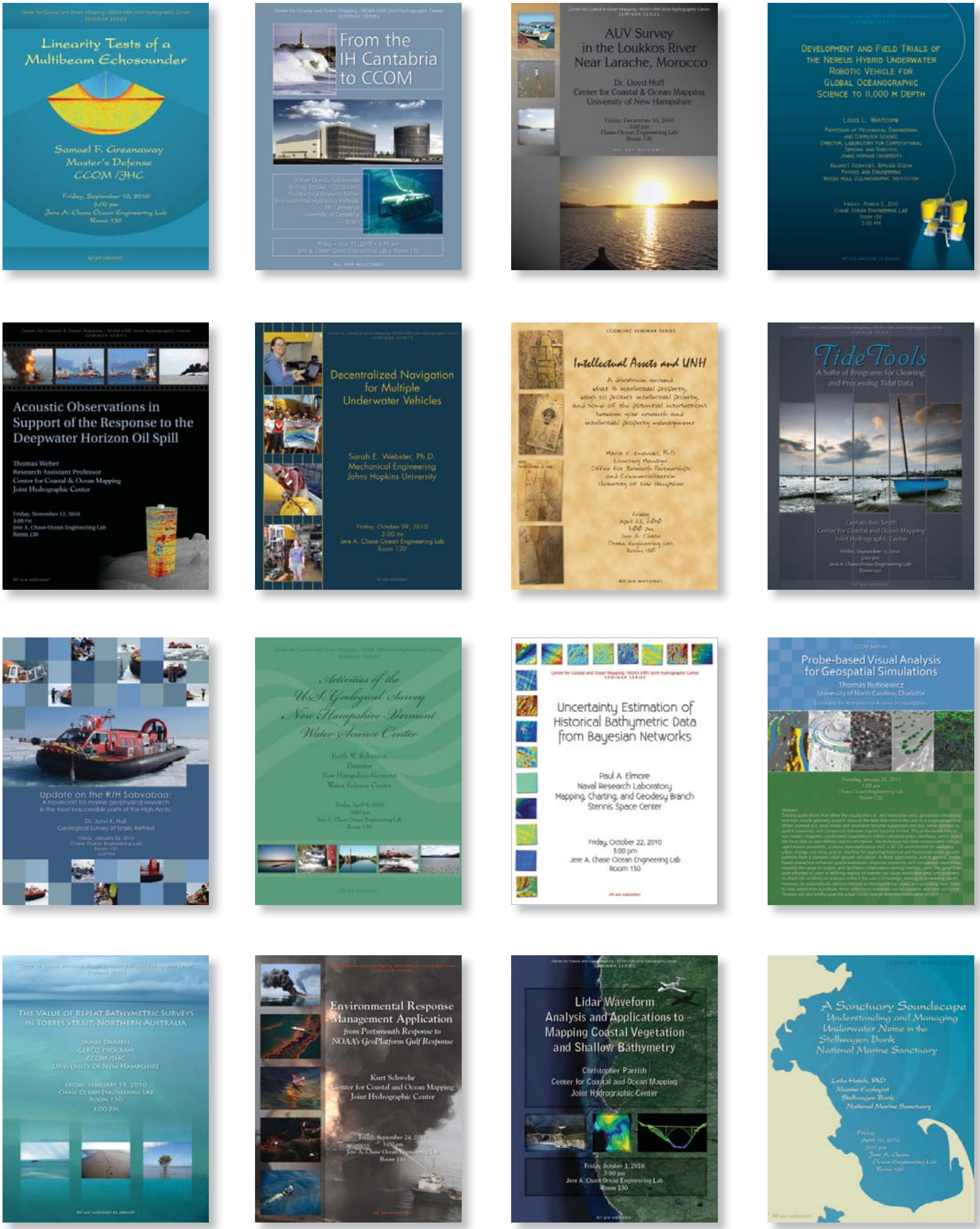




Flyers from the 2010 CCOM/JHC Seminar Series.

The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded eleven years ago with the objective of developing tools and offering training that would help NOAA and others to meet the challenges posed by the rapid transition from the sparse measurements of depth offered by traditional sounding techniques (lead lines and single-beam sonars) to the massive amounts of data collected by the new generation of multibeam echo sounders. An initial goal of the Center was to find ways to process the massive amounts of data and high-resolution sidescan sonars coming from these Multibeam and sidescan sonar systems at rates commensurate with data collection; that is, to make the data ready for chart production as rapidly as the data could be collected. Over the years, we have made great progress in attaining 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. This past year the concept of IOCM was epitomized when we were able to quickly and successfully apply tools and techniques developed for hydrographic and fisheries applications to the Deepwater Horizon oil spill crisis.

In the relatively short period of time since our establishment, we have built a vibrant Center with over 70 employees and an international reputation as the place, *"where the cutting edge of hydrography is now located"* (Adam Kerr, Past Director of the International Hydrographic Organization in Hydro International). In the words of Pat Sanders, President of HYPACK Inc., a leading provider of hydrographic software to governments and the private sector:

> *"JHC/CCOM has been THE WORLD LEADER in developing new processing techniques for hydrographic data. JHC/CCOM has also shown that they can quickly push new developments out into the marketplace, making both government and private survey projects more efficient and cost effective."*

Since our inception, we have worked on the development of automated and statistically robust approaches to multibeam sonar data processing. These efforts came to fruition when our automated processing algorithm (CUBE) and our new database approach (The Navigation Surface), were, after careful verification and evaluation, accepted by NOAA, the Naval Oceanographic Office and other hydrographic agencies, as part of their standard processing protocols. Today, almost every hydrographic software manufacturer has, or is, incorporating these approaches into their products. It is not an overstatement to say that these techniques are revolutionizing the way NOAA (and soon the rest of the ocean mapping community) is doing hydrography. These techniques reduce data processing time by a factor of 30 to 70 and provide a quantification of error and 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, NOAA IOCM Coordinator and former director of NOAA's Office of Coast Survey).

The acceptance of CUBE and the Navigation Surface represents a paradigm shift for the hydrographic community—from dealing with individual soundings (reasonable in a world of lead line and single-beam sonar measurements) to the acceptance of gridded depth estimates (with associated uncertainty values) as a starting point for hydrographic products. The research needed to support this paradigm shift has been a focus of the Center since its inception and to now see it being accepted is truly rewarding. It is also indicative of the role that the Center has played and will continue to play, in establishing new directions in hydrography and ocean mapping.

Another long-term theme of our research efforts has been our desire to extract information beyond depth (bathymetry) from the mapping systems used by NOAA and others. We have made significant progress in developing a simple-to-use tool (GeoCoder) for generating a sidescan-sonar or backscatter "mosaic"—a critical first step in analyzing the seafloor character. There has been tremendous interest in this software throughout NOAA and many of our industrial partners have now incorporated GeoCoder into their software products. Like CUBE's role in bathymetric processing, GeoCoder is becoming the standard approach to backscatter processing. An email from a member of the Biogeography Team of

NOAA's Center for Coastal Monitoring and Assessment said:

> *"We are so pleased with GeoCoder! We jumped in with both feet and made some impressive mosaics. Thanks so much for all the support."*

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 have been 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 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 3-D in real-time. Although the ability to map 3-D targets in a wide swath around a survey vessel has obvious applications in terms of fisheries targets (and we are working with fisheries scientist to exploit these capabilities), it also allows careful identification of shallow hazards in the water-column and may obviate the need for wire sweeps or diver examinations to verify least depths in hydrographic surveys. These water-column mapping tools were a key component to our efforts to map submerged oil and gas seeps and monitor the integrity of the Macondo 252 wellhead as part of the national response effort to the Deepwater Horizon oil spill.

The value of our visualization, water-column mapping, and Chart of the Future capabilities have also been demonstrated by our work with Stellwagen National Marine Sanctuary aimed at facilitating an adaptive approach to reducing the risk of collisions between ships and endangered North American Right Whales in the sanctuary. We have developed 4D (space and time) visualization tools to monitor the underwater behavior of whales as well as to notify vessels of the presence of whales in the shipping lanes and to monitor and analyze vessel traffic patterns. Describing our interaction with the sanctuary, Craig MacDonald, superintendent 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., 3-D 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 EMB requirement that is often neglected. These contributions have allowed NOAA and the sanctuary to occupy a lead position in CMSP and EMB, 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. Although we believe the Center has met its initial goals, 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.

Our efforts in 2010 represent a careful combination of the continued growth and refinement of successful ongoing research programs with the initiation of several exciting new tasks. 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 LT JG Glen Rice (currently assigned to the JHC/CCOM IOCM Processing Center) have begun to investigate the use of 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) and preliminary testing has taken place. These tests show that the mechanisms designed to estimate data density from raw data are working and that data density can be transformed into resolution estimates that appear to be sufficiently smoothly varying enough to allow the system to operate as expected.

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.

Work continues on identifying and attempting to reduce many of the sources of uncertainty associated with hydrographic data. With the arrival to the Center of Jonathan Beaudoin, we have begun to take a serious look at one of the largest sources of uncertainty, the temporal and spatial variability of the sound-speed structure in water-column. The community is increasingly relying on high-speed sound-speed profiling systems to provide our sound-speed profiles, yet little is known about the response time of the sensors mounted on these profilers. To address this, Jonathan is looking at the impact of sensor latency on sound-speed derived from these systems as well as attempting to estimate the total sensor-suite uncertainty. He is also looking at the effect of internal waves on sound-speed estimates and thus multibeam sonar accuracy. Our efforts to quantify and limit uncertainty also extend to backscatter as Mashkoor Malik is finishing a Ph.D. project that has attempted to quantify the sources of uncertainty in multibeam-sonar backscatter.

Our efforts to understand uncertainty and improve data-processing flow have also expanded to an alternative type of swath-mapping sonar – those that use multi-rows of offset side-scan sonar 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

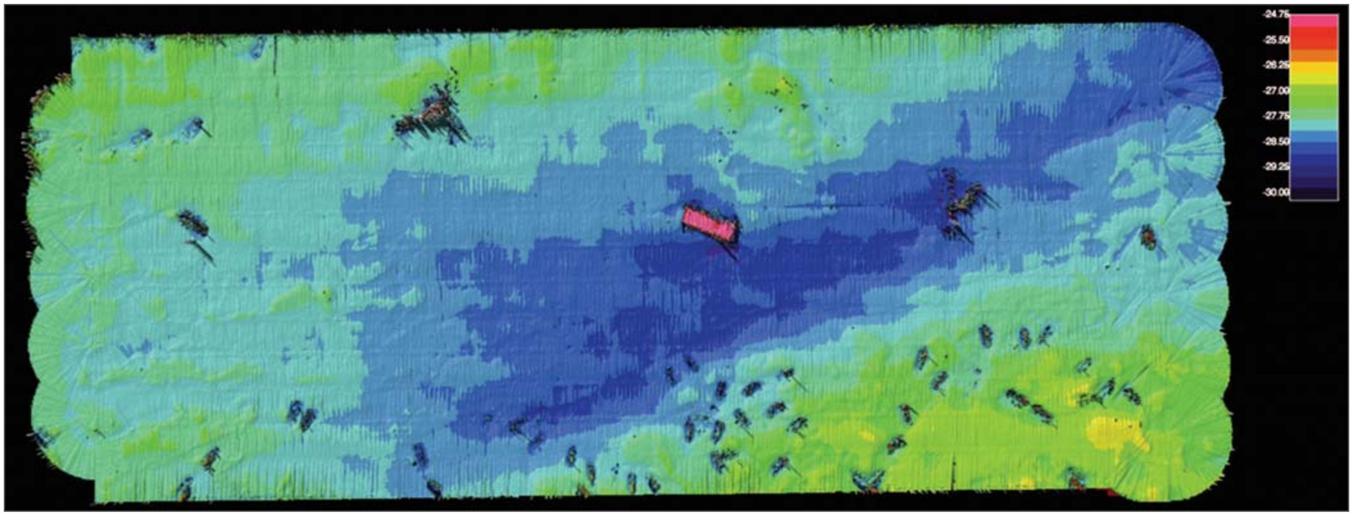


Figure 1. Phase-measuring bathymetric sonar data processed by "Most Probable Angle" algorithm. Survey site is off the Delaware coast. Several sunken subway cars, a shipwreck and a sunken barge are clearly evident.

difficulties associated with processing. To address these issues, a team led by Val Schmidt has 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 (Figure 1).

The efficiency of multibeam-sonar mapping decreases as the water depths get shallower, yet the risks to navigation are typically magnified in the shoaliest 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. New and ongoing research at the Center is addressing how and when LIDAR can be applied operationally, how data can be used to support a broad range of coastal science and management objectives through the IOCM initiative, and how hardware and software improvements can help overcome current limitations. A team led by Shachak Pe'eri has conducted studies to empirically investigate the relationship between seafloor characteristics and LIDAR bottom detection through comparisons of data collected with two different bathymetric LIDAR systems and a multibeam sonar. The team's results illustrated the danger of assuming that the lack of a LIDAR bottom return indicates greater depths than those in adjacent areas with good bottom detection; there is strong correlation between detection patterns and bottom characteristics, independent of water depth. In fact, some areas in which there was no bottom detection were found to be shoaler than adjacent areas. The results of this work are proving beneficial to hydrographic agencies in planning LIDAR acquisition and interpreting results of existing surveys.

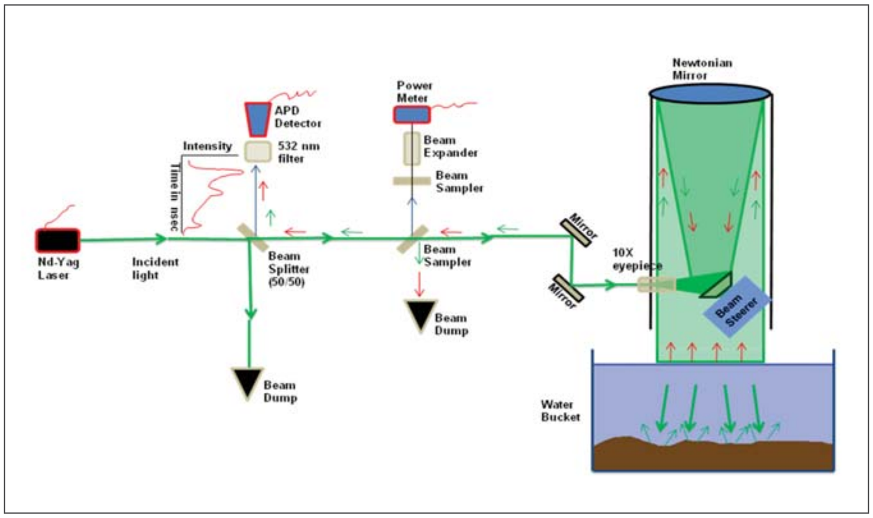


Figure 2. Schematic illustration of the bathymetric LIDAR simulator.

Our LIDAR-based efforts have also focused on developing techniques for using airborne LIDAR data for mapping shorelines, evaluating the uncertainty associated with terrestrial LIDAR determinations of shorelines and approaches for fusing multi-sensor data (LIDAR, hyperspectral data and optical imagery) so that a more complete suite of information can be derived about the coastal zone. With the seconding of Chris Parrish from the National Geodetic Service (NGS) to the Center, we are expanding our LIDAR-based activities and looking more closely at LIDAR waveform processing for enhanced target recognition and very shallow-water bathymetric measurements. We will also be looking at the performance of topographic LIDAR (operating at eye-safe 1550 nm wavelength) for coastal mapping.

As our focus turns to trying to understand the value of LIDAR-derived data for a number of hydrographic applications, it is becoming increasingly apparent that there are many uncertainties associated with airborne LIDAR bathymetry (ALB) measurements that are not well understood. Most critical among these uncertainties is the question of what happens to the laser beam once it strikes the sea surface and enters the water-column. To address this, the Center obtained a Q-switched Nd:YAG laser with a second-harmonic generator and constructed a "LIDAR simulator" (Figure 2) that will allow us to monitor the interaction of an appropriate laser beam under many different "sea" conditions. When deployed in our test tanks (which can generate many wave conditions and have depths up to 6 m), the LIDAR simulator will aid in understanding the ray-path geometry of the laser pulses from the laser into the water and its interaction with the seafloor and back through the water to the LIDAR detectors. From this understanding, a better estimate of the LIDAR propagation error can be produced.

In an attempt to extract more than just bathymetric data from seafloor surveys, we also are developing approaches for the quantitative determination of seafloor type that is so critical to habitat and other studies. Beyond GeoCoder, our sonar mosaicing software, the Center has developed analytical tools for the quantitative analysis of seafloor properties from sonar-backscatter data. This year we re-invigorated our seafloor characterization activities with the establishment of a research team focused on further development of characterization

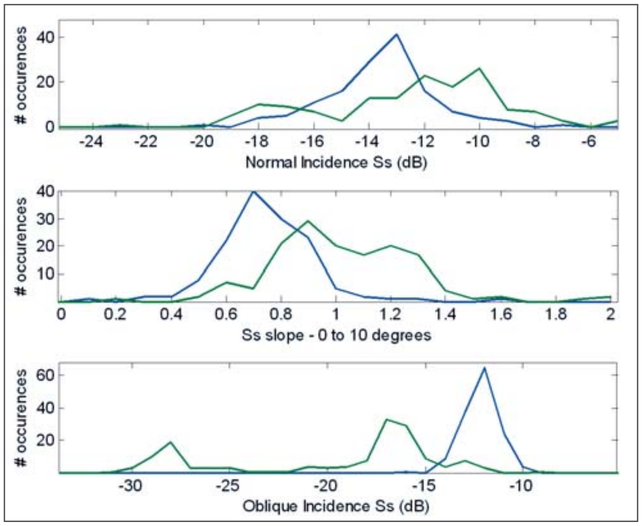


Figure 3. Three backscatter parameters and their relationship to whether the seabed is trawlable (green lines) or untrawlable (blue lines). Top: normal incident backscatter; Middle: the slope of the angular dependent backscatter between 0-10 degrees; Bottom: the oblique incidence backscatter (average between 30-60 degrees).

approaches. Concurrently, Tom Weber has successfully analyzed seafloor backscatter data from an ME-70 fisheries multibeam sonar and extracted useful information on the "trawlability" of the seafloor in the Gulf of Alaska (Figure 3).

In further recognition of the importance of developing techniques for very shallow-water mapping, the Center is also exploring other approaches. Tom Lippmann is continuing the development and upgrade of the CBASS (Coastal BAthymetry Survey System, a personal watercraft equipped with differential GPS, an on-board navigation system and a purpose built (for this environment) 192-kHz single-beam sonar (Figure 4). The CBASS has been used very successfully to map the shallowest regions of Portsmouth Harbor, NH and was able to survey all of Great Bay at 100-m line spacing, plus smaller regions at higher resolution (25-m line spacing or less) in 18 hours of survey time (300 line-kms). This year the system will be upgraded with a new single-beam sonar with full-waveform recording capability, a small multibeam sonar, an ADCP and motion sensors, and will be extensively tested during an ONR experiment in New River Inlet, NC.

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 project has made important advances with the successful demonstration of the use of the Automatic Identification System (AIS) combined with our visualization tools for display of warnings of the presence of acoustically detected Right Whales in shipping lanes into and out of Boston Harbor (Figure 5). This project was cited by the White House Council on Environmental Quality as a prime example of Marine Spatial Planning. The ability of the AIS system to provide automated two-way communications with a vessel has opened up a world of possibilities in the context of safe navigation and other applications. Among the AIS-related

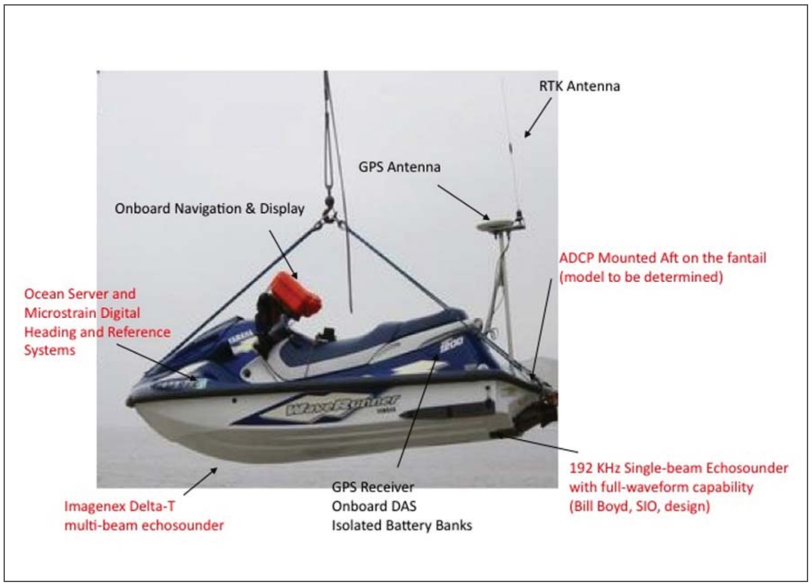


Figure 4. CBASS with 2010 upgrades (in red).

projects we are working on are: transmission of real-time water levels via AIS; the use of AIS data for hydrographic survey planning; approaches for using data from the Voluntary Observing Ship (VOS) of the World Meteorological Organization and NOAA's Automated Mutual Assistance Vessel Rescue System (AMVERS) for long-range tracking of vessels; and the use of satellite-based AIS (S-AIS) for world-wide AIS coverage. Efforts are also underway to ensure that the tools and outputs we develop are compatible with Google Earth. The Center has also developed software to display and distribute NOAA's Bathymetrically Attributed Grids (BAGS) in Google Earth and on EarthNC's Amazon S3 cloud service (Figure 5).

As a transitional entry in the world of the "Chart of the Future," the Center has developed and released a fully digital and interactive version of the Portsmouth Harbor section of the commonly used Coast Pilot books (GeoCoast Pilot). With such a digital product, the mariner can, 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 2-D or 3-D) of the object in geospatial context. Conversely, a click on a picture of an object will directly link to the full description of the object as well as other relevant information. GeoCoastPilot turns the NOAA CoastPilot® manual into an interactive document linked to a 3-D map environment, and provides links between the written text, 2-D and 3-D views, web content, and other primary sources such as charts, maps, and related federal regulations. A critical component of this effort has been devising methods and tools to transform the current text of the Coast Pilot into an XML form that allows for integration with other kinds of data, especially georeferencing information. It is this aspect that has generated the greatest interest from both NOAA and the commercial sector.

The Center is now working to deliver much of the GeoCoastPilot capability on small, spatially-aware, hand-held devices like the iPhone or a small tablet PC. The idea is to be able to point the device at the object of interest and have it provide necessary navigation information. In order to evaluate the human factors issues surrounding hand-held chart displays, we have developed a semi-circular virtual reality display (Figure 6). It has four projectors driven by a single high-end PC and runs open-source flight simulator software. This system enables us to take advantage or the terrain modeling and water rendering capabilities developed by others. It also allows us to simulate different times of day and different environmental conditions. Our software adds buoys and other targets for the purpose of the study. Although it is being developed primarily to understand the human factors associated with hand-held devices, the new semi-circular display offers numerous options for visualizing large geospatial datasets.

While our early visualization efforts focused on the 3-D interactive display of static features like the seafloor, the Center's recent efforts have expanded to the visualization of dynamic systems by bringing time in as a fourth dimension. We have developed four-dimensional, interactive software to aid in studies of the behavior of marine mammals as well as time-varying oceanographic and atmospheric processes. This past year, Colin Ware and Roland

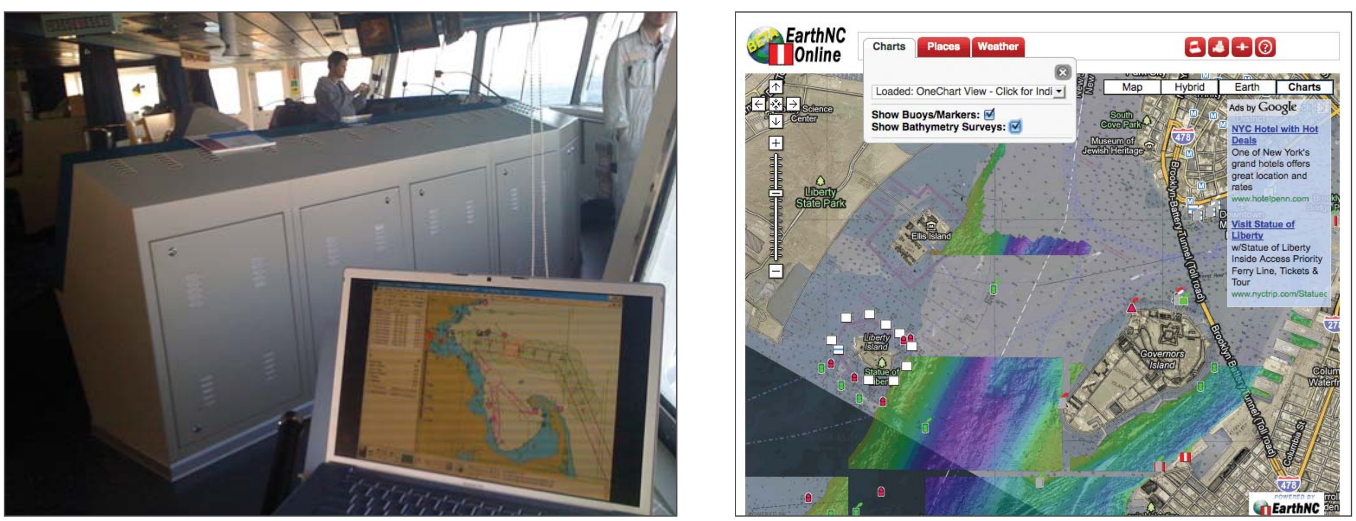


Figure 5. Aldebaran II on the bridge of an LNG carrier with Right Whale alerts on the ENC (left) and BAG displayed in EarthNC's online chart viewer (right).

Figure 6. The virtual environment shipboard simulation developed to test alternative chart display techniques. Note eye-tracking apparatus on the participant's head.

Arsenault continued to demonstrate the power of these software tools through their separately funded participation in a research project aimed at investigating predator-prey interactions and fine foraging behaviors of Humpback whales in fjords around Antarctica. With the tools developed at the Center, researchers were able to produce real-time 3-D maps of krill distributions (the prey) and then examine the behavior of tagged whales traveling through these prey-fields. Other tools have been developed at the Center to explore the feeding behavior (lunges) of whales as well as the reaction of whales and other marine mammals to the exposure to external sound sources.

As we acknowledge (and can now more precisely measure) that the environments we study change in both space and time, our ability to visualize both spatial and temporal changes opens up a world of opportunities for studying many components of the ocean that are important to NOAA and others. Foremost among these have been our interactive 4D visualization of the 26 Dec 2004 Indian Ocean tsunami and our recent work on three-dimensional ocean flow fields. The Center has teamed up with NOAA (and other) ocean modelers to produce high-resolution visualizations of multi-level flow that can be useful for better understanding local navigation (e.g., a component of the "Chart of the Future") or global circulation. Colin Ware's representation of global ocean circulation using particle fields is now featured as part of the permanent "Science on a Sphere" exhibit at the Sant Ocean Hall of the Smithsonian Museum of Natural History in Washington, DC. Our optimized flow visualization software (FlowVis2D) has now been operating in NOAA's nowCoast since last year and played a key role in the GeoPlatform software that helped support the Deepwater Horizon spill response. Upgrades to the flow visualization software have added the ability to show flow for different depths and vertical cross-sections.

Following from the flow-visualization software, Colin Ware has been working with Matt Plumlee to develop methods to optimize multivariate scalar maps. In particular, they have developed an optimized approach for simultaneously visualizing winds, pressure and temperature fields (Figure 7). These approaches seem far superior to traditional techniques and just as applicable to multivariate oceanographic data.

One of the most exciting advances of the Center's visualization effort has been our adaptation of a new generation of multibeam sonars to allow the real-time visualization of targets in the water-column. We are now working with NOAA Fisheries to apply our techniques to the new generation of multibeam fisheries sonars (ME-70) currently installed on the NOAA ships Bigelow and Dyson and soon to be installed on two more fisheries vessels. These new multibeam sonars have been designed for fisheries studies but the Center is working closely with NOAA to see how well these sonars can be used for simultaneous seafloor mapping. As discussed above, Tom Weber has successfully produced both bathymetry and backscatter from the ME-70. Weber and Roland Arsenault have

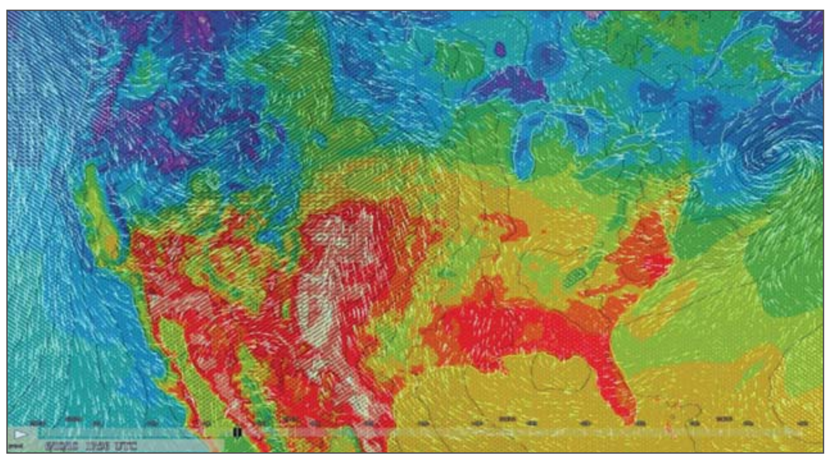


Figure 7. The Vislab display based on the National Climate for Environmental Prediction NAM Model. The animated streaklets show wind patterns very clearly. Pressure is indicated by means of textures and contours.

also worked collaboratively with industrial associate IVS3D on the development of more generic software that allows us to extract water-column data from any of the multibeam or single-beam sonars that allow the collection of these data. Our goal is to employ NOAA's multibeam sonars as efficiently as possible—use hydrographic sonars to also map the water-column and fisheries sonars to also map the seafloor. This is a basic tenet of the new Integrated Ocean and Coastal Mapping program and an approach that the Center strongly supports.

Our water-column mapping tools proved to be particularly valuable this year as researchers at the Center were called upon to evaluate the applicability of acoustic techniques to determining the fate of submerged oil and the background input of natural seeps associated with the Deepwater Horizon oil spill. NOAA invited the Center to help plan and execute an acoustics program leading to the participation of Tom Weber, Larry Mayer, and NOAA Corps Officers (and Center students) Sam Greenaway and Glen Rice on cruises of the NOAA Ships Gordon Gunter and Thomas Jefferson with the express purpose of mapping subsurface oil. Rice also spent several months assigned to the Subsurface Monitoring Group in Houma, MS., a group established to track vessels engaged in the monitoring of subsurface oil. During the course of the summer, the Center's team used scientific echo sounders (EK-60s) to map the many natural methane gas seeps in the area, to directly observe oil in the upper ocean, and to examine some of the effects of the oil on marine organisms (Figure 8). A primary tool in this work was the use of the water-column mapping tool, the product of a successful collaboration (though a Granite State Grant) with industrial associate IVS3D. In mid-July when the well was capped, our focus shifted from mapping subsurface oil to monitoring the integrity of the well and acoustically searching for gas escaping either from the wellhead or the nearby seabed (gas was considered to be the bellwether of something gone awry deep beneath the seabed). Both natural seeps and small leaks in the Macondo 252 and other wellheads were successfully mapped (Figure 8). During this phase, Mayer reported daily (often several times per day) to the Secretary of Energy and his Science Review Team. After the well was capped, Weber was chief scientist for a cruise that mapped the signature of the oil more than 400 km west of the wellhead. Both Weber and Mayer are the only two academics that are officially part of the Unified Command's Joint Analysis Group (JAG).

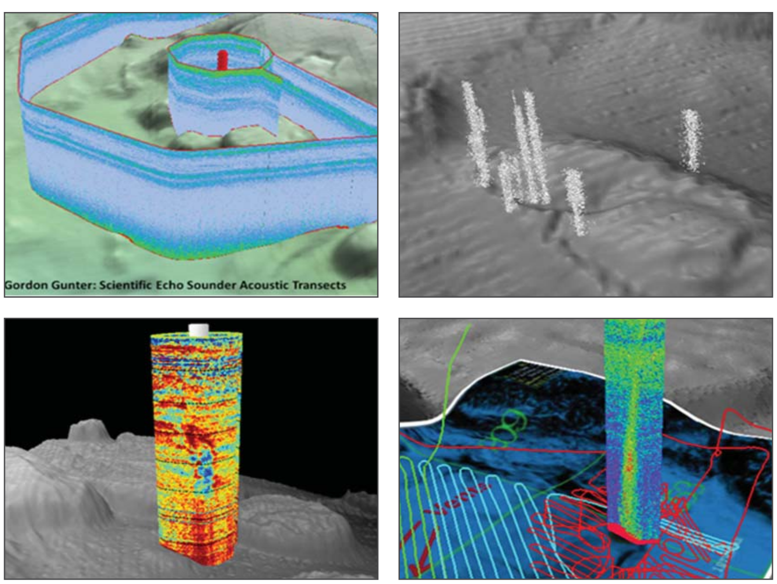


Figure 8. Clockwise from upper left: An 'acoustic curtain' representing the backscatter from organisms in the Deep Scatter Layer; Seeps mapped on the edge of a salt dome a few miles from the well head; Perturbations in the acoustic backscatter from marine organisms mapped a few km from the wellhead; acoustic backscatter suggesting a small amount of gas is seeping from the wellhead.

The Center is also exploring the use of multibeam sonar and visualization tools to map the distributions of juvenile bluefin tuna in conjunction with aerial imagery (the classic approach to estimating abundance). The multibeam sonar data adds a vertical dimension to the distribution.

Each of these research themes supports the concept of the Integrated Ocean and Coastal Mapping (IOCM) Center. This new Center brings to fruition years of effort to demonstrate to the hydrographic community that tools developed and 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. The plan is to have NOAA employees from several different NOAA lines and divisions (NOS Coast Survey, Sanctuaries, Fisheries, Ocean Exploration, etc.) at the new IOCM Center so that they can work hand-in-

Figure 9. New NOAA OER ROV (top) and secure facility built for it at the JHC (bottom).

hand with our researchers to ensure that the products we develop meet NOAA needs.

This past year researchers from NOAA's Office of Ocean Exploration and Research and Office of Coast Survey have joined us at the IOCM Center. Working with our NOAA colleagues, we have provided support for the development of tools and protocols for data collection, processing, and visualization onboard NOAA's new vessel of exploration, the *Okeanos Explorer*, and remotely supported missions on the *Okeanos Explorer* from our Telepresence Console. We have also worked closely with OCS staff to better understand and develop approaches to the processing and utilization of backscatter data from multibeam sonars and on numerous Deepwater Horizon issues. As an offshoot of our collaboration with NOAA's OER, the Center has become the staging area for the development of their new deep-water Remotely Operated Vehicle (ROV – Figure 9). 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. While we hope that access to the Center facilities will be helpful to OER in their development of the ROV, we know that having this development done on campus will be a tremendous advantage to our students and staff as it will expose them to the state-of-the-art deep-sea vehicle technology. Already, several students have become involved with the project.

The Center has also accelerated efforts to explore the applicability of using small Autonomous Underwater Vehicles (AUVs) for collecting critical bathymetric and other data sets. Our efforts this year focused on the GAVIA AUV (shared with the University of Delaware) and its GeoSwath phase-measuring bathymetric sidescan. This year's efforts saw a deployment of the system in Lake Rotoiti, N.Z., (Figure 10) where gas seeps were mapped from backscatter data collected by the AUV. We have also made much progress in identifying and correcting for the source of motion artifacts in AUV-derived bathymetry and in processing AUV-derived GeoSwath phase-measuring bathymetric data.

In support of the Center's AUV efforts, we have also developed a real-time kinematic GPS tracking buoy system to provide accurate positions for the AUV (and other objects) while submerged and to provide a two-way communication system for the AUV (allowing dynamic mission control). This system was upgraded this year to include solar cells and in support of AUV activities at our annual AUV boot camp and as an RTK-tide buoy in support of the thesis work of one of our graduate students.

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 has 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 more than 1,649,000 sq. km of bathymetry and backscatter data that have provided an unprecedented high-resolution view of the seafloor.

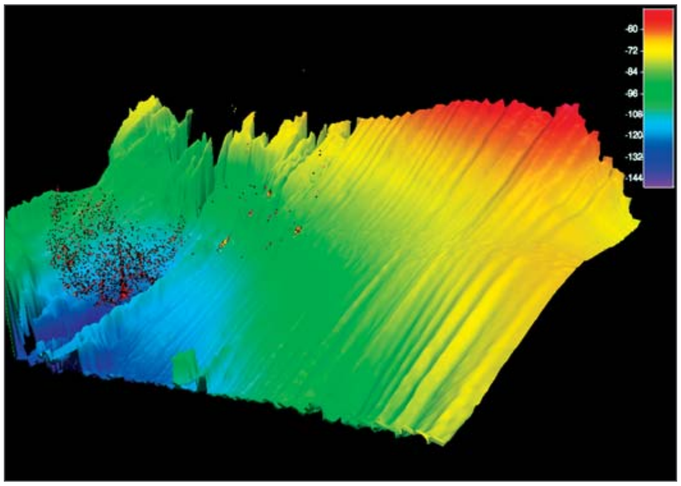


Figure 10. Lake bathymetry and locations of individual returns associated with rising gas from a methane seep in Lake Rotoit, N.Z.

These data are revolutionizing our understanding of many margin processes, and will result in significant additions to a potential U.S. claim under UNCLOS, particularly in the Arctic.

In 2010, the Center, under the direction of Jim Gardner, organized three month-long bathymetry cruises in the Pacific. Two of the cruises were in the Mariana Trench and Trough areas of the western Pacific and the third was in the Kingman Reef-Palmyra Atoll area of the Line Island chain in the Central Pacific. The Mariana Trench mapping revealed four "bridges" that span from the inner trench wall on the west to the Pacific Plate (Figure 11). Each bridge clearly blocks the deep bathy-metry of the trench axis and forms a continuous bathymetric high across the trench, a fact that may have great significance with respect to an extended continental shelf under UNCLOS Article 76.

The deepest depth recorded in the Mariana Trench was 10,994 m, somewhat shallower than the presently accepted deepest depth in the world's oceans. Because quality control was assured by the collection of XBT casts at a minimum of one every 6 hr to correct the refracted ray-traced depths, we believe the maximum depth from this survey is the most precise and representative.
Finally, this year we have expanded our outreach activities including increased web presence through Facebook and Flickr. We have hosted a number of community groups (high-school students, marine docents, etc.) and the activities of the Center have, this year, been featured in many international and local media outlets including *Science*, *The Washington Post*, *The Miami Herald*, NECN, CNN, *The New York Times*, Reuters, and Alaska Public Radio. Unquestionably the largest effort involved our participation in the University's first "Know the Coast Day." During this event, the Center hosted several hundred visitors who watched demonstrations and videos, attended presentations, participated in activities and visited our research vessels.

Our involvement with Bob Ballard's E/X *Nautilus* and its "Educators at Sea" and "Educators Ashore" programs 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), the researchers on the Nautilus and took part in the Mystic Aquarium's Nautilus Live Theater and the Nautilus Live website.

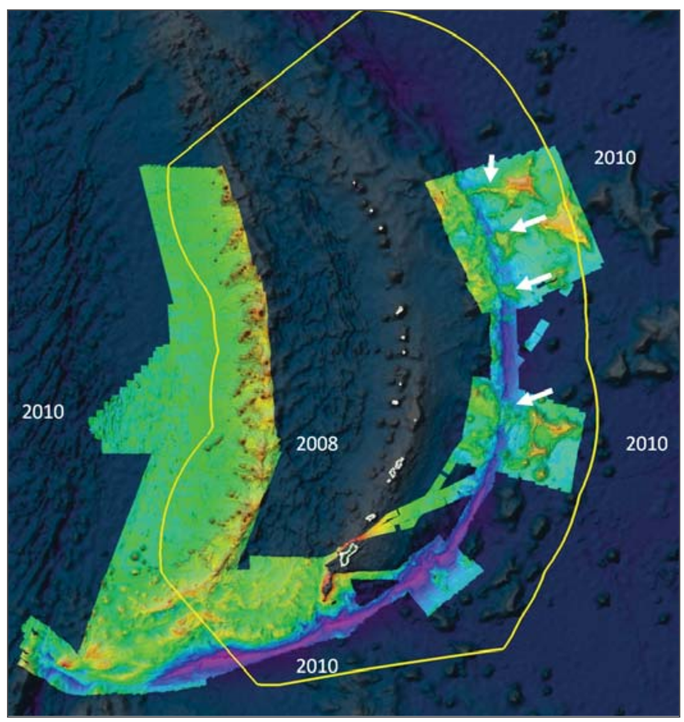


Figure 11. Composite bathymetry map of the four Law of the Sea cruises in the Mariana Trench area. Background bathymetry from version 12.1 of Smith and Sandwell (1997). Yellow polygon is U.S. EEZ. White arrows represent potential "bridges."

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. At that time, 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 fifteenth 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 2010. As such, it represents a progress report for the initial five-year grant (NA0NOS4001153) as well as the first progress report for the new 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.

Infrastructure

Personnel

The Center has grown, over the past 11 years, from an original complement of 18 people to now more than 70 faculty, staff and students. Our faculty and staff have been remarkably stable over the years but as with any large organization, inevitably, there are changes. In 2010, Jonathan Beaudoin joined our research staff, filling Luciano Fonseca's position. Jonathan is a recent Ph.D. from the Ocean Mapping Group at the University of New Brunswick and is well known in the community as one of the leading researchers in the analysis of sound-speed variability and the processing of acoustic backscatter data. Additionally in 2010, Megan Greenaway ended her assignment at the IOCM Center and returned NOAA in Silver Spring and Chris Parrish joined us as a NOAA employee seconded to the Center (Chris also holds an appointment as an Affiliate Professor in the Dept. of Earth Sciences). Finally, Lloyd Huff retired after ten years of invaluable service to the Center. Although Lloyd is now officially retired, we are sure we will continue to interact with him.

Faculty

Lee Alexander is a research associate 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, and the U.S. Coast Guard.

Brian Calder has a Ph.D. in Electrical and Electronic Engineering, completing his thesis on Bayesian methods in sidescan-sonar processing in 1997. Since then he has worked on a number of signal-processing problems, including real-time grain-size analysis, seismic processing, and wave-field modeling for shallow seismic applications. His research interests include methods for error modeling, propagation and visualization, and adaptive sonar-backscatter modeling. His work has focused on developing methods for textural analysis of seafloor sonar data, as well as exploring innovative approaches to target detection and seafloor property extraction. Dr. Calder is an associate research professor with the Center and the Dept. of Electrical and Computer Engineering focusing on statistically robust automated data-processing approaches and tracing uncertainty in hydrographic data (the CUBE algorithm) and new approaches for precise timing of measurements.

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 CCOM curriculum.

Luciano Fonseca received an undergraduate degree from the University of Brasilia and his Ph.D. from the University of New Hampshire (the first Ph.D. produced by the Center). Luciano's research is focused 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 may be used to remotely predict seafloor properties. More recently he has focused on developing the GeoCoder tool for the rapid production of sidescan-sonar and backscatter mosaics. Dr. Fonseca is an Assistant Research Professor in the Center and in the Ocean Engineering Program. In June 2009, Luciano took a position as a Program Specialist, Ocean Science Section for UNESCO-IOC in Paris but retains an association with the Center.

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. Jim is a Research Professor in the Center and in the Dept. of Earth Sciences and is leading our field efforts in support of Law of the Sea studies.

Lloyd Huff has almost 40 years' experience 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 Systems of 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. Lloyd is a Research Professor in the Center and in Ocean Engineering.

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.

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 Program and Earth Science Department. His Ph.D. is from the Scripps Institution of Oceanography 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.

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. (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 and Geodetic Science. Dr. Lippmann's research is focused on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning inner continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 14 nearshore field experiments and spent over 18 months in the field.

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 CCOM, 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 the 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. He is currently 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 hydrographic 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 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 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 CCOM, 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, 3-D visualization, and on-board driving software for NASA's Mars exploration program. Fieldwork has taken him from Yellowstone National Park to Antarctica. At CCOM, 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 Ocean Engineering and the Department of Computer Science. Dr. Ware has a background in human/computer interaction (HCI) and has been instrumental in developing a number of innovative approaches to the interactive 3-D 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 3-D 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 just arrived at CCOM in the spring of 2010, he plans to carry on in the field of his Ph.D. research—that of 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 will also be helping out with the Geocoder project, bringing his experience in processing and normalization of backscatter measurements from Kongsberg and Reson multibeam echosounder systems.

Margaret Boettcher received a Ph.D. in Geophysics from the MIT/WHOI Joint Program in Oceanography in 2005. She joined CCOM in 2008 as a post-doctoral scholar after completing a Mendenhall Postdoctoral Fellowship at the U.S. Geological Survey. Although she will continue to collaborate with scientists at CCOM indefinitely, Margaret became a member of the faculty in the Earth Science Department at UNH in August 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.

Jordan Chadwick is the Systems Manager at CCOM/JHC. 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 CCOM/JHC 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 Group 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.

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 and continue to work here during the summers.

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 Masters 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 Master's 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 CCOM as the Center's graphic designer. She is responsible for the graphic identity of CCOM 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 CCOM. She has worked at CCOM since 2002. She oversees the day-to-day operations at the Center, as well as supervises the administrative staff. She earned her B.S. in Management and Leadership from Granite State College. In 2006, she completed the Managing at UNH program, and in 2009, she received her Human Resources Management certificate at the University of New Hampshire.

Les Peabody works full-time as an IT technician with the Center, and is finishing his B.S. in Computer Science part-time. The responsibilities Les is charged with include, but are not limited to, desktop support for CCOM'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.

