UNH/NOAA Joint Hydrographic Center
Performance and Progress Report

Project Title: Joint Hydrographic Center
Principal Investigator: Larry A. Mayer

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The NOAA-UNH Joint Hydrographic Center (JHC/CCOM) was founded ten 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 coming from these multibeam 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 Processing Center to support NOAA and others in delivering the required products of this new legislation.

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, 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; to now see it being accepted is truly rewarding. It is also indicative of the role that the Center has been playing 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 it 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 coastal mapping applications. We are also bringing many of the tools we have developed together as we 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

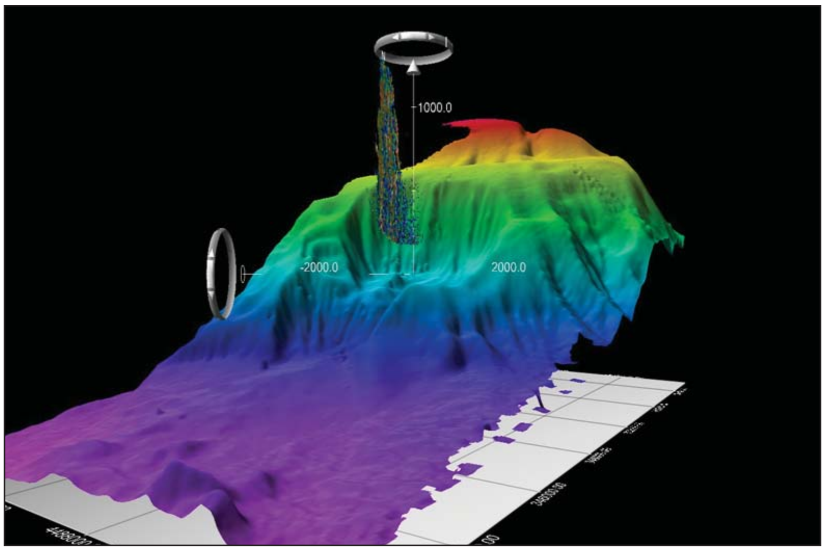


Figure EX-1. 1400 m high gas plume discovered on the Mendocino Fracture Zone by mid-water multibeam sonar on the NOAA Vessel OKEANOS EXPLORER during the initial testing of the multibeam sonar.

developing visualization tools that allow this mid-water 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 examination to verify least depths in hydrographic surveys. The unexpected discovery, this year, of giant gas plumes in the water column off Mendocino, California (Figure EX-1) is illustrative of the tremendous potential of this powerful new capability.

The value of our visualization, mid-water 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 4-D (space and time) visualization tools to monitor the underwater behavior of whales as well as to notify vessels of the presence of whales in the shipping lanes and to monitor and analyze vessel traffic patterns. Describing our interaction with the sanctuary, Craig MacDonald, superintendant said:

"…… JHC/CCOM has been instrumental in creating novel tools to provide sound scientific understanding and information central to NOAA's ability to make informed spatial decisions that support ecosystem-based management in the sanctuary. As the National Marine Sanctuaries Act requires decisions to be made in an inclusive and transparent manner, the ability of JHC/CCOM to provide complex information in a form that can be readily understood by stakeholders (e.g., 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 we have met the initial goals we set, 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, they provide a starting point for the delivery of a range of hydrographic and non-hydrographic mapping products that set the scene for many future research efforts.

Highlights of Our 2009 Program

Our efforts in 2009 represent a careful combination of the continued growth and refinement of successful on-going research programs, and 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. During a visit to the *Ranier* in 2008, Dr. Calder discovered problems with the CARIS HIPS implementation of CUBE. In 2009, Dr. Calder developed a software tool (CRUFT—Coherent Region of Uncertainty Focus Tool) that identifies those areas where difficulties are likely to be encountered and highlights them to the operator. The tool has been provided to the crew of the *Fairweather* for testing. Hopefully this tool will become redundant when CARIS corrects their implementation, but in the meantime, it allows NOAA crews to process data much more efficiently. Given the importance of CUBE to the NOAA processing pipeline, Calder has spent time on NOAA vessels (*Fairweather* in 2009), has participated in the Field Procedures Workshops, and taught a seven-hour CUBE training session in both Seattle and Norfolk.

One of the ongoing issues with CUBE has been the choice of the appropriate resolution with which to grid that data. This past year Calder, in collaboration with NOAA Ens. Glen Rice (currently assigned to the JHC/CCOM IOCM Processing Center), has 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. The theoretical basis for the algorithm has been completed and was presented at HYDRO 2009 in Norfolk. An offshoot of this effort is the work of Calder, Rice and James Hiebert (NOAA HSTP) looking at approaches to accommodating multi-resolution data in hydrographic products. Though in its early stages, they are focusing on a two-pass system with the creation of a "SuperGrid" of coarse estimation cells and then the refinement of each cell after the first pass by overlaying a sub-grid at the resolution appropriate for the data.

A logical outgrowth of CUBE's ability to attribute an uncertainty estimate to hydrographic data is the development of a framework by which this uncertainty can be combined with an understanding of vessel characteristics and environmental conditions to present a quantitative estimate of the risk of a vessel running aground under different scenarios. A new effort began in 2008 to develop a model that attempts to capture the biggest components of the under-keel clearance (UKC) and their uncertainties by expressing their probability over space and time. The model includes factors for the ship's dimensions, settlement and squat characteristics, motion dynamics and operational conditions (e.g., difference between speed over ground and speed through water, etc.) and allows for differing densities of known bathymetry as well as for the potential presence of "unseen objects" (e.g., anthropogenic artifacts or geological objects). The combination of these effects allows us to predict, at any position and time, the under-keel clearance (including effects of the potential unseen objects) in a mathematically rigorous manner. This allows us to address many questions about UKC (e.g., what is the mean UKC or what is the probability of grounding at this position and time). This work is just beginning but holds great promise for the future (Figure EX-2).

In 2009, Calder and Kurt Schwehr developed tools to automatically extract information necessary to inform the model from Automatic Information System (AIS) transmissions. They found many problems with the information contained in the AIS messages but after much filtering were able to extract needed information in a form appropriate for input into the model for a given vessel type entering and leaving the Port of Norfolk.

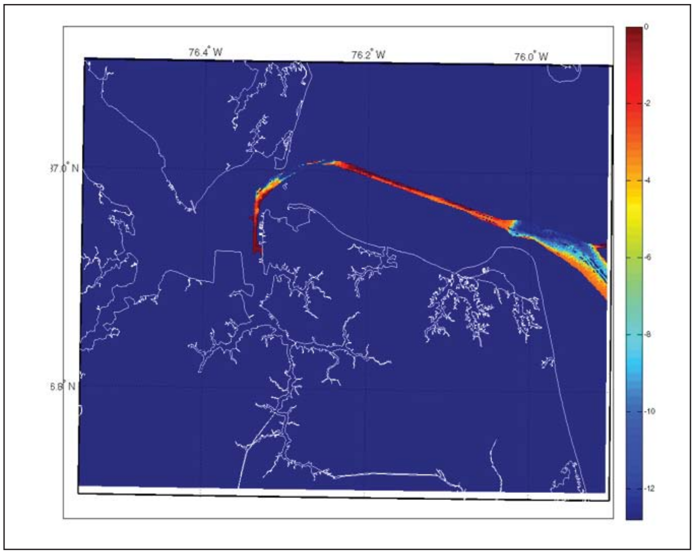


Figure EX-2. Log. of maximum probability of grounding in each 100 m x 100 m area in the approaches to the Port of Norfolk, based on activity and sizes of the Cargo-class ships associated with the container terminal.

Work continues on identifying and attempting to reduce many sources of uncertainty associated with the quality of hydrographic data. Included in this are the efforts of Calder, Beaudoin (of UNB but soon to move to UNH) and NOAA's James Hiebert and Gretchen Imahori to assess the uncertainty in soundings due to variability in the sound-speed profile, and the continuing effort of Calder to work with manufacturers to implement his new "Software GrandMaster" timing algorithm that has been shown to significantly reduce timing latencies within a survey. Our efforts to quantify and limit uncertainty also extend to backscatter as Mashkoor Malik has begun a Ph.D. project aimed at quantifying the sources of uncertainty in multibeam-sonar backscatter.

The efficiency of multibeam-sonar mapping decreases as the water depths get shallower yet the risks to navigation are typically magnified in the shoalest of waters. To address this issue. NOAA and others have looked to airborne LIDAR techniques as a possible means of providing rapid mapping in very shallow waters. Although the potential of airborne LIDAR is great, there are many unknowns associated with these systems and thus we have begun a research program aimed at better understanding the capabilities and limitations of these systems. Studies conducted over the past two years have demonstrated the importance of substrate type in determining the ability of the LIDAR to detect the bottom—we found that no bottom returns were detected in shoal areas of certain bottom types whereas bottom returns were detected in deeper waters with different bottom types. This result undermines the basic assumption of airborne laser bathymetry—that no bottom detection means water deeper than the optical extinction depth of the laser. This result has forced several hydrographic agencies to reconsider how they use and report laser bathymetry.

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 (ALB) 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 and constructed a "LIDAR simulator" (Figure EX-3) 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.

Figure EX-4. CBASS surveying very shallow water through surf.

In further recognition of the importance of developing techniques for very shallow water mapping, we are also exploring other approaches. This past year, Tom Lippmann joined our team with the CBASS (**C**oastal **BA**thymetry **S**urvey **S**ystem, 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 EX-4). The CBASS has been used very successfully to map the shallowest regions of Portsmouth Harbor and this year 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).

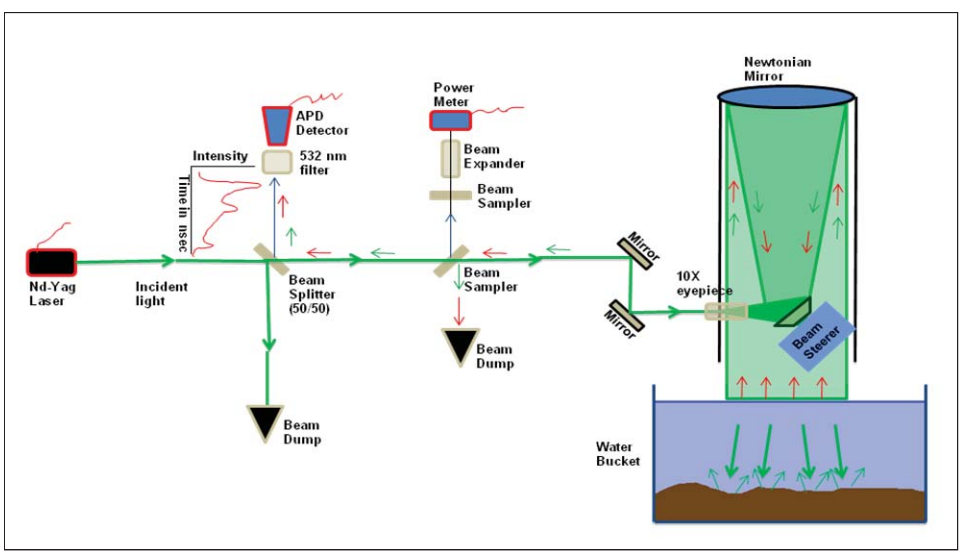


Figure EX-3. Schematic illustration of the bathymetric LIDAR simulator.

Our LIDAR-based efforts this year 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.

As we seek 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, we have developed an analytical tool (ARA) that uses the variations in the amplitude of the sonar return as a function of the angle of incidence to predict the nature of the seafloor (sand, silt, clay, etc.). This year we have further developed automated techniques to segment backscatter data into "themes" and then calculate the angular response for each theme rather than for fixed size patches of the seafloor. 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.

Inherent in our 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 our 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 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. As mentioned above, 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 projects we are working on are: 1- the use of AIS for Sanctuary management (we are working with the Stellwagen National Marine Sanctuary to track vessel types and traffic patterns through the sanctuary); 2- the use of AIS data for hydrographic survey planning; 3- 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; 4- 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.

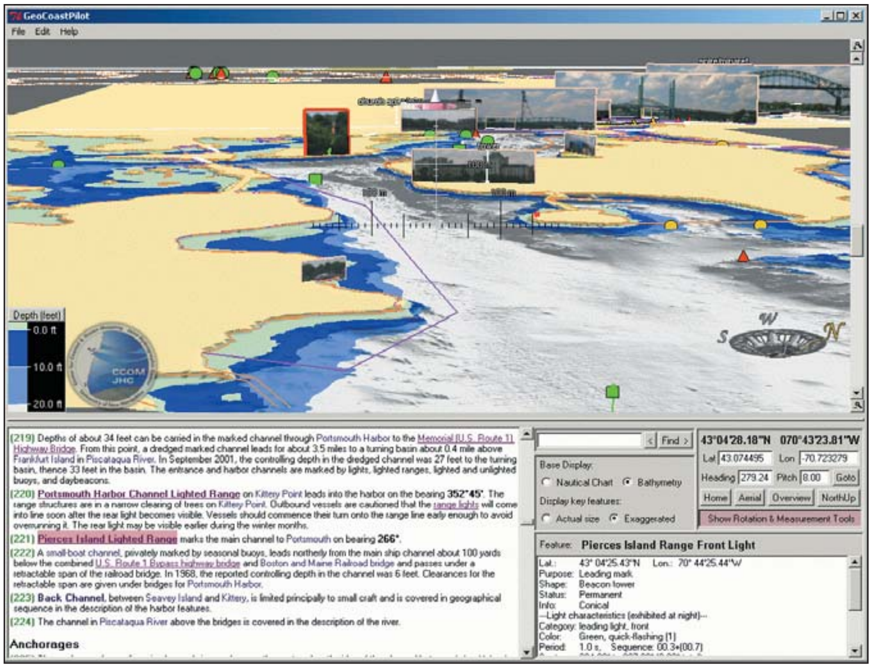


Figure EX-5. Image captured from the "Digital Coast Pilot" showing approach to bridge in Portsmouth Harbor.

As a transitional entry in the world of the 'Chart of the Future,' we have developed and released a fully digital and interactive version 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, through the click of a mouse any object identified in the text and see a pictorial representation (in 2 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 3D map environment, and provides links between the written text, 2D and 3D views, web content, and other primary sources such as charts, maps, and related federal regulations (Figure EX-5). 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. We are now exploring the idea of delivering 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.

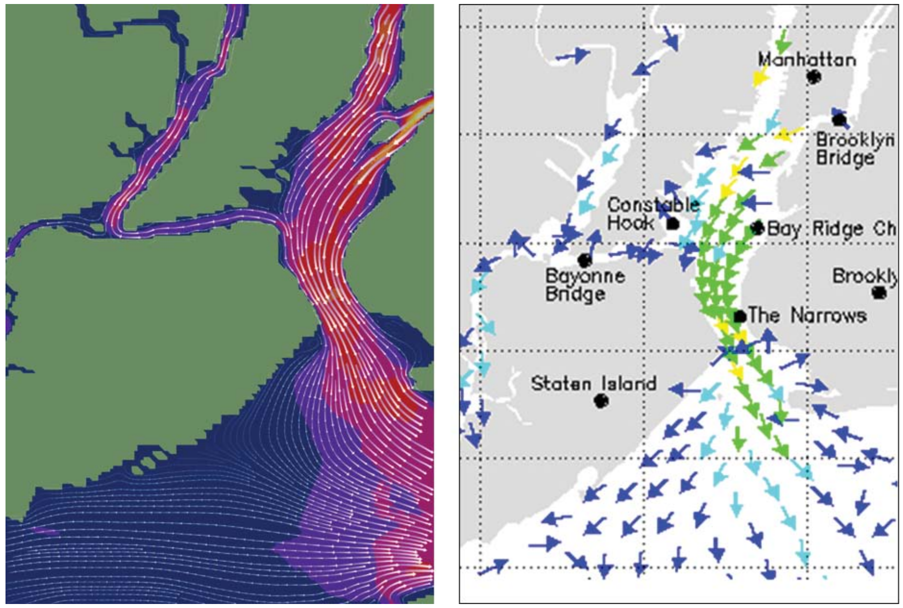


Figure EX-7. FlowVis2D representation in NowCoast of the New York Operational Forecast System on left; standard representation on right.

While our early visualization efforts focused on the 3-D interactive display of static features like the seafloor, our recent efforts have expanded to the visualization of dynamic systems by bringing time in as a fourth dimension. We are developing 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 Arsenault demonstrated the power of these software tools through their 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 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 (Figure EX-6).

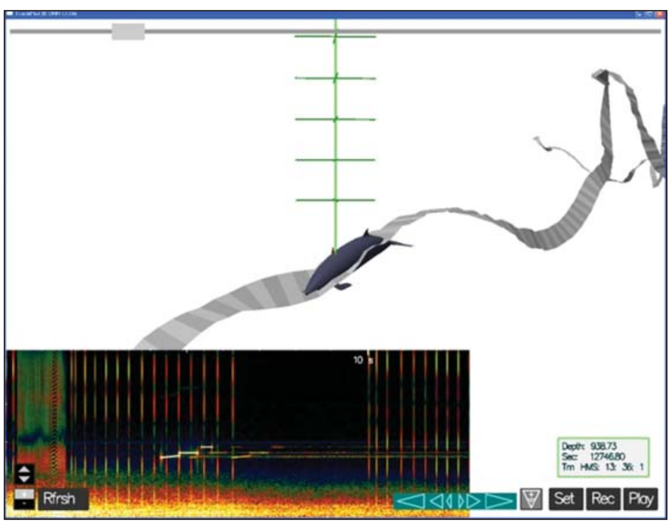


Figure EX-6. Trackplot of trajectory of Cuvier's beaked whale in response to the acoustic signal of a subbottom profiler. Lower plot shows whale vocalizations and subbottom profiler output both recoded on hydrophone on whale.

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 4-D visualization of the 26 Dec 2004 Indian Ocean tsunami and our recent work on three-dimensional ocean flow fields. We have 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 for several months (Figure EX-7).

One of the most exciting advances of our 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 we are working closely with NOAA to see how well they can be used for simultaneous seafloor mapping (Figure EX-8).

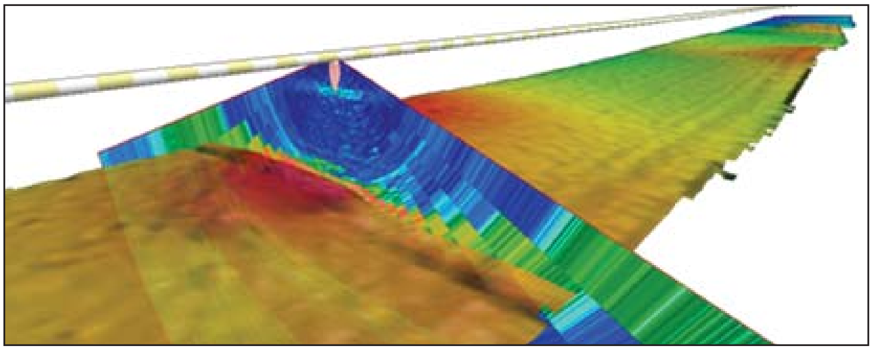


Figure EX-8. ME70 water column and seafloor bathymetry visualized in the new Fledermaus mid-water tool (bathymetry processed off-line by CCOM/JHC software).