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.

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

Briana Sullivan received her M.S. in Computer Science at UNH in 2004. She is now employed at CCOM full-time with 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. Her second responsibility is being the CCOM outreach coordinator. In this capacity, she is in charge of informing the public of the work going on here at CCOM-JHC. This is done through 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 CCOM as Relief Captain in 2009. She focuses her efforts on operating and maintaining the Research Vessel *Cocheco*. She came to 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 **Brittany Edgar** 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 Officer Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. Captain Armstrong has specialized in hydrographic surveying and served on several NOAA hydrographic ships, including the NOAA Ship Whiting where he was Commanding Officer and Chief Hydrographer. Before his appointment as Co-Director of the NOAA/UNH Joint Hydrographic Center, Captain Armstrong was the Chief of NOAA's Hydrographic Surveys Division, directing all of the agency's hydrographic survey activities. Captain Armstrong has a B.S. in Geology from Tulane University and a M.S. in Technical Management from the Johns Hopkins University. Capt. Armstrong is overseeing the hydrographic training program at UNH and organized our successful certification submission to the International Hydrographic Organization.

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 Univ. 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 the PI for a NOAA web mapping portal to real-time coastal observations and forecasts. John is working with CCOM/JHC 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.

Megan Greenaway is a physical scientist with NOAA/Office of Coast Survey (OCS)/ Hydrographic Surveys Division/Operations department. Megan has a M.S. in Hydrographic Science from the University of Southern Mississippi. She joined CCOM/JHC in the fall of 2009 on a temporary detail assignment. Her main focus is the incorporation of acoustic backscatter into the current OCS data-acquisition and processing pipeline. She is also the lead of the OCS Feature Management team.

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 from UNH in 2006 with a B.S. in Computer Science and a minor in French.

Carl Kammerer is an oceanographer with the National Ocean Services' Center for Operational Oceanographic Products and Services (CO-OPS), now seconded to the Center. He is a specialist in estuarine and near-shore currents and presently the project leader or manager for two projects; a traditional current survey in Southeast Alaska, and a more 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 water level data. He has a BS in Oceanography from the University of Washington and is an MBA candidate at 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 Masters 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 who received his M.S. degree from the University of New Hampshire in 2007 has been hired by NOAA (through ERT) as a physical scientist assigned to the new NOAA vessel of exploration Okeanos Explorer. In this capacity, Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the *Okeanos Explorer*. While not serving on the vessel, Mashkoor is assigned to CCOM/JHC where he is part of the new Integrated Ocean and Coastal Mapping Center. Mashkor also continues to be a Ph.D. student at the Center, his research focusing 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, 3-D object detection, sensor modeling and calibration, uncertainty analysis, and sensor fusion for coastal mapping applications. Chris will be serving as an Affiliate Professor at CCOM-JHC beginning in fall 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' 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 lieutenant (JG) in the NOAA Corps and has joined the Center on a three-year assignment as the Integrated Ocean and Coastal Mapping Team Leader. In this capacity, he expects to extend the use of data collected for charting to other fields and to improve the workflow for outside source data to be applied to the charts. Glen comes 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 a M.Sc. in Ocean Engineering and in 1999 with a B.S. in Physics.

Other Affiliated Faculty

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 3-D graphics and 2-D 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 through1974 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 Masters of Science and Technology in GIS Technology and a Bachelors of Science from the University of New 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 error 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.

In 2010, three new visiting scholars spent time at the Center.

Jean-Marie Augustin 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 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 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.

Facilities, IT and Equipment

Office and Teaching Space

The Joint Hydrographic Center at the 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 sq. ft. 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 sq. ft. addition has been constructed (through NOAA funding), resulting in 18,000 sq. ft. of space dedicated to JHC/CCOM research, instruction, education, and outreach activities (Figure 12).

Of the 18,000 sq. ft of space, approximately 4,000 sq. ft are dedicated to teaching purposes and 11,000 sq. ft to research and outreach, including office space. Our teaching classroom can seat 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, three 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 12, 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).

Figure 12. Aerial view of Chase Ocean Engineering Lab and the NOAA/UNH Joint Hydrographic Center.

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 ten printers scattered throughout the lab; all computers and peripherals are fully integrated into the Center's network and are interoperable regardless of their host operating system. A computer training classroom consists of fifteen small-form factor computer systems, and a ceiling-mounted NEC high-resolution projector. The Center's new presentation room is the home of a Telepresence Console, which is used for real-time communications with the Okeanos Explorer or other vessels equipped with a satellite link (Figure 13), as well as a GeoWall high-resolution display system; these will be described further in the Computing Facilities section (Figure 14). Our visualization lab includes an ASL eye-tracking system, 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.

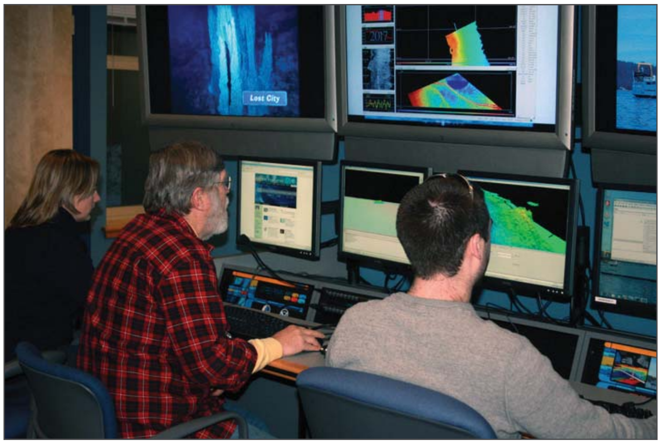


Figure 13. "The Telepresence Console" located in the Presentation Room.

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 5,000 lb. capacity forklift is available.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 8 ft. deep. It provides a 90 ft. length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wavemaker that can produce two-to-five second waves of maximum amplitude approximately 1.5 ft. Wave absorption is provided by a sawtooth style geo-textile construction that has an average 92% efficiency in the specified frequency range. The wavemaker 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 ft. long by 40 ft. wide with a nominal depth of 20 ft.. 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 ft. 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.

Figure 14. Global circulation model displayed on CCOM/JHC Geo-wall II.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 750 sq. ft, 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 sq. ft 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 for students and researchers. A 12 x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist (supported by the University) is on staff to support fabrication activities.

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 ft. long and 25 ft. wide 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 ft. LOA, 60 ft. breadth, Small Waterplane Area Twin Hull (SWATH) Coastal Mapping Vessel (CMV), the first of its kind to be constructed for NOAA. Services provided on the new pier include 480V - 400A and 208V-50A power with TV and telecommunications panel, potable water and sewerage connections. In addition to the new pier, the University has constructed a new pier support facility, approximately 4,500 sq. ft. of air conditioned interior space including offices, a dive locker, a workshop, and storage. Two additional buildings (1,100 sq. ft. and 1,300 sq. ft.) are available for storage of the variety of equipment and supplies typically associated with marine operations.

Information Technology

The IT Department currently consists of three full-time staff and two part-time help desk staff. Jordan Chadwick fills the role of Systems Manager and deals primarily with the day-to-day administration of the Center network and server infrastructure. The position 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 Center 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.

The Center is continuing its development and implementation of server virtualization, both for decreased administrative overhead and increased cost-efficiency. Virtual servers also allow for the same level of security that separate physical computers benefit from. In the event of a virtual server being compromised, the damage is isolated to a single virtual server instance and can be contained. The IT Group continues to utilize an OpenVZ/Red Hat Linux platform for many of the Center's production servers, in addition to this year's deployment of VMware vSphere. The OpenVZ server currently hosts eight virtual servers, including the Center's mail server, web file transfer services, the CCOM Wiki, CCOM Web Calendar services, the Shallow Survey 2008 Website, the Open Navigation Surface website, and the MMAP website. The Center has begun the implementation of a VMWare vSphere infrastructure to replace the existing OpenVZ virtualization platform.

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 new virtualization infrastructure consists of two high-end 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. Currently, the Center is hosting five virtual machines with vSphere, including Intranet services, Subversion version control, the Center helpdesk system, root certification authority (CA), and the Visualization Lab development server. In 2011, the IT Group plans to have all the OpenVZ servers and the majority of physical servers migrated to vSphere virtual machines.

The Center is also currently in the process of migrating away from Subversion version control to a new version control system. Several products were evaluated, and the decision was made to deploy Mercurial. Mercurial deployment is now underway, and is expected to replace the current system in the first half of 2011. Mercurial uses a decentralized architecture that is less reliant on a central server, and also permits updates to repositories without direct communication to that server. This allows users in the field to continue software development while still maintaining version history. In addition, the new version control server also hosts Trac, which provides project management and bug tracking capabilities for software developers. This is also scheduled to come online in the first half of 2011.

In addition to upgrading the version control server, the IT Group is currently 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 of 2010, with the next priority being purchasing and library systems. Both of these modules are expected to be complete in 2011.

With the migration of the IT Group's Helpdesk system to a vSphere virtual machine, the Request Tracker software was upgraded to version 3.8.8, providing improved reporting and a more user-friendly interface. Request Tracker allows the IT Helpdesk to better track the resolutions to technical problems and reduce the duplication of effort among the staff, not to mention improve the service provided to the rest of the Center. Center staff, students, and faculty have submitted over 1200 Helpdesk support requests since its inception in mid-2009. Between June and December of 2010, the IT Staff was able to resolve 90% of these requests within three days.

With the completion of the New Castle, NH Pier Support Building in 2009, the Center expanded its network presence into the lab through the use of a Cisco ASA VPN device, our 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 CCOM/JHC 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 CCOM launches while docked at the pier.

In January of 2010, the Center installed a new Cisco Adaptive Security Appliance to replace the Microsoft ISA Server 2006 firewall. This device has increased the external security of our 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. 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 network, security remains a chief concern for the Center. Members of the Center staff have been working closely with OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and CCOM/JHC 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 network, including the Center's email server.

The IT Group has also deployed a server running Microsoft Windows Server Update Services (WSUS). This server provides a central location for Center 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. This server also provides a central repository for system logs, and has the capability to install custom modules to meet a variety of additional logging needs.

These security measures, as well as others, were independently assessed by UNH's Research Computing Center in February 2010. 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, we have added 10TB of formatted storage to the Network Appliance FAS960c iSCSI Storage Area Network (SAN), along with an additional storage node. The SAN now provides 64TB of raw storage capacity. In addition, the Center has 12TB of legacy direct-attached storage (DAS) that is being repurposed, 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 datasets to the SAN is nearly complete. The SAN provides higher throughput than conventional disk drives, decreasing processing time for 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 purchased in August of 2010 and is in the process of being deployed.

Larger 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. In addition, the IT Group is also exploring a supplemental backup solution for laptop computers. Testing of a cloud-based solution from Iron Mountain was completed in the fall of 2010 and deployment of the product is expected to begin in early 2011. Cloud-based backup over the Internet will allow computers deployed outside the Center network to perform secure, encrypted backup and restore functions anywhere in the world, and will reduce the load on the local backup system.

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

Currently, all Center servers are consolidated into seven full-height cabinets with one or more Uninterruptible Power Supply (UPS) per cabinet. At present, there are a total of 37 servers, including 14 virtual servers, one SAN with nine 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 Web Mapping Portal and Open-ECDIS.org. The Web Mapping Portal project hosts a server that mirrors the primary 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, three 3Com 4924 24-port Gigabit Ethernet switches, one Dell PowerConnect 2924 switch, two enterprise-level Cisco wireless access points, and one Foundry wireless access point. The two RX-8s are currently handling the bulk of network traffic and are responsible for all internal routing. The Dell and 3Com switches handle edge applications such as the Center's Electronics Laboratory, Geowall, and Telepresence Console. The Cisco and Foundry wireless access points provide wireless Internet connectivity for employees, while additional consumer-grade wireless points are in place to accommodate visitors.

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 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 Presentation Room houses the Telepresence Console as well as the Geowall high-resolution display system. The hardware for the Telepresence console consists of five Dell PowerEdge servers used as data processing workstations, 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 server and rack-mounted equipment is housed in the larger server room, located down the hall from the Presentation Room. As with the Center's other servers, all of the Console equipment is mounted in Dell server racks and are connected to a Powerware UPS to protect against power surges and outages. In 2010, the Telepresence Console was occupied much of the summer and fall working with both the NOAA Ship Okeanos Explorer and The Ocean Exploration Trust's vessel Nautilus on their respective research endeavors. Scientists and educators ashore were able to collaborate, process data and lend their expertise in real-time to scientists working in the field.

The Center's computer classroom is populated with 15 small form-factor Dell computer systems and a ceiling-mounted NEC high-resolution projector. All training that requires the use of a computer system is conducted there. Students also frequently use the classroom for individual study and collaborative projects.

The Center has continued to upgrade end user's primary workstations, as both computing power requirements, and the number of employees and students have increased. The grand total of faculty/student/staff workstations is 185 high-end Windows XP/7 and Linux desktops/laptops, as well as several Apple Mac OS X computers and one SGI workstation. In 2010, the IT Group began deploying Microsoft Windows 7, the next generation of Microsoft's desktop operating system, to new workstations, and to older workstations that require 64-bit support. 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 as Active Directory objects, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. 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 us to take advantage of the enhanced security and management features offered in Windows 7 and in Windows Server 2008 Active Directory. In addition, we also maintain 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, whereas 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 re-distributed on a range of media types.

The Center has a full suite of printers and plotters including a pair of 60 inch large format color plotters. Users have the ability to scan documents and charts up to 54 inches using our wide format, continuous feed, high-resolution scanner. All computers and peripherals are operational and fully integrated into both Center and University networks. All systems are interoperable regardless of host operating system and files are shareable between all systems. With the increased need for document processing, the Center deployed a new professional photo printer in late 2009, a new large format plotter in early 2010 and a new color laser printer in the fall of 2010.

Research Vessels

The Center operates two dedicated research vessels (Figs. 15 and 16), the 40-foot R/V *Coastal Surveyor* (CCOM/JHC owned and operated) and the 34-foot R/V *Cocheco* (NOAA owned and CCOM/JHC maintained and operated). In 2009, the *Coastal Surveyor* operated for nine months (April through December) with much of its operation focused on collecting data in support of the Summer Hydrography Field Course. The *Cocheco* operated for this same period, focusing on reconnaissance work and bottom sampling. This will be the second year that both vessels will be left in the water over the winter at the UNH pier facility in New Castle. This winter mooring has reduced the winter costs and added the advantage that vessels are at the ready through the entire year.

The vessels are operated primarily in the area of Portsmouth, NH, but are capable of transiting and operating from Maine to Massachusetts. Although neither vessel is designed for offshore operations, they are ideally suited to near-shore and shallow water (in as little as four meters depth).

Figure 15. R/V *Coastal Surveyor* with bow ram.

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 EPIRB (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 a permanent captain and permanent relief captain.

In addition to the two research vessels, the Center also has a personal watercraft equipped with differential GPS, single-beam 192-kHz acoustic altimeter, and onboard navigation system (CBASS—see Coastal Processes discussion below) and has partnered with the Blodgett Foundation to help equip a hovercraft (RH *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 9 knots)

The *Coastal Surveyor* (Figure 15) was built by C&C Technologies (Lafayette, LA) approximately twenty-five 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 CCOM-JHC in 2001. She has become a core tool for CCOM/JHC's operations in New Hampshire. The Coastal Surveyor continues to be invaluable to the Center. Thanks to the improved hydraulic stabilizers (in 2005), the high precision of boat offset surveys and the remarkably stable transducer mount, she remains one of the finest shallow-water survey vessels in the world. A marine survey was completed in 2008, acknowledging that the vessel is sound but beginning to show her age. The main engine, a 200 BHP Caterpillar diesel with over five thousand hours, although running reliably, does not run efficiently. Additionally, the Isuzu-powered 20 kilowatt generator requires several repairs each season. Minor electrical and plumbing issues were identified in the survey and were addressed. The autopilot is antiquated and no longer supported by the manufacturer. A ship's AIS transponder was installed this year. In 2010, a new Simrad AP28 autopilot was installed to replace the non-operative Robertson 3000, the HVAC seawater pump and manifold and the engine room bilge pump were also replaced. Finally, estimates for the replacement of the generator engine and generator have been obtained with replacement scheduled for 2011.

Figure 16. R/V *Cocheco*.

R/V COCHECO

(34 ft. LOA, 12 ft. beam, 6 ft. draft, cruising speed 20 knots)

R/V *Cocheco* (Figure 16) is designed for fast transits and for over-the-stern operations from her A-Frame. Two 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. Last year, 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. This past year routine maintenance including, cleaning, painting, and replacing docklines was undertaken along with an investigation of options to address a leaky diesel manifold and to fill a cut-out in her keel in order to improve handling. A second VHF radio and antenna was installed and several battery banks were replaced and upgraded.

Figure 17. R/H *Sabvabaa* deployed on ice and collecting data near Spitsbergen.

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 17), was underwritten by the Blodgett Foundation. The vessel has been operated out of UNIS, a University Centre in Longyearbyen, Svalbard, since June 2008. Through donations from the Blodgett Foundation, the Center for Coastal and Ocean Mapping provided a Knudsen 12-kHz echo-sounder, a four-element Knudsen chirp sub-bottom profiler and a six-channel streamer for the *Sabvabaa*. Using a 20 to 40 in^3 airgun sound source, the craft is capable of profiling the shallow and deep layers over the most interesting areas of the Alpha Rise, a critical component to understanding the origin and history of the Arctic Ocean.

Figure 18. Hydrostatic corer being tested from Hovercraft Sabvabaa.

In 2010, the R/H *Sabvabaa* made three trips onto the ice pack. To date, over the past three summers, it has traveled over 10,000 nm above the Arctic Circle. This year's work on the ice pack consisted of bathymetry, airgun and chirp seismic profiling, and 13 dredge hauls over the Yermak Plateau. The basaltic rocks are being analyzed at the University of Bergen. Testing was also carried out on an autonomous bathymetric profiling buoy and an autonomous drifting seismic buoy. Tests were also carried out on a forward underhull skirt to improve steering.

A fourth trip was made with UNIS staff to the mud flats in a large fjord southeast of Longyearbyen, Svalbard, where sediment sampling was carried out


Figure 19. Polar bear looking in window of Hovercraft Sabvabaa.

demonstrating that the craft is also well-suited for work on impassible mud. After the summer, tests were made of a new 73 kg, 2 m corer with hydrostatic boosting (Figure 18). In 250 m of water the corer developed 1.3 tons of thrust into the sediments. Extrapolated to 2500 m of water, this thrust would be approximately 13 tons. We have decided that tests will continue for one more summer in 2011, beginning perhaps late in the spring.

The hovercraft also saw much polar bear activity, with one inquisitive bear putting his head in through the driver's window (Figure 19).

NOAA ROV

The new NOAA cooperative agreement includes much closer and formalized collaboration with the NOAA's Office of Ocean Exploration and Research (OER). As part of this collaboration, the OER program has chosen to use the facilities of the Center as the staging area for the development of their new deep-water Remotely Operated Vehicle (ROV). In support of this effort, the Center has constructed a large, secure work area in proximity to our deep acoustic test tank so that as development is underway, components or the entire system can be tested in the tank (Figure 20).

The NOAA ROV system is comprised of two vehicle systems – an ROV (Figure 21) and a Camera Sled (Figure 22). The ROV, which is currently being upgraded by OER at the Center, is connected to the Camera Sled via a flexible electro-optical tether, which is, in turn, connected to the support vessel via a standard oceanographic .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, which is now being built by OER at the Center facility, 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.


Figure 20. New room constructed in Highbay for ROV storage.


Figure 21. New 6000 m ROV being developed by OER at the JHC.

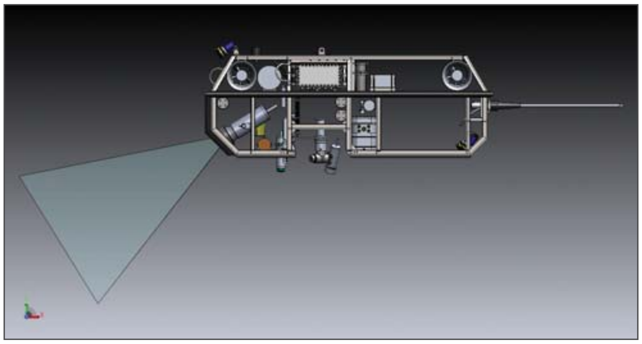
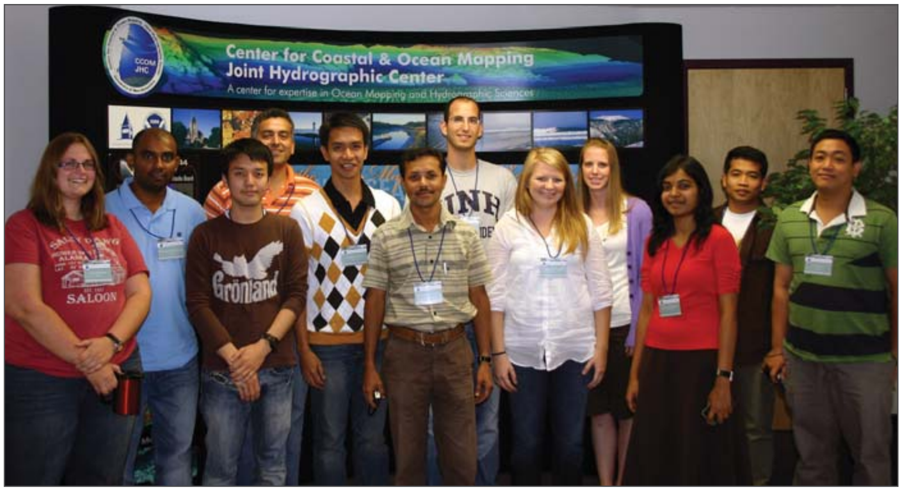


Figure 22. Camera sled for ROV being developed by OER at JHC

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 done on campus will be a tremendous advantage to our students and staff. Students and staff will be able to participate in this development and it will be exposed to the state-of-the-art in deep-sea vehicle technology. Already, several students have become involved with the project.

Education Program

The Center, under the guidance of Capt. Armstrong, has developed an ocean-mapping-specific curriculum that has been 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. The Center offers both M.Sc. and Ph.D. degrees with a specialization in Ocean Mapping through the Ocean Engineering Program, the Dept. of Earth Sciences (now expanded to include the School of Natural Resources), the Dept. of Electrical and Computer Engineering, the Dept. of Computer Science, and the Institute for the Study of Earth, Oceans and Space. The path chosen depends on the background of the student, with physical scientists typically entering through the Oceanography or Earth Science programs, engineers entering through Ocean or Electrical Engineering programs, and computer scientists through the Computer Science program. We also have established a post-graduate certificate program in Ocean Mapping. This program has a minimum set of course requirements that can be completed in one year and allows post-graduate students who cannot spend at least the two years necessary to complete a master's degree a means to upgrade their education and receive a certification of completion of the course work.



2010 incoming students.

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 graduated in 2009; and six more students graduated in 2010. The Nippon Foundation continues to fund the program beyond 2010 and we currently have another six students enrolled for the 2011 academic year and are in the process of selecting the class of 2012. 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.

With the establishment of these programs, we now turn to our longer-term goal of establishing the training and certification programs that can serve undergraduates, as well as government and industry employees. We have already begun by offering the Center as a venue for industry and government training courses and meetings (e.g., CARIS, Triton-Elics, SAIC, Geoacoustics, 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 are allowed to 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 Intergovernmental Working Group for Integrated Ocean and Coastal Mapping (IWG-IOCM).

Although our students have a range of general science and engineering courses to take as part of the Ocean Mapping Program, the Center teaches several courses specifically designed to support the Ocean Mapping Program. In response to our concern about the varied backgrounds of the students entering our program, we have created, in collaboration with the Dean of the College of Engineering and Physical Sciences and the Dept. of Mathematics, a specialized math course, taught at the Center. This course is designed to provide Center students with a background in the math skills needed to complete the curriculum in Ocean Mapping. The content of this course has been designed by Semme Dijkstra and Brian Calder specifically to address the needs of our students and is being taught by professors from the UNH Math Dept. In 2008, in recognition of the importance of our educational program, we created the position of full-time instructor in hydrographic science. This position has been filled by Semme Dijkstra, who is leading the effort to renew our IHO CAT-A certification in 2011.

In preparation for the renewal of our IHO CAT-A certification we have also undertaken a comprehensive review of our entire curriculum, in part to ensure that it is consistent with the IHO CAT-A requirements but also to ensure that we are offering our students an appropriate balance of course and lab material that is manageable in the time frame allowed and serve them well after graduation. We expect to start the revised curriculum in the fall semester of 2011.

JHC – Originated Courses

COURSES	INSTRUCTORS
Fundamentals of Ocean Mapping	Armstrong, Dijkstra, Mayer
Ocean Mapping Tools	Monahan, Gardner 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

Recognizing the need for advanced training for NOAA personnel, we have also begun the design of several modular "short courses," each focused on a particular topic of interest to NOAA hydrographers. These courses will be delivered over three to three and one half days (approximately six hours per day) with a combination of lecture and class exercises. The first of these modules, "Introduction to Acoustics and Single Beam Sonars," is now complete and will be delivered to NOAA students in Seattle and Norfolk in February 2011.

We have 29 full-time students currently enrolled in the Ocean Mapping program, including the six GEBCO students, one NOAA Corps officer and a NOAA physical scientist. We have already produced five Ph.D.s: Luciano Fonseca (2001); Anthony Hewitt (2002); Matt Plumlee (2004); Randy Cutter (2005); and; Dan Pineo (2010). This past year we have graduated three Master's students and six Certificate students, bringing the total number of M.Sc.s from the Center to 31 and the total number of Certificates to 34.

STUDENT	PROGRAM	ADVISOR
Jorge Alvera	MS ESci	Armstrong
Anastasia Ambromova	MS ESci	Monahan
Roland Arsenault	Ph.D. OE (PT)	Undetermined
Chukwuma Azuike	MS OE	Armstrong
Tami Beduhn (NOAA)	MS ESci	Armstrong
Robert Bogucki	Ph.D. OE	Calder
Sean Denney	OE	Armstrong
Olumide Fadahunsi	Cert OE	Armstrong
Christina Fandel	MS ESci	Mayer
Bert Franzheim	MS ECE *(Rec'd 2010)*	de Moustier
Rohini Grandhi	MS OE	Calder
Sam Greenaway (NOAA)	MS ESci *(Rec'd 2010)*	Armstrong
Tianhang Hou	Ph.D. OE (PT)	Huff
Nikki Kuenzel	MS ESci	Gardner/Mayer
Amaresh Kumar	Ph.D. ECE	Peeri/Calder
Carlo Lanzoni	MS OE	Weber/Irish
Christina Lacerda	MS. ESci.	Monahan
Mashkoor Malik	Ph.D. NRESS	Mayer/Calder
Lindsay McKenna	MS Esci	Lippmann/Ward
Dandan Miao	MS OE	Calder
Garrett Mitchell	MS Esci	Gardner
Brian O'Donnell	Ph.D. ECE	Calder
Rachot Osiri	MS Esci	Armstrong
Daniel Pineo	Ph.D. CS (Rec'd 2010)	Ware
Glen Rice	Ph.D. OE	ArmstrongCalder
Maddie Schroth-Miller	MS Math	Weber
Rohit Venugopal	MS CS	Calder
Monica Wolfson	Ph.D. NRESS	Boettcher

GEBCO Students: (2010-2011)

STUDENT	INSTITUTION	COUNTRY
Hadar Sade	Nat. Bathy. Survey	Israel
Mohammad Uddin	Univ. of Chittagong	Bangladesh
Hiroaki Saito	Coast Guard Hydro	Japan
Jonathan Pason	Hydro Dept. NMRIA	Philippines
Kittisak Nilrat	Thai Navy	Thailand
Samarappulige Ranaweera	Nat. Hydro Office	Sri Lanka

Hydrographic Field Course

The summer 2010 Hydrographic Field Course brought the R/V *Coastal Surveyor*, nine CCOM/JHC students, one visiting scientist and several technical staff, under the supervision of Andy Armstrong and Semme Dijkstra, to the Isles of Shoals on the border of Maine and New Hampshire. A survey was conducted to the north of the Isles. The survey is in a Priority 1 area as defined by the NOAA Hydrographic Survey Priorities document and a continuation of earlier surveys performed in the context of the 2005 and 2009 Hydrographic Field Courses into the waters north of the Isles. The result of this survey is presented in Figure 23.

The 2010 survey also overlaps with the 2005 NOAA lidar survey H11296 that partially falls within the area and junctions with the NOAA multibeam survey H10771. This allowed direct comparisons to be made with the previous surveys (Figure 24). The remoteness of the site provided numerous challenges but presented a realistic work environment. The 2010 survey discovered several Dangers to Navigation (DTON) and results of the field course will, if deemed suitable, be used to update NOAA charts.

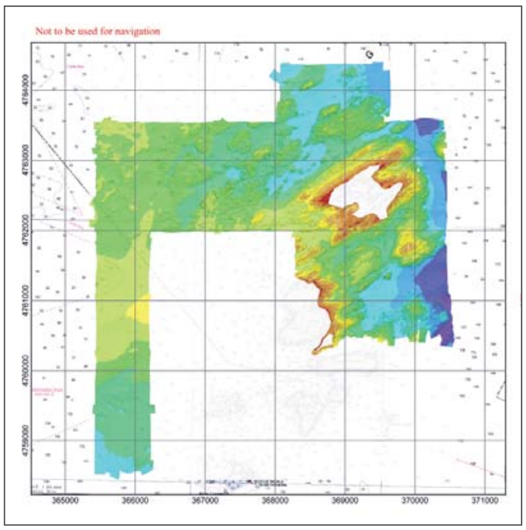
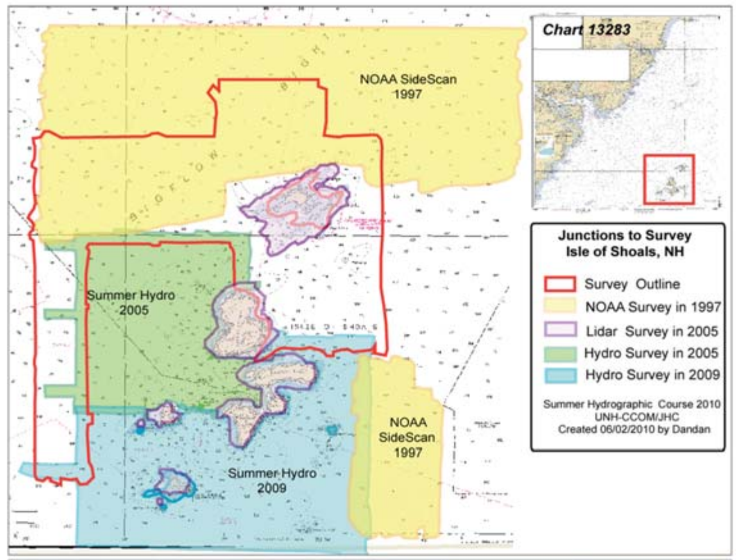


Figure 23. Survey conducted by Center students during the 2010 Hydrographic Field Course.



2010 With / Static Values	1997 H10771	2005 Hydro	2005 Lidar	2009 Hydro
Median	-0.11m	-0.22m	0.20m	-0.02m
Mean	-0.29m	-0.23m	0.10m	-0.03m
Std Dev	1.07m	0.19m	0.79m	0.23m
Height Range	[-10.949, 15.601]	[-7.796, 5.193]	[-15.613, 6.915]	[-5.740, 4.237]

Figure 24. Overlap of 2010 Hydrographic Field Course survey area with previous NOAA surveys and statistics of differences in overlapping areas.

Status of Research: January–December 2010

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 have been 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 has progressed and evolved, 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 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. In reviewing the accomplishments of our 2010 program, we will continue to discuss them under the context of these themes because the 2010 work was completed within this context. However, the new cooperative agreement, has prescribed somewhat different 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;
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;
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;
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;
5. Developing 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;
6. Developing innovative approaches and concepts for the electronic chart of the future and e-navigation, and;
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.

These new thematic headings do not represent a significant departure from our research endeavors but in future progress reports our work will be described under these thematic headings to be consistent with the new cooperative agreement.

Deepwater Horizon

This past year saw the catastrophic events associated with the explosion of the Deepwater Horizon drill rig and the subsequent three month spill from the Macondo 252 well. Staff from the Center (both NOAA and CCOM staff) responded quickly to the national call for help and continue to be active in Deepwater Horizon-related activities. In mid-May the White House sponsored a meeting hosted by Presidential Science Adviser John Holdren and attended by the Secretary of the Interior, the EPA Administrator, the Director of the USGS and a number of top government officials, to discuss with representatives of the academic community the role that they might play in addressing the many challenges posed by the Macondo spill.

Center Director Larry Mayer was invited to this meeting and suggested that acoustic techniques may be of some value in determining the fate of submerged oil and the background input of natural seeps. NOAA invited the Center to help plan and execute an acoustics program leading to the participation of Tom Weber, Larry Mayer, and NOAA Corps Officers (and Center students) Sam Greenaway and Glen Rice on cruises on board the NOAA Ships *Gordon Gunter* and *Thomas Jefferson* with the express purpose of mapping subsurface oil. Rice also spent several months assigned to the Subsurface Monitoring Group in Houma, MS., a group established to track vessels engaged in the monitoring of subsurface oil.

During the course of the summer, the team used scientific echo sounders (Simrad EK-60's) to map the many natural methane gas seeps in the area, to directly observe oil in the upper ocean, and to examine some of the effects of the oil on marine organisms (Figure 25). A primary tool in this work was the use of the IVS3D Fledermaus mid-water mapping tool, the product of research at the Center and the result of a successful collaboration (though a Granite State Grant) with industrial associate IVS3D. Numerous adjustments were made in the mid-water software to optimize its use for the data collected in the Gulf.

In mid-July when the well was capped, our focus shifted from mapping subsurface oil to monitoring the integrity of the well and acoustically searching for gas escaping either from the wellhead or the nearby seabed (gas was considered to be the bellwether of something gone awry deep beneath the seabed). Both natural seeps and small leaks in the Macondo 252 and other wellheads were successfully mapped (Figure 25).

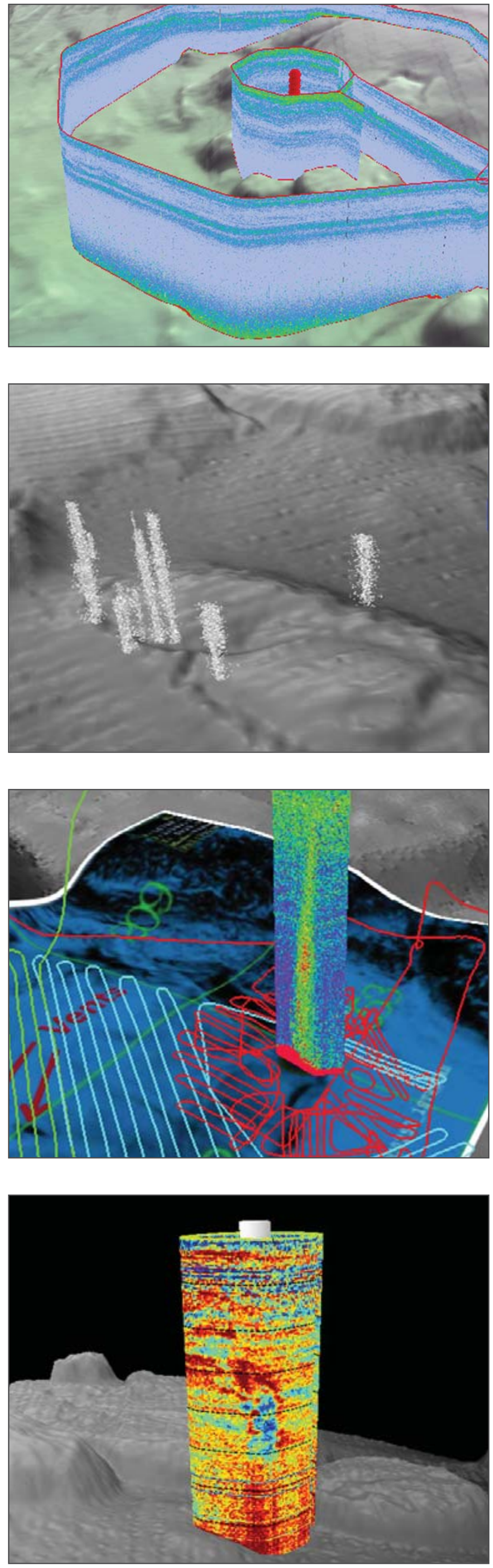


Figure 25. Top to bottom: An 'acoustic curtain' representing the backscatter from organisms in the Deep Scatter Layer; Seeps mapped on the edge of a salt dome a few miles from the wellhead; Perturbations in the acoustic backscatter from marine organisms mapped a few km from the wellhead; acoustic backscatter suggesting a small amount of gas is seeping from the wellhead.

Concurrently, Kurt Schwehr worked with the Environmental Response Management Application (ERMA) team in support of the Deepwater Horizon incident response seven days a week for several months. Schwehr joined the original ERMA engineering team of Rob Braswell and Michele Jacobi in 2007 and gained valuable first-hand experience through his participation in the 2010 Spill of National Significance (SONS) drill in Portland, Maine in March of 2010. Schwehr's work with ERMA focused on vessel tracking using the maritime Automatic Identification System (AIS) received through the USCG National AIS network of receivers. In response to the Deepwater Horizon event, 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 both 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 water way. The USCG has designated the CCOM/JHC ERMA NAIS feed as a "Critical Client."

On June 14, 2010, NOAA released ERMA to the public and, by a decree of Admiral Thad Allen, the responder vessel positions from NAIS were released in near real-time (every two minutes). This was a first for the NAIS system, which is usually used behind the scenes by government staff. The public GeoPlatform site (Figure 26) is available at http://gomex.erma.noaa.gov/erma.html and the protected responder site is https://gomex2.erma.unh.edu/ (account required).

The GeoPlatform system uses the ERMA databases, map layers, and visualizations on the NOAA WOC server farm to provide a public Gulf Response. As a result of the success of ERMA and GeoPlatform, the team won a Government Computer News award.

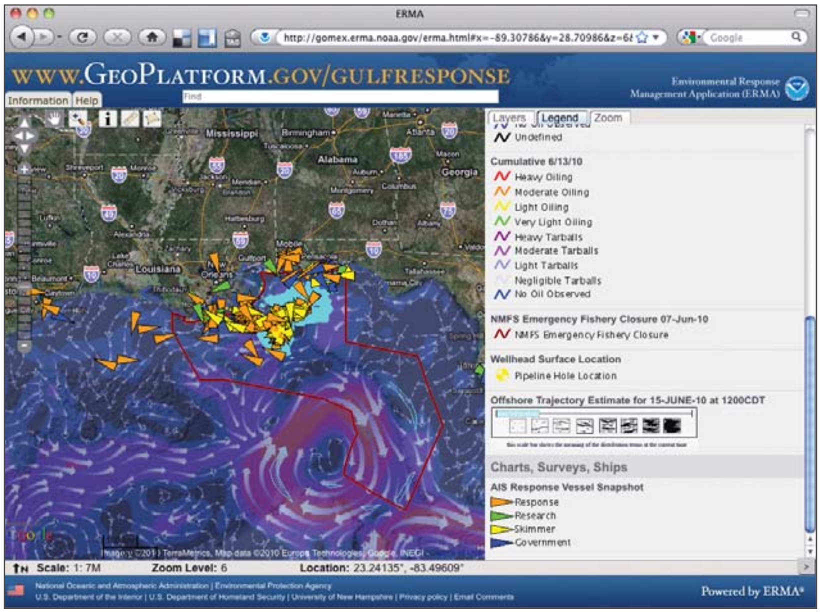


Figure 26. The Environmental Response Management Application (ERMA) as available to the public with NAIS response vessels and NCOM flow.

Both support at sea and on shore (data processing, cruise planning, data visualization) were provided during the Deepwater Horizon response; seagoing support was provided until mid September and lab-based support is still on-going. Weber participated in four cruises (two as chief scientist) aboard the NOAA Ships *Gordon Gunter* and *Pisces*. During the single cruise on the NOAA Ship *Thomas Jefferson* that gained close (1500 m) access to the wellhead during the spill, Weber provided round-the-clock, on-shore analysis of the data being collected. During this time, Mayer was providing daily four-dimensional (space and time) data visualization products for the Unified Command's Subsurface Oil Unit. Over the course of the wellhead integrity monitoring mission (several weeks from mid July to early August), Weber was responsible for examining all acoustic data collected by the NOAA Ships *Pisces* and *Henry Bigelow* (this includes cruises for which Weber did not participate: data were uploaded in near real time). During this phase, Mayer reported daily (often several times per day) to the Secretary of Energy and his Science Review Team.

After the well was capped, Weber was chief scientist for a cruise that mapped the signature of the oil more than 400 km west of the wellhead. Weber also represented the acoustic mapping team at the June 2010 oil spill workshop in Miami, and participated heavily in cruise planning and execution throughout the summer. Both Weber and Mayer are the only two academics that are officially part of the Unified Command's Joint Analysis Group (JAG).

Innovative Sonar Design and Processing for Enhanced Resolution and Target Recognition

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 RMS levels of the transmitted and received channels can be computed in real-time.

Carlo Lanzoni has evaluated and calibrated (against a digital oscilloscope) the system's ability to measure both transducer impedance and transmit voltage response and free-field voltage sensitivity. Operation manuals were written for these procedures as well as for electro-acoustic radiation-pattern measurements and frequency-response and impedance measurements; these manuals and other acoustic test-tank-related information (including safety information) have been added to the JHC/CCOM Wiki. Additionally research has been carried out to better understand the effect of the water filtration system on calibrations and code written to generate digital modulated and arbitrary signals from the calibration system computer. This ability will be essential for the new work being done by O'Donnell and Calder investigating multi-ping possibilities for future hydrographic sonar systems (see below).

The primary focus of sonar calibration activity in the tank in 2010 has been Carlo Lanzoni's thesis work aimed at developing field-calibration procedures for multibeam sonar 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 during the MBES calibration procedure. This procedure can reduce the time necessary for a MBES calibration compared to the standard indoor tank method. Depending on the target strength of the sphere and the source level provided by the MBES, it is expected that the proposed method can achieve angular accuracy values between 0.01 and 0.08 degree.

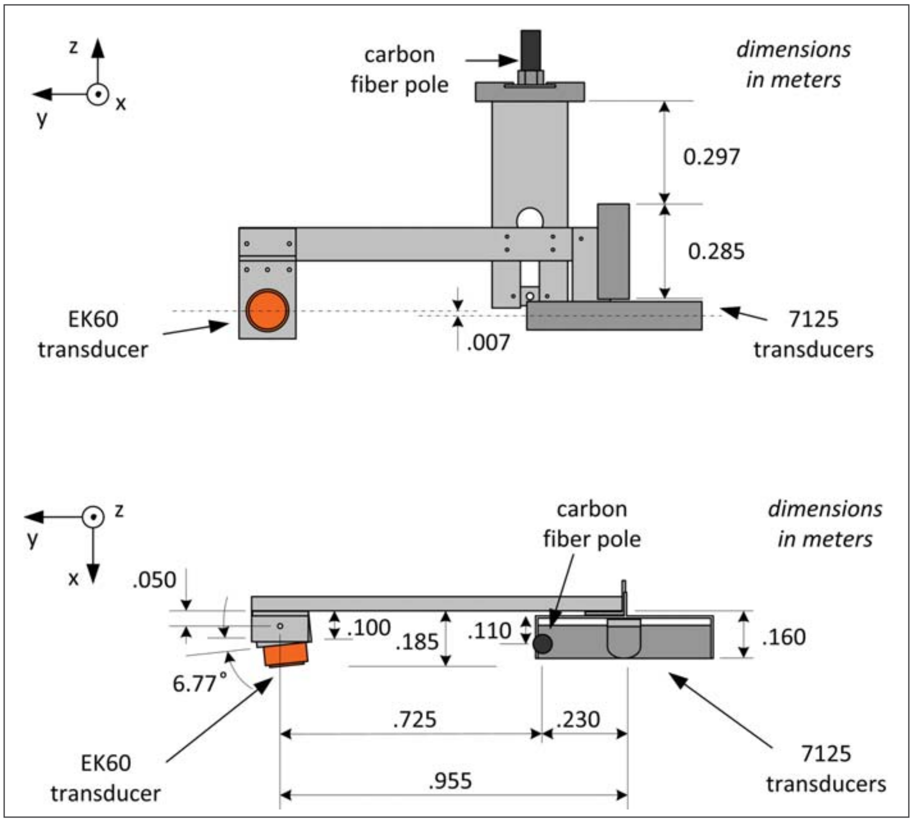


Figure 27. Test mounting for sonar calibration trials.

For his thesis work, Lanzoni worked with a Reson 7125 MBES and a Simrad EK60 split beam sonar operating at 200 kHz. The target sphere was a tungsten carbide calibration sphere (WC38.1 — 38.1 mm), that has an average target strength of -39.38 dB at 200 kHz. A method of coordinate transformation was designed to convert the target sphere position from the split-beam system to the MBES system. A support to hold the MBES and EK60 transducers was designed and built during the summer with the help of Paul Lavoie (Figure 27).

A series of measurements have been made to evaluate the saturation range of the MBES with the target sphere placed at a distance of ten meters from the transducers (this is the distance in use for the calibration procedure). A plot of the gain curves for different power settings was built from these measurements allowing the operator to choose a proper value for the power and gain settings of the MBES, avoiding saturation on the received signals when using the target sphere.

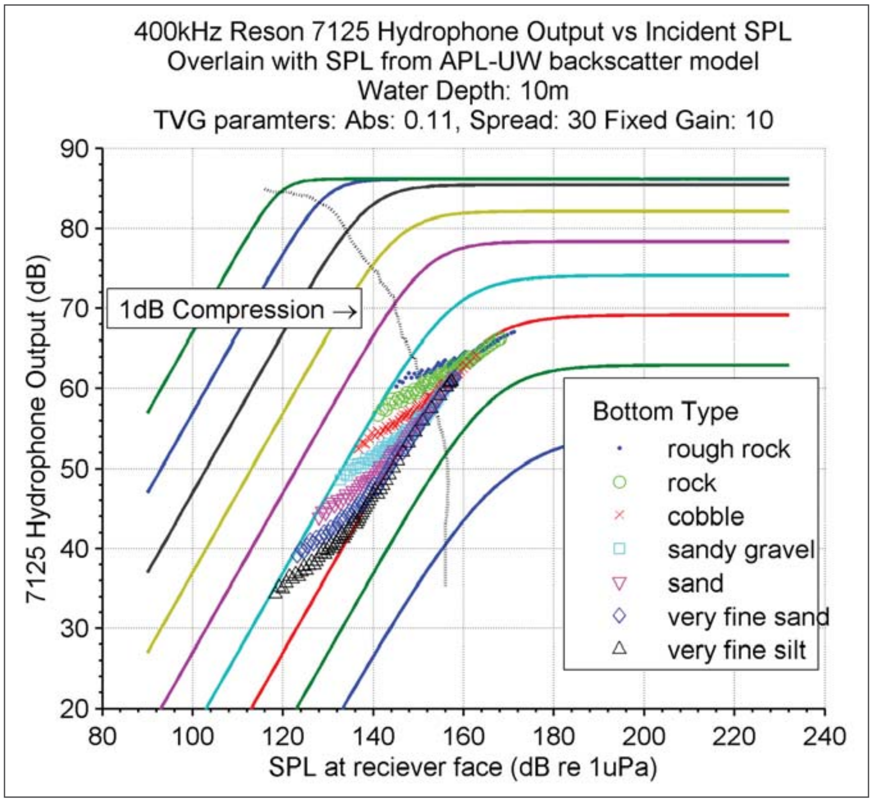


Figure 28. Modeled return from various bottom types for the 400 kHz Reson 7125. One symbol is plotted for each incidence angle from 0 to 64 degrees. The assumed transmit power is 220 dB (full). Data to the right of the 1 dB compression point experience a significant non-linear system gain that can confound Geocoder-like applications. (Image taken from S. Greenaway's MS Thesis).

Data is currently being collected over the operational angular range of the EK60 system. It is expected that this data will provide the statistics to determine the range of usability of the EK60 within the beam pattern of the multibeam system. When these are completed, measurements of the radiation beam pattern of the MBES for the range covered by the EK60 system will be made.

Graduate student and NOAA Corps Officer Sam Greenaway's M.S. thesis, which was defended in September 2010, focuses on an examination of the linearity of Reson 7125 multibeam echosounders. These systems are increasingly tasked with collecting seafloor backscatter for a variety of purposes (including characterizing the seafloor as an aid to determining essential fish habitat), and any non-linearities within the system can greatly confound the processing and subsequent results. Greenaway found that it is in fact quite possible (perhaps even likely) to use the Reson 7125 in a non-linear regime (Figure 28), particularly in shallow water. This can have large impacts on software packages like GeoCoder that are designed to look at the backscatter response of the seafloor and could confound our ability to properly characterize the seafloor. It is hoped that this work will lead to modifications in the way the Reson 7125 is used to collect seafloor backscatter.

Additionally the calibration facility was also used in 2010 to determine the Transmit Voltage Response (TVR), the Free Field Voltage Sensitivity (FFVS) and the frequency response of acoustic transmitters installed on the GAVIA AUV as part of an ONR project run by the University of Delaware to evaluate Multiple Input-Multiple Output (MIMO) communications from an acoustic modem on the AUV.

Field Tests of New Sonar Systems

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

Kongsberg 2040

In 2010, these systems included the first field trials of the new Kongsberg EM2040 high-resolution multibeam sonar. The prototype 2040 was tested from the *Coastal Surveyor* in the outer reaches of Portsmouth Harbor in an area where lidar targets had been deployed as well as in the region of the Portsmouth Harbor Common Data Set (see earlier annual reports). Given the weight of this unit (150 lbs), we had to develop a new method for installing on the Coastal Surveyor's ram. The method involved the use of an air mattress as an adjustable buoyancy device and proved to be very successful.

Klein L3 Bathy 5000-V2

The new Klein phase measuring bathymetric sidescan, the Bathy 5000-V2 was also tested in 2010 from the *Coastal Surveyor*. Klein has built their own adaptor for mounting on the vessel's sonar ram and with this setup installation takes as little as 20 minutes. Surveys were conducted in regions of the Portsmouth Harbor Common Data Set to allow direct comparison to high-resolution multibeam sonar results.

Sea Acceptance Trials

The expertise of the researchers at the Center has been sought of late to help assure that that new multibeam sonar systems being installed by the U.S. academic fleet are working properly. Over the past year, Jonathan Beaudoin and Val Schmidt have participated in acceptance trials of two multibeam systems. Jonathan participated in the sea acceptance trials for the USCGC *Healy's* new EM122 multibeam sonar, testing achievable swath coverage, accuracy and precision of the system. Beaudoin and Val Schmidt also participated in the SAT for the University of Washington's EM302 on their 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. The National Science Foundation is attempting to formalize this process with the establishment of a multibeam sonar oversight process which will involve a number of Center personnel.

Multi-Ping, Multi-Chirp Sonar

Graduate student Brian O'Donnell, under the supervision of Brian Calder, has begun a Ph.D. project aimed at looking at how time-frequency coding of signals for multibeam echosounders can be used to improve discrimination between subsequent pings. The ultimate goal is to allow the sonar to have multiple pings in the water simultaneously (thus allowing higher along-track data density), but avoid any range ambiguity through appropriate signal processing.

The time-frequency codes being proposed are linear frequency modulated (LFM) chirps and phase shift keyed (PSK) sequences. Both kinds of waveforms are used in radar, electromagnetic and acoustic communications and medical ultrasound. The characteristics of time-frequency coded seafloor echoes are essential for predicting what the sonar's performance will be. An upcoming data collection at Newcastle pier will show LFM and PSK waveform echo characteristics for relevant ranges of bandwidth, waveform duration, signal-to-noise ratio, and scattering angles.

The entire data collection setup has been assembled and tested in CCOM's acoustic test tank. The results showed that the Reson TC 2132 single beam echosounder had unacceptably high sidelobe levels, and echoes heard through these sidelobes would have made much of the data unusable. The EK 60 was identified as an alternate transducer, and the data collection setup will be tested with the EK 60 in the early spring of 2011.

New Approaches to Multibeam and Sidescan Sonar Data Processing

Improved Bathymetric Processing

CUBE and Improved Uncertainty Management

One of the major efforts of the Center has been to develop improved data-processing methods that can provide hydrographers with the ability to very rapidly and accurately process the massive amounts of data collected with modern multibeam systems. This data-processing step is one of the most serious bottlenecks in the hydrographic "data-processing pipeline" at NOAA, NAVO, and hydrographic agencies and survey companies worldwide. We explored a number of different approaches for automated data processing but have focused our effort on a technique developed by Brian Calder that is both very fast (10's to 100's of times faster than the standard 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 current, very time-consuming process of subjectively examining all data points.

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

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, Sonartech Atlas, 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 2010 is described below.

Multiresolution Grids and CUBE V2/CHRT

Development work on the new multiresolution grid structure at the core of CUBE V2 has continued in 2010. We have adopted as a working name CUBE with Hierarchical Resolution Techniques, or CHRT. The code base is now essentially complete and preliminary testing has taken place. As part of a more rigorous testing process compared to CUBE V1, considerable time has gone into providing formal test-vectors and unit testing code for the algorithm and data structure, designed to show that it is functioning as expected and generating results without untoward side effects. These tests are particularly strong on the data structure itself, to show basic functionalities, but also exist for data processing, and are being extended as the algorithm functionality is being extended. Full documentation of the source code has also been undertaken using the doxygen application. This is intended primarily for internal use in the current context, but will hopefully prove useful to any of our Industrial Associates who choose to implement this algorithm at a later date.

Preliminary tests of the algorithm with field data (NOAA's H11825, a mixed multibeam survey in typical Alaskan fjord-like environments) appear to show that the mechanisms to estimate data density from raw data are working adequately (Figure 29(a)), and that density estimates can be transformed into resolution estimates (Figure 29(b)) that appear to be sufficiently smoothly varying to allow the system to operate as expected. The algorithm has also been extended to allow for multiple methods of resolution determination, and to allow for user-specified preferred resolution bands, or a constriction to a dyadic resolution scheme. These were requested as options by some parts of NOAA and some Industrial Associates.

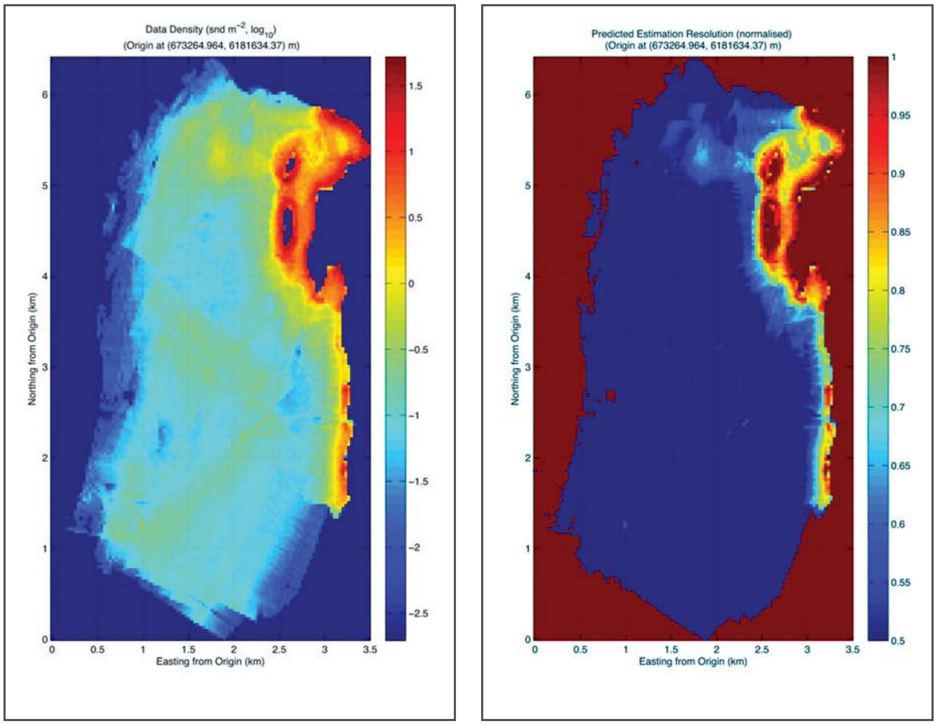


Figure 29. Example of data density [(a), left] and predicted stable estimation resolution [(b), right] for data from NOAA Ship *Fairweather* (NOAA reference H11825). The data density is computed directly from the raw data as a first pass of CHRT, and varies from below 0.003 snd/m^2 to over 30 snd/m^2 (note logarithmic color scale). The predicted resolution is on a normalized scale for clarity of presentation, but varies from a (user specified) minimum of 0.5m to the system estimation scale of 32m.

In addition to the base algorithm, Calder has been working on mechanisms for distribution of the algorithm over multiple machines, and within a networked environment. This effort represents an adopted design goal for the algorithm that it should not necessarily have to reside and operate on the same machine as the user client software: users are now able to poll the network for computational resources, and utilize any that are currently available and appropriately configured for their current needs. This is an approach to implementation of a 'headless data processing computer' and is also adaptable to parallel processing schemes. The protocol is designed so that it could also have a number of servers clustered together under a single 'head' controller so that we could aggregate multiple machines as one logical server for more heavily dedicated processing. This should give us the full blade-server implementation that was originally envisaged, but also allow us to implement more complex partitioning and balancing schemes that are developing from Venugopal's work on the parallel processing scheduler (see below).

In addition to the technical work on this project, Calder has worked with NOAA's Coast Survey Development Lab to outline a formal process by which the algorithm will be tested for NOAA approval. This is an attempt to promote a more rigorous testing environment than was previously used in code transfers and to provide the environment to improve NOAA's software quality assurance program. That is, if the algorithms are implemented in such a way that they could be used in a production environment, and NOAA formally tests those algorithms for acceptance, implementation of those algorithms by vendors are more likely to be what was intended by CCOM. (This assurance has been an issue in the past.) The goal is not to generate 'commercial' code, but to go much farther down this road than we have previously in order to avoid some of the transition difficulties we have experienced in the past. Emphasis on this point in the initial designs makes them more difficult to build, but ensures that they do not have to be redesigned after testing in order to be effective.

Calder has also conducted a number of briefings on the technology, design of the interfaces and algorithm development for NOAA, and a number of our Industrial Associates. This has led to some suggestions for modifications which have been incorporated and detailed discussions about use patterns for this software in vendor products.

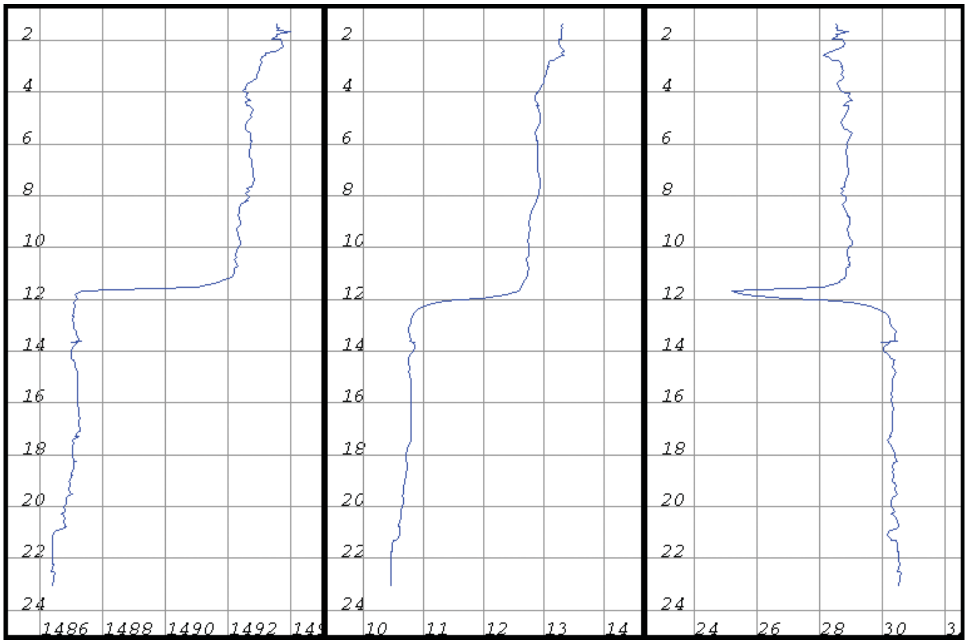


Figure 30. Vertical profiles of sound-speed, temperature and calculated salinity (left to right) from the 2009 UNH/CCOM Field Camp trials with the ODIM Brooke Ocean MVP30. The differing response times of the sound-speed and temperature sensors lead to artifacts in the calculation of salinity over depth ranges where the vertical gradient in sound-speed and/or temperature are significant.

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 the largest single source of error within our measurements. With the arrival of Jonathan Beaudoin to the Center, our efforts focused on developing methods to assess the uncertainty in sounding due to the variability in the sound-speed profile (SSP) and the way that the profile is determined have increased dramatically. There are several aspects to this effort including: looking at the impact of sensor latency on sound-speed profile data, estimation of total sensor suite uncertainty for sound-speed measurement systems, the effects of internal waves on MBES accuracy, the incorporation of the World Ocean Database into sound-speed analysis software, examination of salinity assumptions used with XBT measurements, and approaches to streamlining sound-speed profile pre-processing. Jonathan has initiated a dialog with NOAA's HSTP to ensure that these efforts meet their needs.

Impact of Sensor Latency in High-Rate CTD/ Sound-Speed Profiling System

In anticipation of the arrival of Beaudoin to the Center in 2010, the UNH Hydrographic course was asked to acquire data sets with the ODIM Brooke Ocean MVP30 during their field operations in June of 2009. The MVP30 was equipped with an AML SV&T probe, allowing for the measurement of sound-speed and temperature. A section of the Piscataqua River was sampled repeatedly over a period of several hours in an attempt to provide an initial understanding of the temperature/salinity characteristics of the main river channel over a range of tidal conditions. Salinity profiles were calculated through iterative inversion of the Chen-Millero sound-speed model; a sample profile is shown in Figure 30. Salinity spiking artifacts were encountered; these were found to be caused by the differing sensor-response times of the sound-speed and temperature sensors with the temperature sensor having a much slower response time as compared to the sound-speed sensor. The differing response times provide incorrect calculated parameters in conditions of pronounced thermoclines and/ or haloclines. A correction method, proposed by the SV&T probe manufacturer (AML Oceanographic), was attempted in order to improve salinity estimates; however, results proved unsatisfactory and the salinity spikes persisted.

The spiking problem is especially troublesome with sensors that experience a high drop rate through the water column. The MVP30 allows the tow fish to freefall through the water-column and drop rates of up to 5 m/s have been reported. The high drop rates and slow response time of the temperature sensor can cause problems for MVP users who chose to instrument the tow body with a CTD sensor instead of a sound velocimeter. In the CTD instrumented towfish installations, a mathematical model is used to calculate sound-speed from the observed temperature and salinity and sound-speed spiking artifacts can occur as shown in a sample profile in Figure 31.

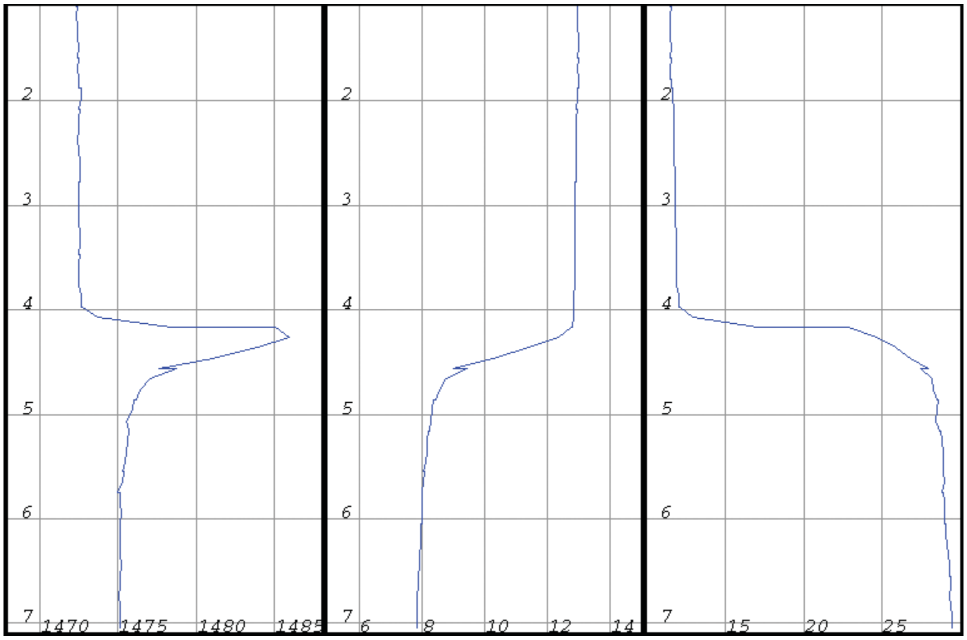


Figure 31. Sample sound-speed, temperature and salinity profile (left to right) from the mouth of the Saint John River in Saint John, New Brunswick, Canada. Temperature and salinity are observed directly and are used to calculate sound-speed. Note the positive spike in sound-speed at the thermocline/halocline depth.

An investigation has been undertaken to quantify the potential sounding uncertainty associated with such artifacts and to ascertain whether or not corrective measures should be taken. This is being done in collaboration with Tom Dakin of AML Oceanographic, manufacturers of CTD and sound velocimeter instrumentation. Tom's contribution is to provide realistic estimates of the latency and uncertainty characteristics of the various sensor types used in this investigation.

Estimation of Total Sensor Suite Uncertainty for Sound-Speed Measurement Systems

Other work with Tom Dakin includes total sensor-suite uncertainty budgets that accommodate the uncertainties and latencies of common sound-speed profiling instrumentation, e.g., to be able to compute and compare the total propagated uncertainty of varying methods for measuring sound-speed. Examples of differing techniques include: XBTs that measure only temperature and estimate salinity and depth, CTDs that measure conductivity, temperature and pressure and calculate sound-speed using mathematical models, and velocimeters that measure sound-speed and pressure. The varying sensors have different characteristics such as latency, bias and noise, each of which can have different impacts on the ability to adequately and accurately model the speed of sound through water-column.

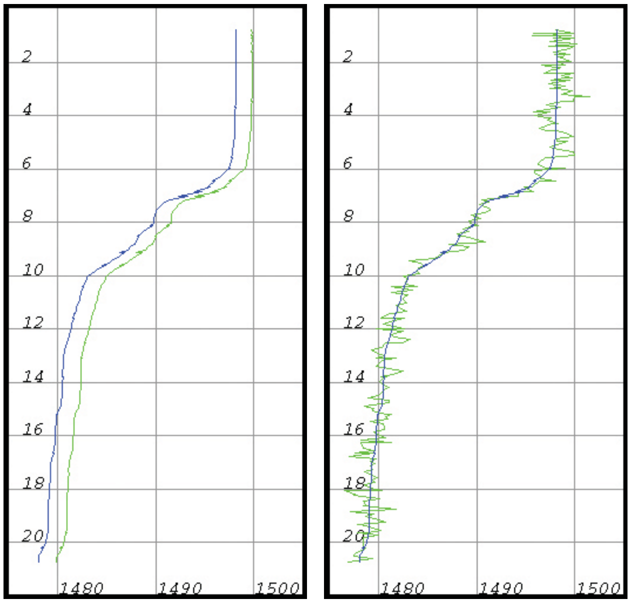


Figure 32. Sample sound-speed profiles used in simulation of the effects of a biased (left) and noisy (right) sensor.

An initial investigation has examined the effect of sound-speed uncertainty in isolation, primarily to assess the simulation's consistency with existing uncertainty models (that do not examine the total instrumentation suite uncertainty). Monte Carlo simulations were used for a series of ~900 sound-speed casts acquired in the Piscataqua River mouth and offshore in the vicinity of the Isles of Shoals. The simulation applied random biases and then random noise, both with a specified 1-sigma sound-speed uncertainty to create pseudo-casts (Figure 32).

These pseudo-casts were then compared with the uncontaminated cast via an uncertainty analysis to assess the impact on sounding bias.

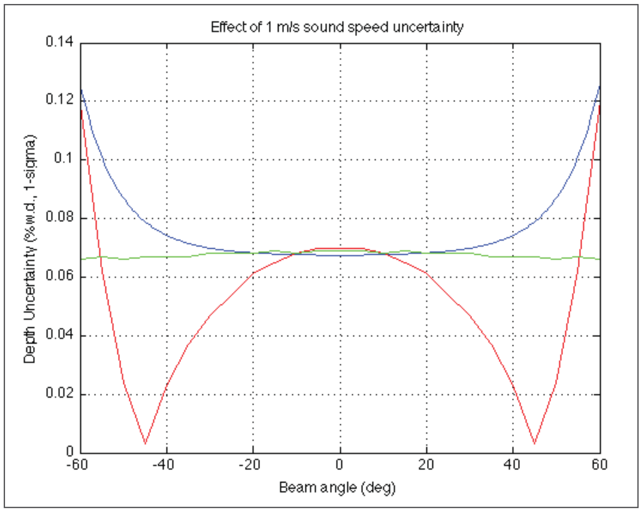


Figure 33. Comparison of Monte Carlo sound-speed uncertainty simulations (green and red) to Hare-Godin-Mayer uncertainty model.(blue). Green and red represent simulation results which, respectively, incorporate and ignore surface sound-speed measurements as an augmenting aid to ray tracing.

Each cast of the 900-cast data set was subjected to 1000 runs of the Monte Carlo simulation for both the bias and noise, yielding a set of sounding biases for the chosen sound-speed uncertainty. Repeating this process with increasing levels of sound-speed uncertainty showed the sounding uncertainty at a 60° beam angle for a given sound-speed uncertainty. As expected, the biased sensor simulation shows an order of magnitude increase in uncertainty relative to the effect of a noisy sensor: i.e., it is better to be accurate and imprecise than precise and inaccurate. Comparison of these results to the Hare-Godin-Mayer model is shown in Figure 33. The simulations agree well with the model near nadir but diverge beyond ~20°. Further work must be done to examine why this is the case, but it is suspected that the simplistic treatment of sound-speed uncertainty in the model may be to blame.

Examination of the Effect of Internal Waves on MBES Accuracy

Under the general rubric of trying to understand the effect of water-column structure on mapping, Beaudoin is also looking into the effects of internal waves upon the sounding accuracy of MBES (see Figures 34 and 35). During the summer of 2009, Beaudoin spent six weeks offshore and supervised an undergraduate student in the construction of a mathematical model that allowed for a 3-D estimation of the uncertainty impact associated with internal waves. Further data has been opportunistically acquired to help validate the model during the R/V *Thomas G. Thompson* EM302 SAT in October 2010 (see following discussion). Internal wave perturbations of the acoustic ray paths are believed to have been the dominant source of sounding uncertainty during this brief survey on the continental shelf off the Washington coast, as shown in Figures 36 and 37. Further examination of the ADCP data might provide evidence of internal wave activity and aid in determining the wave parameters such that the internal

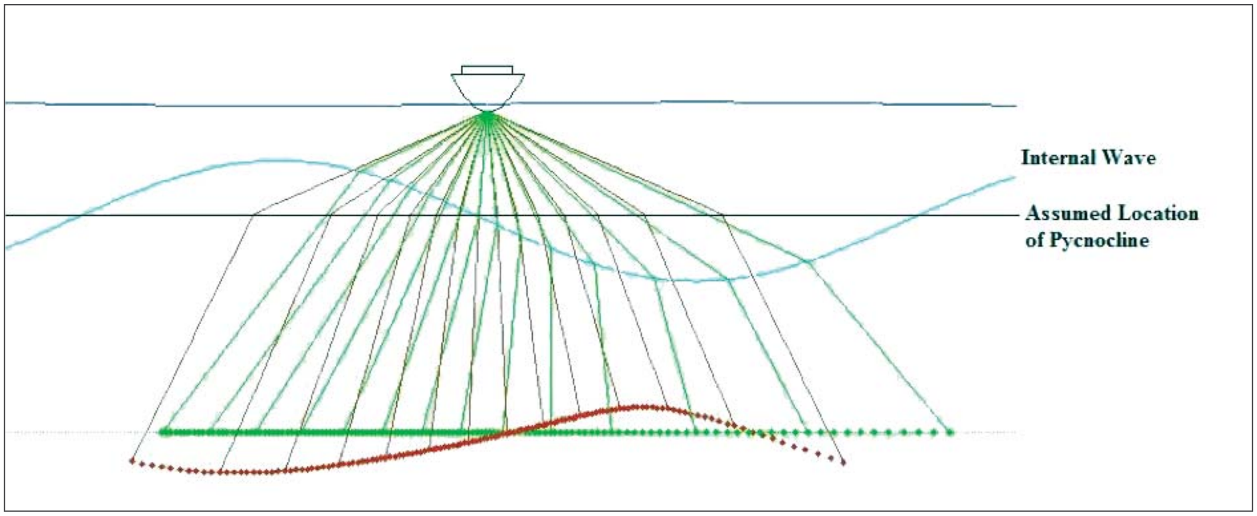


Figure 34. Example of the impact of internal waves on MBES sounding accuracy. A synthetically flat seafloor is used in conjunction with a mathematically modeled internal wave to estimate the ray trajectory for a series of angles across a typical MBES angular sector. These travel times are then reduced with a traditional ray tracing algorithm, yielding the red soundings. Illustration courtesy of T. Hamilton.

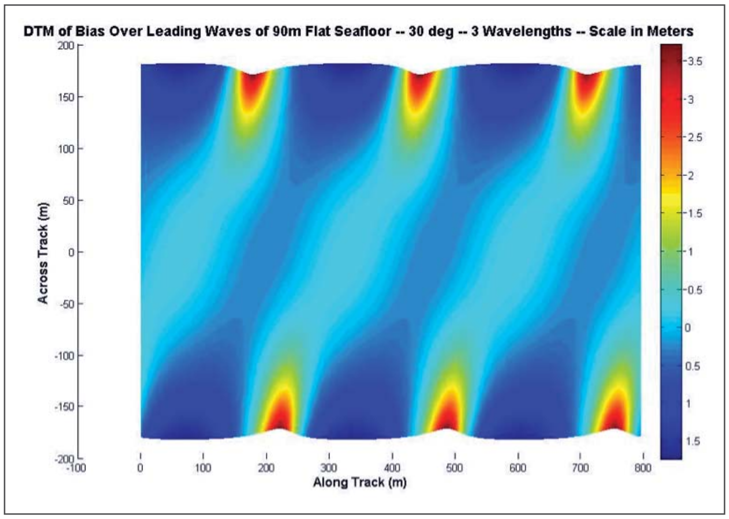


Figure 35. Output from 3-D internal wave model showing the depth bias that results from the presence of internal waves examined in a case study of internal wave activity over Banquereau Bank on the Scotian Shelf just offshore of Nova Scotia, Canada.

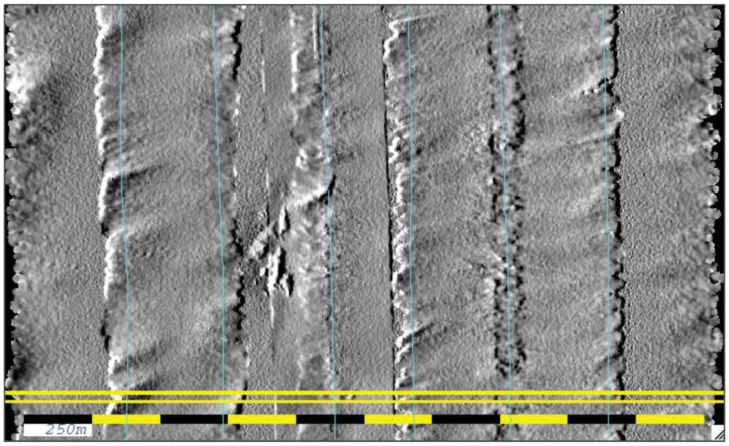


Figure 36. Sun-illuminated topography of the southeastern section of the shallow survey area. Only the small outcrop feature just slightly left of center is real, all other features are refraction type artifacts likely due to internal wave activity perturbing the acoustic ray path. The long rectangular area highlighted in yellow is shown as a cross-section of soundings in Figure 37.

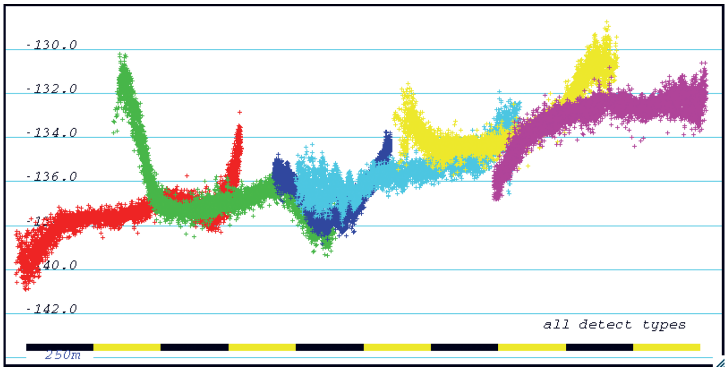


Figure 37. Cross-section of soundings from the image of Figure 36. Inconsistencies in areas of overlap are due to refraction type artifacts commonly associated with internal wave perturbations of the thermocline (note the asymmetric refraction artifact on the green soundings).

wave uncertainty model can be further tested. Ongoing collaboration between UNB and UNH is critical to furthering this research.

XBT Optimal Salinity

Expendable bathythermographs (XBTs) are a common tool used in oceanography to provide underway data that can be used to calculate the sound-speed profile. These devices only measure temperature as a function of depth and a constant salinity must be assumed. Beaudoin has been investigating the impact of making this constant salinity correction. Little guidance has been found in the XBT documentation or in the literature on methodologies to account for salinity structure or on selection of an optimal constant salinity that best accounts for salinity structure effects on sound-speed. Beaudoin has used his sound-speed profile comparison software to reverse-engineer the optimal salinity for the world's oceans as a first attempt at providing some guidance to the deep water mapping community on how to best implement the salinity correction for deep water MBES data. The reverse-engineering analysis was done using the World Ocean Atlas (2001), with results shown in Figure 38. Future work will include analyses on the near-shore areas of the world in order to provide guidance on the use of XBT in regions of freshwater influence.

Incorporation of World Ocean Database Into Sound-Speed Analysis Software

Following up on the XBT work described above, Beaudoin has also been looking at the use of The World Ocean Database (WOD) as a general tool to support hydrographic mapping. The WOD contains approximately ten million measurements of oceanographic parameters covering the world's oceans. These data provide a valuable resource in the planning stages of hydrographic surveying as they give a sense of the magnitude and nature of variability in the water-column. This type of information can provide the basis for better decisions regarding sound-speed profiling selection and operation. Access to this database has been added to Beaudoin's sound-speed analysis software, allowing for querying of the database and then analysis of the results.

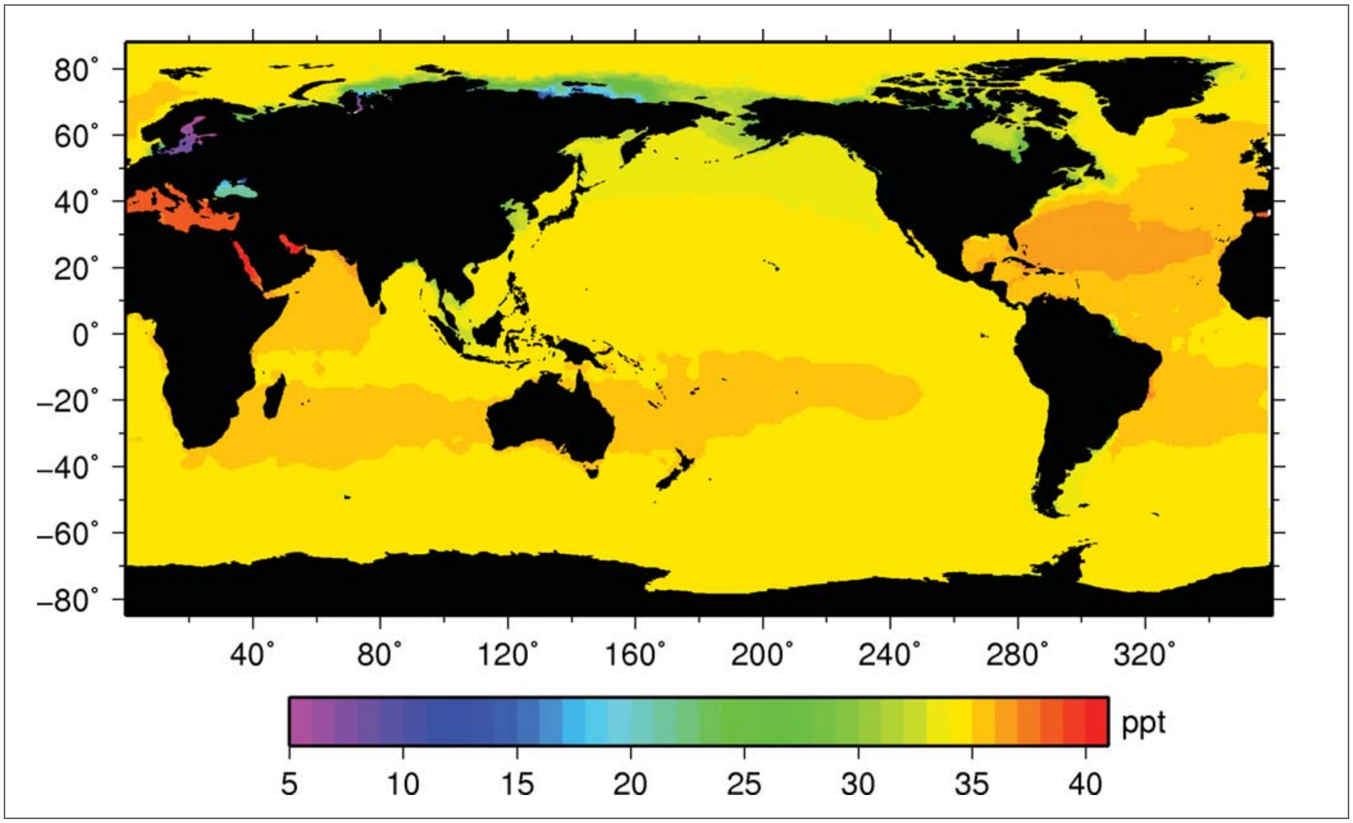


Figure 38. XBT optimal salinity based on World Ocean Atlas 2001 (August grid). The analysis was done for the upper 760m of the world oceans, this being the sampling depth for T-7 and Deep Blue XBT probes.

Extracted casts can be exported and used for other purposes, for example, depth extension of observed casts.

The tool was used prior to Jim Gardner's Law of the Sea cruise off the Mariana Islands (see section on Law of the Sea work) to ensure that the Deep Blue XBT probes would indeed capture the range of oceanographic variability in the area. An example of the data used for this is shown in Figure 39. Note that the variability in the temperature signal is minimal below the Deep Blue's maximum sampling depth of 760 m, thus Deep Blue XBTs would prove adequate for providing sound-speed solutions for the seabed mapping efforts. The tool was also used prior to an SAT off the coast of Washington state to assess the impact of spatio-temporal water-column variability prior to the cruise.

Streamlining Sound-Speed Profile Preprocessing Case Studies and Field Trials

Beaudoin also continues his work with ODIM Brooke Ocean aimed at improving and adding functionality to their MVP controller interface, most notably in the field of uncertainty monitoring, and including streamlining sound-speed profile pre-processing procedures such that the data flow between sound-speed measurement and application in acquisition software that is automated as much as possible. Example procedures that sometimes must be applied include vertical extension of the measured cast to a user-defined minimum depth, reduction of the number of data points in the vertical profile to a user-defined maximum, etc. Beaudoin has suggested methods to address both of these problems and these methods will be presented at the upcoming U.S. Hydro Conference. Results from a field trial in the French Mediterranean will be used to assess the improvement in real-time MBES acquisition workflow and survey accuracy and will also highlight where further improvements can be made in the preprocessing pipeline.

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 may lend themselves to a parallel-processing approach. Consequently, Calder is supervising graduate student Rohit Venugopal

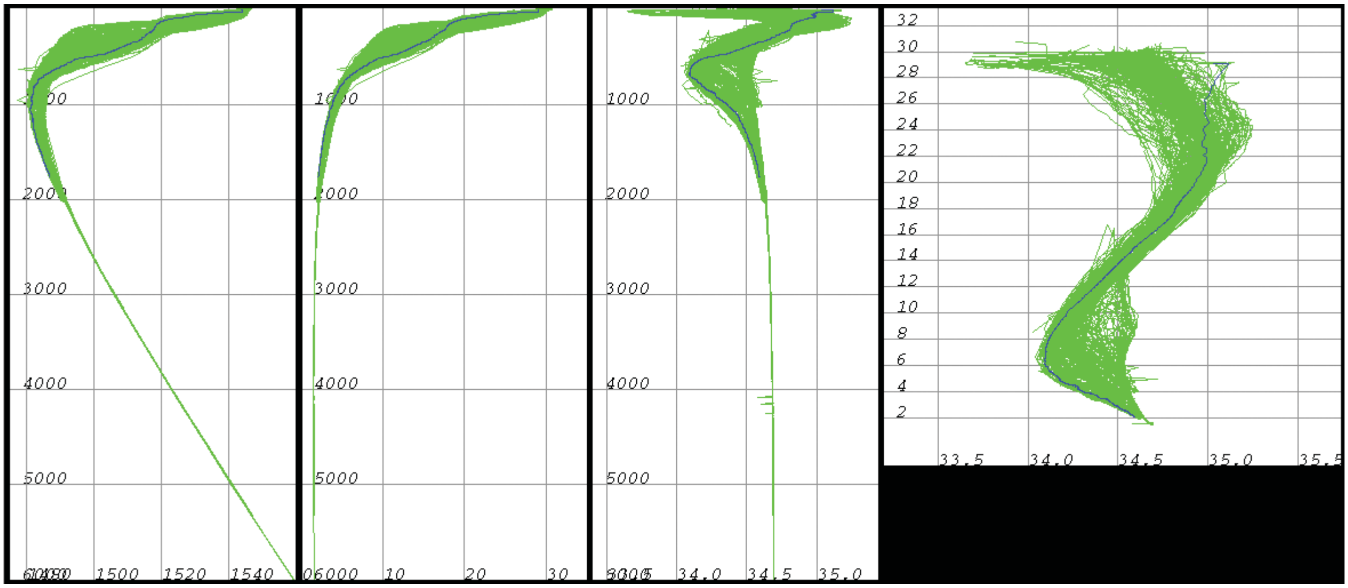


Figure 39. Depth profiles of sound-speed, temperature and salinity and a T/S plot of the same in the vicinity of the Mariana Islands, August (left to right, respectively).

in an M.Sc. thesis that focuses on the concept of a parallel-processing system for hydrographic data. The Center has acquired seven Dell Poweredge Blade Servers (see IT section) that are 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.

Specifically, work has been completed to understand the structure of raw data files (XTF) and to produce processing time estimates by analyzing the metadata or the headers present in the files. From this study, it appears that the size of the raw data file and the processing time required to extract the metadata are independent of each other. However, the code developed provides useful metadata of the raw XTF files that are helping in the next stage of analysis and, in particular, we have the exact number of bathymetry packets, data packets, and the total size of the file that we need to compare the accuracy of our estimator. Since each bathymetry packet requires a fixed amount of time for processing, our efforts have been concentrated on the estimation of the number of bathy packets by reading only the initial small portion of the file. This helps in the estimation of the processing time for that particular file without scanning it completely. Reading only the start of the file, the estimator produces an average error of 0.13 %. Our plan is to use this estimator to feed information to the Job Scheduler/Load Balancer module, which in turn will use the information to distribute the processing of different files to the nodes of the cluster in a balanced way. The overall layout of the approach is presented in Figure 40.

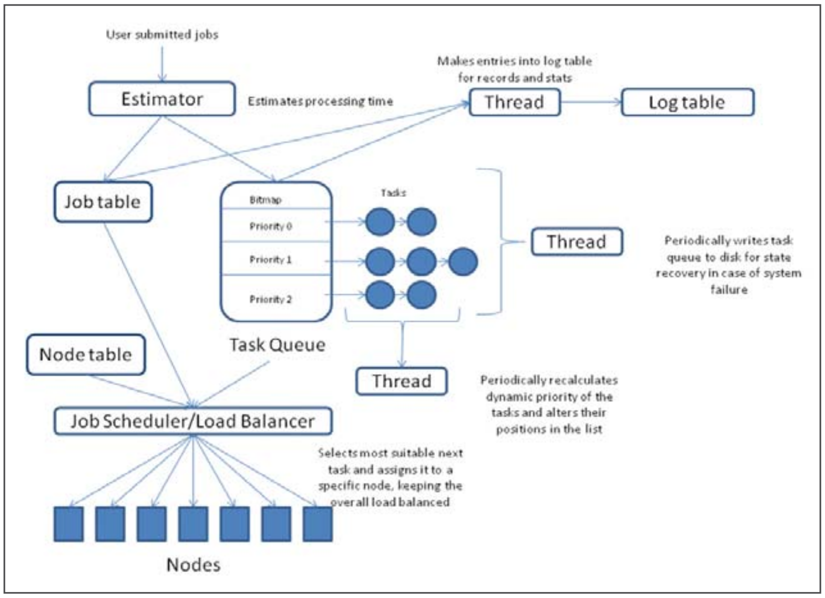


Figure 40. Proposed parallel processing system layout.

An impediment to earlier progress was the lack of a Non-Disclosure Agreement with CARIS, which would allow them to provide us with APIs to their data-processing library. This is required in order for the system being developed in-house to use the algorithms that NOAA currently uses for their data processing. The negotiations on the NDA were finally completed and a copy of the agreement hand-delivered to CARIS in January 2010. We have had subsequent meetings with CARIS to develop API requirements. While we believe that there is support for this effort at the highest levels of management within the company, at the time of writing, we still have not received the software libraries required.