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 we strongly support. This past year Tom Weber has been working with ME-70 data collected on board the *Dyson* in the Gulf of Alaska, demonstrating its ability to be used to characterize both fish aggregations and seafloor habitat. In particular, the data has been used to classify seafloor as trawlable or untrawlable and to provide the linkages between seafloor type and rockfish abundance (Figure EX-9). We are also exploring the use of multibeam sonar and visualization tools to explore 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.

One of the major events of this past year was the completion of an addition to our building to house the new Integrated Ocean and Coastal Mapping Center (Figure EX-12). 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 will be 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 meet NOAA needs. The first NOAA employees to move into the IOCM Processing Center have come from the offices of Ocean Exploration and the Coast Survey. We have already begun to develop tools and protocols for data collection and processing onboard NOAA's new vessel of exploration, the *Okeanos Explorer*, and we are developing visualization tools for NOAA's NowCoast, and working on new protocols for bathymetry and backscatter data collection with OCS.

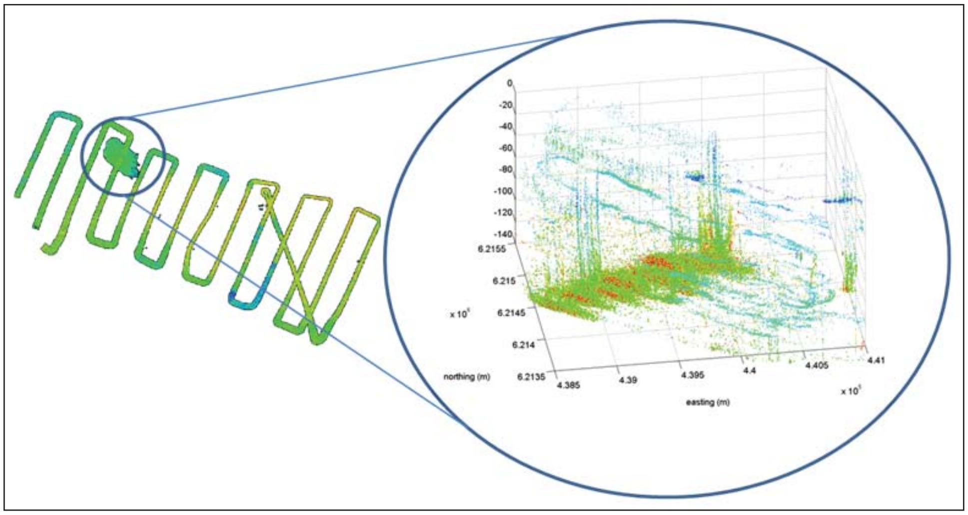


Figure EX-9. Seafloor backscatter from (a proxy for bottom type), and the water column backscatter (Sv) from the highlighted area collected with ME70 on DYSON. In the highlight, apparent bubble plumes appear light blue with a high vertical extent and narrow cross section. Rockfish appear aggregated in a 'carpet' around the base of the plumes (red and green.

We have also accelerated our 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 new GAVIA AUV (shared with the University of Delaware) and its GeoSwath phase-measuring bathymetric sidescan (Figure EX-10). This past year we took part in five AUV missions, including a week-long AUV "boot camp" held at Mendum's Pond, New Hampshire and an ONR-sponsored effort off Martha's Vineyard that focused on the GeoSwath data. The result of this effort has been a tremendously increased understanding of the capabilities and limitations of the vehicle and particularly the identification of several serious problems with the GeoSwath data. We have been able to resolve most of these problems and are now focusing on developing a better path for processing the GeoSwath data and phase-measuring bathymetric data in general.

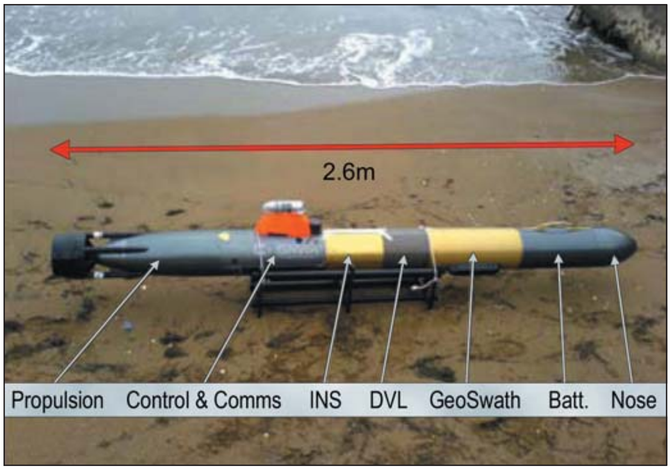


Figure EX-10. GAVIA AUV with GeoSwath Phase Measuring Bathymetric Sonar.

In support of our 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 successfully tested this year (in Mendum's Pond) and also demonstrated another important capability when used as an RTK-tide buoy, providing long-term (more than one month), detailed, ellipsoid-based tide measurements in support of our mapping activities.

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, Mendocino Fracture Zone, and the Marianas, collecting more than

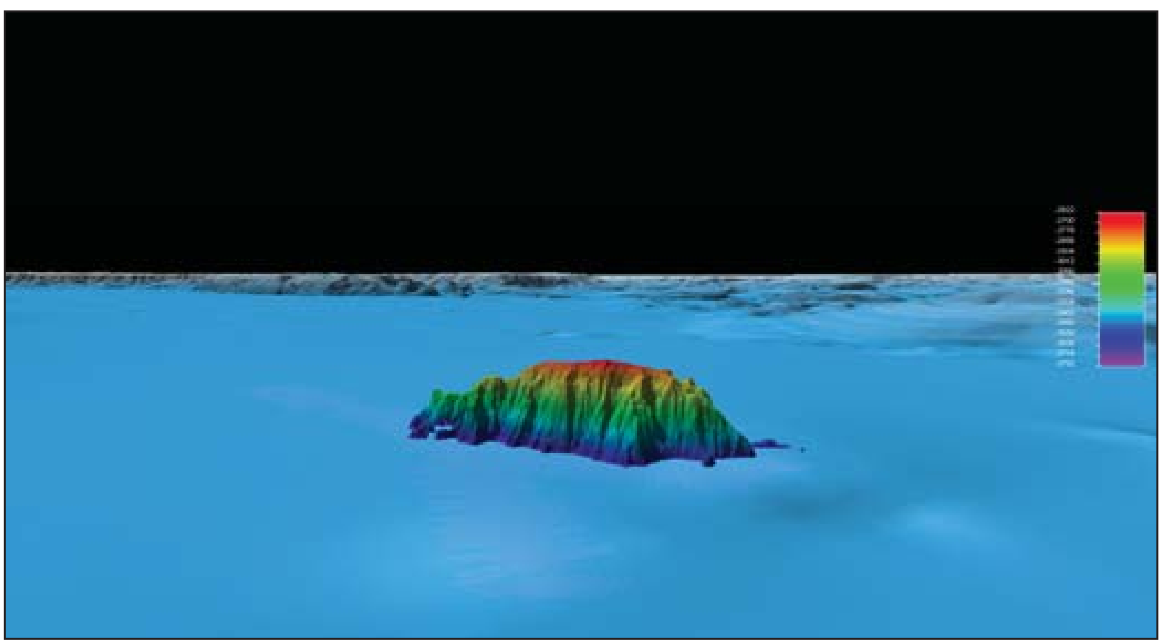


Figure EX-11. Newly discovered 1100 m high seamount in the high-Arctic in a region thought to be very flat.

1,198,000 sq. km of mapping data that have provided an unprecedented new high-resolution view of the seafloor. 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. This past year the efficiency of intra- and interagency cooperation was demonstrated when the *Okeanos Explorer*, NOAA's ship of exploration was used to map areas of potential importance to a U.S. extended continental shelf extension while the vessel was performing acceptance tests of its multibeam sonar. Not only was data of critical importance for a U.S. submission collected, the phenomenal resolution and mid-water capabilities of the new multibeam sonar on the *Okeanos Explorer* allowed for the discovery of many new and unexpected seafloor and mid-water features, including a remarkable 1400-m high gas plume emanating from a slump scarp off the coast of Mendocino, California (Figure EX-1). We also continued our Arctic mapping this year, participating in a 46-day, two-ship operation with the Canadian icebreaker *Louis S. St.-Laurent*. Most of this expedition involved collecting deep seismic data that will be used by both Canada and the U.S. for establishing the sediment thickness needed for an extended continental margin under UNCLOS Article 76, but we also collected new multibeam-sonar data and once again discovered an unmapped seamount in a region thought to be very flat (Figure EX-11).

Figure EX-12. The new addition to the Jere A. Chase Ocean Engineering Lab houses the Integrated Ocean and Coastal Mapping Center.

The research highlights outlined above are not only representative of some of the successes we have had, but they are also indicative of the clear impact that the lab is having on hydrographic and ocean mapping science. We are producing a steady stream of students who quickly find jobs with government agencies or industry and the expertise of members of the lab is often sought by various lines and divisions of NOAA (e.g., advice on protocols for mapping in support of both mid-water targets and essential fish habitat for NMFS, mosaicking video imagery for the Monitor and Macon projects for Sanctuaries, backscatter processing for the Coral Reefs Program of CCMA, advice on multibeam sonar installations for OMAO and the Ocean Exploration Program, surveys in support of ordinance and oil spill mapping for OR&R, etc.) and other agencies (e.g., ONR, NSF, Dept. of State, OSTP and CEQ).

Performance and Progress Report

Further evidence of our contribution to state-of-the-art hydrographic research can be found in the steady stream of publications produced by Center personnel in a variety of top journals and the tremendous interest the media have shown in the activities of the lab including The N.Y. Times, National Geographic, NPR-Earth and Sky, CBC, Science, the Associated Press and even The Colbert Report.

Introduction

On 4 June 1999, the Administrator of NOAA and the President of the University of New Hampshire signed a cooperative agreement outlining a Joint Hydrographic Center (JHC) at the University of New Hampshire. On 1 July 1999, a grant 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.

This report is the fourteenth 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 2009. 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 ten 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 2009, the IT group saw the largest change with the hiring of Jordan Chadwick as our new system manager, and Les Peabody as our Desktop Support Technician. We also hired Emily Evans to serve as the captain of our second research vessel and Colleen Mitchell as a graphic designer to help with outreach and other communications issues. The NOAA contingent at the lab also grew with the arrival of Meme Lobecker, Megan Greenaway, and Ensign Glen Rice as new members of the IOCM Processing Center (see details below). Christian de Moustier was on leave of absence for 2009 and Barbara Kraft's position at the Center ended in October of 2009. Finally, Capt. Jack McAdam retired in 2009, after a long and illustrious career with NOAA, and Luciano Fonseca took a position with UNESCO's Intergovernmental Oceanographic Commission in Paris, although he continues to maintain an affiliation with the Center.

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 the U.S. Navy, the U.S. Army, and the U.S. Coast Guard.

Brian Calder has a Ph.D. in Electrical and Electronic Engineering, having completed 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 (he was 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 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 and Earth Science Departments. 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 with the Integrated Oceanography Division at SIO. He was then a Research Scientist at Ohio State University (1999-2008) jointly in the Byrd Polar Research Center and the Department of Civil and Environmental Engineering & Geodetic Science. Dr. Lippmann's research 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.

Christian de Moustier's faculty position is split between the Ocean Engineering and Electrical and Computer Engineering Departments. He is a world-renowned expert in the theory and engineering aspects of advanced sonar systems for ocean mapping. Christian came to us from the Scripps Institution of Oceanography where he was responsible for the installation and operation of a number of multibeam and other sonar systems. His research interests focus on development of innovative sonar processing techniques and acoustic seafloor characterization. Christian was on leave of absence in 2009.

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, 3D 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 Ocean Engineering. 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.

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.

Emily Evans 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.

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 has worked for the Environmental Research Group (ERG) at UNH since 1999. In July 2009, Colleen joined CCOM as the Center's graphic designer and now divides her time between CCOM and ERG. 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.

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. Currently he is focusing on understanding the behavior of LIDAR pulses as a function of changing environmental conditions and looking at the viability of LIDAR for a wide range of hydrographic applications including shore-line delimitation.

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 built and captains his own 45-foot ketch, *Mother of Perl*.

Briana Sullivan received her M.Sc. 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.

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 eight 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.Sc. in Geology from Tulane University and a M.Sc. 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 "Capt. Jack" McAdam was the Executive Director for Wage Mariner Activities NOAA Marine and Aviation Operations. He graduated from Massachusetts Maritime Academy in 1972 and sailed on NOAA Fisheries vessels for 32 years as a civilian wage mariner starting as a Second Mate on the *Oregon II* in Pascagoula, MS and ending as Master of the *Albatross IV* in Woods Hole. In April 2005, he started his past position, as an advocate for the civilian wage mariners who sail on the 18 NOAA vessels and a liaison between NOAA's wage mariner employees, Marine Operations Center management, and NOAA's Workforce Management Office. One of his duties was to provide the NOAA/UNH Joint Hydrographic Center with assistance in creation of a port office in preparation for deployment of a SWATH vessel to be home-ported at Newcastle, New Hampshire. Capt. McAdam retired in 2009.

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 PI for nowCOAST, 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.Sc. 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 nowCOAST project, **http://nowcoast.noaa.gov**. Jason is a native of Madbury, NH and graduated from UNH in 2006 with a B.Sc. 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 has been project manager for current surveys in the Atlantic, Pacific, Gulf of Mexico and the Caribbean. He is presently the project manager for current surveys in New England. 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 B.S. in Oceanography from the University of Washington and an MBA from the University of Maryland, University College.

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 2 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*. When 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.

Glen Rice is an ensign 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.Sc. 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 new hydrographic program. Dave also helps UNH in its continuing development of the curriculum in hydrographic training and contributed this spring to a UNH course in Geodesy.

Visiting Scholars

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

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

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

Rolf Doermer (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 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.

Facilities, IT and Equipment

With the startup of the Center, the University provided a new 8,000 square foot building. Given the very rapid growth of the Center, space became the limiting factor in our ability to take on new projects. In 2003, we expanded into the second floor of the new building providing greatly needed additional office, graduate student and meeting space. Our growth continues and in early 2009 we opened a new, 10,000 square foot addition housing, among other things, the Integrated Ocean and Coastal Mapping Center and the Center's new IT facilities.

The new IT facilities include additional office space, an IT lab, and a new server room. The IT facilities now consist of two server rooms, a laboratory, the Presentation Room, Computer Classroom, and several staff offices. The server room in the south (new) wing of the building is four times larger than its counterpart in the north (old) wing, and has the capacity to house 14 server racks, allowing space for a total of 20 full-height server racks. The larger room is equipped with redundant air conditioning, a natural gas back-up generator, a security camera, and temperature and humidity monitoring, helping to ensure that the Center network services have as little downtime as possible. Both the larger and smaller rooms are equipped with FE-227 fire suppression systems. The IT lab provides ample workspace for the IT Group to carry out its everyday tasks and securely store sensitive computer equipment. The IT staff offices are located adjacent to the IT lab.

The Center Presentation Room houses the "Telepresence Console" (Figure 1a) as well as a Geowall high-resolution display system (Figure 1b). The hardware for the Telepresence console consists of five Dell PowerEdge servers used as the 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. The multi-display Dell workstation was purchased in October of 2009 to replace the Tandberg MPEG-2 decoders, which became obsolete after NOAA switched their streaming video content to MPEG-4. This new computer performs the same functions as the Tandberg devices at a fraction of the cost. 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. Currently, the Center is working with the new NOAA vessel *Okeanos Explorer* to provide live streaming video to the Telepresence Console over Intenet2 and communication between the ship and her land-based crew at UNH. The Center plans to participate in future expeditions with NOAA and the Institute for Exploration.

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 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 from which separate physical computers benefit. In the event of a virtual server being compromised, the damage is isolated to a single virtual server instance and can be contained. Last year the Center deployed its first virtualization server using an OpenVZ/Red Hat Linux platform. This server currently hosts eight virtual servers, saving the Center in hardware and energy costs, as well as physical space. Building on this success, the IT group implemented another OpenVZ/Red Hat Linux server in March, which hosts five new virtual servers, and has consolidated the roles of two other physical servers, furthering our cost-cutting initiatives. Beginning this year, the Center plans to augment the existing virtual platform with a clustered VMWare vSphere solution. VMWare vSphere allows for centralized management, cross-platform capabilities (hosting Linux and Windows virtual servers on the same physical server), and the

Figure 1a. "The Telepresence Console" located in the new Presentation Room.

ability to create or remove virtual servers on demand. A clustered solution also provides automatic failover in the event of a physical computer failure, drastically reducing downtime.

The IT Group tested and installed a new Helpdesk system utilizing the open source ticketing system Request Tracker in July of 2009. Request Tracker allows the IT Helpdesk to better track the resolutions to technical problems and reduce the duplication of effort amongst the staff, not to mention improve

Figure 1b. Global circulation model displayed on CCOM/JHC Geo-wall II.

the service provided to the rest of the Center. Between August and November of 2009, the IT Staff was able to resolve 89% of tickets within three days.

With the completion of the Newcastle, NH Pier Support Building (designed to provide support for the NOAA Vessel *Hassler*) approximately 11 miles from campus, 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.

The Center has purchased a new Cisco Adaptive Security Appliance to replace the current Microsoft ISA Server 2006 firewall. This new device will increase the external security of the Center's network, and will also serve as an internal firewall, protecting the most sensitive networks from both internal and external threats. The new firewall also offers a host of secure remote access options, including IPSec and SSL VPN tunnels. Currently, remote access is accomplished through secure shell (SSH) to the Center. Although this is a secure and workable solution, it requires end-user configuration, a dedicated computer on the Center network, and is not ideal in many situations.

With the continuing expansion of the network, security remains a chief concern for the Center. Members of the staff have been working closely with OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and CCOM systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. Recent measures taken to enhance security include an upgrade of the Center's Intrusion Prevention System (IPS), which allows the IT Group to monitor and respond to malicious network traffic more efficiently. The Center has also updated its antivirus software from Symantec Enterprise 8 to Avira Antivir 8, providing better virus and malware protection on individual workstations, as well as central deployment and management solution. Avira also has functionality to protect the Center's email server, ISA firewall, and storage servers. Implementation of the mail server client was completed in July of this year. 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 has deployed a new server running Nagios for service and general network monitoring. This server also serves as 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, are to be independently assessed by UNH's Research Computing Center in the first half of 2010 in preparation for an audit of low- and moderate-impact NOAA computer systems. When this audit is complete, NOAA computer systems at CCOM and their dependencies will comply with the Department of Commerce's Information Technology Security Program Policy (ITSPP).

Efforts continue to expand the available storage for projects and research at the Center. This year, the Center has added 10TB of formatted storage to the Network Appliance FAS960c iSCSI Storage Area Network (SAN), which now provides 50 TB of raw storage capacity. In addition, the Center has 12 TB of Legacy direct-attached storage (DAS) that is in the process of being phased out and its data migrated to the SAN. Currently, this process is on hold while the Center is in the process of hiring a new data manager. Plans are in place to reuse the DAS storage for less critical projects, while keeping sensitive and more frequently accessed data on the SAN. The SAN provides higher throughput than conventional disk drives, decreasing processing time of research projects and has given the Center the ability to concentrate all research data in a single location. The maximum capacity of the Netapp FAS960c SAN is 300 TB of raw storage.