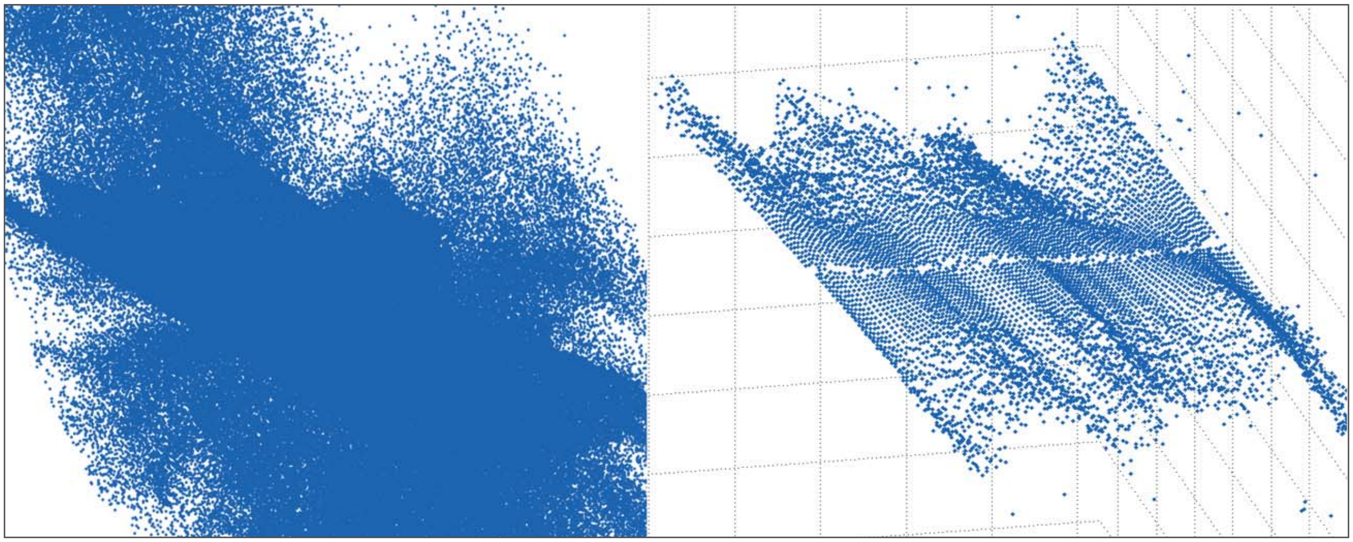


Figure 41. One hundred pings of unfiltered (left) and filtered (right) Geoswath data collected from the GAVIA AUV. Nearly 4000 data points are recorded per port/starboard ping pair, however only roughly half of these are likely to be result from a measurement of the seafloor. Electrical, water colum and surface noise contribute the remainder.

In addition to the use of CARIS primitives for the early stages of the MBES data processing pipeline, we hope to demonstrate parallel processing for CHRT data structures as part of the project. To support this, Calder has developed a client-server architecture for driving CHRT data structures that is sufficiently flexible to allow it to be used on a cluster of machines, or in multiple instances on a partitioned cluster in order to provide dynamic resource allocation and targeted performance groups to address issues of resource contention and starvation.

Improved Processing for Phase Measuring Bathymetric Sonars

Phase measuring bathymetric sonars (PMBS) (multi-row sidescan sonars that look at phase differences between the rows to derive a bathymetric solution) have the potential of offering much wider coverage in shallow water than conventional beam-forming multibeam sonars. NOAA and other mapping agencies have recognized this potential benefit and have begun to explore the potential for PMBS as a hydrographic tool. One of the immediate results of this is the realization that current hydrographic processing software approaches and tools are cumbersome to use with very dense, but inherently noisy, data produced by PMBS. The Center has committed itself to exploring new approaches to processing PMBS data and, in support of this commitment, has teamed with the University of Delaware in the operation of a 500-kHz GeoSwath PMBS that is mounted on a GAVIA Autonomous Underwater Vehicle. This has provided us the opportunity to collect our first 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 at NOAA.

Val Schmidt has taken the lead in exploring problems with (and new approaches to) processing PMBS bathymetric data. Working with data collected by the 500 kHz Geoswath system aboard the GAVIA AUV (see AUV section below), 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. One hundred pings of unfiltered (left) and filtered (right) Geoswath data are shown in Figure 41to illustrate this problem.

Noise in PMBS bathymetric data results from a combination of baseline decorrelation, footprint shift, simultaneous returns from multiple scatterers, or simply low signal-to-noise ratio. Phase measurements such as those shown in Figure 43 may be filtered by binning the data into 1 m horizontal bins (under a flat seafloor assumption) and then choosing a window around the most probable phase measurement in each bin within which measurements are retained. We call this the "Most Probable Angle Algorithm." The method retains individual soundings, makes few assumptions about the seafloor or its continuity and reduces the number of data points by roughly half. Red phase measurements shown in Figure 42 are retained with this method whereas blue measurements are rejected.

An across-track trend filter (shown as dotted lines in the Figure 42) removes occasional poor picks of the seafloor by the Most Probable Angle Algorithm, that would result in clumps of soundings far removed from the actual seafloor. Red circles indicate selections by the Most Probable Angle Algorithm that have been removed by the across-track trend filter. To further reduce the noise and volume of data, one may also choose the most-probable angle in each 1 meter bin. This gives 1 m equidistant soundings much like modes common in multibeam sonar systems (Figure 43).

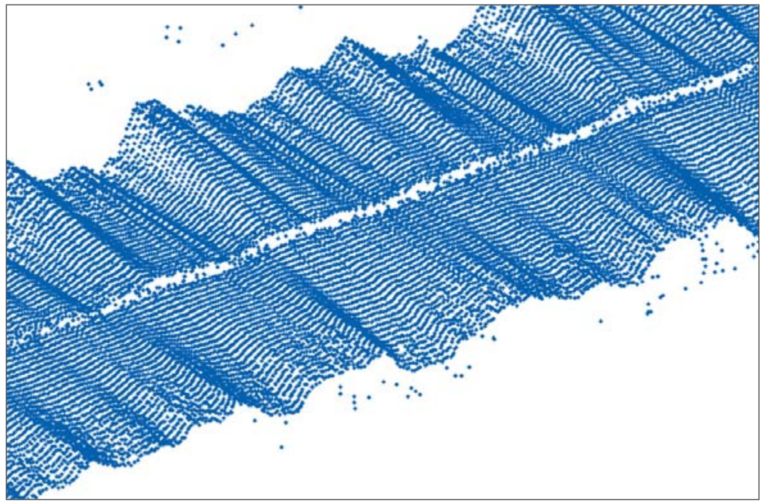


Figure 43. One meter equidistant soundings by taking only the "most probable angle" measurement. Although motion artifacts are evident in this data, the method greatly reduces the noise inherent in PMBS systems.

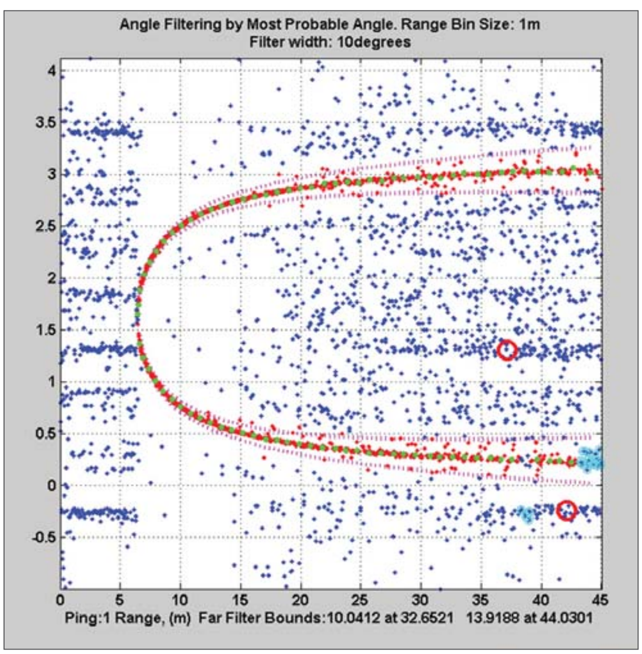


Figure 42. Most Probable Angle Phase measurement solutions from Geoswath data.

Finally, rather than reduce the number of soundings further as shown above, an attempt has been made to utilize the noisy soundings as they are, allowing automated methods such as CUBE to weigh the soundings due to their respective uncertainty. This, of course, requires that we estimate the uncertainty of the angle measurements. This has been done by an established method for non-stationary data, involving the variance of the first derivative of the angle measurement rather than the angle measurement itself. Figure 44 shows uncertainty for the angle measurement using this method. We note that this method is empirical, and therefore, is dependent on local, particular set of conditions and bottom type.

The algorithm has been successfully utilized on a second survey. This site, off the coast of Delaware, contains a shipwreck, a sunken barge and several New York City subway cars, all sunk as part of an artificial reef project (Figure 45). A 5 cm scour depression due to a change in sediment type is clearly evident in the bathymetry and gives some indication of the quality of the result.

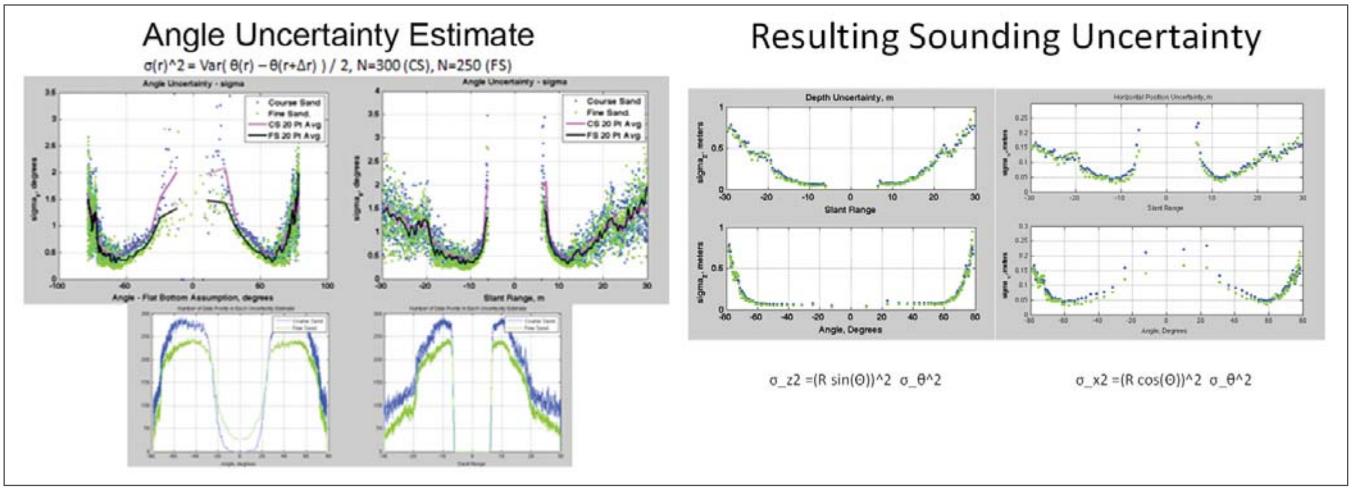


Figure 44. Angle Uncertainty and the resulting sounding uncertainty estimate from the Geoswath sonar system. Note these are not the full sounding uncertainty as vessel position and orientation are not considered.

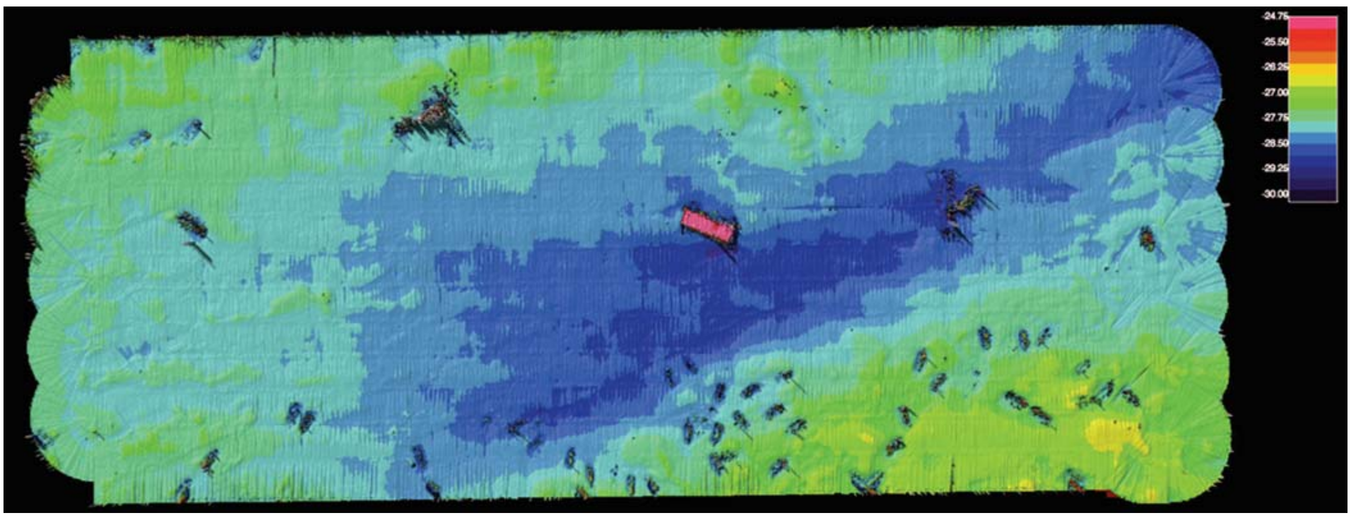


Figure 45. "Redbird" survey site off the Delaware coast in which several sunken subway cars, a shipwreck and a sunken barge are clearly evident.

Rethinking the Patch Test for Phase Measuring Bathymetric Sonars (PMBS)

Another issue associated with PMBS is the question of the appropriate approach to calibration through the patch test. Patch test techniques developed for traditional multibeam sonars are not appropriate for PMBS and new techniques must be developed. Jonathan Beaudoin has been working with Janice Eisenberg from NOAA to develop approaches for geometric calibration procedures for dual-headed phase measuring bathymetric sonars. The driving reason behind this project is that the standard suite of calibration procedures used for MBES do not apply to PMBS because of factors such as poor ranging ability at nadir and relatively poor object detection in the outer swath. Efforts have been made on the part of NOAA to adapt and improvise calibration procedures for a hull-mounted Klein HydroChart 5000 system during field trials in 2010; however, COTS solutions do not currently provide the ability to perform the calibration or assess its validity.

Improved Sidescan Sonar and Backscatter Processing

GeoCoder

Although our initial data-processing efforts were focused on improving bathymetric processing, it became increasingly clear that there was also a great need for improved processing of backscatter data, (from both multibeam sonars and sidescan sonars). With this in mind, a new effort began in 2005 aimed at improving the suite of backscatter processing tools available. The aim was two-fold: to develop easy-to-use tools that would generate "pretty" images of sidescan sonar or multibeam backscatter that will be suitable for small object detection as well as geologic and habitat interpretation, and to develop tools that allow for the quantitative analysis of backscatter data in support of seafloor characterization and small object identification.

A lab-wide effort was started to develop a new suite of backscatter processing tools in an effort to meet these two objectives. The effort was led by Luciano Fonseca with input from many others. The goal was to create an integrated suite of tools that would allow us to import backscatter or sidescan data from a number of sensors, in various forms and formats, convert these data to an internal GSF format, correct these data (where possible) for source levels, beam patterns, gains, area ensonified, attenuation and local slope, and then either analyze and/or display these data in a georeferenced mosaic. The result of this effort is GeoCoder, a C++ mosaicing tool that reads multibeam or sidescan sonar data in GSF, XTF or a range of native formats and applies a series of radiometric and geometric corrections to the data including corrections for beam pattern effects.

Normally, the empirical beam-pattern correction is calculated as the residual necessary to flatten the angular response registered by the sonar system; i.e., to normalize the backscatter at 45 degrees, sometimes adding a Lambertian correction. The approach used by GeoCoder calculates the beam pattern as the residual to the modeled angular response of the ensonified seafloor that then reveals the actual nonlinearity of the transducer angular response. Data are then georeferenced (or geocoded – thus the origin of the name) in a projected coordinate system using an interpolation scheme that emulates the acquisition geometry.

A feathering algorithm smooths the transition between overlapping lines and an anti-aliasing algorithm makes it possible to produce a lower resolution mosaic that is not degraded by aliasing. Slant range is corrected using actual bathymetry, and a trend-adaptive angle-varying gain helps remove artifacts that appear when different bottom types are found along a single swath. Lines can be removed or remosaicked, and the overlap area between parallel lines can be controlled by filter parameters.

GeoCoder also supports a statistical package that identifies patterns in the backscatter response that can be used in support of seafloor characterization (see below). Statistics calculated for backscatter bins include: mean, mode, range, minimum, maximum, standard deviation, variance, percentiles, quartile range, skewness, kurtosis, moments of any order, and also parameters extracted from a gray-level co-occurrence matrix (contrast, homogeneity, dissimilarity, entropy and energy). Taking advantage of the corrections made to the backscatter, GeoCoder also serves as the front end for a new and exciting approach to using multibeam backscatter data for seafloor characterization called ARA (Angular Range Analysis—formally known as AVO). The ARA tool will be reported on in the seafloor characterization section.

Since its development, GeoCoder has become a simple-to-use tool for generating a high quality sidescan-sonar or backscatter "mosaic" that has been greeted with much excitement in the community. There has been tremendous interest in this software throughout NOAA, from our industrial partners and academic institutions. This has led to a number of licensing requests as well as requests for training. We have now offered two training short courses. An email from one of the attendees (from 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." An industrial partner collecting massive amounts of "awful" backscatter data in the Indian Ocean tried GeoCoder and it resolved their data quality problems.

Given the high demand for use of GeoCoder, the list of systems that it supports (and the list of users) is quickly growing. The complete list of systems and formats supported is now:

- Kongsberg/Simrad multibeam .all (beam time series and beam average)
- Simrad Sidescan
- Reson (.xtf, .s7k), snippets, beam average and sidescan
- Klein sidescan, sdf, sdf2
- XTF sidescan (various sonars)
- GSF multibeam (various sonars, beam average and snippets)
- HSX sidescan (various sonars)
- Seabeam (beam average and sidescan)
- Geoswath (.rdf)
- C3D (.xtf)

In further support of our backscatter (and other) processing efforts, Brian Calder has developed and licensed (to industrial partners SAIC and GeoAcoustics) software to convert GeoAcoustics data to GSF format, and; a prototype to convert the native GeoSwath format (RDF) into GSF has also been developed.

The value of GeoCoder is also demonstrated by the growing interest from our industrial sponsors; licenses for GeoCoder have been issued to:

- Caris
- Reson
- Fugro
- Triton
- Hypack
- IVS 3D
- Chesapeake Technology

Additionally, a number of NOAA programs and academic partners are actively using GeoCoder, these include:

- NOAA SANCTUARIES
- NOAA Alaska Fisheries
- NOAA Pacific Coral Reef Program
- NOAA Ship *Thomas Jefferson*
- NOAA Ship *Fairweather*
- NOAA/JIMAR Coral Reef Ecosystem Division
- Jacobs University Bremen, School of Engineering and Science
- University of Galway
- University of Ulster, Northern Ireland
- Oregon State University
- University of Saint Andrews
- Geological Survey of Canada
- CIDCO-Le Centre Interdisciplinaire de Développement en Cartographie des Océans
- Stockholm University, Department of Geology and Geochemistry
- Alaska Department of Fish and Game
- University of Illinois at Urbana-Champaign, Departments of Geology, Geography and Civil Engineering

With the departure of Luciano Fonseca for the UNESCO IOC office in the spring of 2009, support for GeoCoder has transferred to Dr. Yuri Rzhanov supported by others at the Center (particularly Beaudoin and Schmidt). This year, Rzhanov's efforts have focused on the repackaging of GeoCoder so that it is easier to track changes and fix bugs. Additionally, the code has been modified to accept the latest Kongsberg datagram format (revision M—version 12) and the XTF reader has been upgraded. Upgrade of the XTF reader led to a series of mysteries that have been traced to the fact that the newer XTF package internally changes memory packing to 8-byte alignment, while the rest of the code requires 1-byte alignment for proper representation of heterogeneous data structures. This sudden change in packing alignment led to unpredictable and non-repeatable crashes. Explicit enforcement of 1-byte alignment solved the problem. Rzhanov and Schmidt have also implemented the ability to parse backscatter data from Geoswath PMBS on the GAVIA AUV. This software has been successfully demonstrated on data sets collected by the GAVIA during operations in Lake Rotoiti, New Zealand (see AUV discussion).

Beyond GeoCoder, we have developed an analytical tool (Angular Response Analysis—ARA-formerly called AVO) that uses the variations in the amplitude of the return as a function of the angle of incidence to predict the nature of the seafloor (sand, silt, clay, etc.). The Office of Naval Research initially funded this work (their interest is in remotely identifying seafloor properties for sonar-propagation and mine-burial models), yet the application of this technique to fisheries habitat studies is clear and there has been great interest in its use by a number of NOAA labs and researchers. ARA will be discussed further under the theme of seafloor characterization.

Investigation of MBES Acoustic Backscatter Data Formats: RESON 7125 on NOAA Ship *Nancy Foster*

Further efforts to improve multibeam sonar backscatter processing have been undertaken by Jonathan Beaudoin who has worked with scientists from the NOAA Center for Coastal Monitoring and Assessment (CCMA) trying to improve backscatter data they collected and processed in support habitat studies conducted from the NOAA Ship *Nancy Foster* in the vicinity of the U.S. Virgin Islands. Backscatter data from a Reson 7125 were processed with Hypack GeoCoder for both snippets seabed imagery and "intensity" values. GeoCoder output products from these two data streams differed significantly and Beaudoin aided in the assessment of the two products to ascertain why the two products differed so significantly and which might provide a more reliable estimate of seabed acoustic backscattering strength. Samples of seabed imagery from the two data formats are shown in Figures 46 and 47; note the enhanced effect of topography in the "intensity" data as compared to the even grey level of snippets seabed imagery. CCMA scientists preferred imagery from the Reson "intensity" data as they felt it provided more contrast and better information for habitat assessment than the snippet seabed imagery. A team consisting of Beaudoin, Tom Weber, Glen Rice and Sam Greenaway examined the data and concluded that the "intensity" data were not correlated with the seabed snippets imagery even though, according to the Reson 7125 Operator's Manual, they were expected to represent the mean intensity over the receiver beam footprint. A dialog was started with the manufacturer and it was eventually found that errors in the Reson software were causing the discrepancy between the two data types and that the snippet seabed imagery data provided a more accurate depiction of bottom scattering properties until the error can be rectified.

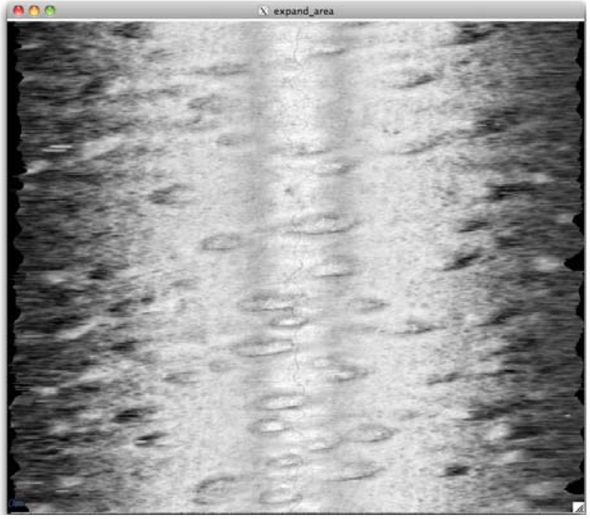


Figure 46. Waterfall display of "intensity" seabed imagery data.

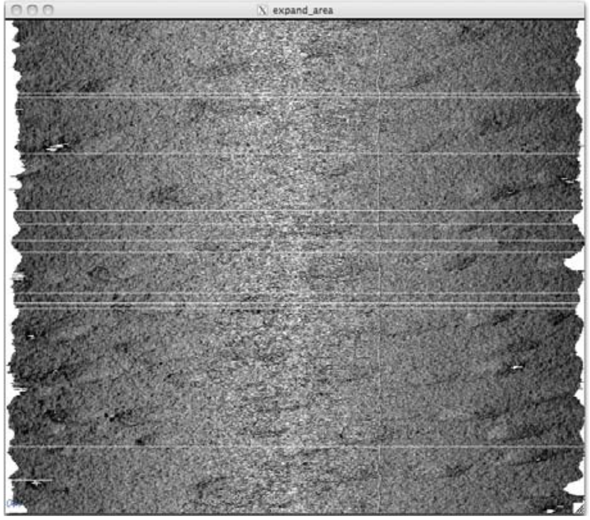


Figure 47. Waterfall display of snippets seabed imagery.

Uncertainty of Backscatter Measurements

As tools like GeoCoder and ARA make the use of backscatter data more common (and particularly as we begin to use backscatter for seafloor characterization—see below), 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 will 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. In 2008, several experiments were conducted, including tank calibrations and a series of field observations with multibeam sonars mounted rigidly to a pier and collecting data over fixed targets and the seafloor while a full suite of environmental data was collected. The same experiments were then repeated from a vessel. A full description of this experiment can be found in the 2008 Annual Report.

Development of Processing Tools for Kongsberg EM 3002 Backscatter Data

As part of Malik's thesis, software has been developed to process and analyze seafloor backscatter data from the Kongsberg EM 3002 multibeam sonar

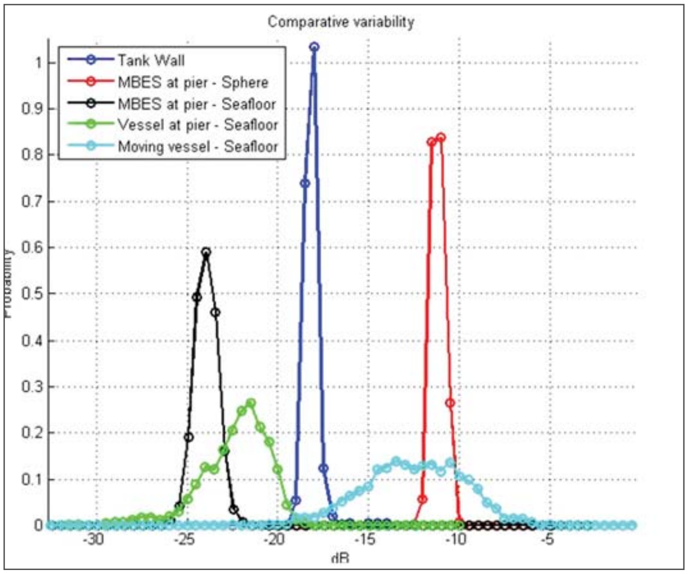


Figure 48. Plot of relative contribution from major sources of uncertainty in backscatter. (Tank Wall refers to sonar system contribution—i.e., variability of backscatter data collected in the calibration tank with all other parameters held constant), "MBES at pier – Sphere" represents the contribution of the environment and refers to data collected with sonar rigidly mounted on a pier collecting backscatter data from a rigidly mounted calibration target while the environment varied. "MBES at pier – Seafloor" represents the same experimental setup as with the calibration sphere but now looking at contribution from changes in the seafloor.

and environmental data from a number of sensors (CTD, bottom video, current meter, ADCP, optical backscatter sensor). MATLAB code was developed that reads the multibeam sonar datagrams and extracts the needed information (time, depth, beam averaged backscatter, full time series backscatter, sound-speed, system settings, etc.) and then allows graphic and analytical comparisons of backscatter and environmental data. This effort was aided greatly by the visit and collaboration of Jean-Marie Augustin (March–June 2010) who provided access to and guidance in the use of IFREMER's backscatter processing tool SonarScope. This collaboration greatly facilitated the processing of backscatter data.

Initial results from this effort (Figure 48) suggest that the approach to isolate contributions from different uncertainty sources (the sonar system, the environment, and the seafloor) have been largely successful.

Additional experiments have revealed a larger variability when the sonar is allowed to move, ensonifying a slightly different area with each ping. This is represented by the 'Vessel at pier' curve in Figure 48 where the sonar was mounted on a vessel that was tied to a pier. The motion observed in this case was only due to the surface waves and tidal currents, yet the variability increased as compared to the rigid pier mount of the sonar. The variability observed was even larger for the observed backscatter when the vessel was moving at the survey speed of approximately five knots over homogenous seafloor (Moving vessel—Seafloor).

Given this ability to separate and roughly quantify the relative general sources of uncertainty in backscatter, the effort has focused on trying to understand their more specific causes. It appears that the major forcing for the environmental variations is tidal change, with changes in temperature that result in changes in the backscatter recorded from the calibration sphere. This is thought to be the result of changes in the refractive properties of the fluid inside the sphere, Figure 49.

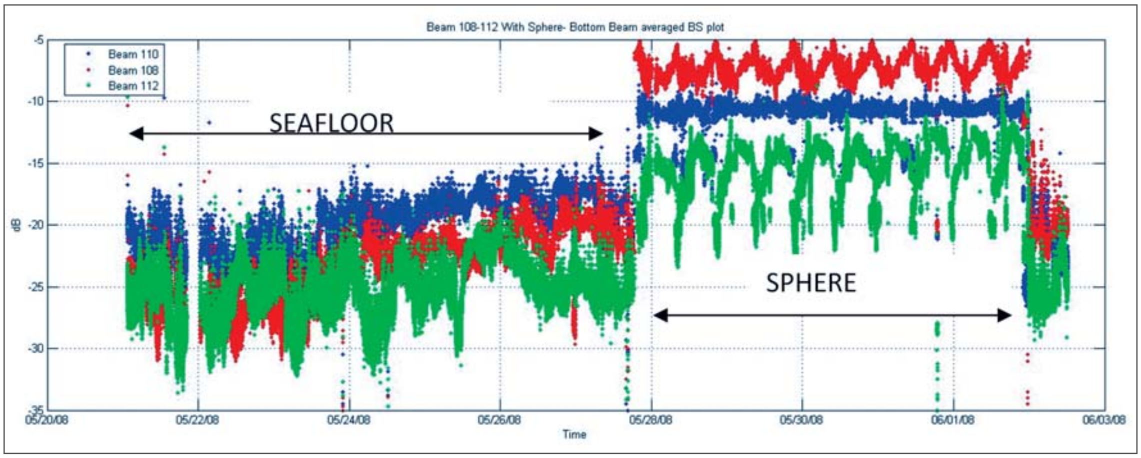


Figure 49. Time series plot of three beams showing tidal influence on seafloor and sphere (14 inch stainless steel sphere filled with distilled water) beam averaged backscatter.

New Approaches to Data Visualization and Presentation

GeoZui-4D

We continue a very strong focus on the development of innovative approaches to data visualization and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team (Arsenault, Plumlee, Sullivan, Pineo and Schwehr), under the supervision of Lab Director Colin Ware, have evolved their novel and innovative 3D visualization environment, GeoZui-3D. This highly interactive 3D visualization system is designed to support a number of different research projects and ocean-mapping applications (see earlier progress reports for details) into GeoZui-4D that allows the incorporation of time-varying data and opens up a world of new visualization possibilities. The GeoZui software has been made available to the public and more than 40 groups have downloaded the software.

In the past, GeoZui-4D required distinct objects to be developed with specific code for interfacing with different sonar types. In 2009, a major update to GeoZui-4D allowed a single generic sonar visualization object to be developed in GeoZui-4D with advanced features without the need to copy these new features to distinct sonar objects. This new modular approach allows functionality to be shared across sonar types without the need to copy code and allows new sonars to be added by just writing modules for the portions of the pipeline that are different from existing supported sonars.

The organic growth of GeoZui-4D over the past ten years has allowed various techniques to be quickly implemented and tested, but has resulted in source code that is now harder to maintain, expand and retrofit so as to keep up with the evolution of related technologies (OpenGL, GUI toolkits and scripting languages).

This past year has seen the introduction of a new generation of GeoZui4D, called GeoZui4D NG (Next Generation) in order to deal with the shortcomings of the original GeoZui4D code base. Much of the functionality originally identified as useful in updating GeoZui4D's graphics capabilities has already been implemented in open source scene graph libraries. Open Scene Graph has been selected as the core of the new GeoZui4D and the 2D GUI elements are implemented using wxWidgets. Both of the libraries are cross-platform and open source yet allow closed-source applications to be built with them. The 2-D GUI portion is written in a modular fashion so GeoZui4D NG can be easily updated with a new GUI toolkit in the future with minimum effort.

The new system will have the ability to depth-sort objects as well as support for loading data from disk as needed on the fly. The initial approach was to build the new GeoZui4D by extending Open Scene Graph's capabilities with some of the basic functionality from the original GeoZui4D. Those include the center of workspace-based widgets, time support and terrain rendering. From this base application, new functionality can be added or existing functionality from the original GeoZui4D can be adapted.

The first task for which GeoZui4D NG is being used is to construct a visualization of ADCP and water property data collected around the Deepwater Horizon site in the Gulf of Mexico. The aim is to provide a tool to help understand how the four dimensional (space and time) relationship of the distribution of measured subsurface oil indicators (fluorescence and dissolved oxygen) to the measured current fields.

Current data from two down-looking ADCP mounted on surface platforms is shown as simple time varying lines aligned with the current direction with a length representing current strength. From these vectors, particles can be released to drift in the water taking the changing currents into account as the particles progress through time. The particles fade away after a preset time and are currently restricted to the depth from which they started.

Whale Tracking and Ecosystem Visualization and Analysis

Over the past few years, we have reported on the exciting work of Ware and Arsenault using GeoZui-4D 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 can be attached to a whale to record depth, pitch, roll and sound for as long as the tag remains on the whale. Our visualization team has taken these data and cre-

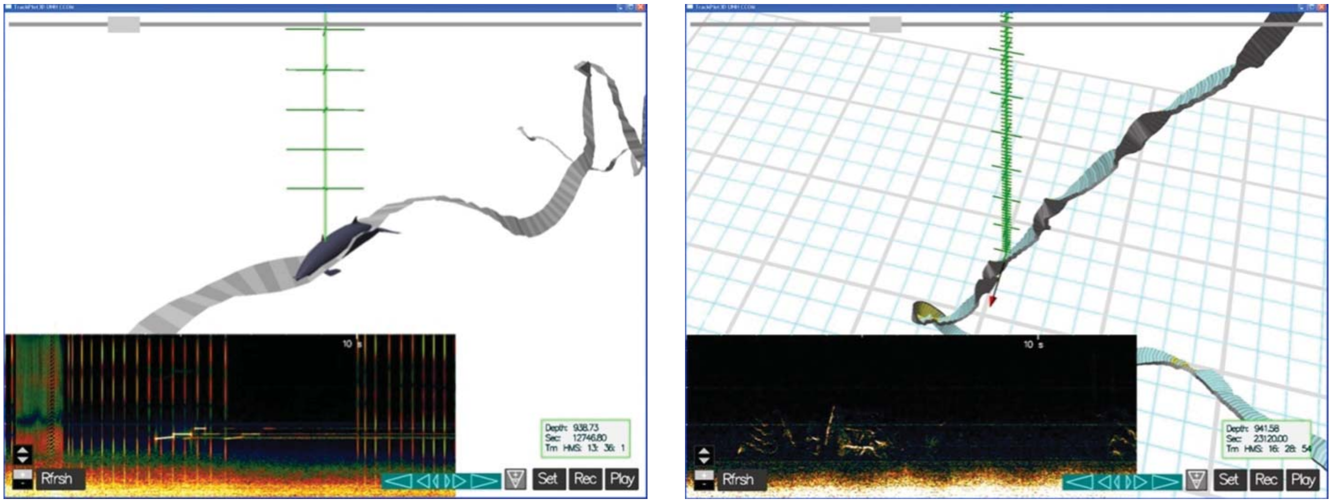


Figure 50. Examples of TrackPlot being used to relate behavior to introduced sounds. Left - the TrackPlot trajectory of a Cuvier's beaked whale. The plot shows whale clicks and the acoustic signal of a sub-bottom profiler recorded. Both signals recorded from a hydrophone attached to a whale. Right - the same whale exposed to killer whale vocalizations. The animal abruptly terminated its dive. The track shows it ascending with repeated 90 degree rolls.

ated fully georeferenced 4D displays of the whale's diving and 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.

Based on these successes, Ware and Arsenault were invited in 2009 and again in 2010 to participate in a major collaborative research project designed to investigate the predator-prey interactions and fine-scale foraging behaviors of Humpback whales in fjords off the Gerlache Strait on the Western Antarctic Peninsula. This project includes scientists from Duke Marine Lab (Douglas Nowacek, PI) who are responsible for whale tagging, animal abundance surveys and Simrad EK60 surveys of krill swarms, the University of Massachussets (led by Meng Zhou) who sampled the prey using MOCNESS, and UNH participants who provide visualization and analysis support. The project's title is Multiscale Interdisciplinary Study of Humbacks and Prey (MISHAP). Its goal is developing a multi-scale trophic-level model encompassing the food chain: mesoscale zooplankton → krill → humbacks. In support of this major multidisciplinary project, Ware has developed his trajectory analysis package TrackPlot (Figure 50) to enable identification and quantification of feeding lunges made by Humpbacks. TrackPlot has allowed for a much more precise estimation of lunge counts than has previously been possible (whale feeding lunges may be the most energetically costly feeding events that exist).

New capabilities that have been added to TrackPlot in the current year include estimating the animal's speed through the water using flow noise, and better capabilities to georeference the tracks that are produced using TrackPlot, using a simple propulsion and drag model. An automatic lung detector was built on the estimated speed and this has been a critical part of the lunge detection (Ware et. al., in press). Lunge counts will be critical to correlating feeding events with local krill abundance estimates. One outcome is a paper (Shallow and Deep Lunge Feeding of Humpbacks Whales in Fjords of the West Antarctic Peninsula, Ware et. al., *Marine Mammal Science*, 2010). This identifies and analyzes all feeding lunges made by animals tagged in 2009 as well as their distribution by depth. While this work has been funded, for the most part, by NSF and ONR, the tools being developed are applicable to a wide range of NOAA issues.

A new pilot project has been initiated to develop an individual behavioral model (IBM) of humpback whale foraging activity. This can be used to test theoretical predictions regarding the benefits and costs of groups size when foraging on patchy prey. We already have a large data-base of foraging activities on Stellwagen Bank that can be used to provide basic parameter values, such as swimming speed between patches and number of animals at a prey patch.

Optimal Data Representation

Multi-Variable 2D Visualization

The success of the visualization tools developed at the Center is based, in large part, on the fact that the tools are developed within a context of understanding the theoretical underpinnings of human perception. To build upon and further develop a

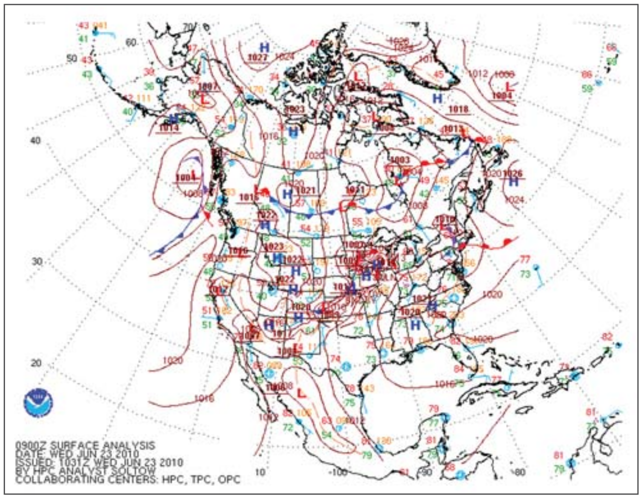


Figure 51. An existing graphic from NWS that shows pressure, temperature and wind.

fundamental understanding of the perception of visualized data, Ware is investigating ways to optimize the presentation of bivariate scalar maps. To better understand how to design measurably effective multivariate map displays, we have set ourselves the task of designing a display that simultaneously shows winds, pressure, and temperature. We believe that we can substantially increase the legible information resolution in comparison with existing displays by means of a combination of careful iterative design and innovation.

Matthew Plumlee worked during the summer to develop a prototype application and an experiment to evaluate it. The core design idea is to use separate perceptual "channels" to display multiple variables. There are three such channels in the primary visual cortex of the brain: the color channel, the texture and form channel, and the motion channel. Using separate channels should mitigate the problems of perceptual interference between the displayed variables. For example, try to find wind patterns or temperatures in Figure 51, which is the standard display of the National Weather Service.

To create visual separation between variables the following mappings are used:

1. Color → temperature
2. Texture + contours → pressure
3. Moving streaklets (+ numbers) → wind direction and speed

Figure 52 shows our current design. This display is smoothly animated over the forecast interval but can be also frozen at any point in time to examine the prediction more carefully. A study has been completed to evaluate these design alternatives using the ability to read accurately quantities at arbitrary map locations using keys, and the ability to rapidly identify important weather features as quality metrics.

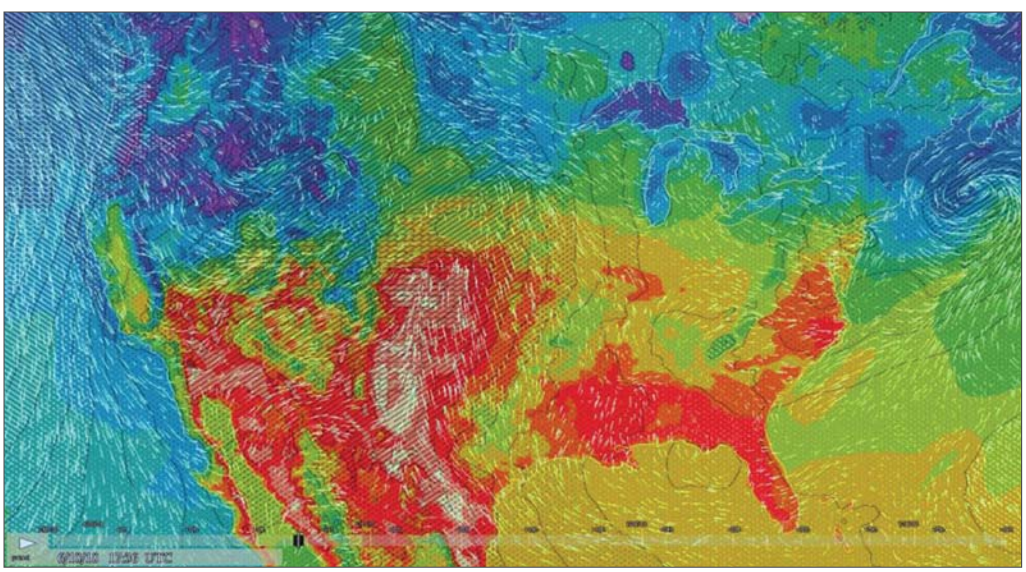


Figure 52. The vislab display based on the NCEP NAM Model. The animated the streaklets show wind patterns very clearly. Pressure is indicated by means of textures and contours. Compare with Figure 51.

Although we have chosen to represent weather data in the initial effort, our methods should readily be transferable to many types of oceanographic data.

Flow Visualization

These same principles of combining design efforts, perceptual factors, and task-oriented empirical testing of effectiveness have been applied to optimizing the visualization of flow models. One concrete outcome of this research has been displays that use the flow-field representations developed by Ware and his students. These currently display NCOM model output for the northwestern Atlantic and northeastern Pacific as well as the output of NOAA operational forecast models (OFS) for the Great Lakes and a number of important ports. New harbors are added as the models come on line. We are also developing displays that show data at different depths and for vertical cross sections. Figure 53 shows an example vertical cross-section through Gulf of Mexico model data.

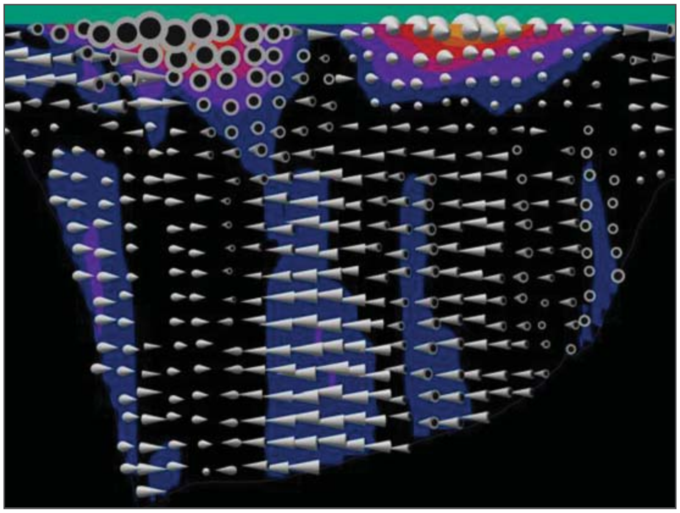


Figure 53. A cross section of the NCOM Gulf of Mexico model at 90W longitude viewed from the east. The loop eddy current is clearly visible near the surface.

Ice Coverage GeoCam

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 into 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 CCOM developer. The preliminary results are encouraging. A set of 750 meter radius images was created along the path of the ship with minimal distortion (Figure 54). Halpin successfully demonstrated that a supervised image segmentation method could be used to classify ice types (grease ice, brash ice, and consolidated ice).

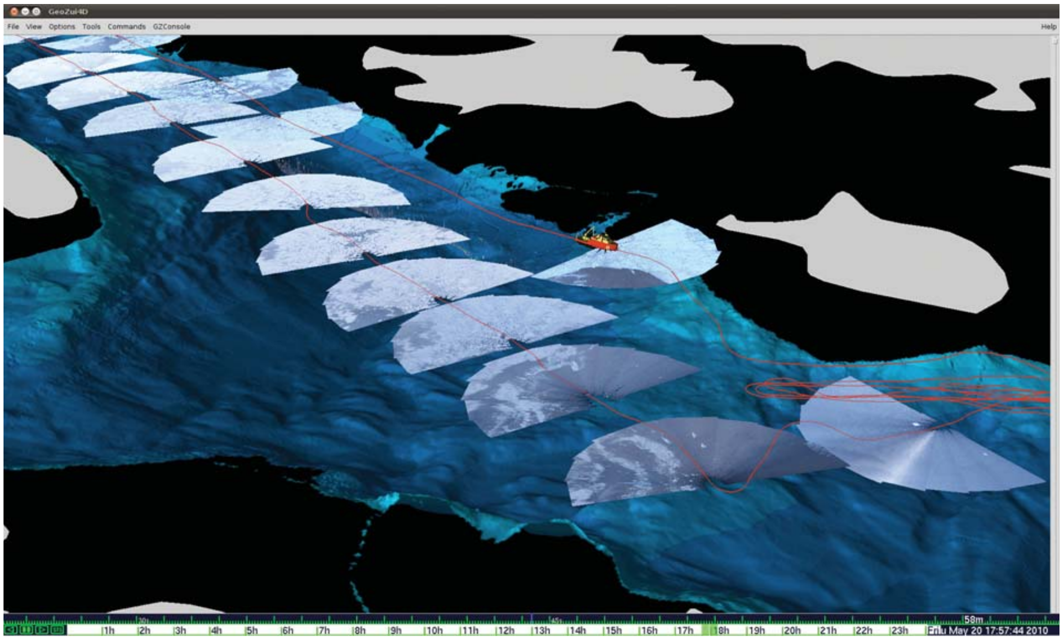


Figure 54. Selected assembled geoCamera image sets from a 2010-05-20 transit in and out of Whilemina Bay, Antarctica.

Seafloor Characterization

We have a number of inter-connected research programs underway aimed at exploring the ability of our mapping systems to provide quantitative information on the composition and character of the seafloor as well as its depth. These programs deal with a range of sensors (single beam, multibeam and sidescan sonars, lidar, video, etc.) and involve theoretical studies, the collection of remotely sensed data, and "ground-truth" samples. These efforts are particularly relevant for the increasingly important topic of essential fisheries habitat characterization.

Multibeam and Phase Measuring Sonars

Substantial progress has been made over the past few years in developing approaches to multibeam seafloor characterization on a number of fronts. These developments have been made using a variety of sonars (Kongsberg EM 120, 121, 300, 1000, 1002, 3000, 3002 302, and Reson 8101, 8111, 8160, 8125 and 7125, as well as GeoAcoustics GeoSwath, Klein 5000 and 5410). These data were collected in support of ONR, NSF, USGS, and other programs, along with multibeam-sonar data collected by NOAA and others in Portsmouth Harbor as part of the Shallow Water Survey 2001 "Common Data Set" and data collected on the NOAA vessels *Thomas Jefferson*, *Nancy Foster*, *Rainier*, *Rude*, *Fairweather*, *Dyson* and *Bigelow*. Significantly, a new "Common Data Set" was collected in 2007 and 2008 in support of the Shallow Survey 2008 Conference hosted by the Center in October, 2008. With the availability of these data sets, much of our recent effort in terms of seafloor characterization has focused on enhancing our ability to extract quantitative information from the sonars we use (through better processing and modeling) and improving our ground-truth abilities. In 2010, efforts focused on the new Simrad ME70 fisheries multibeam sonar deployed on several NOAA vessels and the GeoSwath phase-measuring bathymetric sonar deployed on the GAVIA AUV (discussed later).

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

The GeoCoder software (designed to make fully corrected backscatter mosaics and calculate a number of backscatter statistics) has been integrated with the ARA software package—also developed by Luciano 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 now 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.

While Yuri Rhzanov continues to develop new approaches to data segmentation (see discussions below) the team of Rhzanov, Val Schmidt, Jonathan Beaudoin and Brian Calder are collaborating to fully understand Fonseca's implementation of the GeoCoder ARA analysis and will be developing a plan to further this aspect of our research.

Simrad ME70 Seafloor Characterization

The Simrad ME70 is a fisheries multibeam sonar that is currently installed on two NOAA fisheries vessels (Dyson and Bigelow) and will be installed on at least two more new NOAA fisheries vessels. As currently configured aboard the Dyson and Bigelow, the ME70 is designed to collect data in the water-column, not from the seafloor. However, in the spirit of Integrated Ocean and Coastal Mapping (IOCM—see below), Tom Weber has been developing approaches to extract bathymetry and backscatter from 'standard water-column modes' of the ME70.

Rockfish constitute an important component of marine ecosystems and commercial fisheries in Alaska, but are difficult to assess using standard trawl surveys when they are aggregated in rocky high relief (untrawlable) areas. This North Pacific Research Board-funded study, which is a collaborative effort between NOAA AFSC and CCOM and is expected to be complete in spring 2011, is aimed at developing assessment techniques in untrawlable areas using a combination of acoustic and optical remote sensing techniques, as well as a specialized semi-pelagic trawl.

ME70 data for this study were collected in the Gulf of Alaska in October 2009. Several products have been derived from the ME70 multibeam data, including those related to backscatter (normal and oblique incidence backscatter, the slope of the angle-dependent backscatter between 0 to 10 degrees, and the scintillation index) and those related to bathymetry (e.g., rugosity, slope). These data were then compared to estimates of trawlability derived from a stereo camera system. Images from the camera were analyzed to deem the seafloor either trawlable or untrawlable based on the presence of rocks that were a certain size or larger. Of all the metrics examined, the oblique incidence backscatter was the best predictor of the whether the seafloor was trawlable, with a 2.8% error rate for the region of the seabed considered to be trawlable, and a 9.4% error rate for the seabed considered to be untrawlable (Figure 55). The demarcation between trawlable and untrawlable seafloor occurs at an oblique incidence scattering strength of -14 dB that marks the predicted boundary between a sandy gravel and a cobble. Other derived parameters include the slope of the angular dependent backscatter and

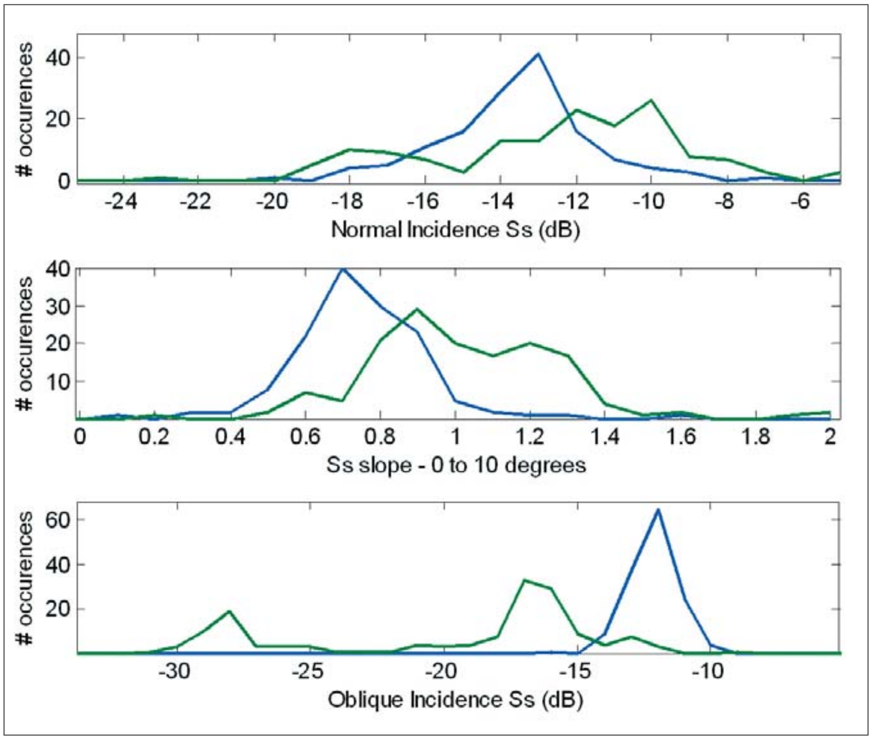


Figure 55. Three backscatter parameters and their relationship to whether the seabed is trawlable (green lines) or untrawlable (blue lines). Top: normal incident backscatter; Middle: the slope of the angular dependent backscatter between 0-10 degrees; Bottom: the oblique incidence backscatter (average between 30-60 degrees).

the scintillation index trended in the direction one would expect (higher scintillation index for untrawlable, higher slope for trawlable) but did not offer as clear of a separation as did the oblique incidence backscatter. Curiously, the normal incident backscatter did not appear to separate the trawlable from the untrawlable very well, and tended to have a distribution that is considerably wider than would be expected based on modeled backscatter, possibly due to gas within the sediment volume for the softer sediments and/or higher than expected roughness in the cobble/rock areas. Rugosity was a relatively poor indicator of trawlable/untrawlable and this may be due simply to system resolution.

Optical Imagery Mosaicing as a Tool for Seafloor Characterization

The development of acoustic techniques for seafloor characterization is dependent on "ground truth" measurements to determine the actual properties of the seafloor. These ground-truthing techniques take the form of direct sampling and optical measurements (typically photos or video) that can provide a direct indicator of the nature of the seafloor. Rhzanov has worked over the years to develop automated techniques to mosaic video and photographic imagery to produce optical imagery on a scale that is commensurate with the acoustic imagery and can then be used to assess seafloor type or the distribution of benthic organisms (Figure 56).

Figure 56. Example of video mosaic demonstrating sponge coverage.

Photomosaics are considered by biologists to be an important component in the quantitative assessment of the seafloor; mosaics allow for accurate counting of animals and identifying interconnections of features that cannot be noticed on a single photograph. Analysis of a mosaic (i.e., for animal counting, quantitative estimation of seafloor coverage, etc.) is remarkably time-consuming if done manually. Rhzanov has been working to develop automated techniques to count organisms and produce a detailed high-resolution 3-D reconstruction of a part the seafloor from its multiple views (i.e., derive small-scale rugosity).

Automatic Classification of Habitat and Quantitative Estimation of Coverage from Underwater Video Footage and Video Mosaics

Among the imagery challenges is the development of tools to automatically count individual specimens in video imagery. Automatic counting of individual species has proved to be a formidable task. Experiments with underwater imagery collected in the framework of the North East Benthic Observatory (NEBO) project have shown that variability in colors, shapes and textures of individual scallops makes robust recognition as yet an unreachable goal. Most reliable cues (brownish color of shells and their roundish shape) become sufficient indicators only from very short ranges; i.e., less than 0.5 meters, when video coverage is almost not feasible. Longer ranges (and wider swaths) cause substantial distortion of colors due to wavelength-dependent absorption of light and smear boundaries between organisms and the background. Shape imperfections because of occlusions and partial burial by fine sediments lower the percentage of correct detections even further. With the current state of affairs, it is difficult to expect the detection rate to be higher than 60-65 percent.

The situation is even worse with the detection of organisms with flexible bodies that can be positioned at different angles with respect to the camera. Despite recent attempts to solve this problem with "eigen" approaches, it is

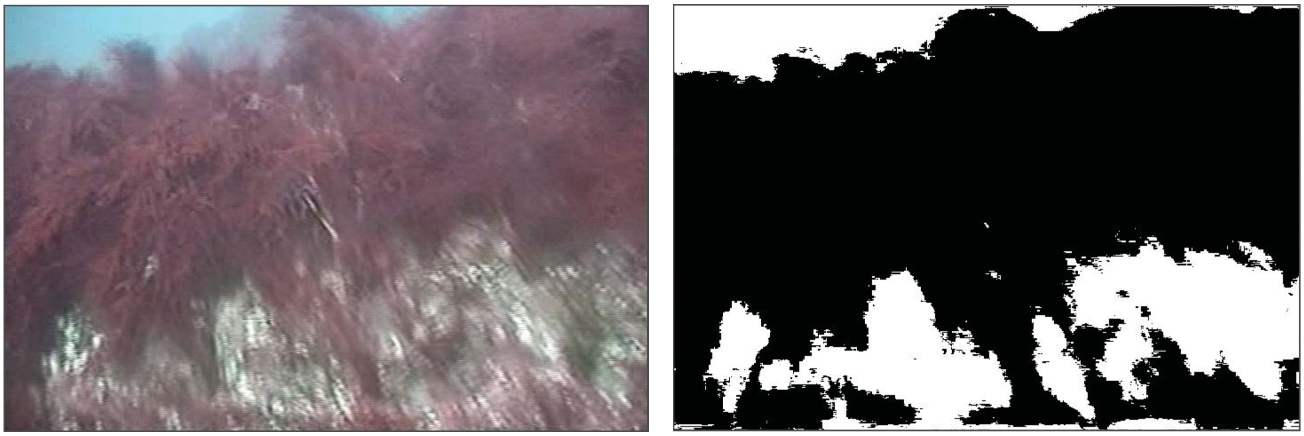


Figure 57. Video frame showing red algae (let) and pixel-based classification of same image (right).

not even clear yet how to formulate the problem. A texture-based approach, however, shows promise. Photo-frames are divided into equal-size squares, small enough to represent a homogeneous patch, and large enough to contain certain spatially varying characteristics (typical size 20-30 pixels). Each frame (subdivided into unit squares) is submitted to a binary classification (presence or absence of certain texture; e.g., energy, entropy, contrast, correlation, etc.).

In some special cases, where the species of interest have a color different from the background (seafloor), classification can be done on a pixel level. Supervised (manual) classification provides clear separation between the cloud of type 1 pixels and the cloud of type 2 pixels (not necessarily in RGB space; HSV or LAB color spaces perform better for these tasks). Then the hyper-plane separating these clouds acts as a classifier—pixels on one side are considered to be of type 1, on another of type 2 (Figure 57).

Stereofish—Application for Dense Underwater Scene Reconstruction

Another aspect of this work is the collaboration with NOAA's Southwest Fisheries Group in La Jolla, CA, on the development of software capable of dense 3-D reconstruction of an underwater scene from stereo photographs. While in-air stereo reconstruction is well understood, the complexity of imaging in the water makes 3-D reconstruction a challenging process. Typical in-air setups assume a short distance between the cameras' focal points as compared to the scene depth. They also rely on the brightness constraint; i.e., they expect any feature to have the same brightness (and/or color) in both photographs of a stereo pair. As both images are acquired simultaneously and from almost the same direction of view, the brightness constraint is a reasonable assumption, and this allows for reliable and efficient algorithms for dense depth reconstruction. Underwater imagery does not usually satisfy the brightness constancy constraint. Figure 58 shows patches from a stereo pair of approximately the same area on a fish body taken by two cameras simultaneously. The reasons for these differences are not well understood.

Rzhanov has developed an algorithm that starts with detection and pair-wise matching of salient features—those that remain recognizable even when observed from different viewpoints. A typical scene without man-made objects contains two to three hundred viewpoints. From the known conjugate pairs, the matching process is extended in all directions. Within a specified search window, normalized cross-correlation scores are calculated and ten

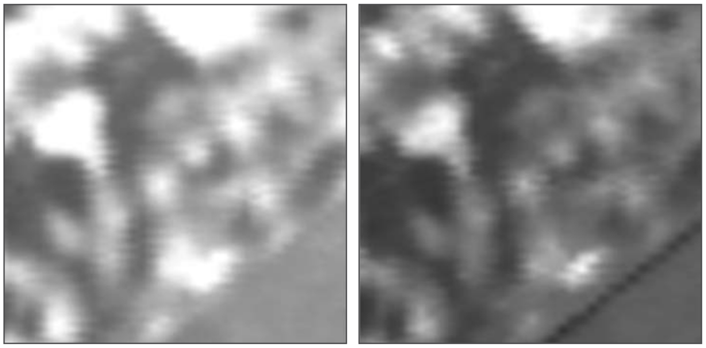


Figure 58. Stereo pair of images of fish body.

matches with the highest scores are stored. One of the basic assumptions is that the scene consists of patches with smoothly varying depth (and, consequently, horizontal disparity). In the next pass, the program attempts to choose for each pixel (from the ten matches) the one that corresponds to the smoothest overall solution.

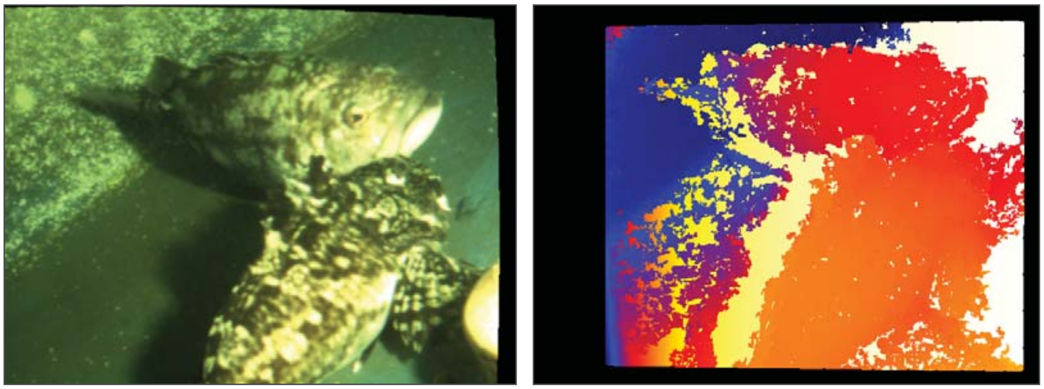


Figure 59. Original image on left and depth reconstruction on right.

Once all the conjugate pairs that can be found on the pixel level are identified, each is refined to a sub-pixel precision. Locations of conjugate pairs of points are converted back from rectified space to lens-corrected space and used for the scene triangulation.

Figure 59 shows the original image acquired by the left camera and the color-coded reconstructed depth of the scene. Black indicates areas not visible in both images. Three areas can be clearly separated in the depth image: nearest fish (orange), second fish (red), and textured background (blue). Note that shadowed areas and areas without pronounced texture have not been triangulated reliably. There is no algorithm that would guarantee correct matching without the presence of a unique texture; however, knowledge of the degree of reliability is itself useful.

Lidar Studies

Given the potential advantages of lidar (speed of coverage and safe operation above potential hydrographic hazards) as a means for addressing a number of critical problems facing NOAA (safety of navigation, habitat characterization, shoreline identification, etc.), the Center has been increasing its focus on trying to understand the benefits and limitations of airborne (mostly bathymetric) laser measurements in the context of NOAA and national needs. This work has been enhanced with the arrival of NOAA employee Chris Parrish who provides added expertise as well as a direct line into NOAA needs with respect to many of the problems associated with lidar work.

The Role of Seafloor Type in Bottom Detection

In the course of our efforts to explore the potential of lidar data as a means to characterize the shallow coastal seafloor, Shachak Pe'eri has been investigating and comparing lidar data sets (Tenix LADS and Optech SHOALS) collected in an area of Portsmouth Harbor, NH and offshore Gerrish Island, ME for which we also have high-resolution Kongsberg EM3002 multibeam-sonar data. The lidar data sets show a remarkable correlation in terms of where the bottom was successfully detected and where the two different systems failed to detect the bottom. Inasmuch as these data sets were collected at very different times of the year and in different states of the tide, and the properties of the water-column that have traditionally been thought to control the success or failure of bottom detection with lidar (particularly the diffuse attenuation coefficient) were vastly different. Comparisons of the lidar data with acoustic measurements and underwater video imagery showed that at depths greater than 7 m, the factor that controls the success or failure of the bottom detection is the nature (composition) of the bottom. The bottom was consistently detected in regions of sand but was not detected in shoal rocky areas. This is a very important result because it indicates that the failure to detect the bottom may not simply indicate that the water is deeper than the attenuation depth of the laser and that, in these situations, shoal rocky targets may be systematically missed.

In order to establish a broader understanding of the environmental factors that affect lidar bottom detection, Shachak Pe'eri and colleagues focused efforts in 2010 on the collection of ground-truth data including the use of man-made targets. The ground truth measurements include bottom sampling, underwater video imaging, and spectral measurements. An underwater camera was developed that can be deployed manually, record the video imagery digitally, and measure features within the frames. Pe'eri, along with Andy McLeod and Paul Lavoie developed a frame that will contain the underwater camera and a mount for an underwater fiber optic cable. The 25-m fiber optic cable was added to the camera frame for measuring bottom reflectance in addition to the seafloor texture by the underwater camera.

Another aspect of our ground truth studies has been the construction and deployment of man-made targets. Acoustic surveying can provide a spatial reference to lidar. However, the use of sampling or video for ground truth can provide spatial information on mm-cm scale over an area of 0.3 x 0.3 m. In order to evaluate larger-scale features, concrete targets were constructed (Figure 60). The designs of the targets are hemispherical concrete shells (0.8 m in diameter) with a shell thickness greater than 5 cm. The idea is to deploy these targets over different seafloor types in a range of water depths and evaluate the ability of both sonar and lidar to locate the target and resolve its morphology. Over the past three years, the targets have been deployed and retrieved twice by CCOM: once at Portsmouth Harbor just north of Cod Rock in ~18 m of water (May-June, 2008) and the second time off Gerrish Island in 7-10 m of water (June–October, 2010).

Figure 60. Sela underwater (November 2, 2010) off Gerish Island, ME.

Our seafloor characterization studies have expanded to include data collected from a Hyperspectral Imaging System (HSI). A collaboration project over Buck Island, USVI started this year between the Center and NOAA's Biogeography Group (Tim Batista, CCMA), Fugro LADS (James Guilford), and The National Park Service (Ian Lundgren). Data to ground-truth hyperspectral surveys were collected this past fall (November 2010) around Buck Island, St. Croix (Figure 61) and an HSI survey is scheduled for January-February, 2011. Data collection was conducted using the NPS's R/V Osprey. The goal of the study is to understand the morphology and reflectance of the seafloor using airborne remote sensing. Currently, studies in the area could not decouple information related to the reflectance from information related to the texture of the seafloor using lidar. In this study, an independent dataset was collected using ground truth measurements and will develop approaches to characterize the seafloor independent of its elevation characteristics.

Figure 61. Left: Ground truth stations (red circles) around Buck Island, St. Croix, USVI.

Lidar Waveform Processing and Analysis

With the arrival of Chris Parrish (NOAA NGS employee) to the Center, our efforts to understand the potential of lidar waveform analysis have been greatly enhanced. Research in lidar waveform processing and analysis within NOAA's National Geodetic Survey (NGS) was initially motivated by airport obstruction surveying applications in NGS' Aeronautical Survey Program (ASP), which operates in support of the FAA. However, there is currently great interest in extending this research to coastal mapping and IOCM-related applications. One example is the ability to use coastal lidar flights to support National Estuarine Research Reserve System (NERRS) wetlands vegetation mapping projects. Areas that contain dense stands of Phragmites, cattail, and other marsh grasses can be difficult to map with discrete-return (non-waveform-digitizing) lidar, prompting interest in full-waveform systems and processing techniques. A related area of interest is estimation of very shallow water depths (< 1-2m) from bathymetric lidar waveforms.

Figure 62. Ranging lab experiment for lidar waveform processing tests/comparisons.

Parrish's research in lidar waveform processing and analysis in 2010 centered on comparisons of different waveform post-processing algorithms from an operational perspective. Data collected in a 2008 ranging lab experiment with multiple targets (Figure 62) were used to test and compare different processing strategies in terms of target resolution (vertical discrimination distance), processing speed, robustness against poor parameter selection, and suitability for NOAA-related applications. Results of this work, conducted in collaboration with colleagues Inseong Jeong, NOAA/NGS, Robert Nowak, University of Wisconsin, and Brent Smith, Optech, Inc. were presented—in various forms—in two conferences (ASPRS GeoTech and the European lidar Mapping Forum), and a paper has been submitted to Photogrammetric Engineering and Remote Sensing, the peer-reviewed journal of ASPRS.

Lidar for Shoreline Mapping

Currently, shoreline mapping involves the manual digitization and interpretation of optical imagery. Two major problems with this approach are the length of time it takes to digitize a shoreline segment and the operator's subjectivity in determining the actual location of the shoreline. The latter problem depends on both the pixel resolution of the image and the dynamic range (optical depth) of the image. The subjective interpretation of this approach leads to the creation of shoreline products that are difficult to reproduce. Recent published studies have investigated the use of high-resolution digital elevation models (DEM) for determination of the mean high-water line from coastal morphology. The shorelines that are produced are referenced to ellipsoidal heights and not directly nor readily linked to a tidal datum.

In 2007, in an attempt to address these limitations, Pe'eri worked with NOAA graduate student Lynn Morgan to look at the use of lidar to provide a non-subjective computerized process for determining the land-water interface. The evaluation included manual digitization of a reference shoreline from aerial imagery, configuring a shoreline extraction procedure based on a commercial-of-the-shelf package (ESRI ArcMap) and a performance analysis of different shoreline extraction algorithms over various coastal areas (sandy, rocky, vegetated and man-made).

In 2008, as a result of discussions at the annual program review for the Center, Pe'eri collaborated with Chris Parrish and Stephen White of NGS/ RSD to extend the shoreline-extraction work. The goal of this project was to produce mean high water (MHW) and mean lower low water (MLLW) shorelines and as well as an estimate of the uncertainty of the shoreline determination.

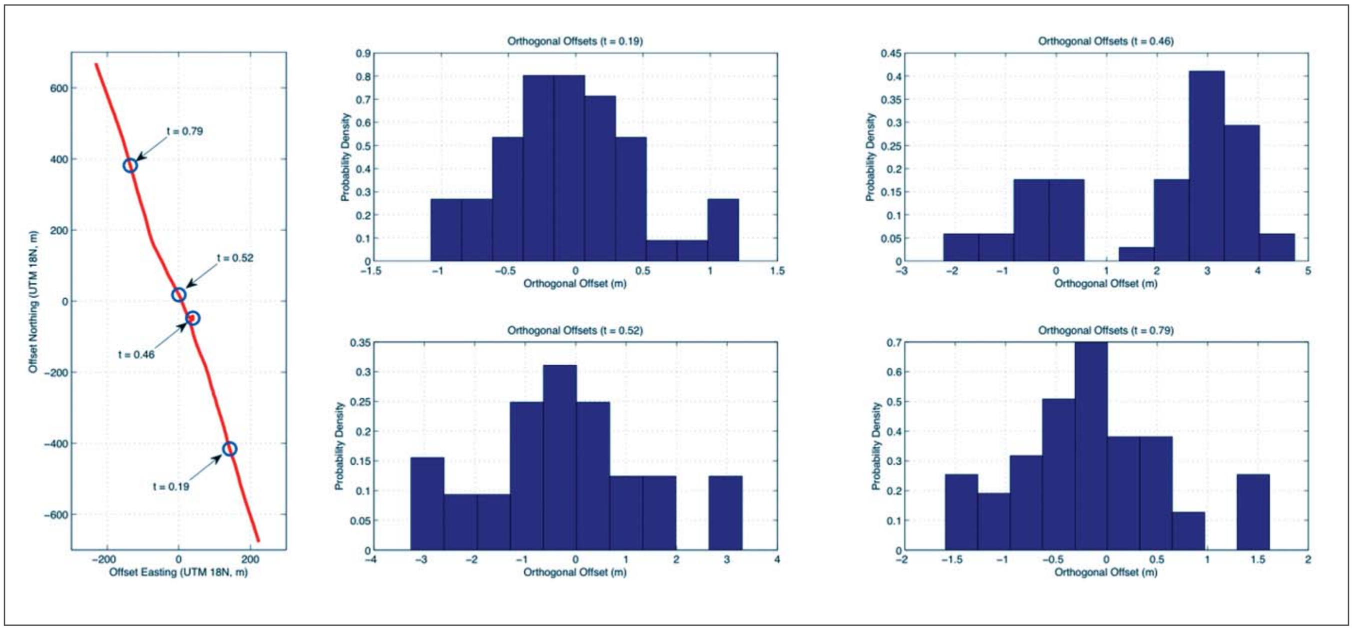


Figure 63. Examples of the distribution of horizontal displacements of the ensemble of shorelines about the nominal (measured) shoreline for four locations along the test data shoreline (shown in red at left). The example data here is from Duck, NC.

In 2009, Morgan's work was reprocessed and reanalyzed for a publication in the Journal of Coastal Research (Pe'eri, Morgan, Philpot, and Armstrong). The shoreline assessment compared the output results of several algorithms to a reference shoreline that was digitized from aerial imagery collected at the time of a lidar survey. A threshold value for each algorithm was determined based on a dataset collected over a training site (Fort Point, NH). The lidar waveforms were then processed by the shoreline algorithms at each study site. The numeric algorithm values were triangulated and converted to TIN surfaces. An algorithm-shoreline vector was produced from a contour that intersects the surface at the threshold value determined from the training set. The location of all vertices was extracted from both the reference shoreline and the algorithm shoreline for comparison. In addition, the algorithm-shoreline vectors were smoothed using a PAEK (Polynomial Approximation with Exponential Kernel) smoothing method with a smoothing tolerance of 20 m. The location of all vertices was also extracted from the smoothed algorithm shoreline.

Uncertainty Evaluation of Shoreline Vectors Derived from Topographic Lidar

Efforts in 2010 focused on assessing the uncertainty associated with the determination of shoreline vectors derived from topographic lidar—a collaborative effort among Calder, Pe'eri, Rzhanov, Parrish and Stephen White (of NGS). Calder has focused on the development of stochastic models required to provide the estimates of uncertainty, and the processing methods to construct the estimates.

The approach taken addresses the uncertainties of the variables that can be measured, and then attempts to assess their effect on the uncertainty of the final product shoreline (much like the Hare-Godin-Mayer uncertainty model for MBES systems), rather than trying to determine an uncertainty of the (x, y) locations of the shoreline directly as other researchers have attempted.

It was quickly realized that formal uncertainty propagation was unlikely to be possible due to the complexity and nonlinearity of the methods that NGS/RSD use to construct the shoreline. Instead, a Monte Carlo approach was used to reconstruct the raw observables for the lidar measurements, and assess the uncertainty of all of the measurements used to georeference them.

Using the Monte Carlo approach to generate a simulated ensemble of possible shorelines allows us to evaluate any statistical measure of similarity that we prefer. For example, we can readily estimate the distribution of horizontal displacements from the nominal shoreline, Figure 63, at various points along the line. We can also readily summarize the horizontal displacements, however, since a simple point estimate of uncertainty is typically the desired product for mapping purposes. In this case, we have chosen to summarize the uncertainty by computing the probable 95% confidence interval for the displacements using an empirical method and, for comparison, a parametric method assuming that the distribution of displacements is, in fact, Normal. Figure 64 shows that the differences between the two methods are small, suggesting that the departure from Normality is not very significant in most cases.

The results show that there are significant variations in estimated uncertainty as a function of location along the shoreline, varying from approximately 1 m at the south end to over 3 m on the north side of a pier. Not surprisingly, this difference can be accounted for in large part by the slope of the shoreline, as estimated from the concurrent field surveying work carried out in this area by NGS/RSD. That is, the smaller the seafloor slope, the larger the uncertainties that are observed by this method, suggesting that the uncertainties are primarily due to horizontal uncertainties of the data, possibly due to the estimates of the horizontal uncertainty model for the positioning of the RTK-GPS on the flight platform, or the model associated with the scan angle estimate of the lidar head.

This work has been accepted for publication in a special issue of Journal of Coastal Research dedicated to lidar issues. We continue to work with NGS/RSD to further test this method and extend it to be suitable for more general use. The eventual goal is to have this develop to production.

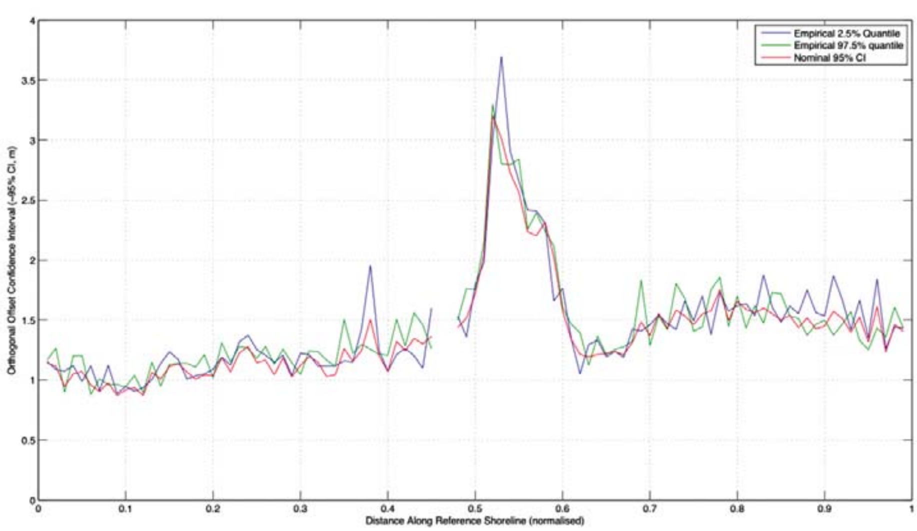


Figure 64. Empirical and theoretical estimate of the 95% CI of the horizontal displacements at 100 equally spaced points along the shoreline. The 95% estimate assumes normality of the displacements; the empirical estimates are non-parametric estimates of the (2.5%, 97.5%) percentiles constructed from the empirical cumulative density function estimate.

Data Fusion for Lidar Surveying—Hyperspectral and Optical

Hyperspectral

A further offshoot of our efforts to look at shoreline mapping from lidar is the work of Rhzanov and Pe'eri looking at the suite of sensors typically carried along with airborne lidar. These efforts take advantage of automated mosaicing techniques that Rhzanov has developed for seafloor imagery and are focused on looking at approaches for registering hyperspectral, lidar and imagery data. The U.S. Army Corps of Engineers (USACE) CHARTS system is an airborne lidar bathymetry sensor suite that includes an RGB DuncanTech DT-4000 camera (currently being upgraded to an Applanix DSS) and a hyperspectral CASI-1500 sensor. The ability to resolve numerous bands (30-300) in the hyperspectral scanner, with small spectral resolution (<10 nm), allows a chemical characterization of the returns that can be used for the characterization of vegetation and geology.

Rhzanov and Pe'eri have developed a procedure that registers the hyperspectral data to the map produced by the RGB camera. This process involves spectral analysis that finds the best channel to be matched for both systems, defining the hyperspectral instantaneous field of view (IFOV) and the pitch angle with respect to the RGB camera, configuring a correlation function between each line of the hyperspectral imagery to the RGB map, and defining a skip mode to advance to the next line-to-map correlation The co-registration of lidar measurements with hyperspectral imagery is also being investigated.

In 2010, the team began working on data collected by Fugro LADS (Lake Superior) in order to create a more robust algorithm that will operate on different datasets. The hyperspectral imagery was reprocessed independently from its georeferencing application. This was done in order to simulate a situation where a mechanical misalignment occurred or a failure in the IMU/GPS systems occurred providing unreliable information.

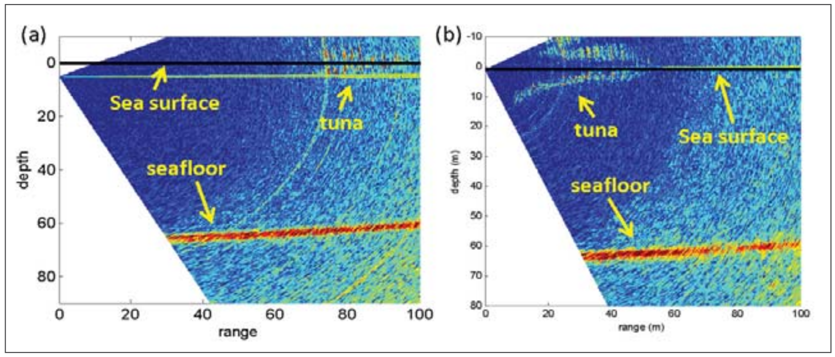


Figure 65. Examples of 400 kHz Multibeam backscatter from juvenile bluefin tuna schools.

Optical Remote Color

Similarly, we have been looking at the fusion of plan-view aerial optical images with sonar images. This study is funded by the New England Council and is being conducted by Pe'eri, Weber, and Rhzanov (collaborating with Molly Lutcavage at the Large Pelagics Research Center) along with graduate student Maddie Schroth-Miller and interns Michelle Heller and Katherine Hack. The project is aimed at determining the feasibility of assessing juvenile bluefin tuna stocks.

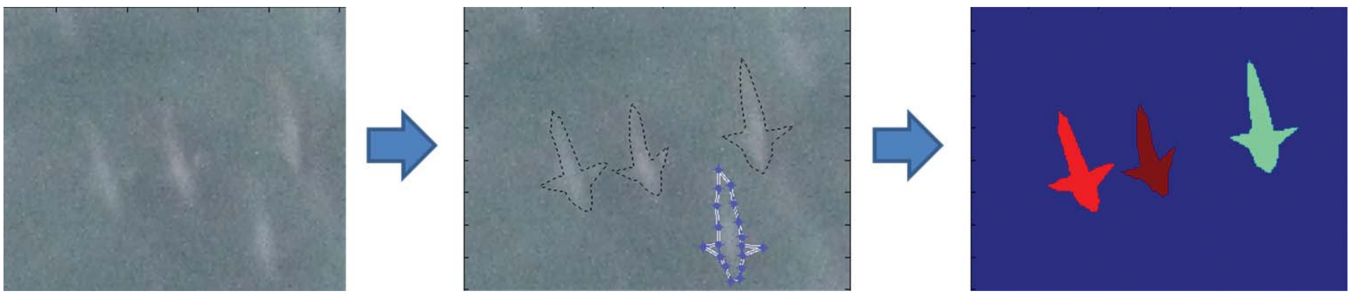


Figure 66. Processing of aerial imagery using custom MATLAB software. The raw data are traced and manually classified as bluefin. The resulting classified image have then been used to calculate school statistics (e.g., nearest neighbor distance, polarization, number of fish).

The multibeam data (Figure 65) are being analyzed by graduate student Maddie Schroth-Miller in order to estimate the school morphology in vertical cross sections, and will also be used as a test bed for statistics-based processing techniques for estimating fish number and density. These data are being combined with the aerial imagery collected from a Canon Rebel EOS T1i camera (Figure 66), integrated with a GPS connected through a PCMCIA card logging at 1 Hz rate, and an attitude sensor logging at 20 Hz rate. The GPS/IMU log files were time stamped using the computer's clock for synchronization. Data for this study were collected on August, 2009, north-northeast of Cape Cod, MA.

The aerial imagery was taken by a spotter pilot, while sonar imagery was collected from a fishing vessel. After reprojecting and georefencing the imagery, the school area and the direction of the fish and vessel were calculated. The study information was archived in ArcMap (Figure 67). The end result will be a characterization of juvenile bluefin tuna schools with unprecedented fidelity that will help to push the boundaries for midwater mapping with multibeam sonar.

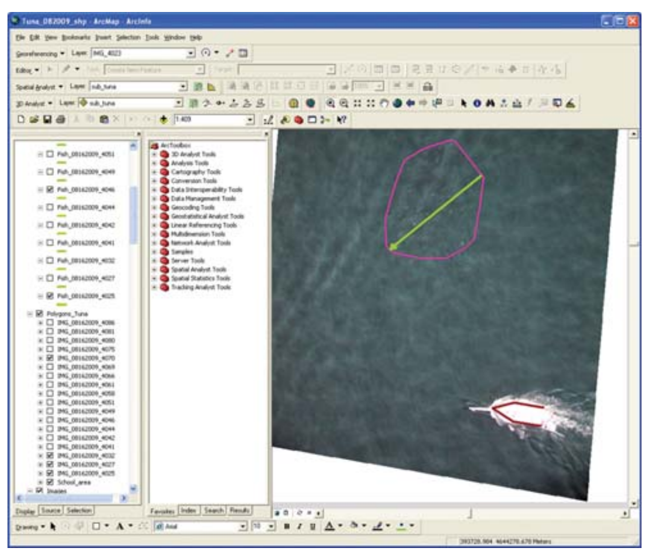


Figure 67. Screen capture of archived project. The preliminary biologic analysis is overlaid on the georectified images.

Lidar Simulator and Target Detection

As we turn our focus to trying to understand the value of lidar-derived data for a number of hydrographic applications, it is becoming increasingly apparent that there are many uncertainties associated with airborne LIDAR bathymetry measurements that are not well understood. Most critical among these are the questions of what happens to the laser beam once it strikes the sea surface and enters the water-column. To address these issues, the Center has obtained a Q-switched Nd:YAG laser with a second-harmonic generator. The generator allows us to transmit laser pulses both in the infrared (1064 nm) and the green (532 nm) wavelengths. With the help of Lloyd Huff, Andy McLeod, Paul Lavoie, and Amaresh M.V. Kumar, a new Ph.D. student, Pe'eri has developed an optical configuration for the LIDAR system with a waveform-recording capability that can be deployed in our tanks. The lidar simulator will aid in understanding the ray-path geometry of the laser pulses from the laser into the water and its interaction with the seafloor and back through the water to the lidar detectors. From this understanding, a better estimate of the lidar propagation error can be produced.

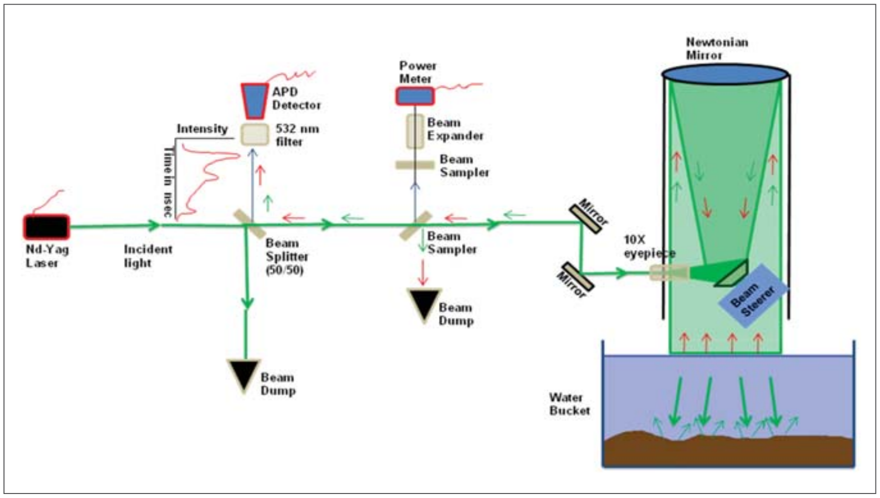


Figure 68. Schematic illustration of the bathymetric lidar simulator.

The primary simulator setup is a Nd:YAG laser (23 mJ at 532 nm) with a pulse width of ~5 ns. The receiver module is made up of beam samplers, beam splitters, a beam expander, a beam-steering mechanism and a Dobsonian telescope. The detector module consists of an avalanche photodiode (APD) with spectral filter (532+/-2 nm) and a 500-MHZ bandwidth oscilloscope (Figure 68). Amaresh is currently characterizing the beam profile of the laser, measuring and simulating the optic losses throughout the simulator hardware and redesigning the simulator to fit on a portable platform. He has also begun the second stage of his research that includes simulating ray-path geometry and laser- beam scattering within the water-column.

Analysis of 1550nm Lidar for Coastal Mapping

NOAA/NGS is in the process of procuring a Riegl topographic lidar system. Unlike many of the commercial, topographic systems currently operating in North America, which utilize 1064 nm lasers, the Riegl systems operate at a wavelength of 1550nm. As this wavelength falls within the so-called "eye safe" region of the electromagnetic spectrum, 1550nm lasers reduce the risk of eye injury for both operators and people on the ground below. However, a tradeoff exists in that water absorption is higher at this wavelength, meaning that signal to noise ratios may be compromised in data collected over wet beach regions. Because NGS's primary use of lidar is in shoreline mapping, it is important to precisely quantify the performance of 1550 nm systems over various beach types and determine mission parameter settings (e.g., flying height, pulse repetition frequency) that yield sufficient signal in the intertidal zone in data collected at low tide.

As a first step in this assessment, NGS acquired data with a Riegl LMS-Q680 system over the Virginia Coast Reserve (VCR) at a variety of flying heights in a test project conducted in December 2009 (Fig. 2). CCOM graduate student, Rachot Osiri, under the supervision of Chris Parrish, has been analyzing these VCR data. To date, the analysis has focused on the falloff of normalized mean intensity and normalized point density with flying height for this 1550 nm system. Although this work is still in a preliminary stage, the results are already providing valuable information regarding suitable operational parameter settings for coastal mapping. Furthermore, analysis of the 2009 data, and issues discovered with that data set, have led to an improved acquisition plan for a second phase of this work, to be conducted in early 2011.

New Projects

The Center tries to be as responsive as possible to national needs and thus over the years we have begun several "new" projects that went beyond the scope of our initial programmatic themes. Among these new efforts are the following:

Law of the Sea

Growing recognition that implementation of United Nations Convention on the Law of the Sea (UNCLOS) Article 76 could confer sovereign rights to resources over large areas of the seabed beyond our current 200 nautical mile (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 submitted to Congress on 31 May 2002. The full report can be found at www.ccom.unh.edu/unclos/reports.htm.

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. In 2003, Center staff participated in two separate cruises to collect data in support of a potential U.S. extended continental shelf submission. For the first cruise, under the supervision of Dr. James Gardner, NOAA contracted with Thales GeoSolutions Inc. to perform the surveys of portions of Bowers Ridge and the Beringian margin in the Bering Sea and a second cruise focused the Chukchi Cap in the Arctic Ocean where permanent ice cover makes the collection of detailed bathymetry very difficult. In 2004, we returned to the Chukchi Cap and, under very difficult ice conditions, mapped another 100 nmi of the 2500-m isobath as well as a 17,800 km^2 (6900 nm^2) region of the margin off Barrow, Alaska. That year we also began mapping of the Atlantic margin off the U.S., covering approximately 255,100 km^2 (98,500 nmi^2) in about 90 days of surveying.

In 2005, we conducted four more Law of the Sea cruises, two legs that continued our mapping off the Atlantic margin of the U.S. and the other two legs in the Gulf of Alaska. The survey work off the U.S. Atlantic margin used the Naval Oceanographic (NAVO) vessel USNS *Pathfinder*, a 329-foot, 5000-ton vessel equipped with a hull-mounted Kongsberg EM121A MBES, under the supervision of Jim Gardner. In addition to the multibeam sonar, the *Pathfinder* also carried an ODEC Bathy2000 chirp sub-bottom profiler and a BGM-5 Bell gravimeter. The first leg of the 2005 Atlantic work mapped a total area of 149,000 km^2 (57,500 nmi^2).

Also in 2005, we mapped the U.S. Gulf of Alaska margin using the University of Hawaii's R/V *Kilo Moana*, a SWATH (small water area twin hull) vessel with a hull-mounted Kongsberg EM120 MBES as well as a Knudsen 320 B/R chirp sub-bottom profiler and a Carson gravimeter. This cruise was divided into two legs, the first leg mapped an area of 91,944 km^2 (35,500 nmi^2) and the second an additional 119,496 km^2 (46,138 nmi^2) for a total of 242,744 km^2 (93,724 nmi^2) in 42 days, at an average speed of 10 kts.