Larger storage needs have created a greater demand on the backup system. Previously, the SAN was backed up by a Quantum M1500 LTO3 backup array. This has been replaced by a Quantum Scalar 50 LTO4 backup array, which has four times the capacity and twice the throughput. The older but reliable LTO3 array has replaced the Center's ailing Dell 132T SDLT array, which was responsible for backing up the Center's servers and workstations. Backups on the whole are now faster and easier to manage.

With the addition of larger, faster storage and network equipment, the Center has implemented a Dell/Microsoft compute cluster for resource-intensive data processing. The cluster utilizes seven powerful Dell blade servers running Microsoft Windows HPC Server 2008. The cluster allows the Center to harness the computing power of 56 CPU cores and over 50 GB of RAM as one logical system, 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. The Center has begun a trial of MATLAB Distributed Computing Server, which utilizes the built-in parallel processing tools that Windows HPC Server provides to process large data sets. We are also working with consortium partners in the development of next-generation, parallel-processing software.

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 26 servers, one SAN with eight storage arrays, the computer cluster consisting of seven nodes, and five DAS arrays. Interface between our internal gigabit local area network (LAN) and the Internet is protected by two NitroSecurity Intrusion Prevention Systems (IPS), the IPS Management Console and a Windows-based ISA firewall. One of the larger projects currently in progress at the Center is the NOAA/Fishpac project which, because of its computer-intensive needs, requires its own dedicated server with 32 TB of DAS, and its own cabinet. The Center also currently hosts three dedicated servers for two field-related projects—NOAA's nowCOAST Web Mapping Portal and Open-ECDIS.org. The nowCOAST project hosts a server that mirrors the primary nowCOAST web server, currently hosted in Silver Spring, MD.

At the heart of the Center's infrastructure lies our robust networking equipment. This consists of two Foundry BigIron RX-8 192-port enterprise-level switches, five 3Com 4924 24-port Gigabit Ethernet switches, two enterprise-level Cisco wireless access points, and one Foundry wireless access point. The two RX-8's are currently handling the bulk of the Center's network traffic and are responsible for all internal routing. The 3Com 4924 switches handle edge applications such as the center's Electronics Laboratory, Geowall, and Telepresence Console. The Cisco and Foundry wireless access points are in place to provide wireless Internet connectivity for employees, whereas additional consumer-grade wireless points are in place to accommodate visitors to Chase Lab.

We have continued to upgrade workstations in the Center, 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 and Linux desktops/laptops, as well as several Apple MacOS X computers and one legacy SGI workstation. The IT Group has begun testing Windows 7, the next generation of Microsoft's desktop operating system.

The Center continues to operate within a Windows 2003 Active Directory domain environment. This allows the IT group to deploy policies to Active Directory objects, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of CCOM to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. The IT Group is currently evaluating Windows Server 2008 and 2008 R2 for use on future server and virtual server systems. In addition, the Center also maintains all moderate and high-impact NOAA laptops with Safeboot encryption software, 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 off-site 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. For this software development, a cooperative code development environment is in place, called Subversion, which allows concurrent development on different platforms with multiple users. A full suite of peripherals (4 mm, 8 mm, DLT, LTO, CD-R, DVD±R and Blu-Ray) are available so that data can be re-distributed on a range of media types.

The Center has a full suite of printers and plotters including both 36- and 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.

Research Vessels

The Center operates two dedicated research vessels (Figs. 2 and 3), 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, New Hampshire, 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).

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 2) was built by C&C Technologies (Lafayette, LA) approximately twenty years ago on a fiberglass hull that had been a U.S. Navy launch. She was built specifically for the purpose of collecting multibeam-sonar data, and has a bow ram for mounting sonar transducers without hauling the vessel. C&C operated the Coastal Surveyor for a decade and a half, and then made a gift of her to CCOM-JHC in 2001. She has become a core tool for CCOM/JHC's operations in New Hampshire.

Figure 2. R/V COASTAL SURVEYOR with bow ram.

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

Figure 3. R/V COCHECO.

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.

R/V COCHECO

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

R/V *Cocheco* (Figure 3) is designed for fast transits and for over-the-stern operations from her A-Frame. This vessel, although five years old, has been only operated for a little over one year. Last year, 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. This 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.

R/H SABVABAA

Dr. John K. Hall, visiting scholar at the Center in 2003 and 2004 has 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 *Sabvabba* (Figure 3), 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 *Sabvabba*. Using a 20 to 40 in^3 airgun sound source, the craft should be capable of profiling the shallow and deep layers over the most interesting areas of the Alpha Rise, a critical component to understanding the origin and history of the Arctic Ocean.

The summer of 2009 saw five expeditions for the *Sabvabba* beyond 80°N, that covered a total of 3,100 nmi. These week-long trips included the collection of two ice cores, 30 km of ice-thickness measurements, 57 CTD stations, 35 km of seismic reflection data collection and three successful rock dredges (Figure 4). More details of the work of the *Sbvabba* can be found at http://www.polarhovercraft.no.

Figure 3. RH SABVABBA deployed on ice and collecting data near Spitsbergen.

Figure 4. Hovercraft operations during 2008/2009.

Educational 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 as a Category A program by the FIG/IHO International Advisory Board of Standard of Competence for Hydrographic Surveyors since May 2001. 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 one-year 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.

In 2004, the Center was selected through an international competition (which included most of the leading hydrographic education centers in the world) to host the Nippon Foundation/GEBCO Bathymetric Training Program. UNH was awarded $1.6 M from the Nippon Foundation to create and host a one-year training program for seven international students (initial funding was for three years). Fifty-seven students from 32 nations applied and in just 4 months (through the tremendous cooperation of the UNH Graduate School and the Foreign Students Office) seven students were selected, admitted, received visas and began their studies. This first class (7) graduated (receiving a "Certificate in Ocean Mapping") in 2005, the second class (5) in 2006, the third class (6) in 2007. The Nippon Foundation extended the program for another three years and the fourth class graduated six in 2008 and the fifth class, another five in 2009; six more students are currently enrolled. At the time of writing of this report, we have unofficial word that the Nippon Foundation will continue to fund the program beyond 2010. 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, IBCAO, SAIC, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, NPS, USGS 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 (in order to explore research paths of mutual interest) and the visit 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 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 also leading a review of the entire curriculum and will spearhead the effort to renew our IHO CAT-A certification in 2011.

JHC – Originated Courses

COURSE	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," will be ready for presentation early in 2010.

We have 24 students currently enrolled in the Ocean Mapping program, including the six GEBCO students, two NOAA Corps officers and a NOAA physical scientist; we have already produced six Ph.D.s: Luciano Fonseca (2001); Anthony Hewitt (2002); Matt Plumlee (2004); Randy Cutter (2005); Matt Quinn (2006) and; Stephan Shaeffer (2007). This past year we have graduated four more Master's students and six more Certificate students, bringing the total number of M.Sc.s from the Center to 27 and the total number of Certificates to 28.

STUDENT	PROGRAM	ADVISOR
Roland Arsenault	Ph.D. OE (PT)	Undetermined
Robert Bogucki	Ph.D. OE	Calder
Tyler Clark	MS ECE	Weber
Sean Denney	OE	Armstrong
Janice Felzenberg	MS ESci (Rec'd 2009)	Ward/Mayer
Bert Franzheim	MS ECE	de Moustier
Sam Greenaway (NOAA)	MS ESci	Armstrong
Tianhang Hou	Ph.D. OE (PT)	Huff
Nikki Kuenzel	MS ESci	Gardner/Mayer
Carlo Lanzoni	MS OE	Weber/Irish
Christina Lacerda	MS. ESci.	Monahan
Mashkoor Malik	Ph.D. NRESS	Mayer/Calder
Dandan Miao	MS OE	Calder
Marc Moser (NOAA)	MS ESci (Rec'd 2009)	Armstrong
Amaresh Kumar	Ph.D. ECE	Peeri/Calder
Brian O'Donnell	MS EE (Rec'd 2009)	de Moustier
Brian O'Donnell	Ph.D. ECE	Calder
Daniel Pineo	Ph.D. CS	Ware
Rachel Soraruf (NOAA)	MS ESci. (Rec'd 2009)	Armstrong
Rohit Venugopal	MS CS	Calder
Monica Wolfson	Ph.D. NRESS	Boettcher

GEBCO Students: (2009-2010)

STUDENT	INSTITUTION	COUNTRY
James Daniell	AGSO	Australia
Francis Freire	Hydro Office	Phillipines
Athur Herwindya	Hydro Office	Indonesia
Bernice Mahabier	Hydro Office	Suriname
Naoto Ujihara	Coast Guard	Japan
Yulia Zarayskaya	Geol Inst RAS	Russia

Hydrographic Field Course

The summer 2009 Hydrographic Field Course brought the R/V Coastal Surveyor, nine CCOM/JHC students, one visiting student 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, where a survey was conducted to the south of the Isles. The survey is in a Priority 1 area as defined by the NOAA Hydrographic Survey Priorities document and a continuation of an earlier survey performed in the context of the 2005 Hydrographic Field Course in the waters north of the Isles. The survey also overlaps with the 2005 NOAA LIDAR survey H11296 that partially falls within the area and junctions with the NOAA multibeam survey H10771. The remoteness of the site provided numerous challenges but presented a realistic work environment. The 2009 survey discovered several Dangers to Navigation (DTON) and results of the field course (Figure 5) will, if deemed suitable, be used to update NOAA charts.

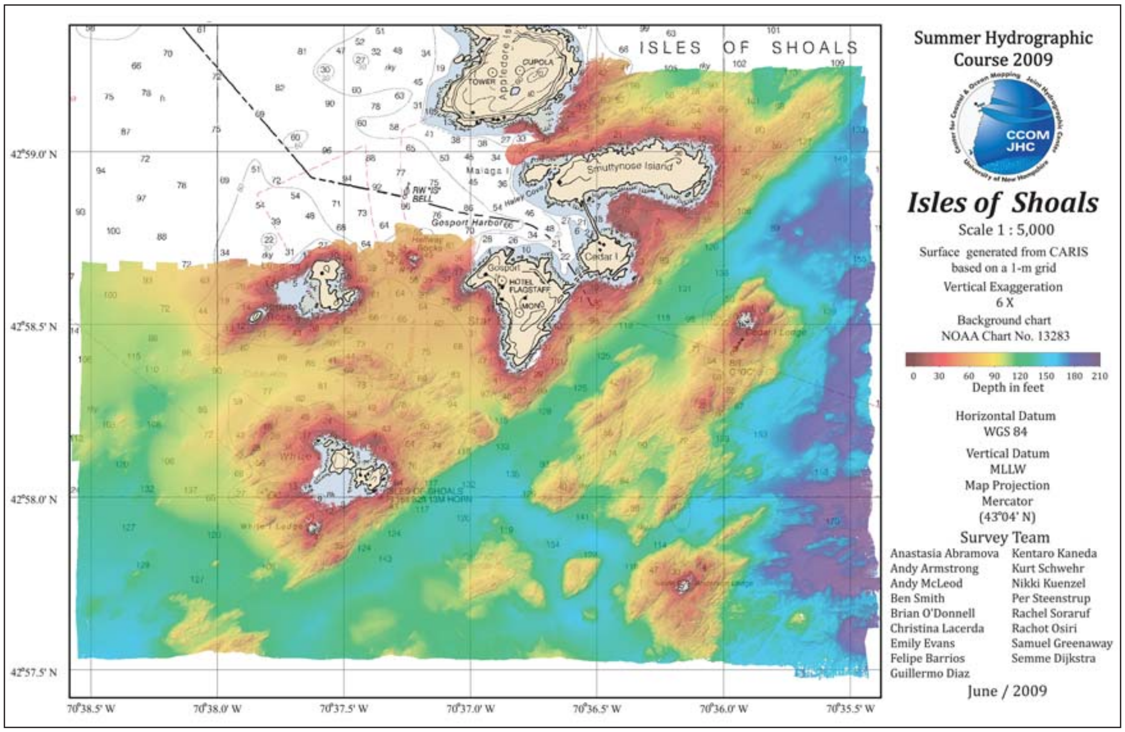


Figure 5. Survey conducted by Center students during Hydrographic Field Course.

Status of Research: January - December 2009

Our initial proposal (1999) identified five research programs, each of which combines long-range research goals designed to make fundamental contributions to the fields of hydrography and ocean mapping with short-term objectives designed to address immediate concerns of the hydrographic community in the United States. As our research has progressed and evolved, the clear boundaries between these themes have become more diffuse. For example, our data-processing efforts (e.g., CUBE) 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. Nonetheless, for consistency, we will use the original program categories to review our progress as well as introduce progress made in a number of new initiatives.

Innovative Sonar Design and Processing for Enhanced Resolution and Target Recognition

We continue to make progress in the upgrades to our sonar calibration facility (originally funded in part by NSF), 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. This past year, Carlo Lanzoni has updated code for, and carefully 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 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 generated 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).

In the past year, the calibration facility was used to better understand capabilities of several sonars including:

SyQuest PO4462-1
In support of Lloyd Huff, Lanzoni calibrated a 10-kHz SyQuest cone transducer. Radiation beam pattern, transmit voltage response, free-field sensitivity and impedance measurements were made.

Reson TC213
Near-field measurements were made for our Reson TC2132 and compared with theoretical predictions for a baffled circular plane piston transducer. The tank results and theoretical predictions closely matched.

Reson 7125
Carlo Lanzoni and Sam Greenaway (under the supervision of Tom Weber) performed a careful series of calibrations of the Reson 7125 multibeam sonar—a system that is now in common use on NOAA hydrographic vessels. Transmit and receive beam-pattern measurements were made as well as source-level measurements and gain calibrations. These tests produced some intriguing results including the identification of a ripple in the beam pattern that appears to be the result of interference with the second frequency projector (either 200 or 400 kHz) and a curvature to the transmit beam pattern (in the across-track direction) that may be an intentional manufacturer design or a system issue. It was also found that at higher gain settings the system's response was non-linear. This finding has important ramifications on the resulting receive-beam pattern. The manufacturer has been contacted about these issues and will be visiting the Center soon to investigate further. See detailed discussion below for further discussion of the 7125.

NOAA has experienced some noise interference on the launch-based 7125 units. This issue appears to be related to the propulsion system and is more pronounced on the lower frequency (200 kHz) band of the system than on the higher frequency (400 kHz) band. The operational effect of this interference is to force a reduction in the maximum effective survey speed while working in deep waters with the low-frequency system. Such interference has not been observed with Reson 8101 (240 kHz), Reson 8125 (455 kHz) or Elac 1180 (180 kHz) multibeam systems installed on similar vessels (although it has not been specifically looked for in these systems).

Graduate student and NOAA Corps officer Sam Greenaway conducted a series of field acoustic measurements in March of 2009 to measure the acoustic signature of the survey vessels in various configurations. Because of test equipment limitations, these tests were conducted with the vessel static (but with propulsion running) alongside a pier. The reverberant test environment and the proximity of other sources limits the usefulness of these measurements as absolute source levels, but the tests did show a significant amount of radiated noise at the sonar frequencies of interest.

Additionally, underwater video images were acquired of the propellers running in both the static environment and while underway. Tip cavitation was observed on the propeller at typical survey speeds and during the static test. Our acoustic measurements agree with published studies that conclude that most of the acoustic energy radiated from a vessel is at much lower frequencies than the sonar frequencies. To investigate the possibility that out-of-band energy was the cause of the interference, a series of measurements in the calibration tank facility at CCOM were conducted to determine the frequency response of a Reson 7125 system. Although the low-frequency limit of these tests was limited by transducer availability and the physical size of the tank, there is no indication that the system was significantly susceptible to an out-of-band acoustic signal.

These tests and recent theoretical work by others seem to indicate that the propeller is generating high-frequency noise in the frequency band of interest and that it is this in-band noise that is causing the observed interference. It is unknown at this time if these particular vessels are generating an unusual amount of noise given the operating conditions or if other vessel designs (outboards, waterjets, etc.) have significantly different high-frequency acoustic characteristics.

Multi-Ping, Multi-Chirp Sonar

Graduate student Brian O'Donnell, with 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 plan is to develop an approach that can use existing multibeam transducers with only the transmit and receiver boards needing to be upgraded. Initial research has been focused on determining the most appropriate waveform set and testing the waveform-generation process in the acoustic test tank (with Carlo Lanzoni).

High-Precision, High-Accuracy Time Synchronization

The ultimate accuracy achievable from a multibeam survey is often constrained by our ability to synchronize the time-stamps among the various sensors (sonar, GPS, motion-sensor, etc.) associated with a survey. Brian Calder has been investigating the use of the IEEE-1588 'Precision Time Protocol' (PTP) as a solution for low-overhead time synchronization, primarily in survey systems (e.g., to allow local time-stamping at data generation as a way to eliminate latency issues in data capture). He has been able to demonstrate that on low-specification hardware (both computers – 533-MHz Pentium III systems – and network – desktop workgroup 100-bT Ethernet switches) the National Instruments PCI-1588 cards achieve synchronization and syntonization of local clocks within approximately 100 nanoseconds rms with zero host-computer overhead, and low network overhead. Additionally, he has demonstrated that a software implementation of the PTP can potentially achieve sub-millisecond accuracy when interfaced with a hardware master clock. The limiting accuracy is likely to be on the order of a few hundred microseconds, depending on computer speed and loading. The uncertainty in developing a time-stamp from software, even using hardware oscillators, can be significantly higher than the hardware uncertainty. The estimate of this uncertainty is on the order of 10-20 microseconds depending on computer speed and loading.

In 2008, Calder worked with Reson to integrate the Software Grandmaster algorithm into their 7kCenter control software for 7000-series systems, focusing particularly on the Reson 7125 (as a specific NOAA need). This culminated in a visit to Reson, Inc., in Goleta, CA. to finalize integration with their current generation source code base. During the visit, it was shown that the integrated code, interfaced to an Applanix POS/MV timing signal, can achieve sub-microsecond rms repeatability, typically on the order of a few tens of nanoseconds, even under heavy processor load with stable, and low predicted uncertainty of timestamps.

In 2009, a request was received from Professional Surveyor Magazine for a more general article on the work. The group involved in the original testing was re-assembled to comply and a manuscript was submitted for publication in the August issue. In addition to publicizing the material, this provided a context to investigate the current state of integration into the Reson and Applanix systems. It appears that this process has stalled somewhat because of personnel changes at Reson, indicating that some additional impetus may be required to carry this project to implementation. This will likely remain an activity in the following reporting period. Discussions have also begun with NAVO (Elliot Arroyo-Suarez) about potential implementations with portable survey systems, and Korusys Ltd. (Vernon Middleton) about specialization of their 1588 ASIC for embedded marine survey systems.

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 (see earlier progress reports for descriptions of these approaches) 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 "cleaning" 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.

In 2003, CUBE was subjected to detailed verification studies in 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, IVS-3D, SAIC, Kongsberg-Simrad, 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.

Grid Analysis for Bathymetric Processing

Following a visit to the NOAA Ship *Rainier* during the last reporting period, it became evident that a number of problems with their processing scheme were engendered by the specific implementation of the CUBE algorithm in CARIS HIPS. In response to this, Calder started work on an algorithm that attempts to identify areas where difficulties are likely to be encountered, and highlight them for the operator. The hope is that such a tool would be useful until such time as CARIS corrects their implementation of the algorithm.