In 2006, three more Law of the Sea cruises were scheduled: the continuation of our Arctic work on the Chukchi Cap, a cruise in the Gulf of Mexico, and the beginning our work in the western Pacific. Unfortunately, a fatal diving accident on board the USCGC *Healy* led to her return to Seattle and cancellation of her mission before the start of the 2006 Arctic Law of the Sea cruise. This cruise was rescheduled for the summer of 2007. Equipment problems with the vessel scheduled to do the Gulf of Mexico mapping led to the postponement of that cruise until April 2007. However, we did begin our work in the Western Pacific with the mapping of the western slope of the West Mariana Ridge. The survey work off the Marinas took place on the NAVO vessel USNS *Bowditch*, a sister ship of the *Pathfinder,* equipped with a hull-mounted Kongsberg EM121A MBES, once again under the supervision of Jim Gardner. In addition to the multibeam sonar, the USNS *Bowditch* also carried a Knudsen chirp sub-bottom profiler and a BGM-5 Bell gravimeter. In the course of 30 days at sea, approximately 91,944 km^2 (35,500 nmi^2) of MBES data were collected representing approximately half of the area to be mapped in this region.

In 2007, three more Law of the Sea mapping cruises were conducted; a return to the Chukchi Cap in the Arctic, mapping of two areas in the northern Gulf of Mexico, and the continuation of mapping in the Marianas. The Chukchi Cap mapping was conducted using the Seabeam 2112, 12 kHz MBES on board the USCGC *Healy*. The *Healy* cruise collected approximately 52,835 km^2 (20,400 nmi^2) of MBES and Knudsen 320 B/R chirp sub-bottom profiles in 30 days and reached as far north as 82.17°N. The combination of multibeam bathymetry and high-resolution subbottom profiles on this leg have radically changed our view of where the "foot of the slope" is located on the northern margin of the Chukchi Cap and may have important ramifications for the size of the U.S. extended continental shelf in the resource-rich Arctic.

The Gulf of Mexico cruise mapped the Florida Escarpment and the Sigsbee Escarpment using C&C Technologies' R/V *Northern Resolution*, a 248-foot research vessel equipped with a Konsberg EM120 MBES and a GeoAcoustics GeoPulse 5430A 3.5-kHz sub-bottom profiler. The cruise required 13 days of surveying (plus five days of transits) and mapped 31,079 km^2 (12,000 nmi^2) of seafloor.

The 2007 Marianas cruise, again under the supervision of Jim Gardner, continued the mapping that was started in 2006. The 2007 cruise used the NAVO vessel USNS *Bowditch*, equipped with a hull-mounted Kongsberg EM121A MBES and a Knudsen 320 B/R chirp sub-bottom profiler. The gravimeter had been removed from the ship prior to the cruise. In the course of 31 days at sea, approximately 35,500 km^2 (20,400 nmi^2) of MBES data were collected.
In 2008, the Center returned to both the Arctic and the Atlantic Margin. The new U.S. Atlantic margin data were collected in May, 2008 using the UNOLS ship R/V *Revelle* with a Kongsberg EM120 MBES. Dr. Brian Calder was the Chief Scientist in charge of the cruise. The cruise was plagued by bad weather and equipment problems but, despite these facts, managed to collect 48,173 km^2 (18,600 nmi^2) of useable data that provide important information for the U.S. UNCLOS efforts.

In 2008, we also completed the fourth in a series of Arctic cruises aboard the USCGC *Healy* adding an additional 89,613 km^2 (34,600 nmi^2) of MBES coverage. We also took samples of the seafloor for the first time using a rock dredge. A total of seven dredges were taken, four on the southern Alpha Ridge, two on ridges north of the Chukchi Borderland and one in the northwestern Northwind Ridge area. A variety of rocks were recovered, some of which call into question current theories about the origin of this region of the Arctic. Further study on these samples is currently underway. Three ancillary programs also took place during the cruise: the recovery of High-Frequency Acoustic Recording Packages (HARPs) that are designed to make long-term measurements of ambient noise in the Arctic and that had been deployed the previous year; the deployment of several different types of ice-monitoring buoys by personnel from the National Ice Center (NIC), and the daily observation by a specialist from the Fish and Wildlife Service of both bird and marine mammal sightings.

In 2009, Jim Gardner continued to lead mapping efforts on the U.S. Pacific margin using the NOAA Ship *Okeanos Explorer* on a 22-day cruise that combined field trials of a new Kongsberg EM302 system with mapping in support of a potential extended continental shelf in the area of the Mendocino Fracture Zone. The mapping ranged in water depths from <100 m to deeper than 4500 m and discovered an exciting, 1400 m high, methane gas plume off the coast of California. The cruise collected 14,196 sq. km^2 (4,099 nmi^2) of high-resolution multibeam sonar data in support of a potential extended continental shelf submission.

The Center also continued its Arctic mapping activities in support of U.S. Law of the Sea on board the USCGC *Healy*. The 2009 expedition was part of a two-ship Canadian/U.S. operation whose primary objective was to take advantage of the presence of two very capable icebreakers to collect seismic 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 because of ice-cover. 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 defined by Article 76 that denotes points where the sediment thickness is one percent of the distance back to the foot of the slope. A secondary objective of the joint program was to take advantage of the two vessels to collect high-resolution multibeam bathymetry data in regions where it would be difficult to collect data with one vessel. In addition to the collection of seismic and bathymetric data, each vessel also carried out ancillary projects including meteorological, oceanographic and ice studies; the *Healy* was also equipped to sample the seafloor with dredges. Over the course of the expedition, the *Louis S. St.-Laurent* collected more than 4000 km of high-quality multichannel seismic reflection, refraction and gravity data and the *Healy* collected 9585 km (5175 nmi) of multibeam bathymetry, sub-bottom profiler and gravity data. Assuming an average swath width of 6.9 km the total area mapped was 66,135 km^2 (19,280 nmi^2). When the two vessels separated, the *Healy* transited to the northern end of Chukchi Cap and proceeded to survey and occupy five dredge stations located on relatively steep slopes amenable to recovery of in situ material with a dredge. More than 800 kg (1520 lbs) of rock material was recovered from these dredge sites with much ice-rafted debris but also many samples that appear to be representative of outcrops.

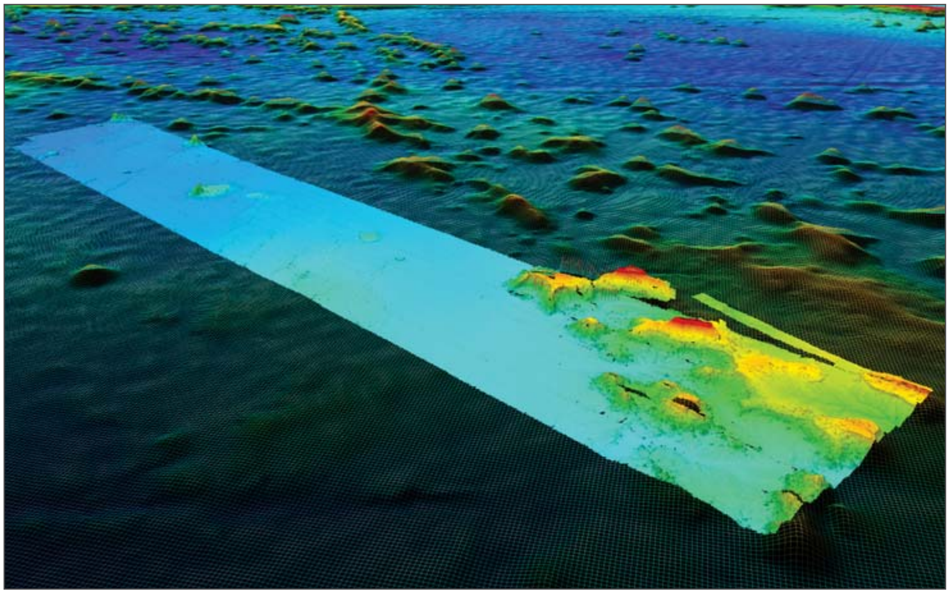


Figure 69. Oblique view of bathymetry of northern end of Line Island chain. Background bathymetry is v. 12.1 of Smith and Sandwell (1997). Vertical exaggeration 3x.

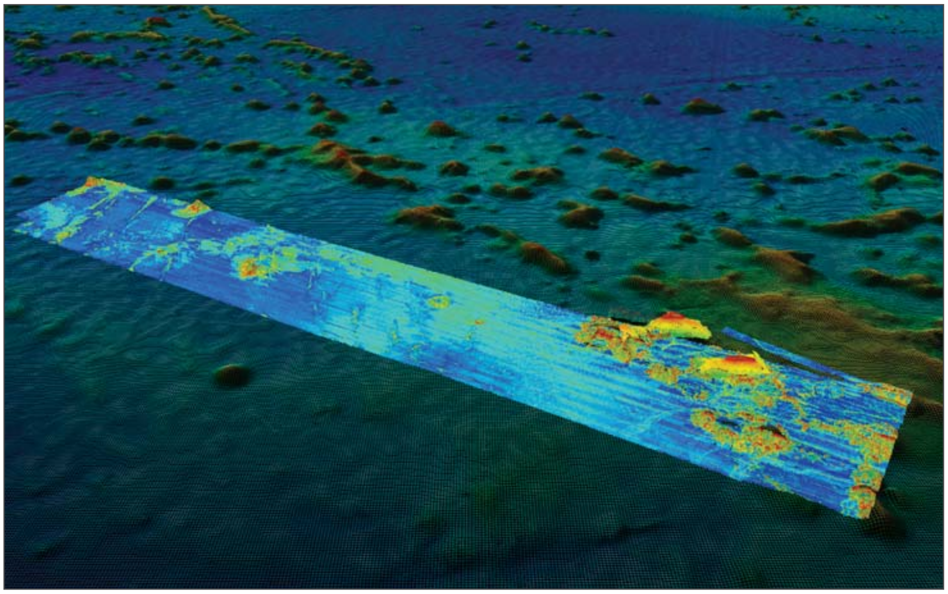


Figure 70. Oblique view of acoustic backscatter of northern end of Line Island chain. Background bathymetry is v. 12.1 of Smith and Sandwell (1997). Vertical exaggeration 3x.

In 2010, Gardner organized three month-long Law of the Sea bathymetry cruises in the Pacific for the U.S. ECS Task Force. Two of the cruises were in the Mariana Trench and Trough areas of the western Pacific and the third was in the Kingman Reef-Palmyra Atoll area of the Line Island chain in the Central Pacific. Jim was chief scientist on the Kingman-Palmyra and first Marianas cruises and Andy Armstrong was chief scientist on the second Marianas cruise.

The first cruise of 2010 was conducted aboard the University of Hawaii's R/V *Kilo Moana* in May and June 2010 using a Kongsberg EM122 multibeam echosounder. The cruise departed from Apia, Samoa and ended in Honolulu, HI and spent 22 days mapping and eight days of transiting to and from ports. The resulting data are all of the highest quality and show, for the first time, the details of the northern section of the Line Islands chain (Figures 69 and 70).

Two observations from the new data that surprised us are an extensive erosional system that funnels sediment from the top of the island chain (Figure 71) and the high degree of collapse of the chain (Figure 72). The backscatter data will be used to construct one scenario for choosing the foot of the slope in this region, although several additional mapping cruises are required to map the entire area.

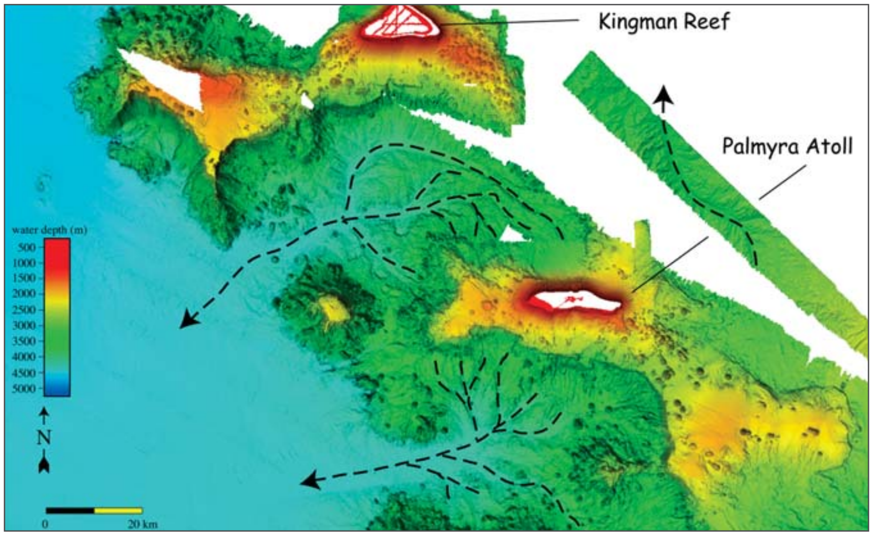


Figure 71. Extensive erosional system in vicinity of Kingman Reef and Palmyra Atoll.

Two cruises in 2010 were devoted to mapping the Mariana Trench and the southern portion of the Mariana Trough (Figure 73) covering an additional 343,526 km^2 (99, 623 nmi^2) of seafloor with multibeam sonar. The Mariana Trench mapping revealed four "bridges" that span from the inner trench wall on the west to the Pacific Plate (Figure 74). Each bridge clearly blocks the deep bathymetry of the trench axis and forms a continuous bathymetric high across the trench. The bridges are formed by seamounts, guyots or ridges the have accreted to the inner wall of the trench. One significant observation from the new data is that extensional faulting caused by the downward flexing of the Pacific Plate as it approaches the trench has fractured the seamounts, guyots and ridges as well. However, once the leading edge of a seamount, guyot or ridge is accreted to the inner trench wall, the faults convert to thrust faults as each sliver of the bathymetric high is jammed beneath its neighboring block.

The deepest depth recorded in the Mariana Trench is 10,994 m, somewhat shallower than the presently recognized 11,034 m deepest depth. Because quality control was assured by collecting XBT casts at a minimum of one every six hours to correct the refracted raytraced depths, we believe the maximum depth from this survey is the most precise and representative.

The Mariana Trough is an area of backarc spreading that lies between the Mariana Arc and the West Mariana Ridge (an area mapped by the Center in 2007 and 2008). The Mariana Trough is an area of massive outpourings of basalt that form two E-W curvilinear ridges broken by a NE-SW seafloor-spreading fabric.

One of the technical surprises occurred when the acoustic backscatter data from the older Kongsberg EM121A multibeam data from the 2007 and 2008 cruises were merged with the

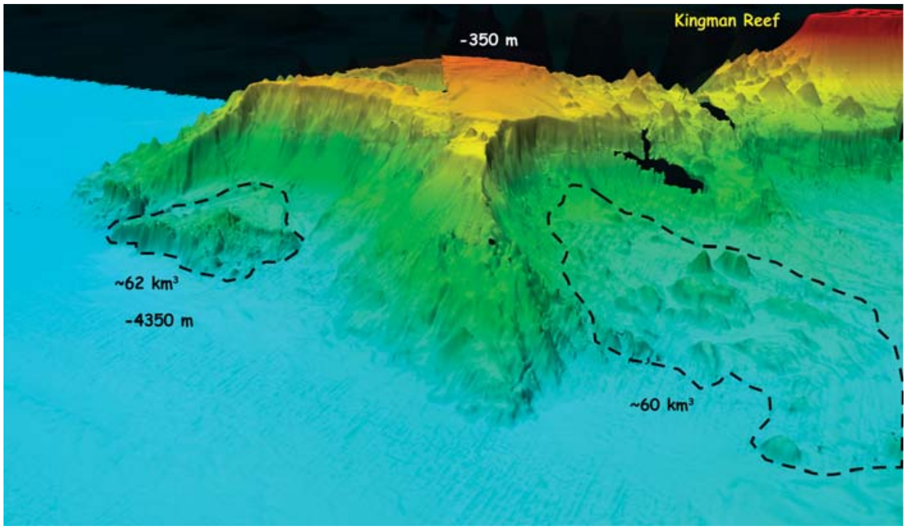


Figure 72. Large landslides on the southwestern flank of Kingman Reef. Vertical exaggeration is 3x.

backscatter from the 2010 Kongsberg EM121A data. The older EM120 backscatter data were shifted 15 dB lower compared to the EM122 backscatter data. This difference in backscatter resulted in a large offset when the two datasets were merged together. After a series of tests to determine whether the backscatter difference was a static offset or was nonlinear, the offset was convincingly shown to be a static shift. In addition, an assumption was made that the newer EM121A data were more accurately reporting acoustic backscatter than was the older EM120. Consequently, the 2007 and 2008 acoustic backscatter data were reprocessed by adding 15 dB to each backscatter value. The merged backscatter data from all four cruises now show a seamless depiction of backscatter over the entire mapped area.

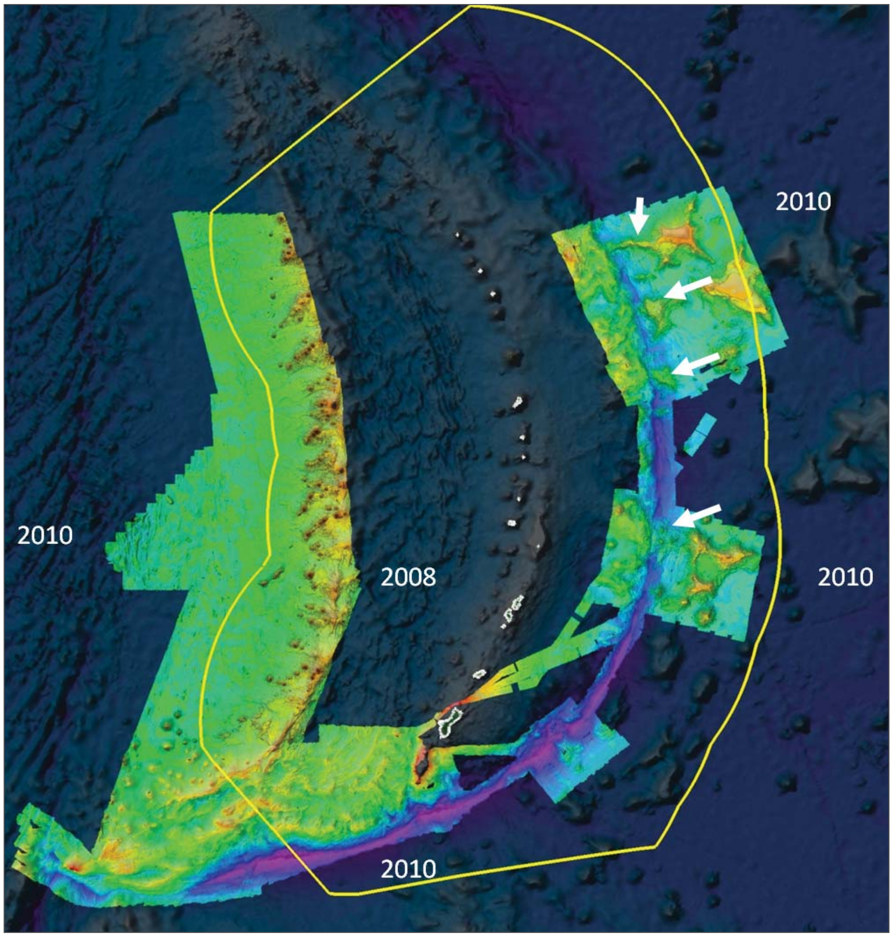


Figure 73. Composite bathymetry map of the four Law of the Sea cruises in the Mariana Trench area. Background bathymetry from version 12.1 of Smith and Sandwell (1997). Yellow polygon is U.S. EEZ. White arrows represent "bridges."

All of the individual soundings and co-registered backscatter values from the Line Islands mapping and the Mariana Trench and Mariana Trough mapping are now been posted on the UNH/CCOM-JHC website and archived at the NOAA National Geophysical Data Center (NGDC). In addition, DTMs and mosaics of the data have been transmitted to the Lamont-Doherty Earth Observatory Marine Geology & Geophysics Data System database for public access via GeoMapApp.

In addition to sea-going activities, the Center has also played an important role in managing and archiving the Law of the Sea data we have collected. The JHC/CCOM UNCLOS website has been updated with the new UNCLOS multibeam grids, with all of these data and metadata files archived at JHC/CCOM as well as at NOAA NGDC in Boulder, CO. This year also saw a major effort to standardize the creation and display of metadata for our Law of the Sea work. Briana Sullivan has been working closely with NGDC to ensure full compatibility between Center products and NGDC. Now, all metadata generated uses the same templates and can quickly and easily be changed and regenerated into an XML format. For user convenience, Briana has also configured NGDC XSLT files that allow for three different views of the same metadata depending on user preference ("classic" HTML, FAQ, FGDC Text).

These views have also helped us to see where our metadata has holes and could be unclear to a user. Jim Gardner and Briana will be revisiting these "holes" during the year to see what data could be included to make it more robust for the user. Additionally, Briana has been making sure that all images are watermarked consistently before they are placed online.

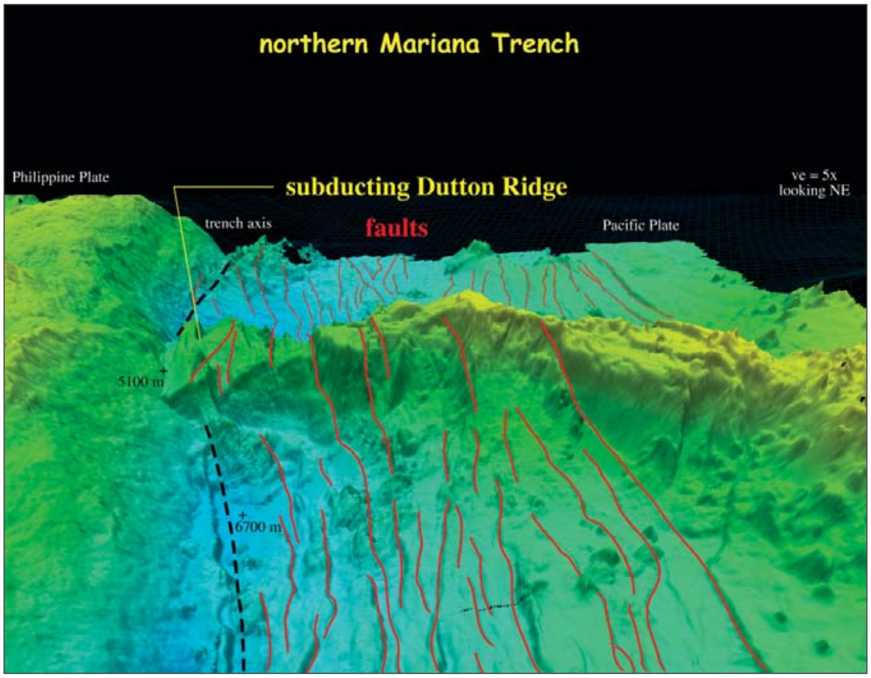


Figure 74. Oblique view of Dutton Ridge subducting into the Mariana Trench. View looking northeast, vertical exaggeration 5x.

To date, the Center has collected more than 1,649,600 km^2 (488,700 nmi^2) of new, high-resolution multibeam-sonar data in regions that have never before been mapped in detail (Figure 75). This mapping has not only provided data that will, unquestionably, add significant territory for which the U.S. will have sovereign rights over resources of the seafloor and subsurface but, from a scientific perspective, has provided tremendous new insights into the nature of continental margin processes and their resources. The data collected on these cruises will be a legacy for generations to come and have already become the focus of several peer-reviewed journal articles by JHC/CCOM and other researchers as well as UNH graduate student theses.

Full cruise reports, details, maps and images from of all of these cruises can be found on the Center website, http://www.ccom.unh.edu/law-of-the-sea.html.

With the formal establishment, under the direction of the State Department, of a joint agency task force to explore the U.S. position with respect to an extended continental shelf submission under UNCLOS Article 76, representatives from the Center (Armstrong, Gardner and Mayer) have become actively involved in the meetings and deliberations of the task force and its working groups. In 2010, the Center has continued to host workshops focused on ECS issues.

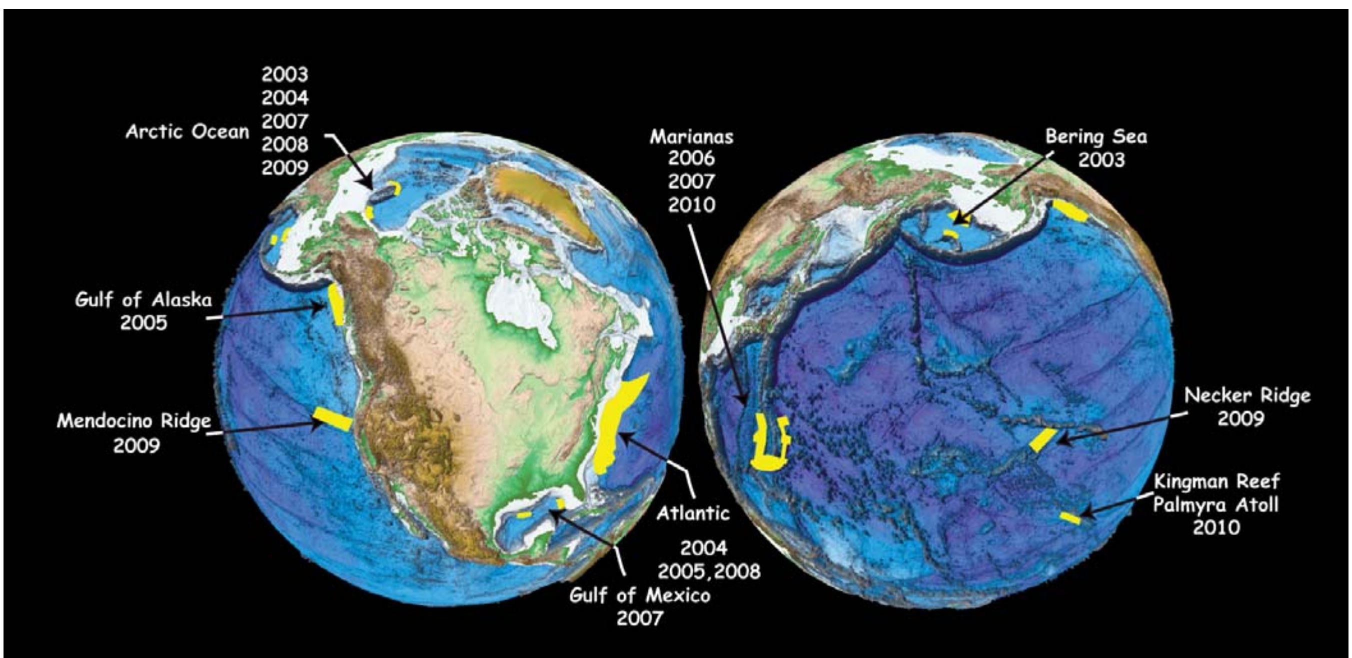


Figure 75. JHC Law of the Sea surveys as of December 2009.

Electronic Chart of the Future

The Chart of the Future project is an evolution of the Navigation Surface concept that also takes advantage of our expertise in visualization. We are taking a two-pronged approach to trying to define the electronic chart of the future. One track of this project is an evolutionary approach to see how additional, non-standard layers (e.g., the navigation surface bathymetric grid, real-time tide information, etc.) can be added to existing electronic charts. This approach requires careful attention to present-day standards and the restrictive constraints of today's electronic charts. This work is being done in conjunction with the standards committees (represented by Center faculty member Lee Alexander) and the electronic chart manufacturers and is intended to provide short-term solutions for the need to see updated electronic charts. In concert with this evolutionary development, we also have embarked on a revolutionary development with researchers in our Visualization Lab exploring new paradigms in electronic chart design, unconstrained by existing standards or concepts. This exercise takes full advantage of the psychology-based human-computer interaction expertise of our visualization researchers to explore optimal designs for displays, the role of 3-D, 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 decimeter intervals. The ENC data is not changed, only the display of safe/unsafe water depending on under-keel clearance of the vessel (a parameter set by the ECDIS user) or changes in tide/water levels (e.g., predicted or real-time values).

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

The ENC is based on decimeter contours/depth areas that are produced from a Navigation Surface/BAG where dynamic/time-varying water level information is applied. To date, this involved water-level information from NOAA's PORTS (Norfolk, VA) and the Canadian Hydrographic Service SINICO (St. Lawrence River between Quebec City – Montreal). In addition, there is interest to expand this effort to trans-boundary waterways in the Great Lakes and St. Lawrence Seaway. Other time-varying information also being investigated includes current flow, sea ice coverage, and weather information. When used with ENCs in ECDIS, these forms of supplemental information are regarded as Marine Information Overlays (MIOs). In the near term, the results of this research can be applied to the use of IHO S-57 ENC datasets, while a longer term goal is to contribute to the development of the "Next Generation ENC" under the future IHO Geospatial Data Standard (IHO S-100.)

AIS Related Projects

As part of the Chart of The Future project, 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 is being led by Kurt Schwehr, and 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 2010, the Center completed their first official interconnect agreement with the USCG NAIS system. As part of the evaluation of CCOM and NOAA needs for AIS, Schwehr proposed to NGDC and OCS that NGDC become the official location for archiving NAIS data for all of NOAA. This would centralize the effort and reduce the load on small offices such as the NOAA Sanctuaries that need AIS traffic information as a part of their Coastal Marine Spatial Planning (CMSP). Schwehr estimates that the archive will be live in the first half of 2011 if the director of NGDC approves the request. Additionally, the USCG OSC team requested that Schwehr participate in the NAIS Increment 2 rollout testing.

Specification Format for AIS Binary Messages and Real-Time Vessel Monitoring

One aspect of the "Next Generation" ENC is the work of Alexander and Schwehr on a draft AIS binary "Environmental Message" (tide/water level, current flow, wind, temperature, sea state, etc.) using an XML schema. In conjunction with NOAA, U.S. Army Corps of Engineers, and other government agencies, the U.S. Coast Guard is conducting a R&D Testbed Project in Tampa Bay, FL whereby NOAA PORTS information is re-formatted and broadcast to mariners via AIS binary messages. Under an IPA Agreement with the U.S. Coast Guard, Alexander supports AIS binary message development by facilitating technical liaison/coordination between U.S. federal agencies, international organizations, manufacturers, and maritime user groups. In addition to Darrin Wright (PORTS), Alexander and Schwehr are also working with John Kelley at the Center to determine an appropriate process to convert selected NOAA data into AIS binary messages that can be broadcast to mariners.

In February 2010, Alexander and John Kelley gave a briefing at NOAA HQ to representatives from CSDL, CO-OPS, and NWS on how NOAA marine weather and hydrographic/oceanographic real-time observations and forecast products could be broadcast via AIS Application Specific Messages (ASM). The main challenge is to convert existing NOS and NWS information content into a suitable format that can be used with existing shipboard equipment/systems. Potentially, NOAA PORTS could be expanded to include new metrological and hydrographic AIS Applications Specific Message (ASM) applications recently adopted by the International Maritime Organization.

Schwehr and Alexander are also working on the implementation of an AIS Binary Message Register (also based on XML) that will be a repository for all international and regional AIS Binary Messages. Additionally, Schwehr has developed an AIS Binary "Zone" message that is being used to broadcast Right Whale locations to LNG vessels transiting the Stellwagen Bank National Marine Sanctuary (see below).

Right Whale AIS Project

One of the most successful applications of AIS technology has been the Right Whale AIS Project. The goal of the project is to provide Automatic Identification System (AIS) binary messages to mariners for acoustically detected Right Whales in the Boston approaches. To date, ten auto-buoys (AB) have been deployed by Cornell University and Woods Hole Oceanographic Institution (WHOI) in the central section of the Traffic Separation Scheme (TSS) between the two directions of traffic. The TSS passes through the Stellwagen Bank National Marine Sanctuary, a seasonal Right Whale feeding ground.

The acoustic detection buoys have a low-noise anchor system and software to automatically detect Right Whale up-calls. The buoys send their detections via IRIDIUM satellite modems to the operations center in the Bioacoustics Research Program (BRP) at

Figure 76. Aldebaran II on the bridge of an LNG carrier with Right Whale alerts on the ENC.

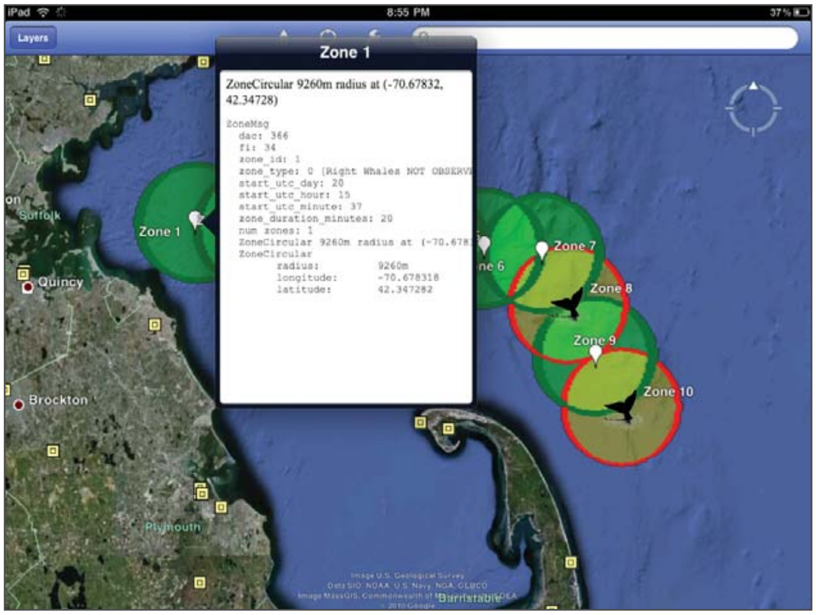


Figure 77. Schwehr's prototype iPad Right Whale application using Google Earth.

Cornell University. Staff at the Center verify the automatic identifications and mark the call for release in the detection database.

To provide the communication channel to vessels, Schwehr has been working on a standard for timed circular-notice messages that can be sent to mariners over AIS to present notifications of areas that have whale detections. The message is designed to be flexible enough to handle other maritime management tasks that require similar notices. Schwehr and Alexander have been collaborating with the USCG Research and Development Center (RDC) to create an official AIS Binary Message for the U.S. authority. ICAN, the electronic chart manufacturer, is working with the project to allow real-time bridge displays of the critical information.

The Right Whale AIS Project is now at the point where mariners are testing the system (Figure 76). The transmitter at Cape Cod has been operational for more than half a year. The system can be seen in action at http://www.youtube.com/watch?v=mN1IFdgAEiA. The Right Whale AIS project has been highlighted by the White House Report on Marine Spatial Planning and a recent editorial in Science Magazine as a prime example of successful Marine Spatial Planning.

Schwehr has also been working with NOAA's New England Fisheries Science Center (NEFSC) to regularize their existing MS Access database of Right Whale sightings from 2002 to 2010, import the data into a new Oracle Database, and display in Google Earth. NEFSC has used this to create a Google Maps interface that is now a part of their live web page. NEFSC and Schwehr plan to have the system update maps live as Right Whale sightings come into the system.

To allow broader distribution of this information, Schwehr has created a prototype iPad application for Right Whale notification using Google Earth (Figure 77). The concept is to use 3G wireless data transfer and/or AIS message when on a ship in range of the Cape Cod AIS ATON transmitter. EarthNC has started work on adding Right Whale messages to their iPad application.

Revolutionary

Within the context of the "revolutionary" effort, Colin Ware, Kurt Schwehr, Matt Plumlee, and Roland Arsenault have been extending the capabilities of GeoZui-4D (as described above) as well as developing specific applications for the Chart of the Future. The GeoZui-4D version that has become the base for the Chart of the Future project is now called GeoNav-4D. Many of the new capabilities were described in past reports. During the past few years, the Center has demonstrated a number of charting components that have gained wide notice. For example, these pieces include:

- Path planning with time dynamic depth contours for safe, caution, and grounding.
- Haptic perception of bathymetry.
- Zooming in time and space
- Pseudo-photo realistic geo-referenced renderings of coastal features in 3-D scene
- Basic ship position decoding from AIS messages.
- Tide based flow modeling.
- Tide –aware bathymetric color coding
- Circular panorama displays for port previews
- Multi-ship and marine mammal coordinated displays.
- Multiple view coordination.
- Analysis of a predictor for ship behavior to assist novice ship drivers.

GeoCoastPilot

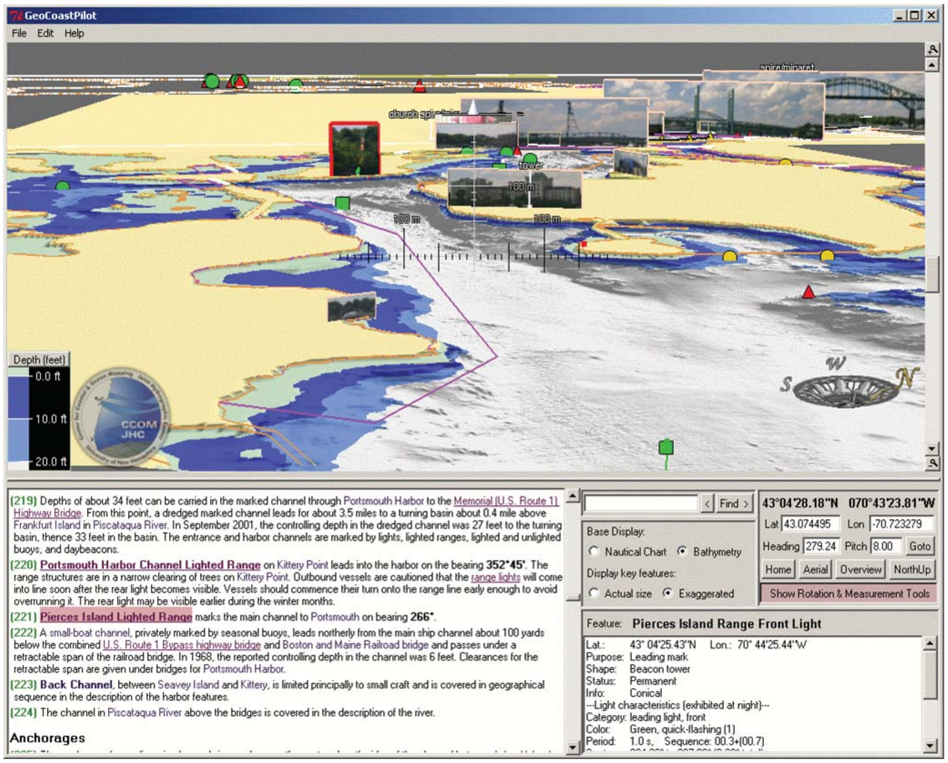


Figure 78. Image captured from the "GeoCoastPilot" showing approach to bridge in Portsmouth Harbor.

In 2007, a decision was made to create a relatively simple focal point for demonstrating some of these capabilities in a tangible, testable form that would not be too radical a change for mariners. GeoCoastPilot is a research software application built to explore techniques for simplifying access to the navigation information a mariner needs prior to entering or leaving a port. GeoCoastPilot is not intended to be used directly for navigation purposes, but instead is intended to demonstrate what is possible with current technology and to facilitate technology transfer. We started with the question in mind: "What might a digital application based on the NOAA Coast Pilot look like if other marine data sources were combined with it?" GeoCoastPilot is intended primarily for operators of smaller vessels—those not under the Safety of Life at Sea (SOLAS) regulations. The concept is to design a fully digital and interactive version of the commonly used Coast Pilot books. With such a digital product, the mariner could, in real-time on the vessel, or before entering a harbor, explore through the click of a mouse any object identified in the text and see a pictorial representation (in 2-D or 3-D) 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 78). GeoCoastPilot turns the NOAA Coast Pilot manual into an interactive document linked to a 3-D map environment, providing linkages between the written text, 2-D and 3-D 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 inside a simplified 3-D 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.

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 3-D scene, 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 multirama development tools. The multirama concept may well have implications beyond GeoCoastPilot. Multirama provides a way of dealing with georeferenced imagery that can have widespread application including in Google Earth.

Spatially Aware Hand-Held Navigation Device

A new initiative started in 2009, and an outgrowth of the GeoCoastPilot work, is the development of a spatially-aware hand-held navigation device. The task of matching chart features to real-world objects in the world is fundamental to navigation in confined waterways and it is 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 that may be critical in an emergency.

Small touch-screen devices, such as tablet PCs or iPhones can be fed GPS position 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 this in mind the Center has initiated a project aimed at designing hand-held spatially aware navigation aids and carry out human factors studies to evaluate them.

In order to evaluate the human-factors issues surrounding hand held chart displays we have developed a semi-circular virtual reality display (illustrated in Figure 79). It has four projectors driven by a single high-end PC and runs open source Flight Gear flight simulator software. This enables us to take advantage of the terrain-modeling and water-rendering capabilities developed by others. It also allows us to simulate different times of day and different environmental conditions. The software adds buoys and other targets for the purpose of the study. We developed this approach when it became clear that conducting human-factors studies using the *Coastal Surveyor* were going to be extremely difficult, costly and time consuming. The chief software developer for this project is Roland Arsenault with Ware leading the design effort and the studies.

We have begun with a study of two tasks: finding an object in the external world (a bouy, another ship, a land-based feature) that corresponds to a symbol on the digital chart display; and finding a symbol on the digital chart display that corresponds to some object already identified in the external world. The study compares a hand-held map display to more conventional fixed heading-up display similar to that found on many bridges. Results show a 10% speed advantage for the hand-held device, particularly for novice mariners. There is also an almost 50% reduction in errors when using the hand-held device. This may be an underestimate, however, because the study does not take into account the time taken by a mariner to move from a location where a clear view of the target is available back to the fixed display on a bridge. A hand-held can be carried anywhere on the ship. A second study is just beginning that is designed to simulate some of the distractions that occur on a bridge, including the need to monitor an audio stream. For this second study, we have added the tracking of the eye movements of the subjects to determine exactly how many times it is necessary to go back and forth between the display and the real-world.

Figure 79. The virtual environment shipboard simulation developed to test alternative chart display techniques. Note the eye tracking apparatus on the participant's head.

Metadata and Google Earth: BAGs as a Mechanism to Distribute Hydrographic Data

The Chart of the Future and almost all Center activities must adhere to stringent requirements to produce metadata, or data about the data. Kurt Schwehr has been looking into ways to make generating metadata for multibeam and seismic surveys easier. By focusing in on this small task and not trying to solve the grand unified metadata problem, he hopes to make a dent in our cataloging of marine geospatial data. He has taken a multi-pronged attack on metadata, with a slow but steady pace. The initial concepts were created in discussion with Monica Wolfson, Jim Gardner, Crescent Moegling, Shep Smith, and Brian Calder.

A critically important aspect of this effort is the work directed at the Bathymetric Attributed Grid (BAG) format that is used by NOAA (and others) for gridded data products. There have been multiple requests for code that will easily show BAGs and provide a simple exporter. Kurt has developed prototype python code to access the BAG HDF5 data and embedded XML metadata. During 2009, Kurt worked with Shep Smith to evaluate the state of Bathymetry Attributed Grids as currently distributed by NOAA's Office of Coast Survey (OCS) to NOAA's National Geophysical Data Center (NGDC). Smith noted that few people outside of the hydrographic community have used or even know about BAGs. Smith and Schwehr decided to create a Google Earth visualization of NOAA's hydrographic BAGs to evaluate the BAG production process and to create a means for people outside of NOAA to discover and download the professionally collected bathymetric data. The first draft in 2009 used a snapshot of BAGs from a NOAA Silver Spring server. However, the second version worked exclusively with the BAGs as they are available on the NGDC website. With the permission of NGDC, Schwehr wrote a script to mirror the web distribution of 2061 BAGs (750GB after they are uncompressed).

Schwehr has created a software package called bag-py that utilizes GDAL (http://www.gdal.org) and Image-Magick (http://www.imagemagick.org) combined with python and bash shell scripts. First, the software processes the BAG grid data into KML tiles to render the bathymetry. The software then creates a database based on the metadata in each of the BAGs. From that database, a second stage of python code creates an overview of the metadata with bounding boxes for surveys and individual bags. For each BAG, there is a placemark that displays a sample image of the bathymetry (Figure 80), a histogram plot of the depths, a link to raw extracted XML metadata from the BAG, a link to the Descriptive Report (DR) PDF, and a link to download the actual BAG file from NGDC's server.

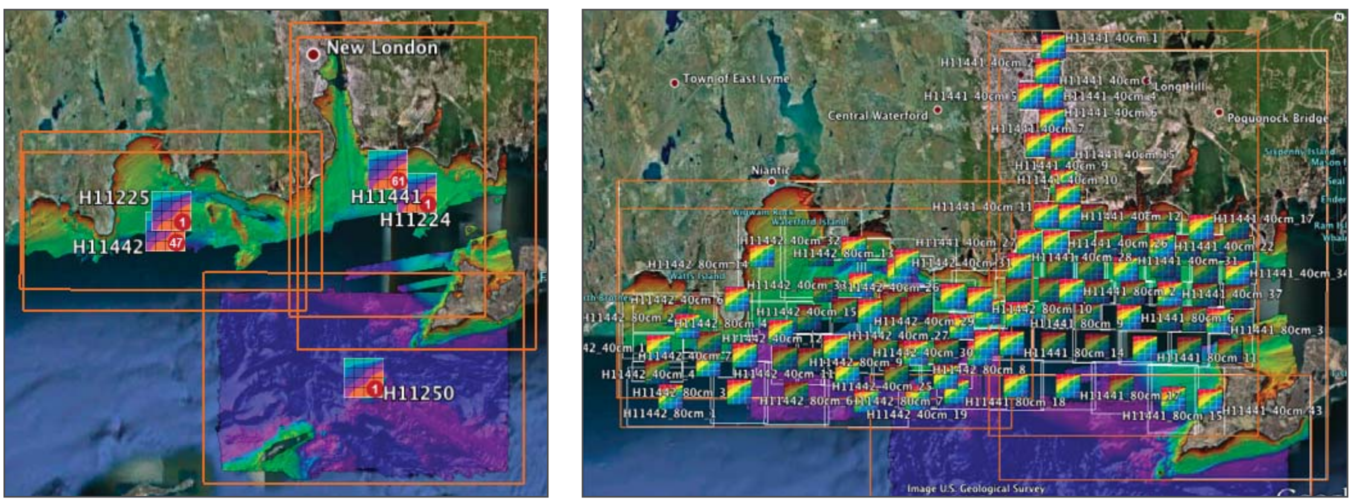


Figure 80. Survey view showing only one icon per survey that masks the BAGs in a survey (left) and closer view (right) where survey icon has been replaced by constituent BAGS.

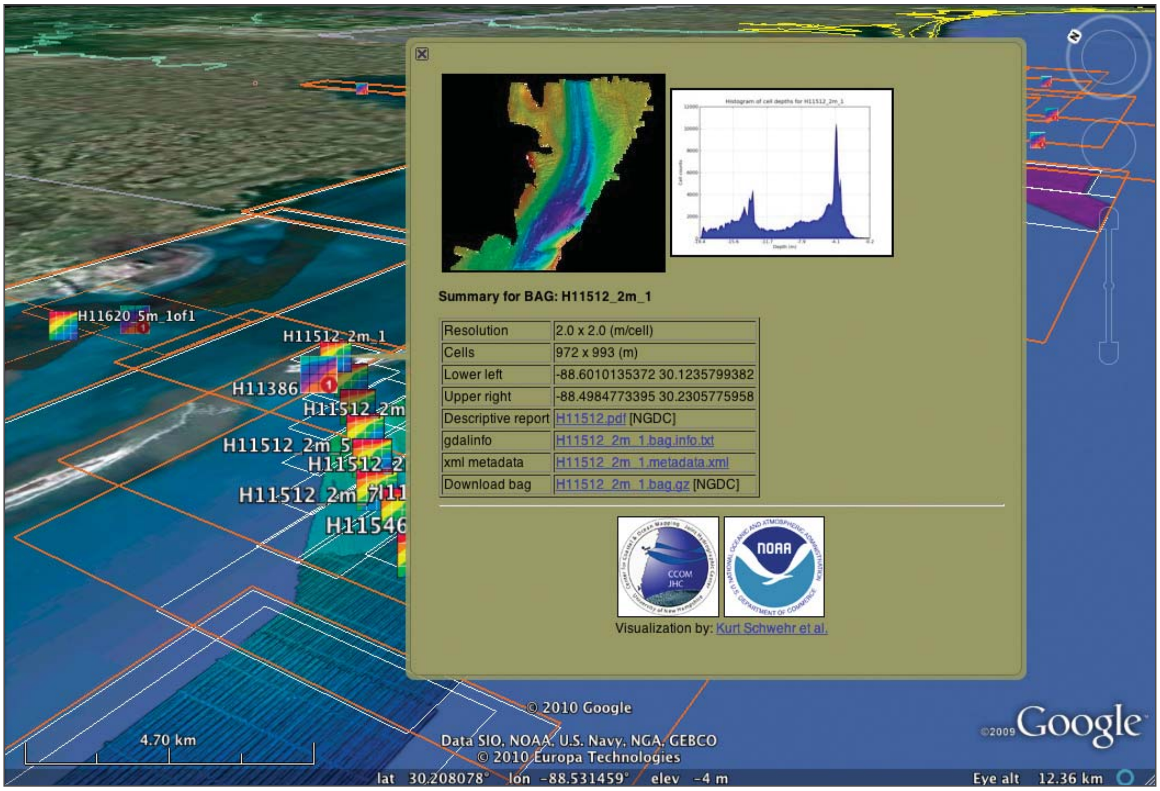


Figure 81. Displaying the popup for a single BAG with a sample image, depth histogram, and links to the data, metadata, and descriptive report.

Some surveys have as many as 61 BAGs creating a confusion of icons. To create a less confusing display, the Google Earth display utilizes a level-of-detail concept from computer graphics: when zoomed out, only a survey icons shows on the screen. The icon is annotated with a red circle containing a number marking the number of BAGs contained within the survey. When the user zooms in close to the survey, the survey icon switches to an expanded view with one icon per BAG file (Figure 81).

NGDC is in the process of converting Schwehr's initial prototype of a Google Earth visualization into a system that works for the NGDC production environment. The system will produce images and content that will be served by ArcGIS web services and is expected in the January or February 2011.

Schwehr has also been working with EarthNC to explore possible uses of BAGs for additional products and services along with NOAA Charts and other coastal data. A test path has been created to deliver BAGs to EarthNC's Amazon S3 cloud service (Figure 82). The results are promising, but will require extra work on presentation, as the data is not full coverage, which will likely confuse users without proper warning.

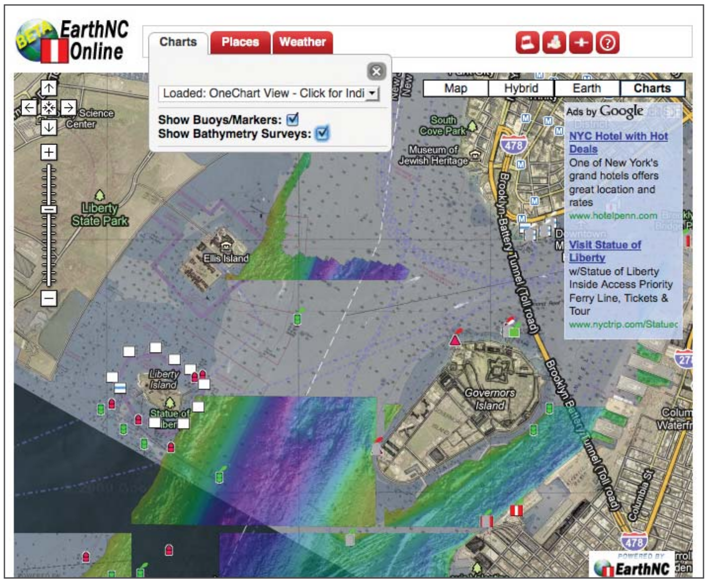


Figure 82. BAGs in EarthNC's online chart viewer.

Water-Column Mapping

In 2006, we began an exciting new project aimed at exploring the use of the new generation of water-column sampling-capable multibeam sonars to allow real-time visualization of targets in the water-column. Visualization of these water-column targets is just the first step as we also hope to be able to extract quantitative information from these returns that can then be used in fisheries and other applications including critical least-depth determinations in hydrographic surveys. The focus of this project, led by Tom Weber, has been the visualization of four-dimensional data (three spatial dimensions plus time) in GeoZui and through software being developed by Weber and Roland Arsenault and through a collaborative effort with IVS3D.

The exciting work of Roland Arsenault and Colin Ware applying some of the new capabilities of GeoZui-4D and TrackPlot to whale tracking and ecosystem studies has already been discussed under the Visualization theme. Our prototype water-column visualization software has evolved to the point where it is now being transferred to the commercial sector. The Center and industrial associate IVS3D have been collaborating on the development of a new multibeam mid-water visualization tool that has been integrated into IVS3D's Fledermaus software. Water-column mapping has great potential for examining wrecks, fish, and gas plumes (including the exciting discovery by Jim Gardner and Mashkoor Malik of the giant gas plumes off the Mendocino coast in 2009 (see Law of the Sea theme). The value of this capability was clearly demonstrated when Center staff were called into action during the Deepwater Horizon spill and used these tools to map submerged oil and gas and to evaluate the integrity of Macondo 252 wellhead after it was capped (see Deepwater Horizon discussion).

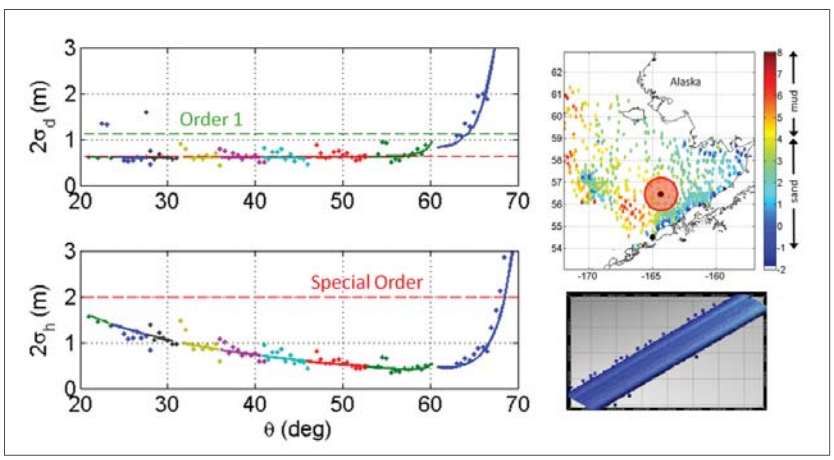


Figure 83. Depth (top) and across-track(bottom) error due to ME70 using a standard water-column mode, collected over fine grain sediments in the Bering Sea.

Simrad ME70 Bathymetry Using Standard Water-Column Modes

The potential to simultaneously map both the water-column and the seafloor opens up a world of opportunities for efficiency amongst various NOAA lines and offices (e.g., Office of Coast Survey and Fisheries). This is a key component to the concept of Integrated Ocean and Coastal Mapping (IOCM) that will be discussed later in the report. To further this capability, Weber has been working with a Simrad ME70, a state-of-the-art fisheries (water-column) multibeam sonar, to see how well it can be used to simultaneously produce high-quality seafloor bathymetry and backscatter.

The basic premise of this project is that bathymetry can be generated using the ME70 in a standard water-column (i.e., fisheries) model. This project has received partial funding from the NOAA Fisheries Advanced Sampling Technology Working Group, and has been ongoing from February 2008 until now (with an anticipated end date of early spring 2011). This work has been done in close collaboration with NOAA AFSC, and has been primarily conducted onboard the NOAA Ship *Oscar Dyson*.

A hybrid phase-differencing (interferometric) / beamforming approach has been used in order to generate hundreds of independent soundings *per ping*, with individual sounding accuracy that is consistent with IHO standards (see Figure 83). Open-source software (MATLAB) for generating bathymetry using any beam mode configuration has been pre-released to each of the NOAA science centers in April 2010. A final version will be released this winter. As part of this project, the ME70 has also been used to explore the physical limitations for phase-differencing systems. Figure 83 shows a comparison between empirical estimates of the angle-estimate uncertainty for the ME70 and the predicted uncertainty based on a combination of signal-to-noise ratio and baseline de-correlation, with excellent agreement. The data in Figure 84 are for a flat, featureless bottom. For bottoms with greater relief (e.g., sand waves), the addition of the effect of a shifting footprint seems to more accurately describe the angle-estimate uncertainty.

Additional water-column multibeam activities by Weber include experiments using a 400-kHz Reson 7125 multibeam sonar to image juvenile bluefin tuna. This was discussed under the LIDAR and data fusion heading. The data sets collected during this experiment will also be used for an ONR-funded program to examine spatial heterogeneities in fish schools and its impact on volume reverberation for low/mid frequency sonars. Finally, we used the sidescan sonar on the GAVIA AUV to map gas plumes in the water-column in Lake Rotoiti, New Zealand. This is discussed below in the section on AUV activities.

Data Compression Techniques for MBES Water-Column Reflectivity Measurements

The massive data volumes produced by water-column data from multibeam sonars (particularly high-frequency, shallow water sonars) present a serious challenge to data processing. In a continuation of research begun at the University of New Brunswick (UNB), Jonathan Beaudoin is investigating the use of lossy data compression methods to reduce MBES water-column imagery data file sizes from Kongsberg EM series MBES. A method using the JPEG2000 compression standard was developed while at UNB and an abstract outlining early results was presented at the 2010 Canadian Hydrographic Conference (CHC2010, June 21-23, 2010). Figures 85 and 86 show raw and compressed water-column imagery acquired over a sunken wreck by a Kongsberg EM3002 in ~25 m of water depth. Further work done at the Center has focused on evaluating the impact of the compression methods from a target detection point of view, specifically that of wreck detection and least-depth measurements over the wreck (see Figure 87) Based on interest generated at CHC2010, Beaudoin has been invited to present these results at the 2011 Kongsberg user's conference (FEMME2011) in Trondheim, Norway.

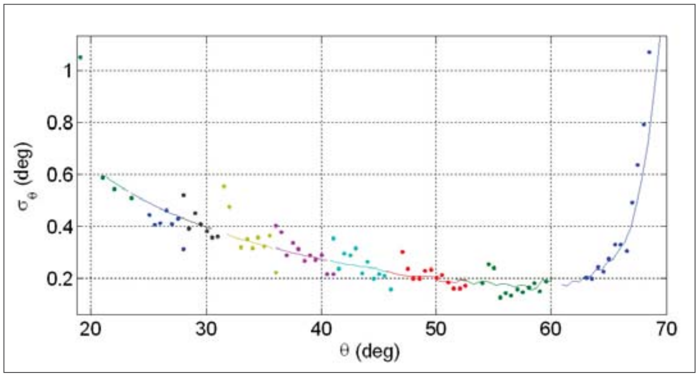


Figure 84. Estimates of the ME70 angular uncertainty (points) shown with the modeled uncertainty (solid lines) accounting for signal-to-noise ration and baseline decorrelation. The different colors correspond to different beams. For angle below ~50 degrees, baseline decorrelation is the primary contribution to the angular uncertainty. For angles greater than ~60 degrees, the weakening signal-to-noise ratio governs the angular uncertainty. These data are collected from a flat, featureless seafloor where Lurton's shifting footprint effect may not play an important role.

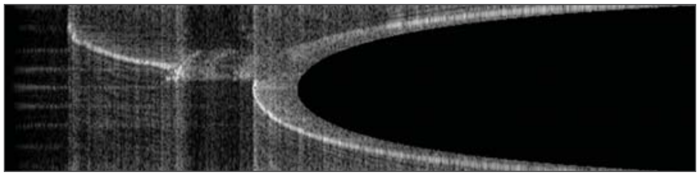


Figure 85. Raw time-angle image of a sunken wreck imaged by an EM3002. Time is on the x-axis, beam angle is on the y-axis.

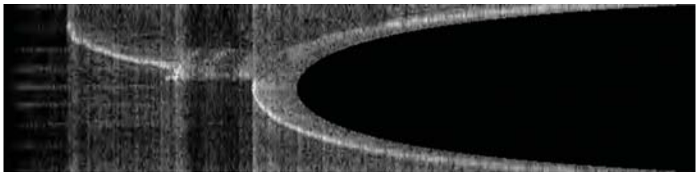


Figure 86. Compressed (20:1) time-angle image of a sunken wreck image by an EM3002. Time is on the x-axis, beam angle is on the y-axis.

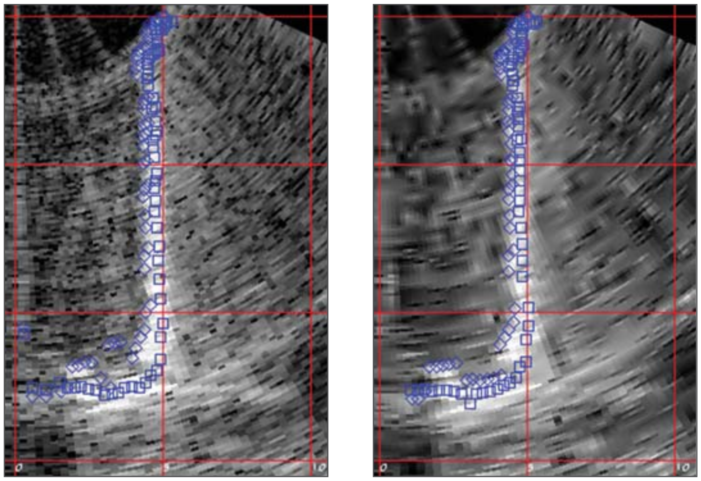


Figure 87. Geometrically projected water-column imagery of the ship mast; raw data is shown on left and 20:1 compressed data on right. Mast detections resulting from a simple thresholding and weighted mean time detection algorithm are plotted as blue diamonds and squares. The mast is still successfully detected by both algorithms after undergoing a 20:1 lossy compression.

AUV Work and the Harbor Tracking and Observatory Project

AUV Activities

In 2006, the Center began an effort to explore the applicability of using a small Autonomous Underwater Vehicle (AUV) to collect critical bathymetric and other data. We teamed with Art Trembanis of the University of Delaware to obtain use of his FETCH 3 vehicle. We purchased, calibrated and integrated a small multibeam sonar (Imagenix Delta-T) into this AUV and over the course of 2007 began to explore its applicability for collecting both hydrographic-quality bathymetric data and seafloor-characterization data. Unfortunately, the FETCH 3 vehicle suffered a catastrophic failure during a mission with Bob Ballard 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 88). Additional capabilities include sensors for temperature, sound-speed, salinity (derived), dissolved oxygen, chlorophyll and turbidity, a downward-looking camera and a Marine Sonics 900 kHz/1800 kHz sidescan sonar. The new system is a much more mature AUV than was the FETCH, with imagery, bathymetry, and particularly positioning capabilities far beyond the original vehicle. We have also purchased a WHOI acoustic modem for the new vehicle that will allow enhanced positioning and two-way communication.

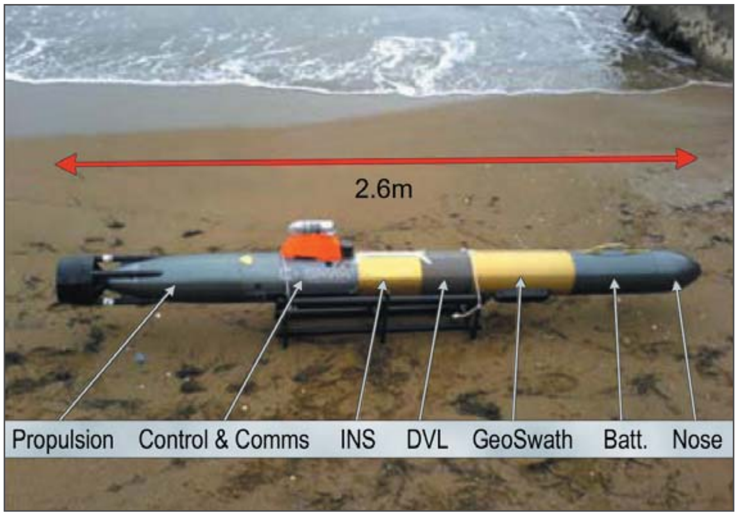


Figure 88. GAVIA AUV with GeoSwath Phase Measuring Bathymetric Sonar.

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

Between the 5th and 12th of June 2010, the Center hosted an AUV Bootcamp for both UNH and University of Delaware researchers, graduate students, and engineers. The event was a great success with participants from industry (both AUV manufacturers and commercial operators), government (NOAA) and academia (University of Delaware, University of Reykjavik, University of British Columbia and the Provincetown Center for Coastal Studies), collaborating and discussing everything from mission planning and operations, to sensor calibrations, mapping water chemistry and sonar processing. The event provides students, operators and data processors an opportunity to learn and experiment without the pressures of "must-have" data or explicit operational objectives. We aim to make mistakes. A long day of lecture and discussion at the Center was followed by four intensive days of field missions at Swain's Lake, NH. Evenings were spent in additional lectures and data processing sessions.

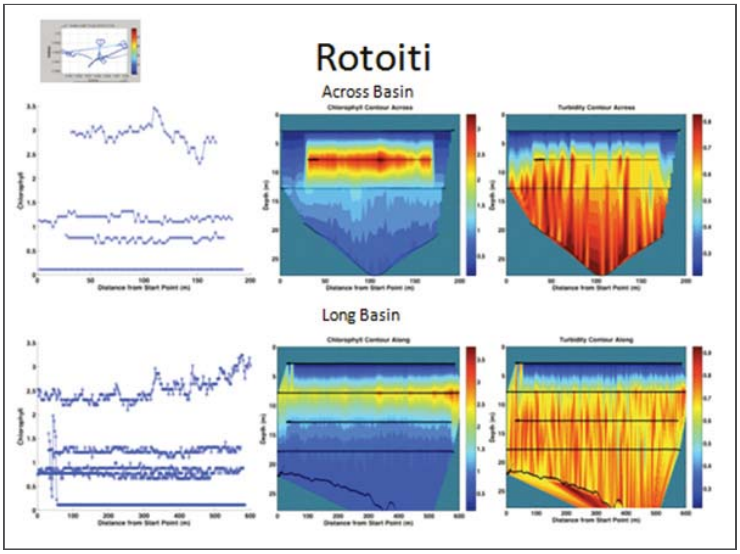


Figure 89. Water chemistry in Lake Rotoiti from AUV transects.

A major AUV survey was conducted in 2010 in Lake Rotoiti, New Zealand. The survey was a collaboration of researchers from the University of Delaware with researchers at the University of Waikato, Hamilton, NZ and the Cawthron Institute and supported by Schmidt from the Center. In Lake Rotoiti, the GAVIA was used to measure chlorophyll and turbidity in across-lake transects (Figure 89).

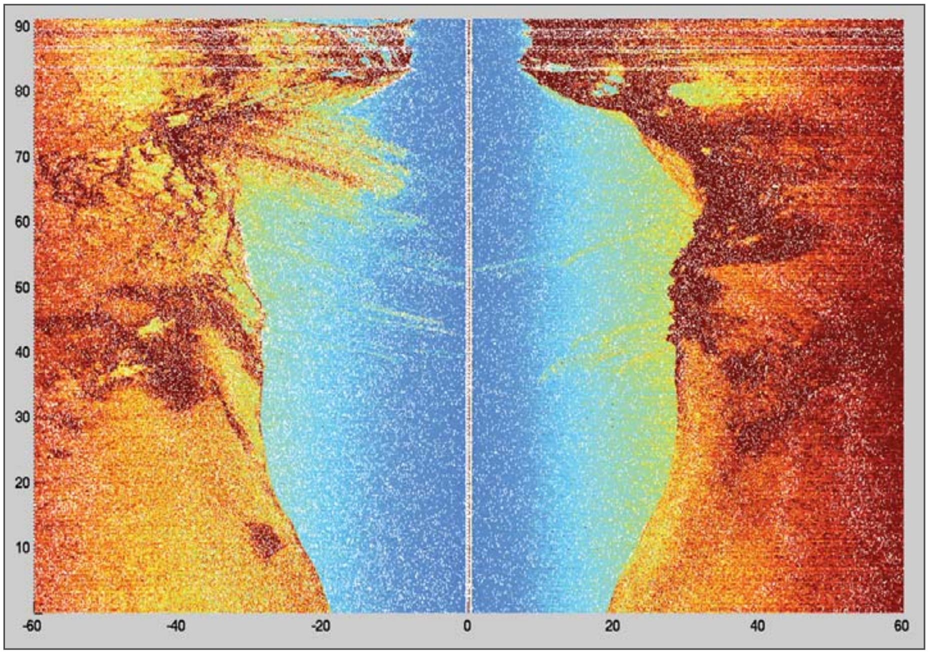


Figure 90. Geoswath sidescan image of hydrothermal and methane seep in Lake Rotoiti.

In addition a bathymetric map was made of a known hydrothermal and methane seeps. These operations proved to be particularly challenging, because the seeps were in a hole nearly 80 m below the surrounding bathymetry resulting in lake-floor slopes that the AUV was unable to recover from, even with a 20 m standoff. Nonetheless, we were able to obtain the sidescan image (Figure 90) in which rising bubbles of gas appear as linear red and yellow segments in the water-column. The apparent slant of these traces is due, in part, to the downward pitch of the vehicle as it terrain follows into the seep area.

Using the sidescan image as a guide, the probable locations were determined of individual returns corresponding to the high-backscatter areas from the gas seeps. The plume of bubble-related scatterers is plotted above the lake-floor topology in Figure 91.

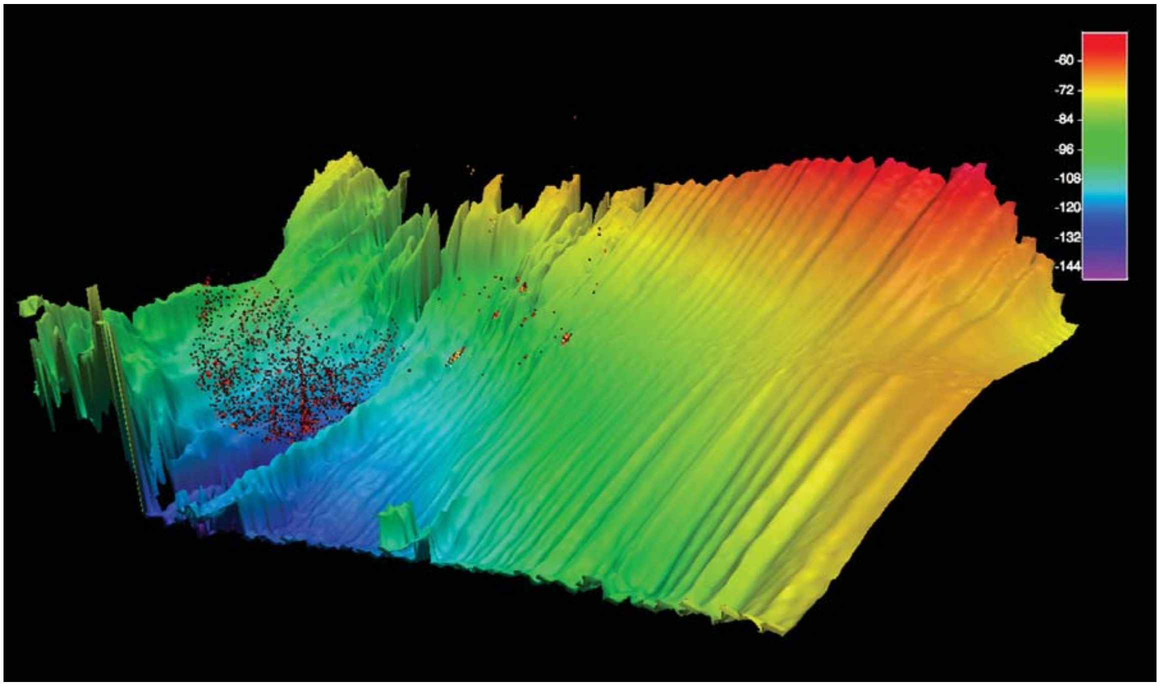


Figure 91. Lake bathymetry and locations of individual returns associated with rising gas from a methane seep in Lake Rotoit, N.Z.

Harbor Tracking Buoys

In support of our AUV effort, as well as to provide a permanent ability to accurately position this (or any other) vehicle, sampler and other devices, the Center also 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 92. One the buoys deployed in Great Bay in November 2010.

In 2010, the harbor tracking buoys were again used during the GAVIA AUV summer boot camp (see above). Since that time, the buoys have been upgraded to include solar panels, and deployed in November-December as a tide buoy (Figure 92) with the support of several Mechanical Engineering interns (Matt Normandeau, Evan Leach, Luke Gregory). This was done partly as an aid to a student thesis on tides and partly as a 'shakedown test' for the new solar panel and power management system. The new solar system performed quite well, maintaining an acceptable (or higher) battery voltage during the ~3 week deployment (see Figure 93).

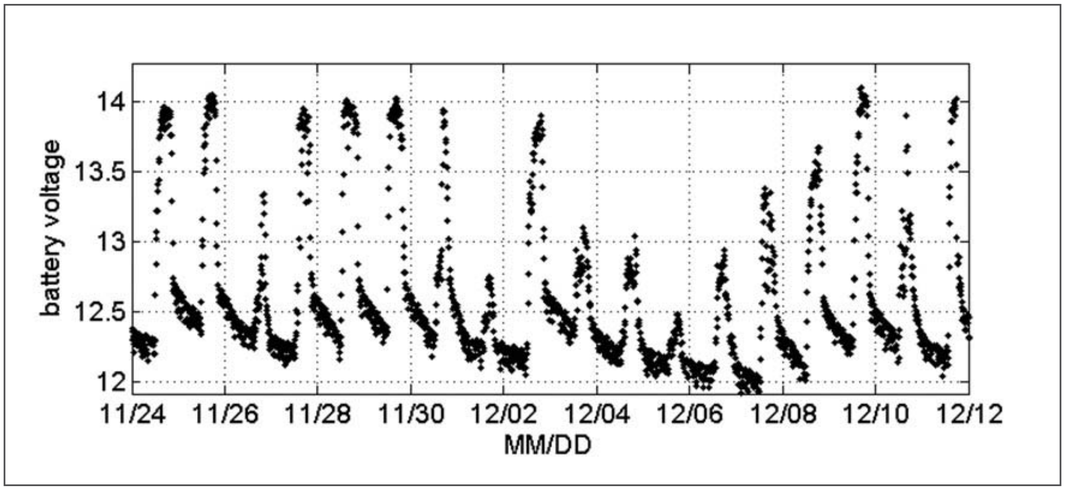


Figure 93. Battery voltage and charging cycle during the buoy deployment in Great Bay.

Coastal Process Studies and Very Shallow-Water Mapping

A proper understanding of the effects of natural and anthropogenic forces in the coastal region depends on an accurate geospatial framework. As the Center develops new tools and techniques to establish this framework, we are also beginning to apply these tools to a better understanding of the critical processes at work in the coastal zone. With the arrival of Tom Lippmann and Larry Ward to the Center, we are building an expertise base that can both collect data and apply it to critical coastal-process questions of relevance to NOAA. In recognition of the importance of coastal studies to the objectives of the Center and to our students, we have also introduced new courses such as Nearshore Processes taught by Larry Ward and Time Series Analysis taught by Tom Lippmann. Included in this course has been the development of four computer-based laboratories (sea level, tides, waves, and CTD profile data analyses). These labs were developed with the aid of the Center's Dr. James Irish who provided the MATLAB expertise, helped with the overall design, and taught the computer aspects of the laboratories.

Very Shallow-Water Mapping

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, Lippmann 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 freshwater 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.

As part of research funded by ONR, NOAA, and NH Sea Grant, Lippmann has been improving the capabilities of the CBASS. The first notable improvement is the integration of a new 192 kHz single-beam echosounder with full waveform measuring capabilities. This new sonar (designed and build by Bill Boyd of SIO) 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, more substantial improvement, is the integration of the Imagenex Delta-T

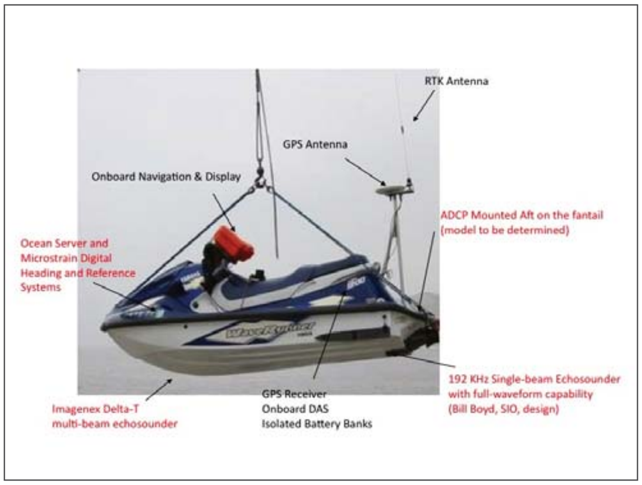


Figure 94. CBASS with principal components labeled. New components are indicated in red.

multibeam echosounder with both an Ocean Server OS5000 three axis, tilt compensated digital compass and a MicroStrain 3DM-GX1 integrated digital heading and reference system. The new multi-beam capabilities will allow for detailed examination of seafloor bathymetric evolution in shallow water, also in the range of 1-25 m water depths. The third improvement will be the onboard observation of the vertical structure of flows from a stern-mounted ADCP. The combination of coincident, repeated observations of both fine-scale bathymetry and mean flow properties over large nearshore areas will allow for models on seafloor evolution to be tested. The components for the CBASS are shown in Figure 94.

The newly configured CBASS will be put to the test in 2011 as part of the ONR River Mouth and Inlet Dynamics Defense Research Initiative (DRI), where it will make repeated large-scale measurements of fine-scale bathymetry coincident with vertical profiles of the mean circulation during a field program scheduled for New River Inlet, NC. The field site is characterized by energetic waves, three-dimensional bathymetry with high sediment heterogeneity (in terms of composition and spatial distribution), and a strong tidally modulated current—all providing challenges to bathymetric mapping. Nonetheless cross-inlet and along-inlet transects will be repeatedly sampled with the CBASS to quantify the spatial and temporal evolution of the seabed, as well as the spatial structure of the three-dimensional mean flow field spanning the inlet. Multibeam bathymetric surveys will be repeatedly conducted along these transects, as well as periodically over the entire region encompassing the inlet. Based on expected typical survey speeds of 2.5-5 knots, the transect lines can all be sampled in 0.75-1.5 hrs, and the entire inlet covered in 2.5 hrs. Periodic CTD casts will be made at regular intervals and locations for refraction corrections to the MBES, particularly important for the outer most beams, and to capture the gross movements of water masses over a tidal cycle.

Nearshore Bathymetric Estimation from Airborne Imagery

Lippmann is also looking at using airborne imagery (collected during LIDAR surveys) to estimate continuous bathymetric profiles in the critical zone from about 10 m water depth to the shoreline. The techniques can be applied to a wide range of oceanic conditions, including high waves with large, wide surf zones, to small wave days with a narrow surf zone, independent of water clarity.

Algorithms have been developed to extract, from a time series of sea surface images, incident wave wavenumbers as a function of frequency using an ensemble averaging approach. This new approach was tested with land-based video records of the nearshore extending from the shoreline to approximately 500 m offshore, and extending from 100-1000 m from the camera location. Although the highly oblique camera view and 8-bit image depth is clearly not optimal for the airborne analysis we are developing, it does allow for extensive testing with readily available ground truth data to ensure that the algorithms are developed correctly. Comparisons between video-estimated water depths and observed beach profiles (obtained independently by the US Army Corps of Engineers) show that the analysis methodology applied to land-based video produces results with root-mean-square errors generally between 0.30-0.50 m, even to distances 1 km away where image resolution degrades rapidly. Results indicate that the algorithms are robust.

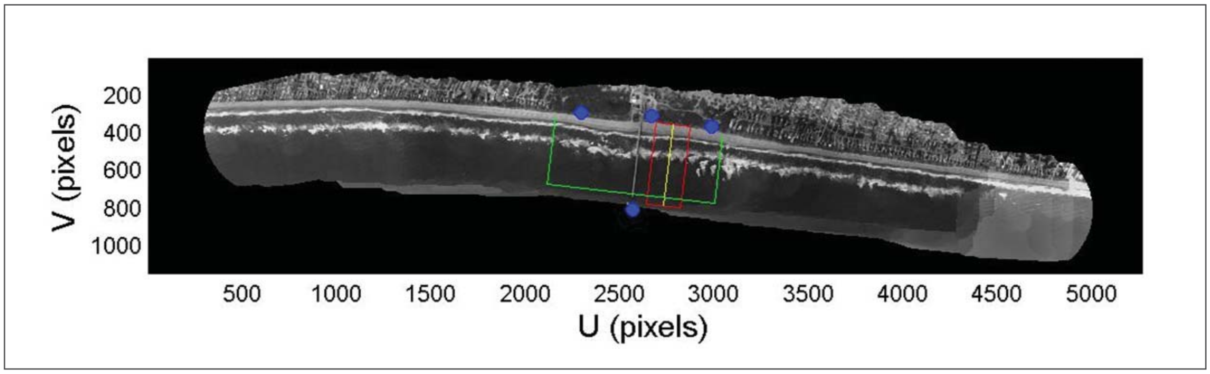


Figure 95. Composite graph-cut image mosaic over approximately 5 km of shoreline in Duck, NC. Coordinate system is in image pixels, each with resolution of 1.12 m on a side. The mosaic consists of image data from all three passes during the overflight mission. Geo-referencing was done by identifying known, surveyed ground control points in the image (blue dots). The region of field ground truth surveys is indicated by the green lines. An example region interrogated is indicated by the red lines, with the center of the box indicated by the yellow cross-shore profile line.

Image mosaicing techniques developed by Yuri 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 (Figure 95). 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. Pixel resolution in the mosaic is 1.12 m on a side. Ground truth bathymetric surveying was done independently with traditional in situ survey methods using differential GPS and sonar depth sounding onboard an amphibious watercraft.

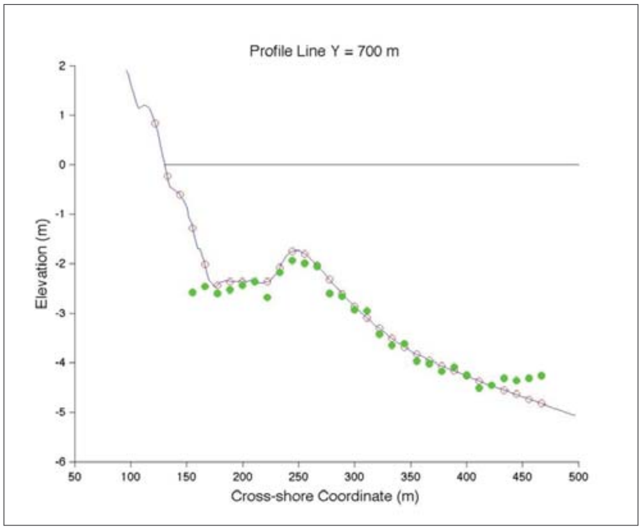


Figure 96. Profile line along cross-shore transect located at alongshore position 700 m indicated by the yellow line in Figure 95. The ground truth survey is indicated by the thin black line and open red circles. The estimates from the image data are the solid green dots. RMS error is 0.27 m. The results along this profile line were tuned to the best frequency range, and thus indicates the best possible result that can be obtained for this particular data set. The tuned frequency ranges were applied to the remainder of the data (shown in Figure 97).

Figure 96 shows the estimate of water depth determined along the test (tuned) transect. The root-mean-square error in the estimates is 0.27 m, essentially the best that can be done considering the tuned selection of frequencies to use. Using this analysis, the remainder of transects in the region of interest were interrogated to produce a bathymetry map shown in Figure 97, along with the ground truth survey. The root-mean-square error over the entire region is 0.57 m. In general, the gross behavior of the bathymetry is extracted with water depths shallowing shoreward over the sand bar and increasing in the trough. Far from shore near the edges of the imagery, the techniques break down primarily because the video data does not completely cover the spatial region of interest. Near the shoreline, the techniques again break down because part of the spatial region is on the dry beach and encompasses the to-and-fro motion of the swash. Errors also increase inside the surf zone (as expected) because of wave nonlinearities that are not accounted for with the linear wave theory.

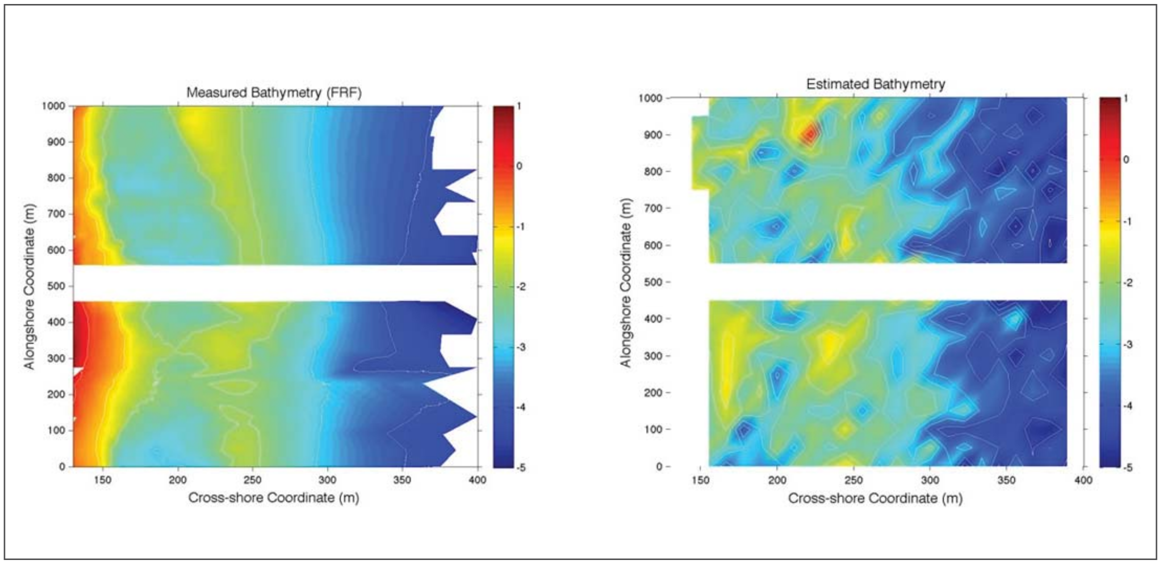


Figure 97. Color contoured plots of the ground truth FRF surveyed bathymetry (left) and image-derived water depths (right). The color scales are the same in each figure. Overall RMS error is 0.57 m. Results shown in Figure 96 are from a transect located at alongshore coordinate 700 m.

Great Bay Survey and Data Compilation

In 2009, Larry Ward began a research project that involves an assessment of bathymetric changes in Great Bay Estuary (GBE). The objectives of this study include: building an archive of bathymetric data of GBE that is of acceptable quality; creating bathymetric maps from several survey periods (1898-1913, 1950-1955, and 2001-2007); and conducting a bathymetric comparison to assess depth changes. Bathymetric archives have been created, the methodology for conducting comparisons between bathymetric surveys developed and tested, and comparisons have been made between two NOS surveys (1913 and 1953-1955) for the upper estuary. A major finding of this study is that the historical surveys chosen for analysis have major problems with vertical datums and determinations of depth changes to the accuracy needed are not possible. However, morphological changes can be determined and will be assessed in future studies.

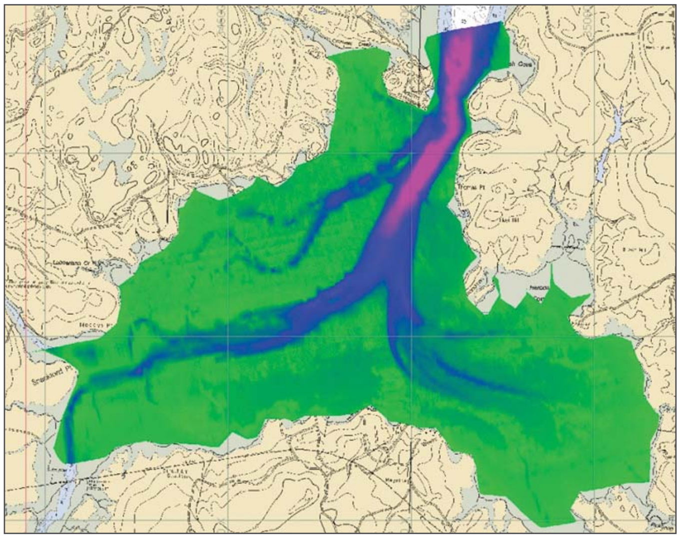


Figure 98. Results of the 2009 Great Bay survey. Note that the presence of eelgrass can be observed by an increased noise level. This data has great potential for post processing with the TracEd tool.

During this analysis, it became clear that many of the historic vertical datums that were used have either been lost or are unreliable, creating a clear need for a new comprehensive baseline survey. Given historical datum issues, it was decided that new bathymetry data would be collected with respect to the WGS84 reference ellipsoid. For hydrographic purposes, the bathymetry must be referenced to tidal datums and thus a number of tide gauges were placed around the Bay including a GPS buoy that will enable a direct tie in between WGS84 and MLLW at its location. This effort was led by Semme Dijkstra.

Data were collected using single-beam sounders on two 15-foot vessels as well as from the CBASS (Figure 98). The CBASS was used to survey the entire bay region at 100 m line spacing and a portion of the southeast part of the estuary was surveyed at 25 m line spacing. An additional fine-scale high-resolution survey over about 600 m of channel was conducted in an effort to determine the feasibility of detailed mapping of the channels with single-beam echosounders. The survey data was obtained over approximately 18 hours of CBASS in-water operation that spanned a total of about 300 km of transect lines. The average speed of the CBASS while surveying was about 5 m/s, or about 10 knots, but varied significantly depending on whether the vessel was operating in the central part of the bay or near the shallow, more hazardous boundary waters.

In 2010, additional work included a limited subbottom seismic survey conducted with Dr. Lloyd Huff. During May 12-13, 2010, subbottom seismic lines were run in Great Bay and Little Bay as an initial effort to examine the subsurface structure of the Holocene and pre-Holocene sediments. To date, no other seismic surveys using modern equipment and navigation have been done in the upper estuary. The ultimate goal of this work is to obtain an understanding of the bathymetry, bathymetric changes, morphologic changes, seafloor characteristics, and the Quaternary subsurface structure of the upper estuary. This understanding would provide insights into sediment budgets, seafloor characterization, and potential seafloor stability of important shallow water habitats in Great Bay Estuary.

Another of Great Bay's characteristics is the presence of large eelgrass beds. There is a significant interest in these beds and their location, but they also constitute a nuisance parameter in the depth determination if the depth is based on consolidated sediment. The data collected and processed so far give a fairly good indication of where the eelgrass beds are located by a high level of noise in the depth data, and a very poor indication of the seafloor depth. The TracEd seafloor characterization application developed by Dijkstra should have great potential for both quantifying the presence of eelgrass and the location of the underlying seafloor.

IOCM Processing Center

Last year marked the completion of an addition to the Center's building to house the new Integrated Ocean and Coastal Mapping Processing Center (IOCM). 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 2009, the first NOAA employees arrived from OAR's Ocean Exploration Program (Mashkoor Malik and Meme Lobecker). We have worked closely with Mashkoor and Meme to define protocols for data collection and processing on board NOAA's new vessel of exploration, *Okeanos Explorer*, including hosting workshops specifically designed to address the question of data production on board *Okeanos Explorer*. We have put the "telepresence console" to good use having provided technical support and science guidance from the Center to the vessel during the successful INDEX/SATAL Expedition. 2010 was the first year where NOAA Ship *Okeanos Explorer* brought all the sensors (including multibeam sonar, ROV) and telepresence capabilities online. As such, this was the first year since the ship's commissioning in 2008 that the full data-processing pipeline for the mapping sensors onboard was implemented. The ship conducted several exploration missions around the Hawaiian Islands, Guam, and North Sulewesi, Indonesia. Considerable data were also collected during the transits from Hawaii to Indonesia and back to the U.S. West coast. All the data were processed near real time and made publicly available, in form of geotiffs, through EX Digital Atlas (http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm).