This tool (named CRUFT—Coherent Region of Uncertainty Focus Tool) has now been developed to a proof-of-concept stage and provided to survey crews on the NOAA Ship *Fairweather* for testing. The tool identifies small areas where problems will likely occur when the data is combined with other resolutions, and highlights them for the user (with an open rectangle of fixed size), as shown in Figure 6. The problems are normally too small to be seen by the operators (or at least are readily overlooked), which leads to operator frustration when these problems appear at later stages of processing. A refinement of the algorithm attempts to estimate the significance of the potential for any region to cause difficulty and presents this to the user through transparency of the indicated regions. We expect that the CRUFT tool may need some modification based on feedback from the field, but that it should have a limited lifespan in any case. Correct implementation of ideas such as the variable-resolution grid data structure described below would correct the deficiencies in implementation within HIPS and obviate the need for the tool entirely.

CUBE V2, Data Density and Multi-Resolution Grids

One of the ongoing issues with CUBE has been the choice of the appropriate resolution at which to process the data. This past year, Brian Calder, in collaboration with ENS Glen Rice, NOAA (currently assigned to the CCOM/JHC IOCM Center), has begun to investigate the use of data density as a means to drive the choice of resolution at which to process data. The argument is that the main goal of the data processing should be to ensure that the algorithm's outputs are stable, and then ensure that they are representative. (If the results

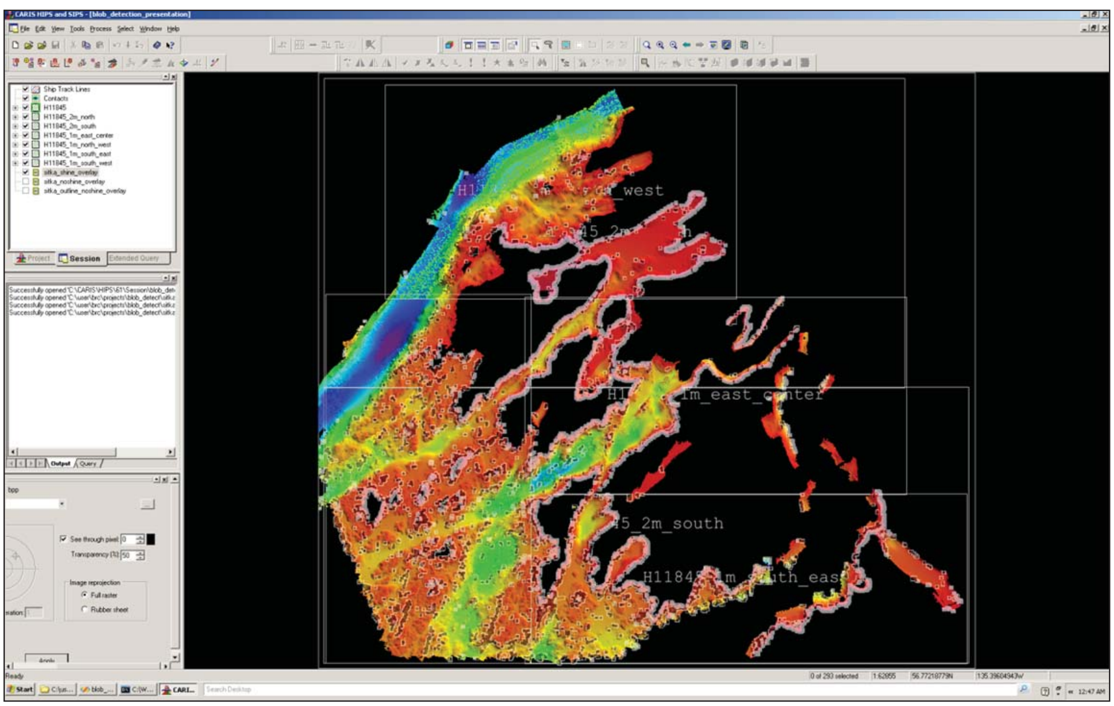


Figure 6. An example of CRUFT applied to the component CARIS HIPS BASE Surfaces used to represent a complex survey in Sitka, AK. The overlay layer highlights areas of potential conflicts between the different resolution levels of the representation, indicating them with a significantly sized marker that draws the user's attention, and showing the expected severity through the transparency of the overlay. The intent is to provide feedback for the user on potentials for difficulty, rather than to resolve them directly, since these problems are often very easy to solve, but difficult to find in the first place.

are not stable, then we run the risk of spending more time chasing algorithmic issues than understanding the data at hand.) With this in mind, estimates of data density can be translated into likely sustainable estimation resolutions with the addition of some assumptions about how many soundings are required to stably estimate a depth in a CUBE-type algorithm. Calder and Rice collaborated on developing the theoretical basis of why the algorithm makes sense for the future and presented it at Hydro 2009.

Further discussion of the implications of these ideas with Rice and James Hiebert (NOAA HSTP) has led to the formation of a project to consider a solution to the multi-resolution problem in hydrographic bathymetric data processing; i.e., how does one make a single surface that can accommodate difference resolutions of estimation in order to follow the changing depth in a survey area? This has been a topic of active investigation before, and this should be seen as the logical extension of those ideas. The project is currently in the development stages, but the primary idea is that we can only construct a variable resolution grid in an area if we have some idea of depths and data densities that we are achieving. Therefore, we expect to have a two-pass system, where the first pass computes an estimate of data density from the available data, which is then used to determine the appropriate resolution for estimation during the second pass, using either empirical data or theoretical models. Variable resolution can be achieved by starting with a low-resolution 'SuperGrid' of coarse estimation cells (over which data density is estimated), and then refining each cell after the first pass by overlaying a sub-grid at the resolution appropriate for the data.

Initial development of the algorithm's memory-management structures took place during the NOAA Ship *Fairweather* cruise in 2009-06, and further development took place during the USCGC *Healy* cruise in 2009-08/09. Implementation efficiency is being addressed directly in the code base because experience with previous codes that were eventually released for implementation was that whatever is provided is what gets used in the end product. Getting the implementation right at the research stage, therefore, appears to be essential to adoption of the technology in the long run. The code base is virtually complete, and we expect to see testing within the next reporting period. We expect to use the standard CUBE approach to estimation in the first instance, but will investigate alternatives that might be more efficient in the future.

CUBE Training

Calder was approached by NOAA staff during the annual Field Procedures Workshop in Norfolk, VA and requested to supply a training module for the annual hydrographic training workshops that they conduct. He consequently prepared a series of seven one-hour lectures on the topic, ranging from "big picture" descriptions of issues with the traditional processing scheme, to detailed descriptions of the effects of configuration parameters on the operation of the algorithm. The training was conducted in Seattle, WA on February 17 2009 and in Norfolk, VA on February 20, 2009. Feedback from both classes was solicited through their respective training managers and was almost universally positive. Based on this success, he has been invited to repeat the class during the training in 2010.

Sparse Uncertainty Management and Under-Keel Risk Models

A logical outgrowth of the ability to attribute hydrographic data with uncertainty is to explore a framework that can express this uncertainty (particularly for sparse data) in a natural manner that can be used by the end-user. Calder has been developing such a framework that incorporates many aspects of uncertainty associated with hydrographic data to assess the integrated risk over an area or line trajectory of a vessel transiting an area.

Calder started this investigation in 2008 by considering a trial model of under-keel clearance (UKC) that attempts to capture the biggest components of the UKC and their uncertainties by expressing their probability density functions over space and time. The model includes factors for the ship's dimensions, settlement and squat characteristics, motion dynamics and operational conditions (e.g., difference between speed over ground and speed through water, etc.) and allows for differing densities of known bathymetry by compensating for the (possibly interpolated) known effects directly and then allowing for the potential presence of "unseen objects" (e.g., anthropogenic artifacts or geological objects) via an associated marked spatial point-process model. The combination of these effects allows a prediction, at any position and time, of the full probability density function (pdf) of the under-keel clearance (including effects of the potential unseen objects) in a mathematically rigorous manner and, therefore, to answer any question about the UKC that can be posed statistically (e.g., mean UKC, probability of grounding at this position and time, confidence interval for the UKC, etc.) in a very flexible way.

The same basic model, once calibrated for a particular hull shape, can be applied in a number of different manners. (Shape controls many factors in the model because it is critical in defining the flux of objects potentially encountered by the hull.) The simplest approach is to model the time evolution of the vessel's track that allows us to estimate the instantaneous probability of grounding and, from this, the cumulative probability of grounding to any time step along the track. This immediately opens up the potential for formulating a variational path-planning scheme to provide the minimum risk route between two points.

Application of these ideas to real-time decision support (e.g., an ENC chart overlay to provide objective decision support data in a crisis) or pre-transit planning is obvious. A Monte Carlo simulation can be applied to assess the risk of transit through a given area (including variations in the motion spectrum, speeds, currents, etc). Products of this type, used as an ENC overlay, could be used in lieu of the traditional source diagram to answer the sort of questions that mariners might legitimately ask, rather than simply qualifying the survey work that was done as is now the case.

Our analyses show that the risk assessment provided to the user has to be specific to the user, rather than generic, in order to be fully accurate. However this does not imply that an average risk could not be computed based on an understanding of the typical traffic that was present in a port approach (for example). In 2009, efforts have focused on the use of AIS-derived traffic statistics as a means to characterize the area of interest for uncertainty assessment, and thereby to calibrate probabilistic models used to compute risk. This work has been done in collaboration with Kurt Schwehr with data from Norfolk, VA supplied by Kyle Ward from NOAA/OCS.

Although the AIS system is in theory ideal for characterization of the traffic of significance in an area, in practice it is not straightforward to extract coherent information from the data stream. Therefore, a major part of this year's effort was to find methods to filter the raw data in an SQL database such that the remaining entries are sufficiently clean to allow for direct queries without concern for consistency checking. After the database was appropriately cleansed, it was possible to build simple statistical analyses of the traffic volume in the area of interest by country of registration, declared class of shipping, etc. However, these analyses are not particularly revealing for risk-model purposes, because they do not have any semantic context; i.e., they do not provide information on what a particular class of ship is doing, or where it is going. We attempted to address this by stratifying the ship traffic into broad classes expected to show consistent behavior (e.g., Pilot Boats, Cargo, Tanker, etc.) and then for each ship within the class. We next extracted all of the positioning information and broke it into periods of consistent motion through use of the speed-over-ground information provided from the ship's GPS. From this, periods of transit can be extracted. Once transits have been established, analysis of the end-points of each transit allows us to establish whether the transit is in-area or trans-area (an important distinction for tug and towing traffic, for example), and where within the area there are clusters of active end-points, indicating a dock or other congregation area (Figure 7). Spatial aggregation of the transit locations allows the code to compute direction and speed distributions for traffic in any particular location. The coherent nature of the statistics developed from this analysis indicates that we have stratified sufficiently to characterize the fundamental behaviors of the ships in this category.

As a final step to provide a baseline calibration for a simple underkeel-clearance risk model for the area, we attempted to compute a plausible predictive model for the physical dimensions of ships associated with the Cargo class in the container-terminal zone. The intent

Figure 7. Automatically detected clusters of transit end-points using Schwehr's k-means clustering algorithm in the Port of Norfolk.

here is to provide a mechanism to allow for ship dimensions to be simulated as part of a Monte Carlo approach to risk estimation. We found that there are strong correlations between the physical dimensions of the ships that we observe in this zone, with the exception that the breadth of very wide ships do not follow the same (quadratic) model against length as the others, and PANAMAX length ships do not have the same (linear) relationship of draft against length. Therefore, we model this relationship by determining how often we see very wide ships, and use this as the most frequent probability estimate for wide-ship occurrence. When simulating ships, we first sample to determine whether the ship is in the wide class or not. If so, the length is computed from the sampling distribution of lengths for ships of this kind; if not, the length is sampled from the prior for all ships and breadth is computed using the predictive model. For draft, we first test whether the ship is a PANAMAX-sized carrier. If so, the draft is chosen from the prior of drafts for such ships; if not, then the draft is computed using the predictive model, with a random component associated with the sample residuals after model fitting.

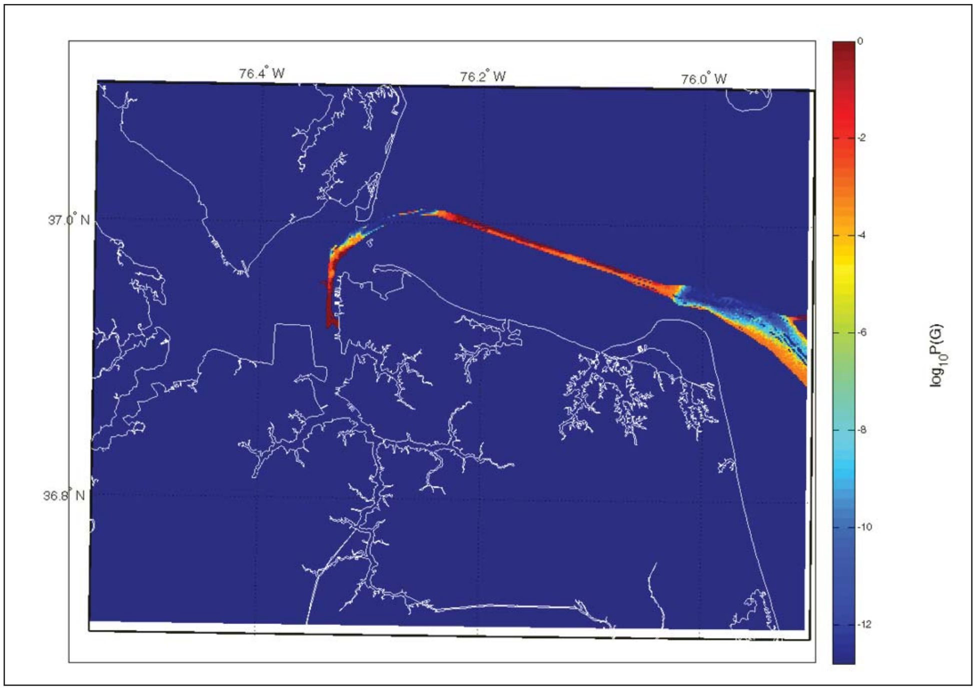


Figure 8. Log. of maximum probability of grounding in each 100 m X 100 m area in the approaches to the Port of Norfolk, based on activity and sizes of the Cargo-class ships associated with the container terminal zone shown in Figure 5. The probabilities are mostly depth related (since these vessels are typically draught-constrained in this area), but some variations due to speed are also observed in the approaches area.

Finally, we combined the derived configuration and calibration data with a previously developed risk model (reported on in 2008) in order to compute an estimate of the risk associated with ships of Cargo-class that made the transit to the zone associated with the container terminal. The risk is computed using the Heaviside step-loss function, that corresponds to probability of grounding and we compute maximum risk in each 100 m X 100 m area, displaying the common logarithm of the probability as color-coding, sampling over N=100 plausible ship sizes, directions and speeds through each area. The results (Figure 8) show that although the majority of the signal is due to the bathymetry (not surprising, since these ships are typically depth constrained in this area), there are variations associated with speed of the traffic, particularly in the approaches where the slower incoming traffic shows different risk, even though the bathymetry in the area is much the same as it is in the outgoing channel. This work has already been reported in a paper at the US Hydrographic Conference, although we hope that a more formal paper for journal publication will also be produced within the next reporting period. Much further work is required, including better calibration for physical sizes of the different classes of traffic, inclusion of multiple classes of traffic into one assessment, and methods to deal with time-stamping issues in AIS traffic as reported to us via the Coast Guard's network feed. In addition, we need to address assessment of risk based on what ships might do, as opposed to what we observe them doing now.

Sound Speed Profile Uncertainty Estimation and Management

Calder continues to work with Jonathan Beaudoin at UNB, and James Hiebert and Gretchen Imahori at NOAA, on methods to assess the uncertainty in sounding due to the variability in the sound-speed profile (SSP). In particular, he has been working on how the result of Beaudoin's Uncertainty Wedge Analysis (UWA) would be incorporated into the TPU workflow that we have established, and what the effects would be for the user applications. Investigation of the current model indicates that this can be achieved simply by setting the component of the current model that encapsulates the spatio-temporal component of sound-speed variability to zero, and then interpolate the uncertainty wedge at the appropriate location for any given sounding in order to form a vertical and horizontal uncertainty pair that can be added directly into the propagated uncertainty models. An example of the results from a particular uncertainty wedge is given in Figure 9 that shows that the effects of a wedge-based model can be distinctly different from that of the current theoretical model, no matter what value is chosen for the assumed spatio-temporal uncertainty of the SSP data. The implication here is that it does not matter which assumed value we choose for the SSP; none will adequately match what is really going on with the data. This project has already been reported in a paper presented at US Hydro 2009, and a paper published in International Hydrographic Review. We expect that at least two more journal publications will derive from this work, especially considering how the effects of the analysis can be localized to a specific area.

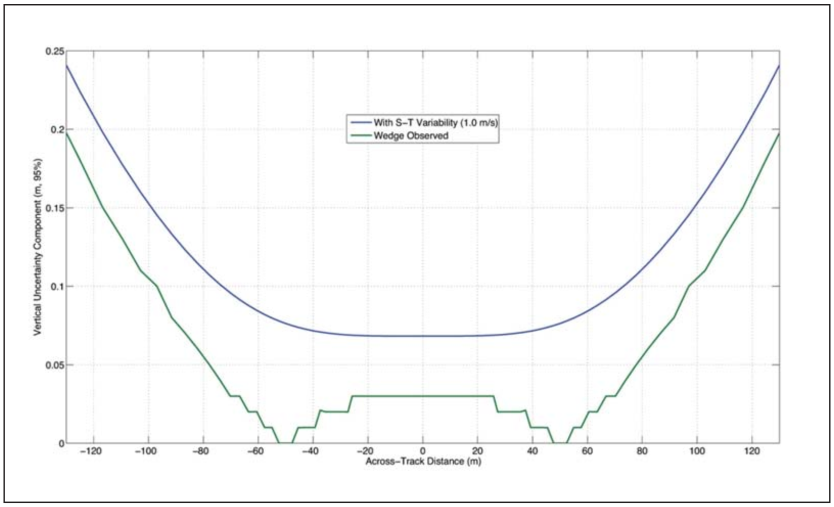


Figure 9. A comparison of the vertical component of uncertainty due to the sound speed spatio-temporal uncertainty using the current model (blue) and an uncertainty wedge analysis (green). The step-effects in the UWA result are due to sampling issues in the wedge construction.

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 Venugopal in an M.Sc. thesis that focuses on the concept of a parallel-processing system for hydrographic data. Progress on this topic has been a little slower than we would have preferred. However, in the last part of this reporting period we have seen significant progress towards our overall goal and we hope to now see more rapid progress towards testable implementations of hydrographic processing software running in parallel. A component of this effort is the establishment of a Collaborative Research Agreement between CARIS and UNH under which CARIS would provide the Application Programming Interface (API) codes required to utilize their hydrographic software from within another application (in this case, the parallelized software under development). Progress at CARIS was interrupted by their focus on V7.0 of HIPS being prepared for release, but they have now agreed, at least in principle, to sign the CRA.

Improved Processing for Phase-Comparison 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 and Yuri Rzhanov have been meeting regularly to begin to outline new approaches to processing these data. This will be discussed further under the AUV theme.

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 (both from multibeam sonars and sidescan sonars). With this in mind, we began a new effort in 2005 aimed at improving the suite of backscatter processing tools available. Our 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.

We started a lab-wide effort 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 GFS 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 geo-referenced mosaic. The result of this effort is GeoCoder, a C++ mosaicking 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 non-linearity 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 for based on 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 other 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; 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 National Marine Sanctuary Program
- NOAA Alaska Fisheries
- NOAA Pacific Coral Reef Program
- NOAA Ship *Thomas Jefferson*
- NOAA Ship *Rude*
- 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. Yuri has been working to learn the code and where necessary, revise and rewrite it. A particular focus of 2009 efforts has been on supporting data collected with the GeoSwath phase-measuring bathymetric sonar (see AUV discussions below) and merging Reson GSF data with backscatter data from Reson 8100 series sonars.

Beyond GeoCoder; we have developed an analytical tool (Angular Response Analysis – ARA-formally 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.

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 in backscatter displayed in a sonar mosaic, does it truly represent a change in seafloor characteristics or can it be the result of changes in instrument behavior or the ocean environment? Mashkoor Malik has begun 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, in-field observations from vessels equipped with multibeam sonars both adrift and tied to a dock and an experiment with a multibeam sonar rigidly mounted to a pier were completed (and reported on in the 2008 Annual Report). The objective of these experiments was to gather a large data set comprising multibeam seafloor-backscatter observations accompanied with detailed observations of the media.

Of particular interest were the pier experiments in which seafloor backscatter was continuously measured for seven days and then a calibrated sphere introduced 1 m above the seafloor and the backscatter from the sphere was continuously measured for another six days (Fig. 10). Initial results indicate that the observed backscatter data from both the seafloor and the sphere seem to fluctuate with tidal variations. It is suspected that with changes in the sound-speed profile (coupled with the tidal cycle), the individual beams may not be ensonifying the same part of the seafloor (or sphere) and their slight movement may be changing the observed backscatter. The observation that tidal variations seem to have an influence on backscatter may have important implications in the long-term interpretation of quantitative backscatter data.

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 3-D visualization environment, GeoZui-3D. This highly interactive 3-D 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 allows 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.

Other specific enhancements made in 2009 include:

- Improved image loading and saving.
- Improved projections and spatial reference support.
- Added ability to load ESRI Shape files.
- Small improvements to beam pattern visualization in GeoZui4D.
- Generic Kalman filter support in libgz4d.

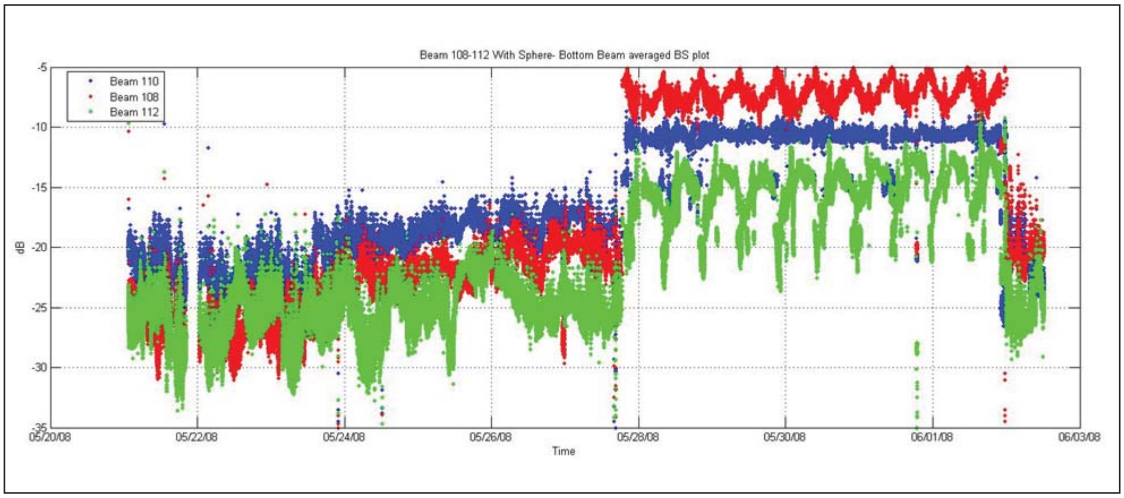


Figure 10. Time series plot of three beams (108, 110, 112) showing seafloor and sphere beam averaged backscatter. A 14 inch stainless steel sphere (filled with distilled water) was placed on the seafloor on 05/27/08 and removed on 06/02/08.

- Added netcdf wrapper to libgz4d that properly handles memory allocation and deallocation. This contributes to more robust code reducing the possibility of memory leaks and segmentation faults.
- Libgz4d build with Visual Studio 2008 Express Edition (VC 9.0).
- Added ability to display depth and/or speed to vessel object in GeoZui-4D. This is the object used in GeoZui-4D for most objects that move in time, such as whales, AUVs and ships.
- Support for controlling GeoZui-4D with a Space Navigator
- Added S57 reading and rendering support
- Improved scene and rendering framework to use view fustrum data to enable culling and level-of-detail type rendering optimizations.
- Improved DTAG reading library. GeoZui-4D can now playback audio and display a spectogram directly for DTAG data.
- Removed dependencies on outdated libraries
- Added support for Jack audio system for displaying the spectrum of multiple real time audio streams.

The GeoZui-4D task is blending more and more with our Chart of the Future (GeoNAV-4D), Water Column Mapping, and AUV tasks. Further developments of GeoZui-4D and Mid-water mapping will be discussed under those headings.

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 are attached to a whale that record depth, pitch, roll and sound for as long as the tag remains on the whale. Our visualization team has taken these data and created fully georeferenced 4-D 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 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 Gerlach Straight on the Western Antarctic Peninsula. This project was carried out with scientists from Duke Marine Lab (Douglas Nowacek, PI) who were responsible for whale tagging, animal abundance surveys, and EK60 surveys of krill swarms, and from the University of Massachusetts (led by Meng Zhou) who sampled the prey using MOCNESS, and JHC/CCOM who provided visualization and analysis support. The project's title was Multiscale Interdisciplinary Study of Humbacks and Prey (MISHAP). Its goal is to develop a multi-scale trophic-level model that encompasses the food chain: mesoscale zooplankton→krill →Humpbacks. In support of this major multidisciplinary project, GeoZui-4D was used to display georeferenced EK-60 and ADCP echo-intensity data in real-time so that targets could be followed (Fig. 11) and prey fields mapped adaptively (Fig. 12).

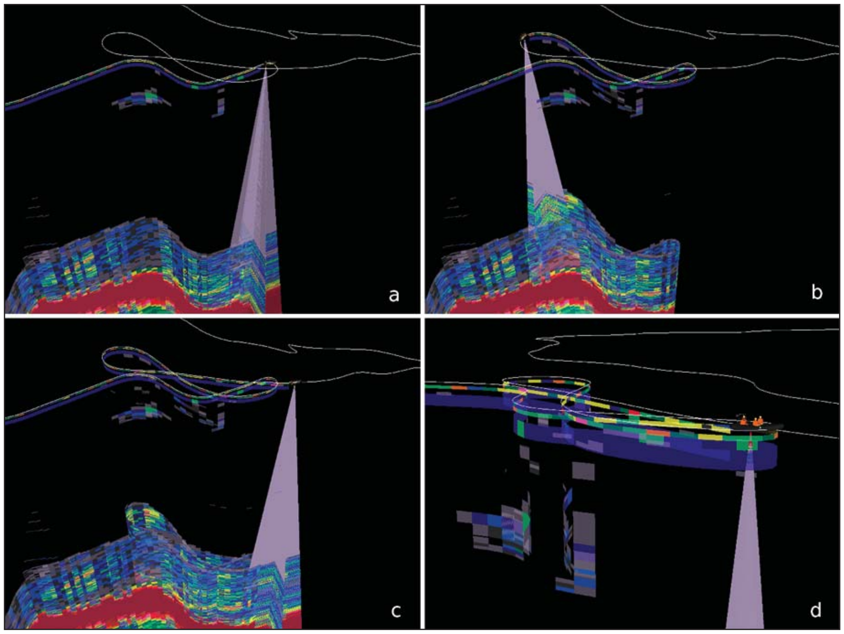


Figure 11. Sequence of passes over a small target near the surface. The real time geo-referenced display of the Simrad EK60 echo sounder data in GeoZui4D was used to steer the subsequent passes over a moving then disappearing target.

In support of this effort, Ware has developed his trajectory analysis package, TrackPlot, to enable identification and quantification of feeding lunges made by Humpbacks. This is the central problem in fine-scale analysis because it will allow both for a much more precise estimation of lunge counts than has previously been possible and, for the first time, an estimation of the energy expended in a single lunge (whale feeding lunges may be the most energetically costly feeding events that exist). These advances have come about through a careful analysis of the raw tag data that allows the accelerations, depth changes and acoustic signals recorded by the tag to be combined.

In addition, TrackPlot is being developed as a general purpose tool for analyzing data from tagged marine mammals, including Florida manatees and various species of whale. Figure 13 shows TrackPlot images from a controlled sound exposure project that involved beaked and Pilot whales (in collaboration with Brandon Southall).

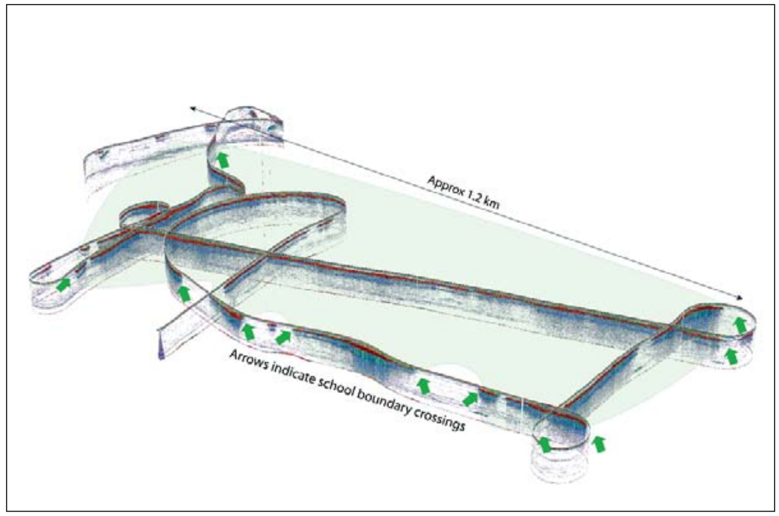


Figure 12. Boundaries of a school of fish adaptively mapped with an EK60 and GeoZui-4D.

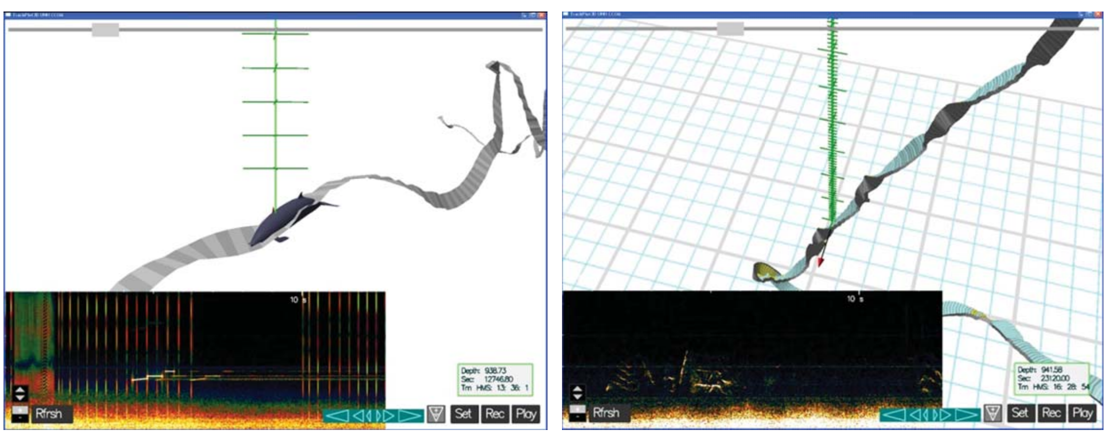
Flow Visualization

Ware's work on flow visualization has opened a range of applications and interest from ocean current and atmospheric modelers both inside and outside of NOAA. Our goal is to provide tools that allow both researchers and members of the public to better understand the output from flow models. This is important to NOAA because of the increase in the number and quality of global, ocean and estuarine flow models. These models are becoming critical to interpreting and generalizing physical oceanographic data, understanding marine ecologies and understanding weather and climate prediction. Optimized presentation of flow may also become a critical part of the Chart of the Future (see below).

The optimized flow visualization package FlowVis2D has been operating in beta testing mode in NOAA's NowCoast for several months. We are now beginning the process with the operational forecast models for the Great Lakes. The operational forecast models for all of the Great Lakes, as well as New York Harbor and Galveston, are now in alpha testing. Figure 14 shows the FlowVis2D representation of New York Harbor.

Optimal Data Representation

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 fundamental understanding of the perception of visualized data,



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.

The same whale exposed to killer whale vocalizations. The animal abruptly terminated its dive. The track shows it ascending with repeated 90° rolls.

Figure 13. Examples of TrackPlot being used to relate behavior to introduced sounds.

Ph.D. student Daniel Pineo, under the supervision of Colin Ware, is developing a neural network designed to simulate the early stages of the human visual system. The neural-network model is capable of simulating a million neurons with more than a billion connections between them. Because this is done on a GPU processor, it is capable of updating at approximately 3 Hz. Pineo will use this model to optimize visualizations of complex data sets. There are far too many parameters that define even a moderately complex visualization

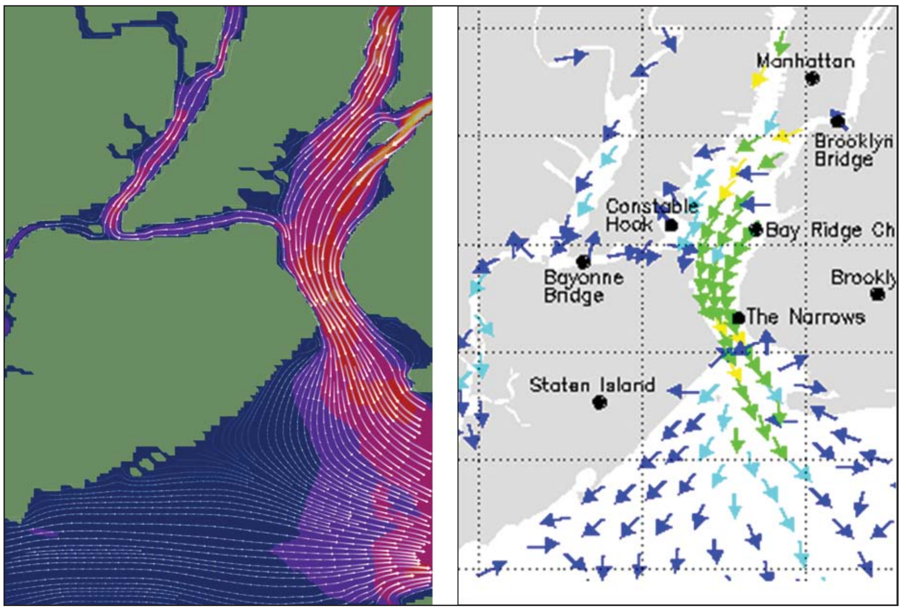


Figure 14. FlowVis2D representation in NowCOAST of the New York Operational Forecast System (left)—contrast this with the standard representation (right).

for it to be empirically validated using experiments with human subjects. The simulated visual system will be able to provide a fitness function for an optimization process and thereby it should become possible to optimize much more complex visualizations than has previously been possible. We plan to apply this to simulated chart displays.

Additionally, Ware is investigating ways to optimize the presentation of bivariate scalar maps. Representation of a bivariate scalar map is a common but difficult visualization problem. One solution has been to use two-dimensional color schemes, but the results are often hard to interpret and are often inaccurately read. An alternative is to use a color sequence for one variable and a texture sequence for another. This has been used, for example, in geology, but much less studied than the two-dimensional color scheme, even though theory suggests that it should lead to easier perceptual separation of information relating to the two variables.

To make a texture sequence more clearly readable, the concept of the quantitative texton sequence (QTonS) has been introduced. A QTonS is defined a sequence of small graphical elements, called textons, where each texton represents a different numerical value and sets of textons can be densely displayed to produce visually differentiable textures. An experiment was carried out to compare two bivariate color-coding schemes with two schemes using QTonS for one bivariate map component and a color sequence for the other (Fig. 15). Two different key designs were investigated (a key being a sequence of colors or textures used to obtain quantitative values from a map). The first design used two separate keys, one for each dimension, in order to measure how accurately subjects could independently estimate the underlying scalar variables. The second key design was two dimensional and intended to measure the overall integral accuracy that could be obtained. The results show that the accuracy is substantially higher for the QTonS/color sequence schemes. A hypothesis that texture/color sequence combinations are better for independent judgments of mapped quantities was supported. We will be exploring the applicability of these results for optimal display of bivariate data in the Chart of the Future.

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 (EM

120, 121, 300, 1000, 1002, 3000, 3002 302, and Reson 8101, 8111, 8160, 8125 and 7125, as well as Geo-Acoustics GeoSwath, Klein 5000 and 5410) data 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 2009, efforts focused on the new ME70 fisheries multibeam sonar deployed on several NOAA vessels and the GeoSwath phase-measuring bathymetric sonar deployed on the *Gavia* AUV (discussed later).

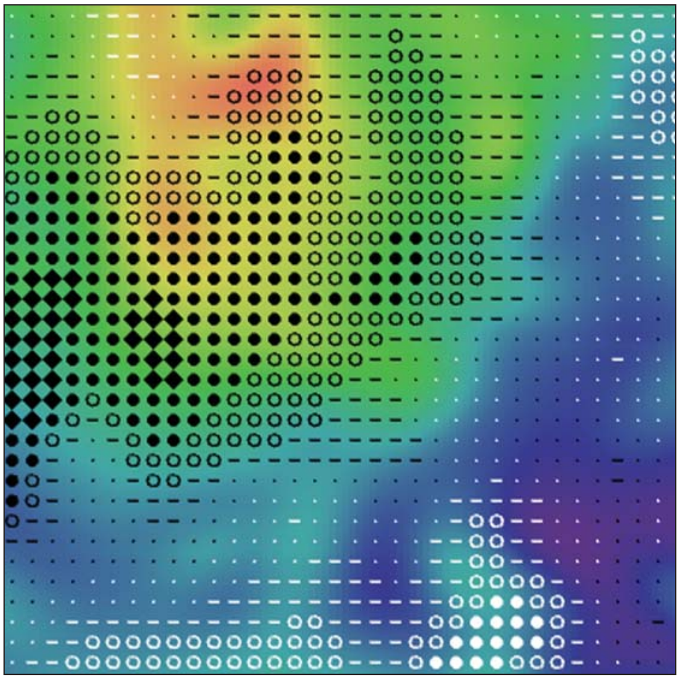


Figure 15. An example of a bivariate scalar map. One variable is displayed using a pseudo-color sequence. The other variable is displayed using the QTonS method.