Post-cruise data processing and product development was conducted at the IOCM Center. The processed data were then made available to National Coastal Data Development Center (NCDDC) which is responsible for the creation of the metadata for all the data generated by the *Okeanos Explorer* and later submission and archival at the National Geophysical Data Center (NGDC).

This past year our collaboration with the Office of Ocean Exploration and Research expanded as the Center became the host for the development of the new OER ROV. A secure work area has been constructed for the vehicle and a number of OER engineers and contractors will be working on the vehicle at the Center (see discussion in Facilities section).

The Center is also hosting employees of NOS's Marine Modeling and Development Office who are working with our visualization group to develop visualization tools for NOAA (see Visualization section). The tools developed under this effort have not only supported the effort, but became a critical component of the ERMA effort supporting the Deepwater Horizon spill response. Indeed, many of the Center's efforts in response to the Deepwater Horizon spill (applications of fisheries anad multibeam sonars for oil and gas detection, use of water-column mapping mapping tools to map oil and gas seeps, and the use of our 4D visualization tools to map the temporal and spatial distribution of submerged oil) epitomize the concept of IOCM. The tools used for this effort were developed for other purposes, but we were able to quickly adapt them to a critical national need.

In 2010, NOAA Corps officer Glen Rice and Physical Scientist Megan Greenaway from the Office of Coast Survey were assigned to the IOCM Center. Within the context of the IOCM initiative, Rice and Greenaway were tasked with improving the backscatter workflow for NOAA vessels. They divided the workflow into several parts, namely acquisition, processing, and archival, and tried to develop an understanding of and solutions for the roadblocks found in each component. Acquisition was clearly limited by ship network storage space issues, and this was resolved by the purchase of additional drives for backscatter storage. Acquired data was sent to the IOCM Center for initial quality control and then transmission to the National Geophysical Data Center (NGDC). Processing was limited by the reliability, speed and availablility of the processing software available to NOAA as well as changes in the manufacturers' data formats. The short-term solution for the 2010 season was to work with the Center to find other software versions that could read NOAA's storage format since it was too late to change the acquisition paradigm on NOAA ships.

Rice and Greenaway joined an IOCM cruise aboard the NOAA Ship *Nancy Foster* to observe and take part in backscatter acquisition and see the workflow implemented by other groups. The primary observation from this cruise was how far the backscatter workflow needed to develop, but also they were able to establish protocols for the number of snippets to be recorded by a Reson multibeam system as a function of depth. This protocol significantly reduced the files sizes that NOAA ships needed to store. Rice also spent time looking at the phase-differencing systems in use by NOAA, USGS, and associated CCOM projects.

Additionally, Rice worked with Center researchers to better understand NOAA's handling of Reson 7125 backscatter data and specifically its s7k format. This led to a request from NOAA to Hypack for Hypack to log backscatter in the Reson internal format. This improves the backscatter workflow because all data associated with backscatter can be contained in the Reson s7k file instead of the fractured Hypack file format, and it streamlines the process because it passes through fewer pieces of software. Another result has been the development of python code to read the Reson format directly from the command line, allowing the user to see settings and graph data directly from the file without the use of proprietary software.

Rice has also focused on improving NOAA's approach to surveying to the ellipsoid (ERS). ERS has many important features that can improve the nature of NOAA's survey quality and usefulness of its products. Recent ERS surveys have focused on validating VDatum through a convoluted method of comparing two mean lower low water (MLLW) surfaces, one derived through traditional means and one derived through ERS and datum reduction through VDatum. Rice has investigated the extraction of the ellipsoid to MLLW separation measurements made by a vessel through the reference to each during survey operations. When averaged over hundreds of meters, this series of measurements provides a VDatum-like surface that can be used to ground truth VDatum directly without entraining addition sonar type errors in the comparison. When viewing raw MLLW to ellipsoid datasets, variations in the measurements over the course of the survey become apparent. These variations range from short-term (seconds) errors in ellipsoid height to long-term (by day) errors that result from the tide model. Viewing the vertical datum references relative to each other could be an interesting new way to critique vertical datums, look for errors and assess uncertainty. If this method is approved for the validation of VDatum, then it indicates this method might qualify to substitute for VDatum in areas where VDatum does not yet exist. Even with the preliminary python code written to extract and consolidate the needed information, a separation surface between vertical datums can be created from hydrographic survey data in a matter of hours. This process can be further optimized for speed and for visualization.

Figure 99. New box-kite posters adorning the High-Bay.

Outreach

Figure 100. Seventh graders visiting the tanks in the High-Bay.

We have formalized and increased our outreach activities with the addition of Colleen Mitchell (graphic design) and David Sims (scientific writing—part-time) to our outreach staff, in addition to Briana Sullivan (web-based outreach). We have hosted a number of community groups (high-school students, marine docents, etc.) and the activities of the Center have, this year, been featured in many international and local media outlets including *Science*, *The Washington Post*, *The Miami Herald*, NECN, CNN, *The New York Times*, Reuters, and Alaska Public Radio. Some highlights are:

2010-11-16, Listening for Oil Spills, *Science Now*

2010-10-07, Mapping the American and Canadian Continental Margins Around the North Pole, *Hydro International*

2010-10-07, Using Multibeam Echosounder Backscatter To Characterize Seafloor Features: Geocoder Processing Gives Multibeam Echosounder Backscatter an Advantage Over Side Scan Sonar in Producing Reliable Seafloor Maps, *Sea Technology*

2010-10-07, 4D Visualization and Analysis Of Seafloor Vents and Plumes: FMMidwater Processing, Generic Water-column Format Allow Rapid Exploitation of Water-column Targets, *Sea Technology*

2010-08-05, UNH Tech Camp Provides Hands-On Science for Secondary Students, UNH Media Relations

2010-08-05, Analysis: Did Gulf Dodge an Ecological Bullet?, Reuters

2010-07-11, Oil below the surface: UNH ocean mapping center tracks Gulf spill underwater, *Seacoast Online*

2010-06-09, Gulf oil dispersants 'lesser of two evils,' NECN

2010-06-03, NOAA ship to search for underwater oil plumes from leak site, *The Washington Post*

2010-06-02, NOAA ship to study underwater oil near site of leak, *The Miami Herald*

2010-03-01, NOAA Tests ROV Little Hercules at Chase Ocean Engineering Lab, *UNH Campus Journal*

2010-02-10, Canada Will Use Robot Subs to Map Arctic Sea Floor, Boost Territorial Claims, *The New York Times*

Figure 101. Educators Ashore at the UNH Telepresence console—part of the Nautilus Live program.

Other outreach activities for this year have included tours for numerous K-12 students, tours for the Durham Rotary Club, delegations from various universities, and "Wild for Innovation" day. Unquestionably the largest effort involved our participation in the University's first "Know the Coast Day." During this event, the Center hosted several hundred visitors who watched demonstrations and videos, attended presentations, participated in activities and visited our research vessels. More than 100 signs and 15 research posters were created including the "box-kite" installations that now adorn our high-bay (Figure 99 and 100).

Our involvement with Bob Ballard's E/X *Nautilus* and its "Educators's At Sea" and "Educator's Ashore" program 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 club), the researchers on the Nautilus and took part in the Mystic Aquarium's Nautilus Live Theater and the Nautilus Live website (Figure 101). See http://www.nautiluslive.com/photo/2010/07/02/educators-ashore-unh-console for more details.

Website Upgrades

Our website is the face of the Center to the outside world. This past year we have undertaken projects to upgrade both the appearance and the functionality of the web site. In an effort to maximize the website's usefulness, Briana Sullivan has been working to make all Center-related publications and activities easily accessible. A new improvement to the publications will be to have them displayed, or at least downloadable, in an XML format. Briana has also been researching two php frameworks: CakePHP and Symfony. Using one of these framework will allow for the same flexibility as before, but will also permit the use of specific standards for organizing the file system, naming conventions for files, function, and classes; and will separate code so the various components to a website are completely separated from one another (presentation, data, structure). This will ultimately make the website more accessible, easier to change in the future if other looks are desired, and easier to maintain.

Figure 103. CCOM-JHC Facebook page.

Concurrently, Colleen Mitchell is working on the layout for a new look and design of the Center website. The first component of this has been the introduction of the new Vislab website (Figure 102).

Figure 102. New Vislab webpage.

Under Colleen's guidance, the Center has entered the social media world with the establishment of a Facebook page – ccom-jhc (Figure 103) and a Flickr site which contains more than 1000 photos.

Colleen and science writer David Sims have also been putting together a series of one- to two-page information sheets that provide a brief description of many of the research projects going on in the lab. These pages can serve both as hand-outs and webpages (Figure 104).

An additional outreach effort involves the work of Kurt Schwehr and Margaret Boettcher in developing interactive visualization materials to help in understanding global and regional geophysical processes. This work, supported by a UNH Advance Collaborative Scholarship Achievement Award, will help students learn to better understand 3- and 4D earth processes (such as complex bathymetry, plates subducting, and vertical exaggeration) through the creation of a series of interactive visualizations.

Figure 104. Examples of "one-pagers" describing various aspect of Center research.

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 post-doctoral fellows at the Center for Coastal and Ocean Mapping. Our interaction with the private sector has been formalized into an Industrial Associates Program that is continually growing. At present members of the Industrial Associates Program are:

- Airborne Hydrography AB
- Atlas Hydrographic GmbH
- ATLIS Informatie Systemen b.v.
- 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
- HYPACK, Inc.
- ICAN, Inc.
- IFREMER
- Instituto Hidrografico, Portugal
- Interactive Visualization Systems, Inc.
- IXSEA, Inc.
- Knudsen Engineering, Ltd.
- Kongsberg Underwater Technology, Inc.
- L-3 Communications Klein Associates
- Marport Canada, Inc.
- Ocean Science Group, Ltd.
- ODIM Brooke Ocean, Ltd.
- Odom Hydrographic Systems, Inc.
- Ohmex
- QinetiQ
- Quality Positioning Services b.v.
- Quester Tangent

- RESON, Inc.
- Science Applications International Corporation
- SevenCs GmbH
- Seismic Micro Technology
- Substructure
- Teledyne Benthos, Inc.
- Triton Elics International, Inc.

In addition, grants are in place with:

- Exxon Mobil (student scholarship)
- N.H. Sea Grant
- National Science Foundation
- Nippon Foundation
- North Pacific Research Board
- Office of Naval Research
- UNH ADVANCE Collaborative
- U.S. Army Corps of Engineers
- U.S. Coast Guard
- Woods Hole Oceanographic Institution

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 $1.23M from a total commitment from other sources of approximately $1.52M (see Appendix C).

Appendix A: Graduate Degrees in Ocean Mapping

The University of New Hampshire offers Ocean Mapping options on the 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). Requirements for the Ph.D. in Earth Sciences and Engineering are described in the respective sections of the UNH Graduate School catalog. MS degree requirements are described below.

Requirements for Master of Science in Ocean Engineering—Ocean Mapping Option

Core Requirements		Credit Hours
ESCI 858	Physical Oceanography	3
OE 990, 991	Ocean Engineering Seminar I, II	1, 1
OE 810	Ocean Measurements Lab	4
OE 845	Environmental Acoustics I	4
OE 846	Environmental Acoustics II	4
OE/ESCI 870	Fundamentals of Ocean Mapping	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	3
OE/ESCI 972	Hydrographic Field Course	4
Thesis—in addition to required coursework		6
At Least Six Additional Credits from the Electives Below		
OE 854	Ocean Waves and Tides	4
ESCI 859	Geological Oceanography	4
ESCI 959	Data Analysis Methods in Ocean and Earth Sciences	4
OE 954	Ocean Waves and Tides II	4
OE/EE 985	Special Topics	3
ESCI 907	Geostatistics	3
OE/ESCI 973	Seafloor Characterization	3
ESCI 895, 896	Special Topics in Earth Science	1-4
ESCI 959	Data Analysis Methods in Ocean and Earth Science	4
ESCI 898	Directed Research	2
EOS 824	Introduction to Ocean Remote Sensing	3
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
OE/CS 867	Interactive Data Visualization	3
OE 995	Graduate Special Topics	2-4
OE 998	Independent Study	1-4
Other related courses with approval		

Requirements for Master of Science in Earth Sciences—Ocean Mapping Option

Required		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
OE 810	Ocean Measurements Laboratory	4
ESCI/OE 870	Fundamentals of Ocean Mapping	3
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI /OE 972	Hydrographic Field Course	4
ESCI 997	Seminar in Earth Sciences	1
ESCI 998	Proposal Development	1
Thesis—in addition to required coursework		6

At Least Six Additional Credits from the Electives Below

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 995	Time Series Analyses	4
OE 998	Independent Study	1-4
Other related courses with approval		

Non-Thesis Option (in addition to courses listed above)

ESCI 898, Directed Research	2
Approved Electives	8

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

Specific Coursework Required to Complete FIG/IHO Category A Certified Program (Either Degree Option)

University Academic Courses		Credit Hours
ESCI 858	Introductory Physical Oceanography	3
ESCI 859	Geological Oceanography	4
OE 990, 991	Ocean Engineering Seminar I, II	2
OE 810	Ocean Measurements Lab	4
OE/ESCI 870	Fundamentals of Ocean Mapping	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	3
OE 895	Special Topics: Seamanship for Ocean Scientists and Engineers*	2
OE/ESCI 972	Hydrographic Field Course	4
OE 990	Ocean Seminar I/or ESCI 997, Seminar in Earth Science	1
OE 991	Ocean Seminar II/or ESCI 998, Proposal Development	1

Non-Credit Classes	Classroom Hours
CARIS HIPS-SIPS Training Course*	40

**For students who have not completed NOAA (or equivalent maritime service) Training Class*

Coursework Required for the Graduate Certificate in Ocean Mapping

Program Requirements

A Graduate Certificate in Ocean Mapping is awarded for completion of three required courses and four elective courses.

Basic Certificate

Required Courses		Credit Hours
ESCI/OE 870	Fundamentals of Ocean Mapping	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	3
ESCI/OE 972	Hydrographic Field Course	4
OE 810	Ocean Measurements Lab	4

Advanced Certificate (Three Additional Courses from the Following)

ESCI 859*	Geologic Oceanography	4
ESCI 973	Seafloor Characterization	3
ESCI 858*	Introduction to Physical Oceanography	4
EOS/OE 854	Ocean Waves and Tides	4
OE 845	Environmental Acoustics I	4
OE 885	Environmental Acoustics II	4
OE/CS 867	Data Visualization	3
OE 995	Special Topics	4
NR 857	Photo Interpretation and Photogrammetry	4
NR 860	Geographic Information Systems in Natural Resources	4
ESCI 895,896	Topics in Earth Sciences	1-4
OE 895*	CARIS Training and Seamanship	4

*Required Advanced Certificate courses for Category “A” Certification

Appendix B: Field Programs

New Zealand, 10-29 January, Lake and coastal estuary bathymetry and water chemistry. (Schmidt)

Fault-related rocks in eastern Massachusetts, 21 January, Survey of the range of deformation styles. (Schwehr)

LNG ship visit for Right Whale AIS Project, 21 January, Excelerate EBRV *Energy Explorer*, Demonstrate system on bridge crew and discuss deployment issues. (Schwehr)

Large Scale Observation of Fine-scale Seabed Morphology and Sediment Characterization in Tidally Modulated Inlets, 01 February-30 September, Coastal Bathymetry Survey System, Develop methods for surveying in shallow water inlet environments, conduct field tests. (Lippmann)

Ship shake down, 23 February-01 March, NOAA Ship *Okeanos Explorer*, Mapping. (Malik)

NOAA Ship *Okeanos Explorer* field trials, 28 April-06 May, NOAA Ship *Okeanos Explorer*, Mapping. (Malik)

Multi-scale and Interdisciplinary Study of Humpbacks and Prey, 04 May-13 June, R/V *Nathaniel B. Palmer*, Develop a system to help assess ice coverage and develop interpretation tools and data from tagged Humpback whales. (Arsenault & Ware)

Kingman-Palmyra UNCLOS Mapping, 06 May-18 June, R/V *Kilo Moana*, Mapping of the southern flank of Kingman Reef-Palmyra Atoll section of the Line Islands Ridge. (Calder, Gardner, O'Donnell)

Great Bay sub-bottom seismic survey, 12-13 May, R/V *Galen Jones*, Collect sub-bottom seismic data. (Ward)

Subsurface monitoring: Deepwater Horizon, 24 May-05 June, NOAA Ship *Gordon Gunther*, Acoustics Lead. (Weber)

2010 Summer Hydro Field Camp, 29 May-02 July, R/V *Coastal Surveyor* & R/V *Cocheco*, Education. (Dijkstra)

Deepwater Horizon Oil Spill, 31 May-12 June, NOAA Ship *Thomas Jefferson*, Chief Scientist for acoustic monitoring. (Mayer)

HLY10TC, 31 May-12 June, USCGC *Healy*, Aid in Sea Acceptance Trials for EM122 MBES, training for EM122 MBES. (Beaudoin)

Deployment of targets (Artificial Rocks for lidar survey), 01-02 June, R/V *Cocheco*, Deployment of targets (Artificial Rocks for lidar survey) and underwater video capture. (Pe'eri)

Project # OPR-N324-FA-10 OCNMS, WA, 01-18 June, NOAA Ship *Fairweather*, Backscatter acquisition and processing support, general bathymetric acquisition, processing, and QC support. (Greenaway)

AUV Boot Camp 2010, 07-12 June, Collaborative event with the University of Delaware and other partners from industry, government and academia involving training, AUV mission planning and operations, AUV data processing method development, AUV ancillary software manufacturer feedback. (Schmidt)

INDEX 2010, 08 June-14 July, NOAA Ship *Okeanos Explorer*, Mapping. (Malik)

2010 CCOM Summer Hydro Field Camp, 14-18 June, R/V *Cocheco* & R/V *Coastal Surveyor*, Acquisition of high-density moving vessel profiler (MVP) data sets in Piscataqua River estuary and near the Isle of Shoals. Development and refinement of real-time uncertainty monitoring algorithms. (Beaudoin)

Wellhead integrity monitoring: Deepwater Horizon, 14-22 July, NOAA Ship *Pisces*, Acoustics Lead. (Weber)

Wellhead integrity monitoring: Deepwater Horizon, 24-29 July, NOAA Ship *Pisces*, Chief Scientist. (Weber)

Mariana Trench, 06 August-05 September, USNS *Sumner* (T-AGS 61), Collect bathymetry and acoustic backscatter along the full extent of the Mariana Trench and "bridges" that extend east onto the Pacific Plate. (Gardner)

Africa Partnership Station, 07-20 August, R/V *Anzone* (Ghanan Naval Vessel), Deploy directional wave buoy in the Gulf of Guinea; instruct African partners in methods and techniques. (Lippmann)

Resolving grain-size analysis, 10-11 August, R/V *Cocheco*, Collecting grab samples and underwater video imagery around Merrimack River, MA. (Pe'eri)

E/V *Nautilus* Eratosthenes cruise, 15-31 August, E/V *Nautilus*, Exploration, ROV & Video. (Mayer, G. Mitchell and Kuenzel)

Nearshore Bathymetric Estimation from Lidar-based Airborne Imagery, 11-14 October, Cessna 172 and 182 aircraft, Develop imaging techniques for shallow water bathymetric inversion; develop airborne video system with applications in shallow water mapping. (Lippmann)

Subsurface monitoring: Deepwater Horizon, 17 August-03 September, NOAA Ship *Pisces*, Chief Scientist. (Weber)

Seafloor morphology targets, 12 October, R/V *Cocheco*, Retrieval of targets (Artificial Rocks for lidar survey)—grappling attempt. (Pe'eri)

R/V *Thomas G. Thompson* EM302 Sea Acceptance Trial, 15-21 October, R/V *Thomas G. Thompson*, Assessment of the EM302 system for bathymetric and backscatter accuracy and repeatability in various modes of operation and survey environments. Documentation of results in report form to the University of Washington. (Beaudoin)

Seafloor morphology targets, 02 November, R/V *Cocheco*, Retrieval of targets (Pet rocks for lidar survey)—Sela-Diving operation. (Pe'eri)

Great Bay Tidal Survey, 17 November–08 December, R/V *Galen Jones*, Assisted with the rework of the Harbor Tracking buoys for sea level time series observations in moored applications other than harbor tracking and AUV support. In this case, the buoys were deployed in Great Bay to determine the tides, and to evaluate the ability of the buoys to measure sea level. This was the repeat of the work started in Great Bay that raised some questions on the data collected. I loaned mooring chain and assisted in the rework of the buoys and the addition of solar panels to lengthen deployment duration. (Irish)

Coral mapping, 22-24 November, R/V *Osprey*, Collecting underwater video imagery and bottom reflection around Buck Island, St. Croix, U.S. Virgin Islands. (Pe'eri)

Appendix C: Other Funding

Name of Project	PI	Grantor	FY Award	Total Award	Length
Electronic Charting Initiative	Alexander, L.	U.S. Army Corp of Engineers	99,952	99,952	1 year
Development of AIS Application-specific Messages	Alexander, L.	U.S. Coast Guard	41,618	41,618	1 year
Mapping Seafloor Uncertaininty	Calder, B.	Office of Naval Research	-	96,593	3.5 years
Large Scale Observation	Lippmann, T.	Office of Naval Research	71,874	71,874	1 year
Africa Partnership Station	Lippmann, T.	Office of Naval Reserach	42,424	91,476	1.5 years
A Mobile Bentho-Pelagic Observatory to Support Fisheries and Ecosystem Management	Mayer, L.	Woods Hole Oceanographic Institute	10,000	86,984	2.5 years
Tyco Endowment Interest from perpetuity	Mayer, L.	TYCO	46,816	-	Perpetuity
GEBCO 7th Year	Mayer, L.	Nippon Foundation	534,455	534,455	1 year
Seafloor Video Mosaic Reserach	Rzhanov, Y.	U.S. Geological Survey	10,000	10,000	1 year
StereoFish	Rzhanov, Y.	U.S. DOC NOAA	54,000	54,000	1.5 years
Visualizating Global and Regional Geophysical Processes - "In the Classroom, in the Lab and in the Field"	Schwehr, K. & Bottcher, M.	UNH ADVANCE - Collaborative Scholarship Advancement Award	40,000	40,000	1 year
HCC Small Interactive Casual Networks	Ware, C.	National Science Foundation	147,931	147,931	3 years
ME70 MultibeamSounder	Weber, T.	U.S. DOC NOAA	2,500	60,697	1.5 years
The Effects of Cluster Scatters on Volume Reverberation	Weber, T.	Office of Naval Research	42,776	89,693	2.5 years
Modeling Statistics of Fish	Weber, T.	Office of Naval Research	180,720	180,720	3 years
Segmented Ocean Transform Faults	Wolfson, M.	Exxon Mobil	7,500	7,500	-
Total			**1,232,614**	**1,516,900**	

Appendix D: Publications

Journal Articles

Alexander, L., and Schwehr, K., 2010, "New Standards for Providing Meteorological and Hydrographic Information via AIS Application-specific Messages," *International Hydrographic Review*, p. 37-44.

Bachmann, C.M., Montes, M. J., Fusina, R.A., Parrish, C.E., Sellars, J., Weidemann, A., Goode, W., Nichols, C., Woodward, P., McIlhany, K., Hill, V., Zimmerman, R., Korwan, D., Truitt, B., and Schwarzschild, A., 2010, "Bathymetry Retrieval from Hyperspectral Imagery in the Very Shallow Water Limit: a Case Study from the 2007 Virginia Coast Reserve (VCR'07) Multi-Sensor Campaign," *Marine Geodesy*, v. 33, p. 53-75.

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Lippmann, T.C., Thornton, E., and Stanton, T., 2010, "The Vertical Structure of Low Frequency Motions in the Nearshore, Part 1: Observations," *Journal of Physical Oceanography*, p. 1-32.

Mayer, L.A., Armstrong, A.A., Calder, B.R., and Gardner, J.V., 2010, "Seafloor Mapping in the Arctic: Support for a Potential U.S. Extended Continental Shelf," *International Hydrographic Review*, v. 3, p. 14-23.

McGonigle, C., Grabowski, J., Brown, C., Weber, T.C., and Quin, R., (in press), "Detection of Deep Water Benthic Macroalgae using Image-based Classification Techniques on Multibeam Backscatter at Cashes Ledge, Gulf of Maine, USA," *Estuarine, Coastal and Shelf Science*.

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Alexander, L., Use of Portable Piloting Units (PPUs): Past, Present, and Future, West Coast Maritime Pilots Conference, Portland, OR, 15-17 April 2010.

Alexander, L., and Ward, R., Production and Use of Nautical Charts, T-Kartor and ERDAS Nordic User Conference 2010, Ahus, Sweden, 10-12 May 2010.

Alexander, L., Presentation of e-Navigation Information on Ship Borne Systems, Nautical Institute, Haugesund, Norway, 18 October 2010.

Ashton, A., Lippmann, T.C., Wiafe, G., Ababio, S., Addo, A., Hapke, C., Roelvink, D., and Vogel, A., Africa Partnership Station: Developing Coastal Processes Research in Ghana, ONR Coastal Geosciences Program Review, Chicago, IL, 02-04 June 2010.

Calder, B.R., CUBE and Variable Resolution Grids, NOAA Field Procedures Workshop, Seattle, WA, 26-28 January 2010.

Calder, B.R., Bathymetric Uncertainty and Composite Products, ONR Quantifying, Predicting and Exploiting Uncertainty, DRI Annual Meeting, Taipei, Taiwan, Republic of China, 01-04 November 2010.

Greenaway, M., Rice, G.A., and Greenaway, S.F., Backscatter Acquisition and Processing, NOAA Field Procedures Workshop, Seattle, WA, 25-29 January 2010.

Irish, J.D., CO_2 Gas Exchange and Ocean Acidification Studies in the Western Coastal Gulf of Maine or What Have Those People Been Doing with the Buoys in the High Bay?, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 08 October 2010.

Irish, J.D., CO_2, O_2 and Wind Stress Studies in the Western Coastal Gulf of Maine or What Have I Been Doing Since I Retired from WHOI?, Coastal Ocean Fluid Dynamics Laboratory of the Applied Ocean Engineering Department of WHOI, Woods Hole, MA, 05 November 2010.

Lippmann, T.C., and Rzhanov, Y., Image Matching for Stabilizing Airborne Imagery with Shallow Water Applications, 11th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, Mobile, AL, 25-28 May 2010.

Lippmann, T.C., The Vertical Structure of Low Frequency Wave Motions in the Nearshore, ONR Coastal Geosciences Program Review, Chicago, IL, 02-04 June 2010.

Lippmann, T.C., Very Shallow Water Mapping and the Seamless Coast, NOAA CCOM Site Review, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, University of New Hampshire, Durham, NH, 21 July 2010.

Lippmann, T. C., Development of an Integrated Coastal Erosion Assessment Program in Ghana, National Society of Black Engineers, University of New Hampshire, Durham, NH, 16 November 2010.

Mayer, L.A., Law of the Sea and Mapping the Extended Continental Shelf in the Arctic, Alaska Marine Science Symposium, Anchorage, AK, 20 January 2010 [Keynote Presentation].

Mayer, L.A., Adding the Third Dimension: High-Resolution Multibeam Sonar as a Tool for Archaeological Investigations, U.S. Naval Academy, Annapolis, MD, 09 March 2010 [Invited Talk].

Mayer, L.A., Marine Spatial Planning: An Academic Perspective, Consortium of Ocean Leadership Public Policy Forum, Washington DC, 10 March 2010. [Panel Moderator and Presenter].

Mayer, L.A., Mapping the Unseen: New Approaches to Ocean Exploration, College of Engineering and Physical Sciences Alumni Association, University of New Hampshire, Durham, NH, USA, 29 March 2010 [Invited Lecture].

Mayer, L.A., Mapping the Unseen: New Approaches to Seafloor Mapping and Ocean Exploration, College of Charleston, Charleston, SC, 2 April 2010 [Invited Lecture].

Mayer, L.A., Seafloor Mapping and the Law of the Sea, University of Delaware, Newark, DE, 22 April 2010 [Invited Talk].

Mayer, L.A., Testimony before the Subcommittee on Insular Affairs, Oceans and Wildlife of the Natural Resources Committee Legislative Hearing on H.R. 2864 – U.S. Congress, Washington, DC, 06 May 2010.

Mayer, L.A., Current Status of Multibeam Sonar Acquisition and Processing on the NOAA Ship *Okeanos Explorer*, NSF Workshop on Multibeam Sonar Operations, National Science Foundation Head Quarters, Arlington, VA, 16 June 2010 [Invited Presentation].

Mayer, L.A., The Center for Coastal and Ocean Mapping and Deepwater Horizon, Board of Trustees, University of New Hampshire, Durham, NH, 24 June 2010 [Invited Presentation].

Mayer, L.A., Marine Geology, Climate Change and Law of the Sea, A Series of Lectures at the Rhodes Academy of Ocean Policy and Law, Rhodes, Greece, 28 June-01 July 2010.

Mayer, L.A., Subsurface Monitoring Activities in Support of Deepwater Horizon, Tele-presentation to Congressional Staffers from E/V *Nautilus*, 24 August 2010.

Mayer, L.A., University of New Hampshire-Center for Coastal and Ocean Mapping Response to the Deepwater Horizon MC252: Subsurface Monitoring, Senate Staffers, Capitol Building, Washington DC, 24 September 2010 [Invited Presentation].

Mayer, L.A., Mapping the Unseen: New Approaches to Ocean Exploration, University of Massachusetts Amherst, Amherst, MA, 25 October 2010 [Invited Five Colleges Lecture].

Mayer, L.A. Delineation of the Continental Shelf in the Arctic, Canadian Council on International Law, Ottawa, Ontario, Canada, 30 October 2010 [Invited Lecture].

Mayer, L.A. New Capabilities in Ocean Mapping and Data Visualization, International Meeting on AUVs and Sensor Capabilities, Waikoloa, HI, 09 November 2010 [Invited Lecture].

Mayer, L.A., Delineating the Continental Shelf in the Arctic, Preserving the Environment of the Arctic Region, Beckman Center of the National Academy of Sciences, Irvine CA, 12 November 2010 [Invited Lecture].

Mayer, L.A., Research Activities at the Center for Coastal and Ocean Mapping, University of New Hampshire, National University of Singapore, Singapore, Japan, 23 November 2010 [Invited Lecture].

Mayer, L.A., Deepwater Horizon and the Arctic: Is There a Need for International Regulation? Globalization and Law of the Sea, Washington, DC, 03 December 2010 [Invited Lecture].

Mayer, L.A., et al., More than the Bottom: Multibeam Sonars and Water-column Imaging, American Geophysical Union Meeting, San Francisco CA, 13 December 2010 [Invited Lecture].

Monahan, D., Boundaries Creatable Under the United Nations Convention on the Law of the Sea (UNCLOS), University of New Brunswick, Fredericton, NB, Canada, 28 October 2010.

Monahan, D., Who Owns the Sea? Know the Coast Day, Center for Coastal and Ocean Mapping, University of New Hampshire Durham, NH, 02 October 2010.

Motamarri, V.A.K., The Uncertainty Measurements of ALB Measurements Within the Water-column, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 14 May 2010.

Motamarri, V.A.K., Pe'eri, S., and Calder, B.R., Simulating an Airborne Lidar Bathymetry (ALB) System, 11th JALBTCX Coastal Mapping and Charting Technical Workshop, Mobile, AL, 25-27 May 2010.

O'Donnell, B., Multiplying Multibeam Echo-sounding Using Time-Frequency Coded Waveform Sets, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 02 April 2010.

Parrish, C.E., Lidar Waveform Analysis and Applications to Mapping Coastal Vegetation and Shallow Bathymetry, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 01 October 2010.

Parrish, C. E., Lidar Coastal Mapping: New Techniques and Applications, Department of Earth Sciences, University of New Hampshire, Durham, NH, 07 October 2010.

Parrish, C.E., White, S. A., Calder, B.R., Pe'eri, S., and Rzhanov, Y., New Approaches for Evaluating Lidar-derived Shoreline, Imaging and Applied Optics Congress, Tuscon, AZ, 06-08 June 2010.

Parrish, C.E., White, S. A., Pe'eri, S., Calder, B.R., and Rzhanov, Y., Modeling Uncertainty in the Lidar-derived NOAA Shoreline, 11th JALBTCX Coastal Mapping & Charting Technical Workshop, Mobile, AL, 25-27 May 2010.

Pe'eri, S., Ground-truth Results of Comparison Airborne Lidar Bathymetry (ALB) in Subtidal Coastal Environments, Haifa University, Haifa, Israel.

Rzhanov, Y., Lippmann, T.C., and Pe'eri, S., Image Matching for Stabilizing Airborne Imagery with Shallow Water Applications, AGU Ocean Sciences, Portland, OR, 22-26 February 2010.

Rzhanov, Y., Practical Approach to Mosaicing of Underwater Imagery, Coastal Research and Planning Institute, Klaipeda University, Klaipeda, Lithuania, 02 March 2010.

Rzhanov, Y., Center for Coastal and Ocean Mapping and Recent Developments in Sea Floor Mapping, Klaipeda University, Klaipeda, Lithuania, 05 March 2010.

Rzhanov, Y., Practical Mosaicing, *GAVIA* AUV Boot Camp 2010, University of New Hampshire, Durham, NH, 10 June 2010.

Rzhanov, Y., Stereo Measure: Measuring Fish Underwater Using Stereo Photographs, Automated Image Processing Workshop, Seattle, WA, 07-09 September 2010.

Schimel, A.C.G., Rzhanov, Y., Fonseca, L., Mayer, L.A., Healy, T.R., and Immenga, D., Automated Delineation of Acoustic Themes from Multibeam Backscatter Data for Seafloor Characterization, GeoHab-2010, Wellington, New Zealand, 04-07 May 2010.

Schmidt, V.E., *GAVIA* AUV Operation - the Nuts and Bolts, Center for Coastal and Ocean Mapping, University of New Hampshire – 2010 AUV Boot Camp, Durham, NH, 08 June 2010.

Schwehr,K.D., Landing Robots on Another Planet, New Hampshire MENSA, Portsmouth, NH, 13 February 2010.

Schwehr, K.D., Open Access and Open Content in Education Panel, Computer Science Department, University of New Hampshire-Manchester, Manchester, NH, 25 March 2010.

Schwehr, K.D., Interplanetary Observation: Mars Rover Platform, Sensors and Applications, MTS Tech Surge, Ocean Observing: Thinking Outside the Basin, Norfolk, VA, USA, 08-09 June 2010.

Schwehr, K.D., Brennan, R.T., Sellars, J., Smith, S., Bathymetric Attributed Grids (BAGs): Discovery of Marine Datasets and Geospatial Metadata Visualization, 2010 Canadian Hydrographic Conference, City of Quebec, QC, Canada, 21-23 June 2010.

Schwehr, K.D., Boettcher, M. Preparing Future Faculty, Graduate Student Association, University of New Hampshire, Durham, NH, 16 June 2010.

Schwehr, K.D., Environmental Response Management Application (ERMA): From Portsmouth Response to NOAA's Geo Platform Gulf Response, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 24 September 2010.

Sullivan, B.M., Wild for Innovation Day Workshop, Presented by NH Division of Economic Development and Public Service of New Hampshire, University of New Hampshire, Durham, NH, 05 March 2010.

Ware, C., The Acrobatic Maneuvers of Feeding Humpback Whales, University of New Brunswick, Fredericton, NB, Canada, 10 March 2010.

Weber, T.C., Acoustic Observations in Support of the Response to the Deepwater Horizon Oil Spill, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, University of New Hampshire, Durham, NH, 12 November 2010.

Weber, T.C., Acoustics and Clustered Oceanic Bubble Clouds, Department of Mechanical Engineering Graduate Student Seminar Series, University of New Hampshire, Durham, NH, 29 October 2010.

Theses

Greenaway, S.F., "Linearity Test of a Multibeam Echosounder," Masters Thesis, University of New Hampshire, Durham, NH.

Pineo, D., "The Application of Computational Modeling of Perception to Data Visualization," Doctor of Philosophy, University of New Hampshire, Durham, NH.

Reports

Intelmann, S., Smith, K., McConnaughey, R., and Rzhanov, Y., 2010, "Adding Ecological Context to Essential Fish Habitat Models Using Groundtruthing Technologies," National Oceanic and Atmospheric Administration, Tech Memo, NMFS-F/SPO-112, Silver Spring, MD.

Lippmann, T.C., and Wiafe, G., 2010, "Africa Partnership Station: Developing Coastal Processes Research in Ghana," Office of Naval Research, Washington DC, pp. 6.

Burdicki, D.M., Moore, G., Grizzle, R.E., Ward, K., Mathieson, A., and Pe'eri, S., 2010, "Baseline Survey of Habitats and Resources of the North Mill Pond," New Hampshire Department of Environmental Services, New Hampshire Coastal Program, Portsmouth, NH, pp. 37.

Nellemann, C., Corcoran, E., Duarte, C.M., Valdes, L., DeYoung, C., Fonseca, L., and Grimsditch, G., 2010, "Blue Carbon: The Role of Healthy Oceans in Binding Carbon," pp. 8.

Alexander, L., 2010, "Canadian e-Navigation User Needs Survey: Report on Comprehensive Results," Canadian Coast Guard, Ottawa, Canada, pp. 27.

Schmidt, V.E., Raineault, N., Skarke, A., Trembanis, A., and Mayer, L.A., 2010, "Correction of Bathymetric Artifacts Resulting from Surface-Wave Inducted Modulations of an AUV Pressure Sensor," University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH, pp. 13.

Lippmann, T.C., 2010, "Large Scale Observations of Fine-scale Seabed Morphology and Sediment Characterization in Tidally Modulated Inlets," Office of Naval Research, Washington DC, pp. 5.

Trusel, L.D., Cochrane, G., Etherington, L., Powell, R.D., and Mayer, L.A., 2010, "Marine Benthic Habitat Mapping of Muir Inlet, Glacier Bay National Park and Preserve, Alaska, with an Evaluation of the Coastal and Marine Ecological Classification Standard III," U.S. Geological Survey, Scientific Investigations Map 3122, Reston, VA.

Beaudoin, J., and Schmidt, V.E., 2010, "R/V *Thompson* EM302 SAT—Cruise Report, University of New Hampshire," Center for Coastal and Ocean Mapping /NOAA-Joint Hydrographic Center, Durham, NH, pp. 41.

Alexander, L., 2010, "Results from Canadian User Needs Survey, Canadian Coast Guard and Ministry of Transport," Ottawa, Canada, pp. 17.

Rice, G.A., 2010, "Trip Report for NOAA Ship *Nancy Foster* IOCM Project 2010," National Oceanic and Atmospheric Administration, Internal Report, Silver Spring, MD.

Gardner, J.V., and Calder, B.R., 2010, "U.S. Law of the Sea Cruise to Map the Southern Flank of the Kingman Reef-Palmyra Atoll Section of the Line Islands, Equatorial Pacific Ocean," University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH, pp. 81.

Gardner, J.V., 2010, "U.S. Law of the Sea Cruises to Map Sections of the Mariana Trench and the Eastern and Southern Insular Margins of Guam and the Northern Mariana Islands," University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH, pp. 82.

Posters

Abramova, A., 2010, "Comparison and Evaluation of Publicly Available Global Bathymetric Grids," 2010 GEBCO, Bathymetric Sciences Day, Lima, Peru, 15 September.

Daniell, J., Ujihara, N., Mahabier, B.G., Herwindya, A.Y., Freire, F.F., Zarayskaya, Y., Schwehr, K., Monahan, D., and Sharma, S., 2010, "A Marine GIS for the Oceania Region (MARGO); An Exploratory Project," 2010 GEBCO Bathymetric Sciences Day, Lima, Peru, 15 September.

Lippmann, T.C., and Rzhanov, Y., and Pe'eri, S., 2010, "Image Matching for Stabilizing Airborne Imagery with Shallow Water Applications," 2010 Ocean Sciences Meeting, Portland, OR, v. 8, 22-26 February.

Parrish, C.E., White, S.A., Calder, B.R., and Pe'eri, S., 2010, "Stochastic Uncertainty Analysis for Lidar-derived Shoreline and Comparison with New Experimental Results," 2010 Ocean Sciences Meeting, Portland, OR, 22-26 February.

Pe'eri, S., Gardner, J.V., Armstrong, A.A., Yoos, C.J., Holmberg, P.S., and Greenaway, M., 2010, "Hydrographic Survey Bottom Sampling Specifications: A Remote Sensing Perspective," Canadian Hydrographic Conference, Quebec City, Canada, 21-23 June.

Schmidt, V.E., Raineault, N., Skarke, A., Trembanis, A., and Mayer, L.A., "Correction of Bathymetric Survey Artifacts Resulting from Apparent Wave-induced Vertical Position of an AUV," Canadian Hydrographic Conference, Quebec City, Canada, 21-23 June.

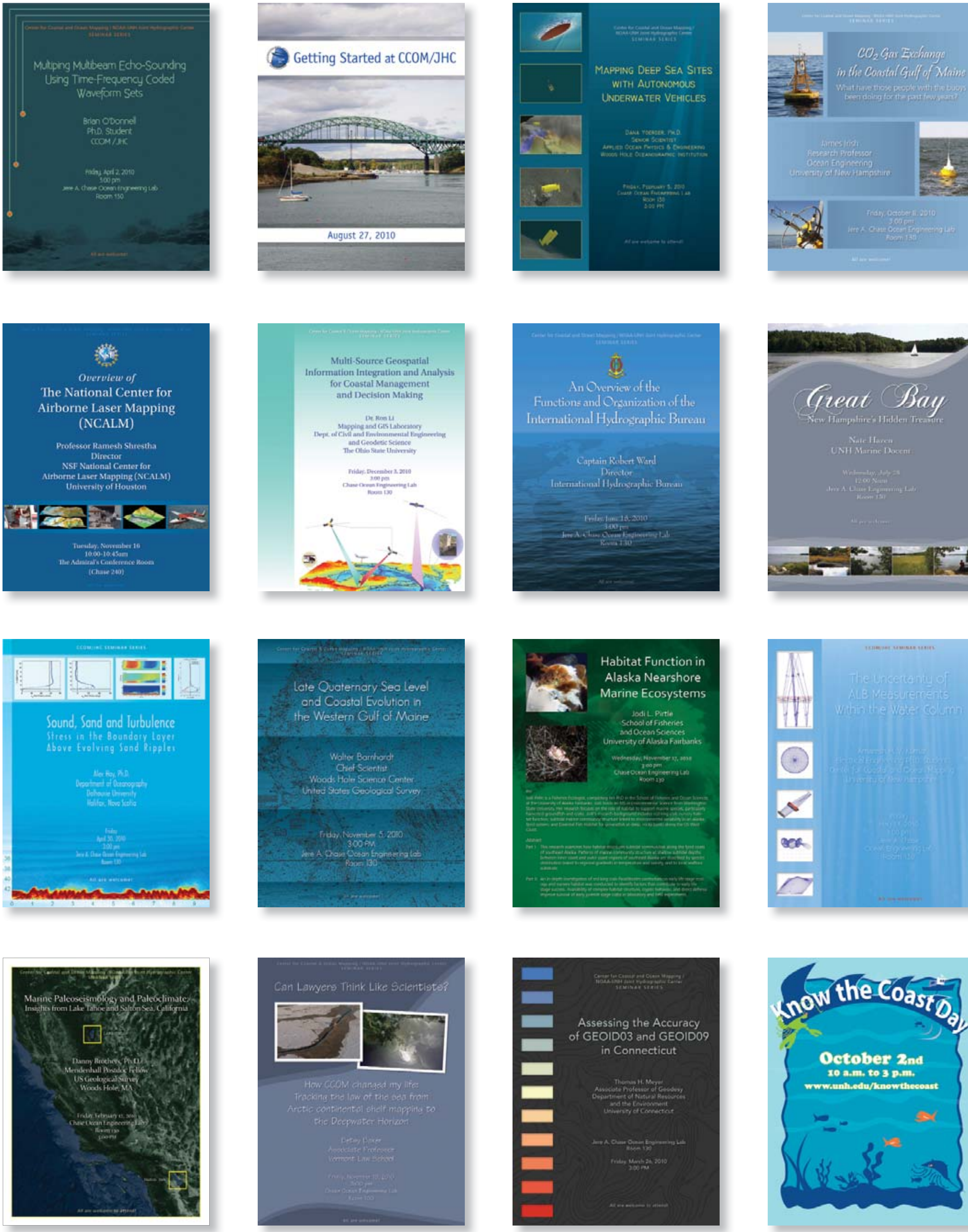
Trembanis, A., Mayer, L.A., Raineault, N., Schmidt, V.E., Rzhanov, Y., and Calder, B.R., 2010, "Remote Acoustic Characterization of Seafloor Properties from an AUV," 2010 Ocean Sciences Meeting, Portland, OR, 22-26 February.

Wiafe, G., Ababio, S., Addo, A., Agyekum, K., Ashton, A., Hapke, C., Lippmann, T.C., Roelvink, D., and Vogel, A., "Progress in Coastal Processes Research in Ghana," 2010 AGU Ocean Sciences Meeting, Portland, OR, 22-26 February.

Appendix E: Meetings and Conferences Attended

Calder, B., Transforming the Marine Transportation System: A Vision for Research and Development, Irvine, CA, USA, 28 June-1 July 2010.

Schmidt, V.E., AGU Ocean Sciences, Portland, OR, USA, 22-26 February 2010.



Flyers from the 2010 CCOM/JHC Seminar Series and outreach events.

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