If we are to use sonar backscatter data to correctly characterize seafloor properties, we want the backscatter that we measure to 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.

This past year, Yuri Rhzanov who has taken over the development of the GeoCoder/ARA program, has continued the evolution of the "thematic approach" by introducing an automatic "oversegmentation" of the mosaics and then a coalescing process that reduces the segments into a limited number of acoustic themes—spatially contiguous areas with nearly homogeneous acoustic response. A typical example of the segmentation process is presented in Figure 16. Currently the software used for the oversegmentation and coalescence stages (utilizing combinatorial optimization) are standalone modules and interaction with GeoCoder happens through intermediate data files (ASCII and images) saved on a hard drive. Future development will see all modules combined into a single binary to make the theme segmentation process almost automatic (user intervention will be needed for choosing of base classes for acoustic themes and a single parameter that describes the relative importance of smoothness of the boundaries between different themes). Acoustic-related aspects of this work were reported on GeoHab-09 conference in Trondheim, Norway.

ME70 Seafloor Characterization

The 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. Much of the work over the last year culminated in a June 2009 cruise in the Gulf of Alaska and Bering Sea during which several different ME70 configurations were assessed for their usefulness in seafloor characterization without sacrificing the ability to collect water-column data (Fig. 17). This work is being supported by NOAA fisheries through a grant from the Advanced Sampling Technology Working Group and is in collaboration with the NOAA Alaska Fisheries Science Center, the Southwest Fisheries Science Center, the Northeast Fisheries Science Center and IFREMER.

Our approach to generating bathymetry and seafloor backscatter from the relatively low beam count (<45) ME70 is to treat the system as a hybrid multibeam/interferometric system. This results in several independent soundings per beam for those beams steered away from nadir. Work to quantify the accuracy of different bottom-detection methods (amplitude or phase) is ongoing. One of the results from this work will be algorithms and software routines (likely to be MATLAB, but possibly a lower-level, higher-speed programming language) to generate soundings from standard ME70 water-column modes, which will be freely available to NOAA fisheries. Requests for help from scientists onboard the NOAA FRV *Henry Bigelow*, which also has an ME70, have led to a preliminary pilot program along this vein. ME70 operators on the Bigelow have been using a compiled version of the development MATLAB code in order to properly collect ME70 data and also to have a preliminary look at the results. One of the interesting outcomes of this work with the *Bigelow* was an examination of the shipwreck *Andrea Doria* (Fig. 18). Other applications of ME70 bathymetry and backscatter data for seafloor characterization will be discussed further under the "Water Column Mapping" theme.

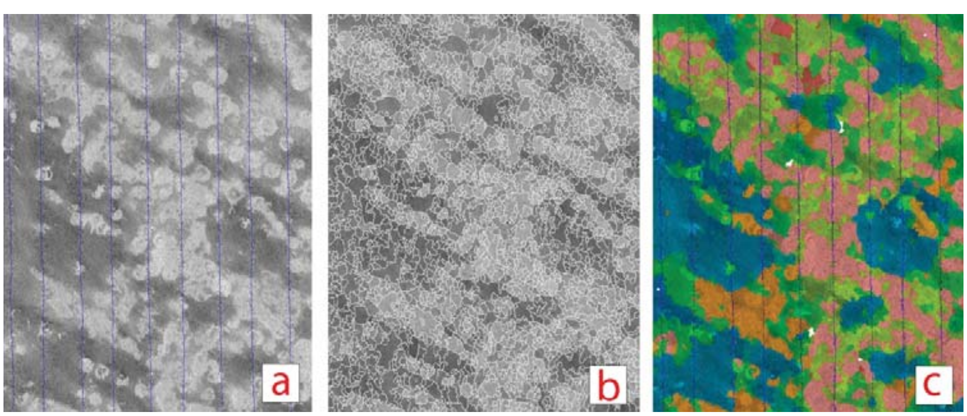


Figure 16. a) shows original backscatter mosaic with ship tracks in blue; b) shows result of oversegmentation—the original mosaic is divided into reasonably small segments, each is considered to be acoustically homogeneous; c) is the result of coalescence of segments into several themes, based on full amount of backscatter data available for each segment (as opposed to the partial data displayed in the mosaic) and proximity between the segments.

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

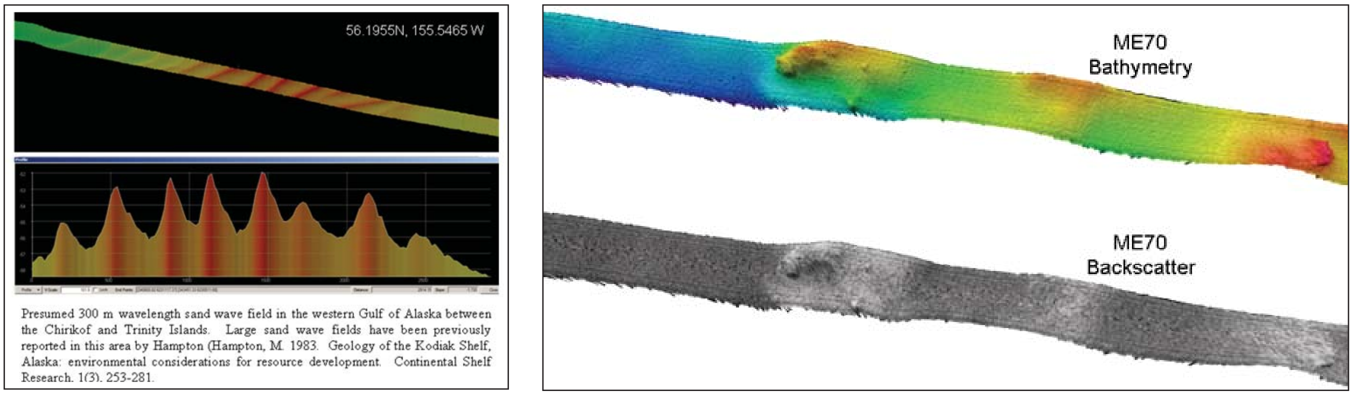


Figure 17. Bathymetry and backscatter in the Shumagins (western Gulf of Alaska) showing rock outcroppings. Depths range from 80-120 m over the 6 km long transect. Data were collected using the ME70 multibeam echo-sounder, processed in custom MATLAB software, gridded and then plotted in Fledermaus. Note that the raw soundings processed in MATLAB have not been cleaned, giving an indication of the fidelity of the ME70 data.

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.

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 EM3002 multibeam-sonar data. The two LIDAR data sets show a remarkable correlation in terms of where the bottom was successfully detected and where the two systems failed to detect the bottom. Inasmuch as these data sets were collected at very different times of the year and different state of the tide, 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 show 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 ALB bottom detection, efforts in 2009 focused on the collection of ground-truth data. Sampling and video surveys were undertaken at Gerrish Island, ME and several additional sites where LIDAR data sets have been collected (Keku Strait, AK; Merrimac River – Salisbury, MA; Portsmouth Harbor, NH-ME). The ground-truth measurements include bottom sampling and underwater video imaging. A new digital underwater camera system was developed with the aid of Andy McLeod and Paul Lavoie. The key aspect of the camera system is its small size that allows easy manual deployment from almost any vessel. More than 50 bottom samples were collected in Keku Strait, AK from the NOAA ship *Rainier* and almost 200 samples were collected along the MA-NH-ME shoreline using the R/V *Chocheco*. Grain-size analyses are currently being conducted on these samples. Additionally, algorithms have been developed to investigate the correlation between the grain size and the bottom return.

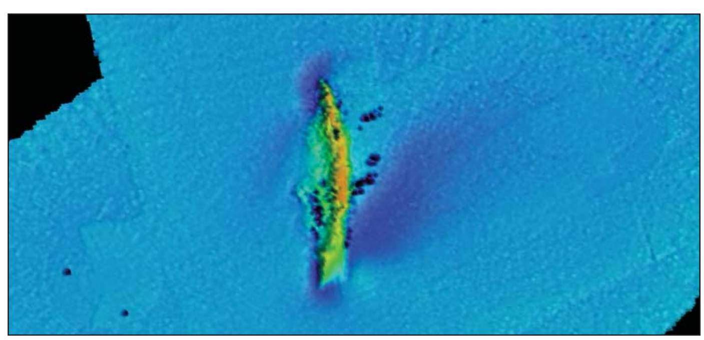


Figure 18. Shipwreck of the Andrea Doria mapped in October 2009 by the NOAA FRV HENRY BIGELOW with the Simrad ME70 multibeam sonar. Data were collected using a standard water column (non-bathymetric) mode.

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 (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.

In 2009, Morgan's work was reprocessed and reanalyzed for a publication in the Journal in Coastal Research (Pe'eri, Morgan, Philpot, and Armstrong). The shoreline assessment was done by comparing the output results of several algorithms to a reference shoreline that was digitized from aerial imagery collected at the time of an ALB survey. A threshold value for each algorithm was determined based on a dataset collected over a training site (Fort Point, NH). The ALB waveforms were then processed by the shoreline algorithms at

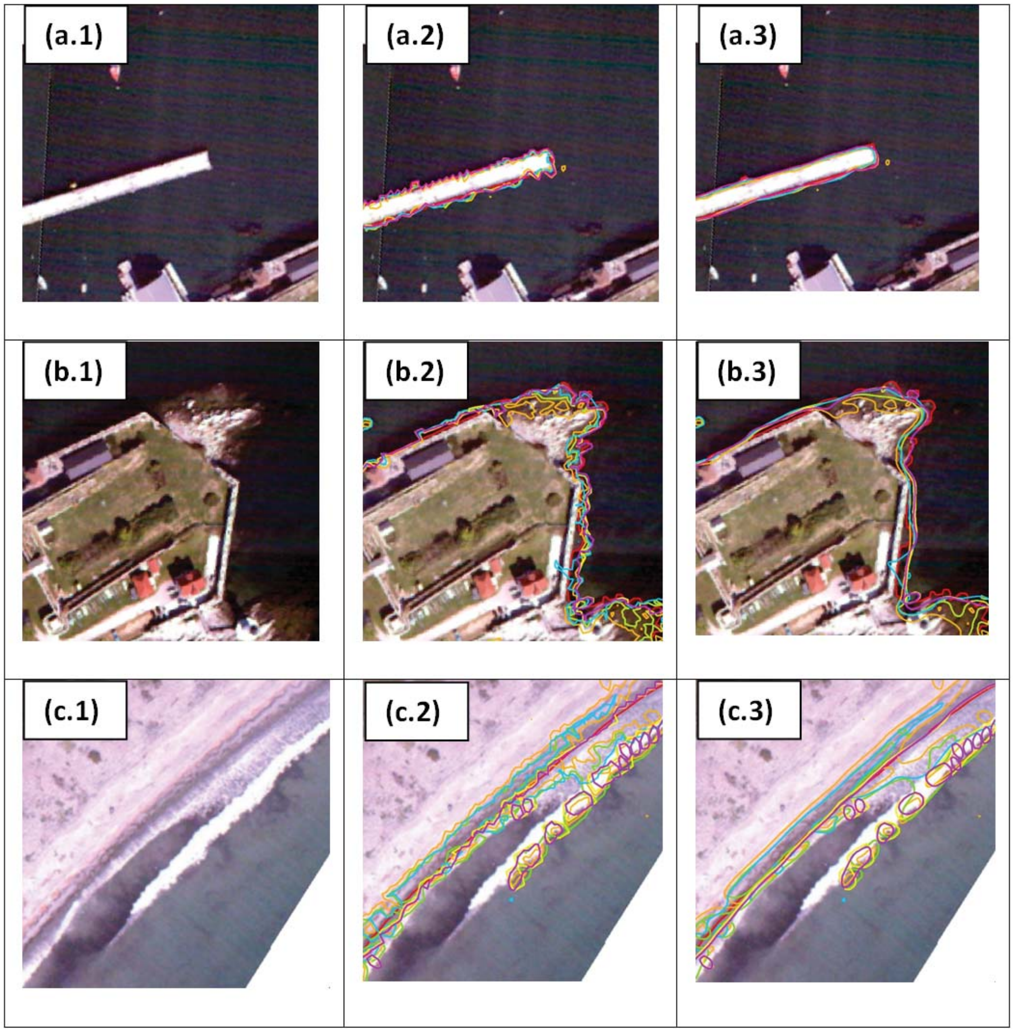


Figure 19. Shoreline mapping procedure over different coastal types showing the aerial imagery collected during the ALB survey (left column), the algorithm-shoreline vectors overlaid (middle column), and the algorithm-shoreline vectors after a PEAK smoothing (right column): (a) man-made feature – New Castle Pier, NH; (b) rocky shoreline with a man-made feature – Fort Point, NH; (c) sandy shoreline – Crescent Beach, ME. The shoreline vectors are colored as follows: IR saturation (purple), IRRc (yellow), IRRm (blue), IRRn (green), and reference shoreline (red).

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 PEAK smoothing method with a smoothing tolerance of 20 m. The location of all vertices was also extracted from the smoothed algorithm shoreline.

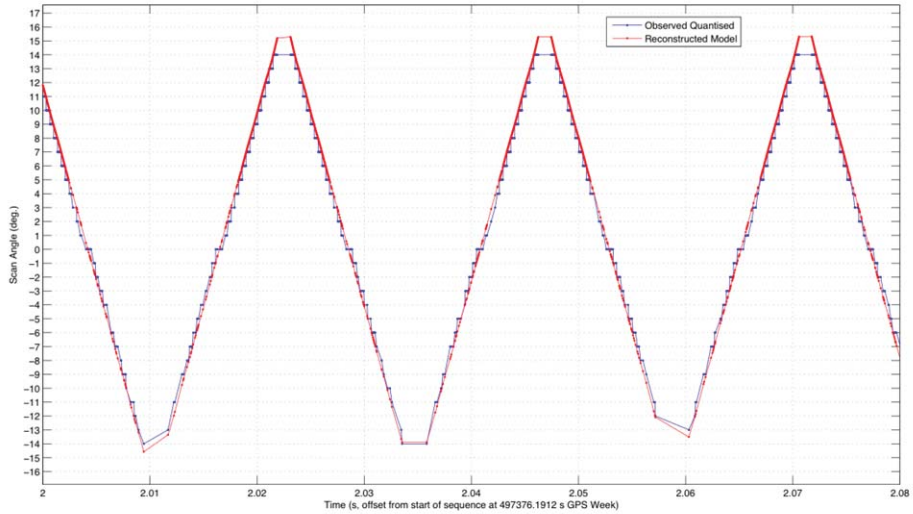


Figure 20. Example of observed, quantized, topographic LIDAR scan angles and reconstructed model angles using a Bayesian estimator. Effects of pattern irregularities, which appear to be active roll-stabilization of the LIDAR, cause complexities in the estimation that are not readily resolved using simpler estimators.

A shoreline vector comparison was conducted by examining the overall offset distance between the algorithm shoreline-vector and the reference shoreline vector at a 95% confidence level. The comparison results show that four out of the five algorithms (IR saturation, IRRn NDI, IRRc NDI, and IRRm DI) produce viable results over different coastal areas (Fig. 19). Presence of vegetation in the rocky shoreline and the presence of surf in the sandy shoreline were noticed as the two main environmental parameters affecting the algorithm results: fluorescence contribution from inter-tidal vegetation produces a bias in the red-channel waveforms, and an increase in scattering strength from bubbles in the surf. Bubbles in the surf affects both the red-channel and the IR-channel waveforms.

Shoreline Mapping—Uncertainty Evaluation of Shoreline Vectors Derived From Topographic LIDAR

An outgrowth of the work on the use of ALB to determine shorelines has been another collaborative project between Pe'eri, Rzhanov, Calder and NOAA's National Geodetic Survey (Christopher Parrish and Stephen White) to evaluate the uncertainty of the shoreline products produced from topographic airborne LIDAR. Recently, NGS has begun to develop, test, and refine procedures for mapping the National Shoreline using topographic airborne LIDAR. As these LIDAR-based procedures are now being implemented in production for certain areas of the country, good empirical accuracy assessments are needed for the purpose of generating metadata for the LIDAR-derived National Shoreline. Statistical uncertainty assessments are of great importance in performing sensitivity analysis (i.e., quantifying the sensitivity of the computed shoreline position to uncertainty in the various observations), determining when and where this method of shoreline mapping is appropriate, analyzing strategies for improving accuracy and/or efficiency in the future and informing policy decisions within NGS's Coastal Mapping Program. To look at this, a study was conducted using ALTM LIDAR data collected over three sites along the North Carolina coastline.

We quickly concluded that the production methods used by NGS for their shoreline precluded a theoretical analysis of the problem. Our approach therefore uses the Monte Carlo method. That is, through an analysis of the uncertainties inherent in the base measurements used to construct topographic LIDAR elevation estimates, we construct a number of plausible realizations of the observed data as it might have been if it were possible to repeat the experiment of the LIDAR flight a number of times. Each realization is then processed as if it were real data, and a shoreline is derived; comparisons of the horizontal positions of the shoreline yield estimates of the effects of the various uncertainty sources and, therefore, an estimate of uncertainty for the shoreline as a function of position. Effects such as slope, non-linearities in the uncertainties and other complicating factors are automatically incorporated into this analysis without further effort.

One of the complicating factors in this analysis was that the raw data did not retain the true measurements used for the elevation determination and we had to deduce these from the preserved quantized versions of angle estimates. The complex non-linear relationships between the components of the estimation, lack of knowledge of the true value of the core parameters for the LIDAR and quantization effects in the observed data necessitated a flexible estimation scheme. This problem was approached using a Bayesian estimator implemented using Markov Chain-Monte Carlo techniques. The results (Fig. 20) show a good match to the observed data and are being used for further processing and analysis.

Figure 21. HSI co-registration: HSI co-registered (top) to a mosaic frame imagery (bottom).

The first results from this analysis will be presented in a collaborative paper with NGS for a special issue of Journal of Coastal Research. We hope that this will be the start of more in-depth analyses and collaborations with NGS on the topic of LIDAR uncertainty models.

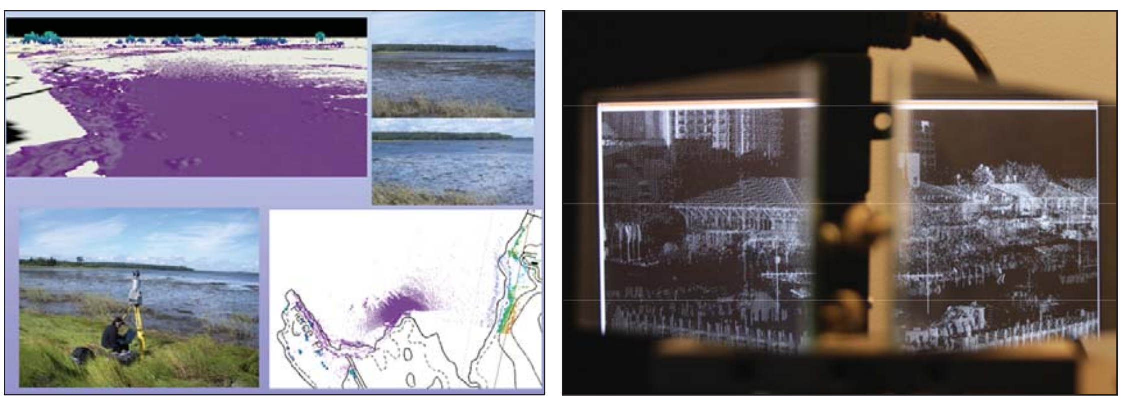


Figure 22. Left - Terrestrial laser scanning in Great Bay (September 10, 2009). Right - View of the Norfolk, VA vessel mounted LIDAR point cloud seen through the two mirrors of the stereoscope. The observer's brain will fuse the two images for stereo vision at the resolution of the human eye.

Data Fusion for LIDAR Surveying—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 mosaicking techniques that Rhzanov has developed for seafloor imagery (see seafloor characterization theme) 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 (ALB) sensor suite that includes an RGB Duncan-Tech DT-4000 camera 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 a spectral analysis that finds the best channel to be matched for both systems, defines the hyperspectral instantaneous field of view (IFOV) and the pitch angle with respect to the RGB camera, configures a correlation function between each line of the hyperspectral imagery to the RGB map and defines a skip mode to advance to the next line-to-map correlation (Fig. 21). The co-registration of LIDAR measurements with hyperspectral imagery is also being investigated. Pe'eri and Semme Dijkstra have also begun a collaboration with the Remote Sensing Division (RSD) and Spatial Reference Systems Division (SRSD) of NOAA's NGS (Christopher Parrish, Galen Scott and Nishanthi Wijekoon), aimed at understanding the potential value of terrestrial laser scanners as a tool for coastal mapping. Five sites that represent different coastal environments were surveyed: Fort Mclary and Fort Point are rocky shorelines that contain man-made features, York Harbor with a sandy shoreline confined by rocky cliffs, Point Pierce, Great Bay is a saltwater-mash coastline (Fig. 22), and Odiorne Point is a gravely/rocky shoreline that contains gravel/cobble berms. The laser surveys were accompanied with frame imagery in order to provide RGB values for each of the laser measurements. Along with understanding the optimal configuration characteristics for the system, the current effort is also exploring the potential use of laser-scanner data to establish reference networks for topographic and bathymetric LIDAR surveys, and the use of laser-scanner data in conjunction with advanced visualization tools to provide mariners, coastal managers, and others with a full three-dimensional picture of the complete coastal zone (onshore and offshore). This past summer, Kurt Schwehr acquired laser ranging (LIDAR) data from the Norfolk, VA area that was collected in 2007 by Rick Brennan. Roland Arsenault converted the X,Y,Z NAVD-88 range points to X3D and loaded them into GeoZui on the VisLab StereoScope. The results are excellent (Fig. 22).

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 (ALB) 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.

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 (Fig. 23). With the completion of the simulator ,we will be able to start conducting beam diagnostics and measuring the ray-path geometry of the LIDAR. Modeling and measurements of the laser beam will be conducted through the water column and as received from above the waters.

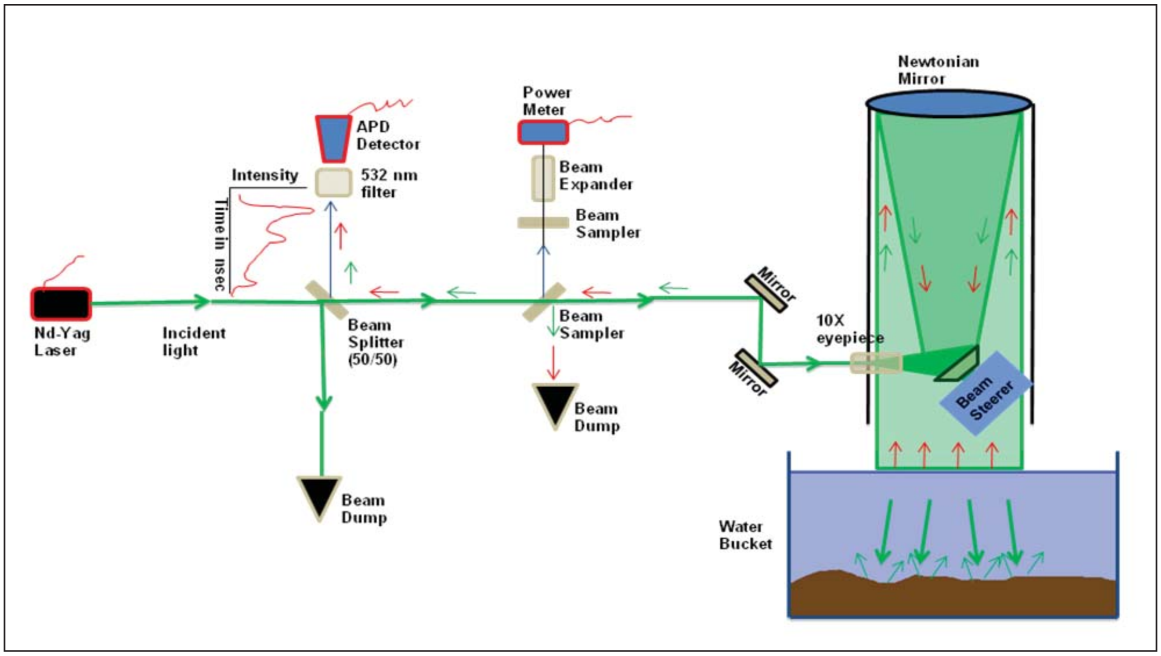


Figure 23. Schematic illustration of the bathymetric LIDAR simulator.

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 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 University of New Hampshire's Joint Hydrographic 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 http://www.ccom.unh.edu.

Following up on the recommendations made in the UNH study, Congress funded the Center (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential claim under UNCLOS Article 76. 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. Jim Gardner, NOAA contracted with Thales GeoSolutions Inc. to perform the surveys of portions of Bowers Ridge and the Beringian margin and a second cruise focused the Chukchi Cap in the high Arctic 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 125 km^2 (325 nmi^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 NAVO vessel *USNS Pathfinder*, a 329-ft, 5000 ton vessel equipped with a hull-mounted Kongsberg Simrad EM121A MBES, under the supervision of Dr. Jim Gardner. In addition to the multibeam sonar, the *Pathfinder*, also carried an ODEC Bathy2000 chirp sub-bottom profiler and a BGM-5 Bell Gravity Meter. 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 also mapped the U.S. Gulf of Alaska margin using the University of Hawaii's RV *Kilo Moana*, a SWATH (small water area twin hull) vessel with a hull-mounted Kongsberg Simrad 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 329-ft, 5000-ton vessel equipped with a hull-mounted Kongsberg Simrad EM121A MBES, under the supervision of Dr. Jim Gardner. In addition, to the multibeam sonar, the *USNS Bowditch* also carried a Knudsen chirp sub-bottom profiler and a BGM-5 Bell Gravity Meter. 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, mapping in 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* from August 17 to September 17. The *Healy* cruise collected approximately 52,835 km^2 (20,400 nmi^2) of MBES and Knudsen 320 B/R chirp sub-bottom profiles 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' *RV Northern Resolution*, a 248-ft research vessel equipped with a Simrad EM120 MBES and a GeoAcoustics GeoPulse 5430A 3.5-kHz sub-bottom profiler. The cruise required 13 days of surveying (plus 5 days of transits) and mapped 31,079km^2 (12,000 nmi^2) of seafloor.

The 2007 Marianas cruise, under the supervision of Dr. James Gardner, continued the mapping that was started in 2006. The 2007 cruise used the NAVO vessel *USNS Bowditch*, a 329-ft, 5000-ton vessel equipped with a hull-mounted Kongsberg Simrad EM121A MBES and a Knudsen 320 B/R chirp sub-bottom profiler. The gravity meter 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 *RV Revelle* with a Simrad 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 this fact 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 (HARP's) 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.

Several UNH Law of the Sea activities occurred in 2009. In April 2009, Dr. James Gardner was approached by the Cruise Coordinator of the NOAA Ocean Exploration Program to explore potential areas along the U.S. Pacific margin where the NOAA ship *Okeanos Explorer* could conduct deep-water testing of its EM302 multibeam system and to train the shipboard Survey Techs in methods of deep-water mapping. Together, they chose the Mendocino Ridge off northern California as the best location to perform these operations. This feature is one of the target areas identified by the U.S. ECS Task Force for a potential extension of the continental shelf under Article 76 of UNCLOS.

Dr. Gardner participated in the 22-day cruise that spent the first ten days in determining the causes of excessive noise infiltrating the MBES data, locating installation problems with the MBES and ancillary systems, and tracking down power-supply problems. Ultimately, a Kongsberg engineer had to join the cruise to install software and firmware patches to the system. Eventually, all of the problems were overcome and high-quality MBES data was collected. An extinction test was run in the deepest water in the area (5350 m) and the system had no problem with bottom detection at this depth.

The mapping portion of the cruise was very successful. We were able to collect almost all of the data required for an eventual ECS Task Force review of the potential of Mendocino Ridge for an extension. The mapping ranged in water depths from <100 m to deeper than 4500 m and the data were gridded at 40 m resolution.

In addition to the requirements for the ECS Task Force (2500-m isobath and zone where the foot of the slope can be located), many unexpected discoveries were made during the cruise. Perhaps the most dramatic discovery is a water-column plume (Fig. 24) that rises ~1000 m from a large failure along the margin (Fig. 25). This margin is seismically active with many known

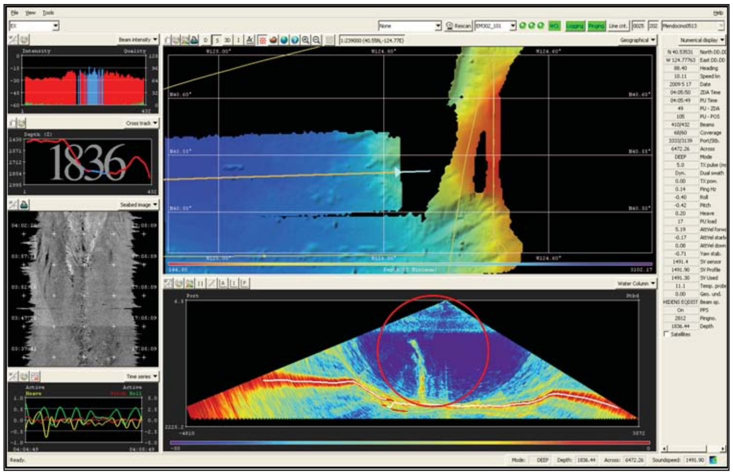


Figure 24. Screen shot of plume (lower panel red circle) rising from the seafloor.

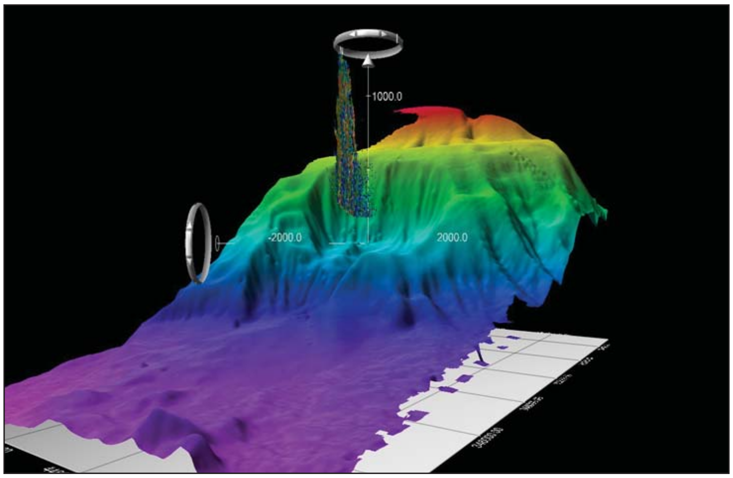


Figure 25. Perspective view of large landslide where plume rises 1400m from seafloor. Vertical exaggeration 6x, looking NE.

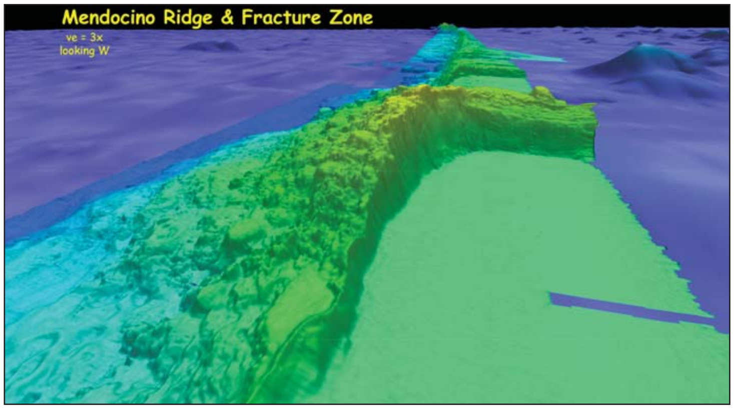


Figure 26. Perspective view of extensive volcanic field at large drag fold between younger (right side) and older (left side) sides of the Pacific Plate. Vertical exaggeration 3x, looking to the west.

failures, so the failure was not surprising. However, the plume of that size was quite a surprise.

Other discoveries include areas of intense volcanism at the outer bends of large drag folds developed between the Gorda Ridge section of the Pacific Plate and the adjacent, presumably defunct section of the Pacific Plate (Fig. 26), zones along the Mendocino Fracture Zone where the ridge changes from a single ridge to a double ridge with what appears to be a pull-apart basin between them, and the mapping of the meandering Mendocino channel (Fig. 27). The channel has a sinuosity index of 1.38 and has developed many features that resemble those found on similarly meandering subaerial channels.

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 1% 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.

The Canadian icebreaker *Louis S. St.-Laurent* (*LSSL*) departed Kugluktuk, NU on 6 August while the *Healy* departed Barrow, AK on 7 August, hoping to rendezvous on the 9th or 10th of August. The *LSSL* was delayed by heavy ice and a detour to Barrow to allow a crewmember to disembark. During this time the *Healy* scouted for the ice pack, encountering it at approximately 75° N. The vessels rendezvoused on 11 August and conducted a seismic source calibration experiment to document the source levels and source signatures of the *LSSL's* airgun array.

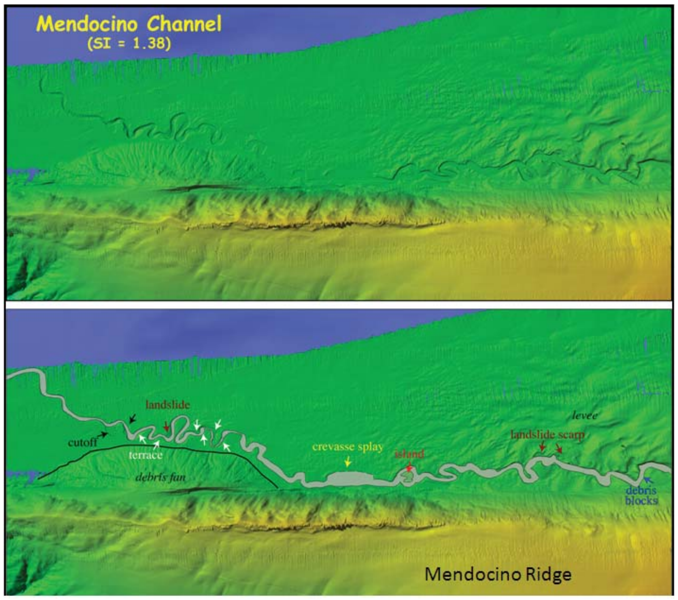


Figure 27. (Top panel) Map view of Mendocino channel and (bottom panel) interpretation of channel features.

After concluding the seismic source calibrations on 12 August, the *LSSL* deployed its hydrophone streamer, the *Healy* took the lead and the vessels stayed together in the ice until 7 September. By 7 September, the ice had diminished to the point that the vessels were able to separate, the *LSSL* continuing to collect seismic data and the *Healy* collecting multibeam bathymetry and sampling the seafloor with dredges. Over the course of the expedition, the *LSSL* collected more than 4000 km of high-quality multichannel seismic reflection, refraction and gravity data (Fig. 28) 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 – Fig. 29).

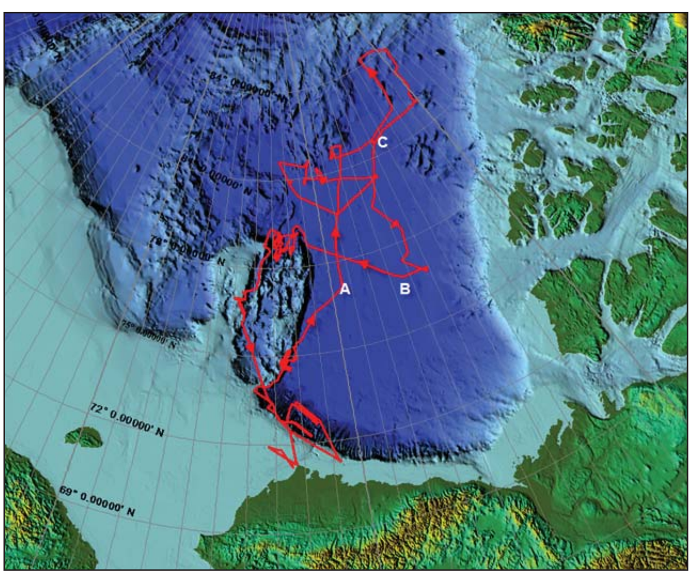


Figure 29. HLY-0905 track line. Point A is the rendezvous point for LSSL and HEALY on 11 August. Point B is where the two vessels separated on 7 Sept. 2009. Point C is the newly mapped seamount.

During the time the two ships were together, the *Healy* mostly broke ice ahead of the *LSSL* during long transects across the deep Canada Basin. The multibeam bathymetry collected during these transects revealed a remarkably flat abyssal plain with an average depth of around 3850 m and changes in depth of less than 20 m over hundreds of kilometers. On several occasions, the mapping priorities changed and the bathymetric surveys were conducted over targets of interest. Among these targets of interest were the mapping of the foot of the slope in an area on the southern side of the Alpha-Mendeleev Ridge complex (at approximately 81°30'N, 143° 45'W) and the examination of several topographic features that were implied on earlier bathymetric compilations. One such feature that appeared as a single 100-m isobath (above the abyssal plain) on a Russian chart turned out to be an 1100-m high, 26-km long, 7.5-km wide seamount. Most remarkably, this seamount appears in a region of the abyssal plain where there are no other bathymetric features for hundreds of kilometers in all directions (Fig. 30).

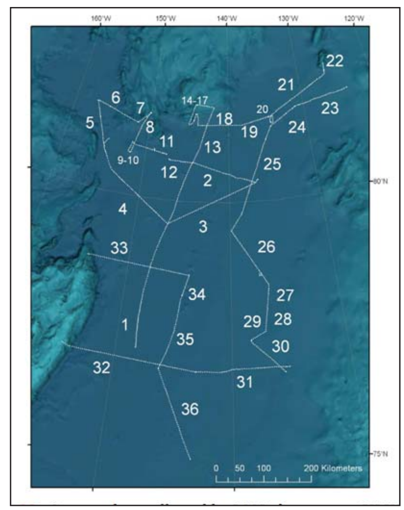


Figure 28. Seismic data collected by LSSL during joint HLY0905.

On 7 September, the ice conditions had evolved to the point where the *LSSL* could continue to collect seismic data without the *Healy* breaking ice ahead. At that point, the *Healy* left the *LSSL* and started to map independently. 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. The majority of the material recovered appeared to represent several types of basalts.

There was also a large amount of manganese crust and in the Chukchi region, numerous metamorphic rocks. These samples have been sent to the appropriate labs for full description and analyses.

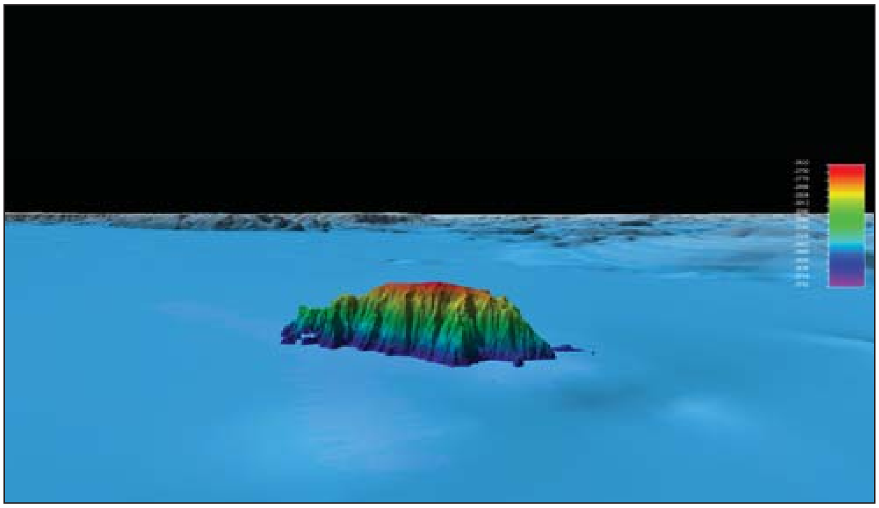


Figure 30. The newly mapped seamount (see Figure 29 for location).

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. In May 2009, Jim Gardner received all of the multibeam bathymetry collected by the USGS during the their 2008 UNCLOS Arctic seismic cruise. Data were separated into that portion collected in the Canadian EEZ and that collected within the U.S. EEZ. The Canadian data were archived on a secure and restricted server, whereas the U.S. data were added to our publicly available archive. The data were converted from raw datagrams, exported into an ASCII xyz format, and projected into a north polar stereographic projection so that they could be combined with all the previously collected Arctic multibeam data archived at JHC/CCOM. Additionally, the JHC/CCOM UNCLOS website has been updated with the new UNCLOS multibeam data (2009 Mendocino Ridge and Arctic surveys). This involved generating metadata files for all gridded data as well as metadata for each multibeam line (122 files for the Mendocino survey and 504 files for the Arctic). All of these data and metadata files are archived at JHC/CCOM as well as at NOAA/NGDC in Boulder, CO.

To date, the Center has collected more than 1,198,000 km^2 (462,550 nmi^2) of new, high-resolution multibeam-sonar data in regions that have never before been mapped in detail (Fig. 31). 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 (should the U.S. choose to make a submission to the United Nations for and Extended Continental Shelf under UNCLOS Article 76), but from a scientific perspective, has provided tremendous new insights into the nature of continental margin processes and our 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 non JHC/CCOM researchers as well as UNH graduate student theses.

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

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 2009, the Center hosted a major workshop focused on data management related to ECS issues.

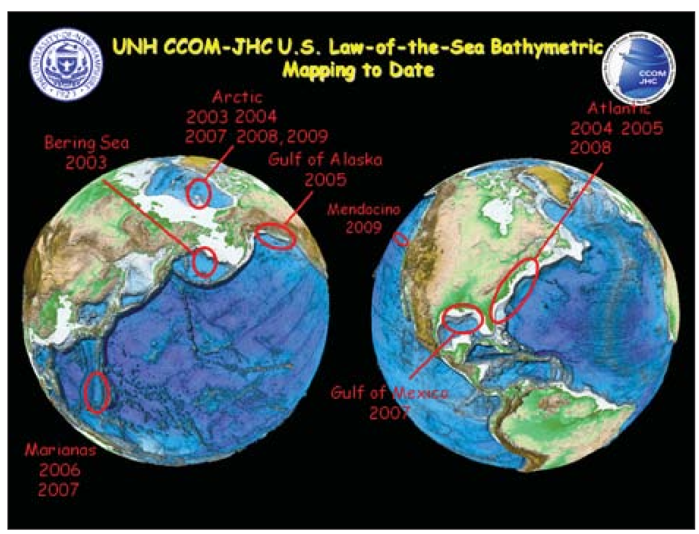


Figure 31. JHC Law of the Sea surveys as of December 2009.

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 is taking 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."

In conjunction with electronic charting component of e-Navigation, Alexander continues working with three of the Center's Industrial Consortium partners (CARIS, SevenCs, and ICAN) on a prototype "Tide Aware" ENC. 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 has involved water-level information from NOAA's PORTS (Norfolk, VA) and the Canadian Hydrographic Service SINICO (St. Lawrence River between Quebec City – Montreal). In July 2009, Alexander was invited to attend the Dynamic ENC Project Meeting at the Korea Maritime and Ocean Engineering Research Institute (MOERI) in Daejeon, South Korea.

In addition to tides/water level, 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 required for use in an ECDIS. 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, we have 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. Highlights of some of these applications are described on the next three pages.

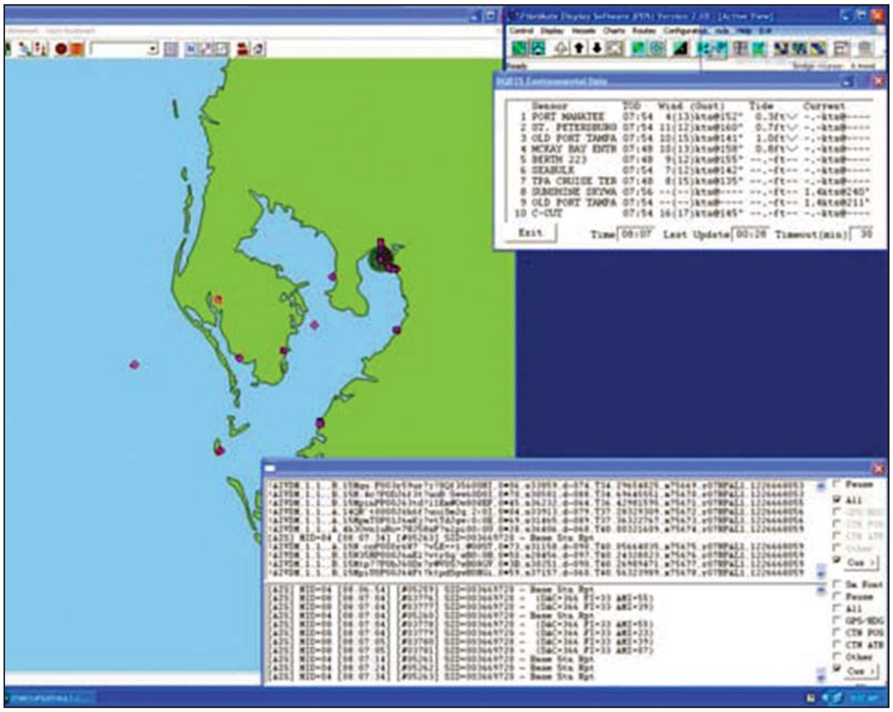


Figure 32. NOAA PORTS information displayed at the Tampa Bay Cooperative VTS Center.

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 US 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 (Figure 32). 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 to determine an appropriate process to convert selected NOAA nowCOAST data into AIS binary messages that can be broadcast to mariners. They 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). Alexander co-chairs the RTCM SC121 Working Group dealing with the extended use of AIS within VTS. Recently, the work of this group was merged with that of a European working group through an IMO correspondence group. This new group was able to generate a document that was presented the IMO NAV 55 conference: Revision of the Guidance on the Application of AIS Binary Messages, Report from the AIS Binary Messages Correspondence Group, Submitted by Sweden, Annex 1, Guidance on the use of AIS Application Specific Messages. The Area Notice message (DAC 01, FI 22) is based on Schwehr's initial work on the Right Whale notice message for the Boston approaches.

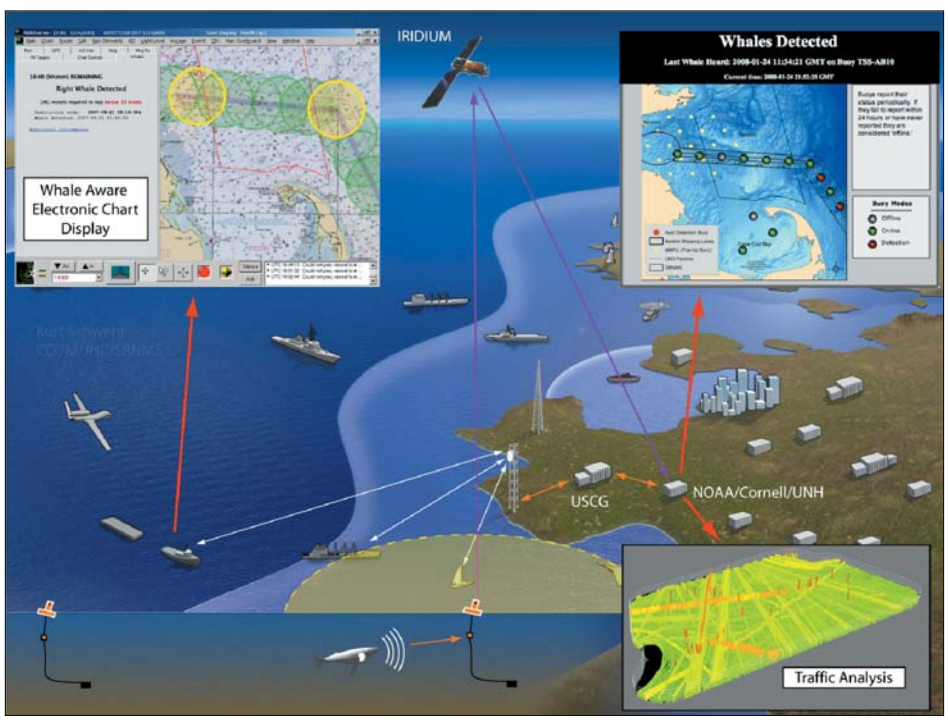


Figure 33. AIS binary message broadcast scheme for Right Whale locations in Stellwagen Bank National Marine Sanctuary.

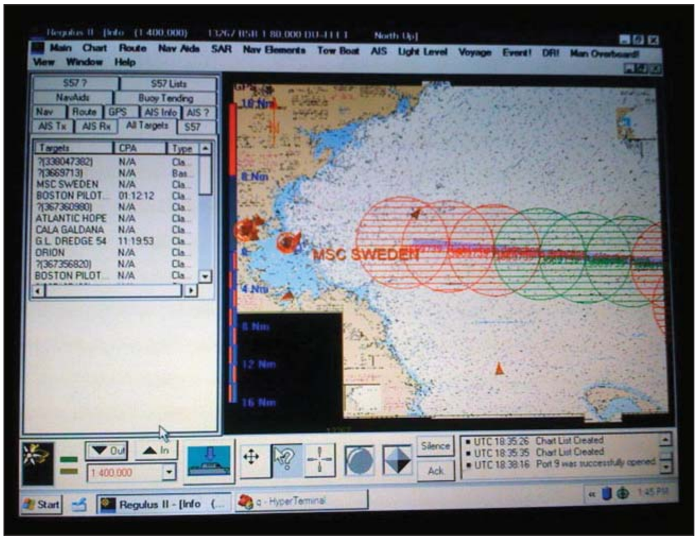


Figure 34. ICAN Regulus II being operated by the SBNMS to view the right whale AIS notices.

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 (Fig. 33). 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 Cornell University. Staff in 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 (Fig. 34).

The Right Whale AIS Project is now nearing the point where mariners will be able to test the system. The transmitter at Cape Cod has been operational for more than half a year. However, the USCG has decided to go with a new zone message and Schwehr is working to create the reference implementation and transitioning to using this new message format for the messages being sent out over the Boston approaches. Schwehr had his first meeting with Gateway and Neptune, the two companies with LNG terminals off of Boston. The system can be seen in action at http://www.youtube.com/watch?v=mN1IFdgAEiA.

It should be noted that the Right Whale AIS project has been highlighted by the White House Draft 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 Cornell to help the Neptune terminal construction comply with their reporting requirements by providing ship tracking information for the vessels involved in the construction of the terminal. The visualizations are able to show the vessels backfilling the pipeline from the terminal back towards the shore (Fig. 35).

Figure 35. AIS ship tracks showing just the Neptune Construction vessels for approximately a two month period in 2008.

AIS for Sanctuary Management

Schwehr is continuing to work with the Stellwagen Bank National Marine Sanctuary on techniques for processing AIS data to support management of marine sanctuaries including interfaces to Google Earth (Fig. 36).

AIS Vessel Traffic for Hydrographic Survey Planning

Schwehr and Brian Calder have continued discussions with Kyle Ward and other NOAA staff on how to use AIS data to help better understand hydrographic survey priorities. The group met at the US Hydro Conference and is working to define a test scenario that can be used to understand the issues. NOAA is now able to log its own AIS data and is using Schwehr's noaadata software library to put AIS traffic into databases.

Figure 36. Transit evaluation visualization in Google Earth for detailed analysis of SBNMS ship transits in 2008.

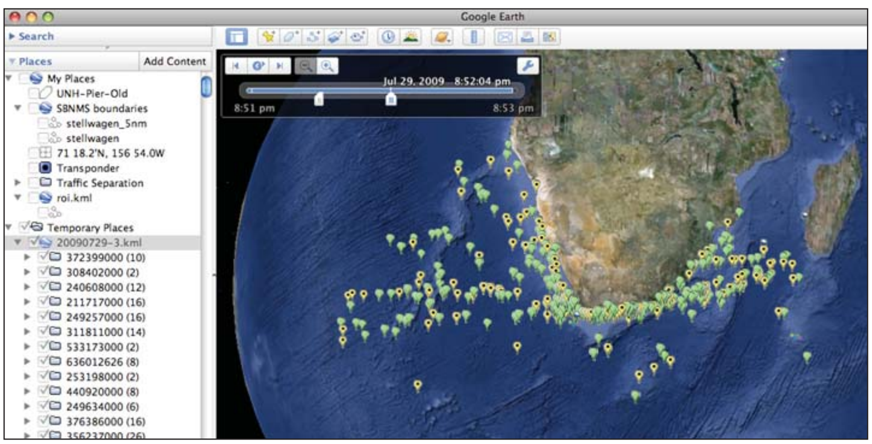


Figure 37. Two minutes of data from AprizeSat 3 and 4 over South Africa. This was Kurt's first visualization of Space base AIS (S-AIS). Data courtesy SpaceQuest.

AMVER, VOS, Satellite AIS and LRIT

Existing AIS technology is good for short line-of-sight tracking. The Center is looking at ways to extend these analyses to longer ranges. Ben Smith completed initial work on parsing the NOAA Automated Mutual assistance Vessel Rescue System (AMVERS) and the WMO Voluntary Observing System (VOS) reports. The results are good, but the system only has volunteer reporting. Schwehr has been working with Mark Kanawati and Glenn Richardson of Space Quest to evaluate AIS receivers in Space (S-AIS – Fig. 37).

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 (and in the description of the flow visualization above). 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 scenes.
- 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

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

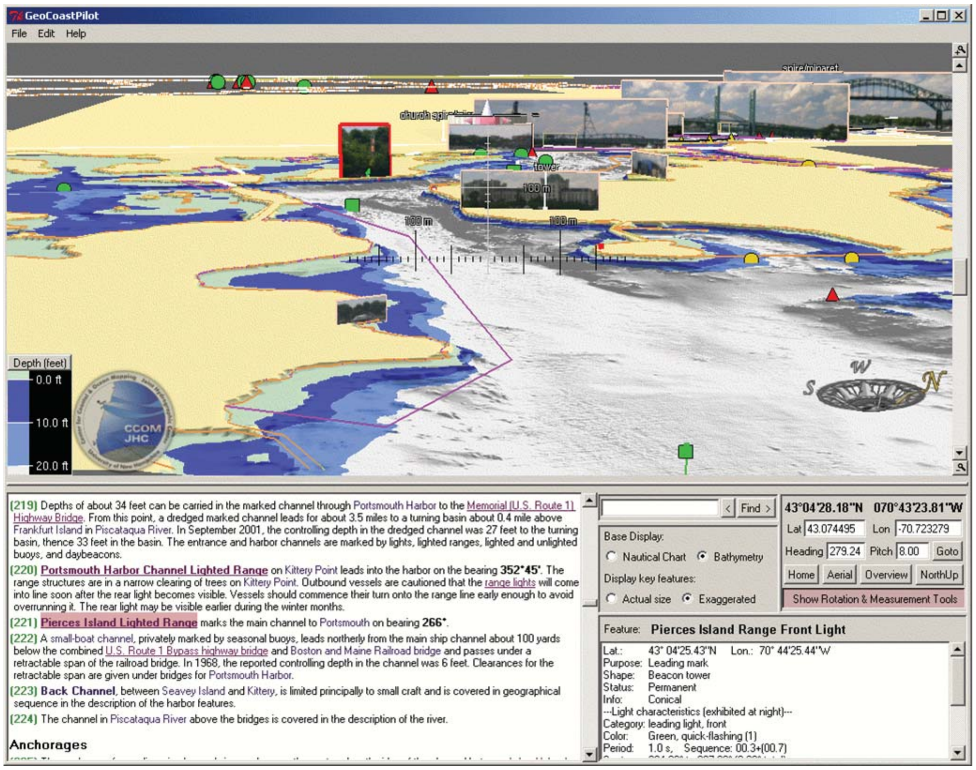


Figure 38. Image captured from the "GeoCoastPilot" showing approach to bridge in Portsmouth Harbor.

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 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 (Fig. 38). GeoCoastPilot turns the NOAA Coast Pilot manual into an interactive document linked to a 3D map environment, providing linkages between the written text, 2D and 3D views, web content and other primary sources such as charts, maps, and related federal regulations.

GeoCoastPilot introduces two new capabilities to existing marine information products: multiramas and hyperlinks. First, a multirama is a collection of photos of a landmark or a navigation aid taken from multiple vantage points. The multiamas 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 (ENC's), 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 first place in the Coast.

New developments in GeoCoastPilot include the ability to deal with maps at multiple scales that 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 geo-referenced imagery that can have widespread application including in Google Earth.

In an effort to help in the future direction of the GeoCoastPilot, Briana Sullivan has been working on a web-based GeoCoastPilot. The plan is to utilize the Google Earth API and the Google Earth browser plug-in to display the locations (Boston and Portsmouth for now) of the Coast Pilot with associated Coast Pilot text and eventually the images, S-57 data as well as bathymetry data. The hope is that these GeoCoastPilot features will be placemarks in Google Earth, where clicking on a model or image will show its associated information. This will make the proof-of-concept quicker to code, make it available for others to develop on a commonly used platform (instead of just within GeoZui4D) and make it more accessible.

Kurt Schwehr presented a paper for the GeoCoast Pilot group at the IEEE Oceans MTS/Biloxi Fall 2009 Conference. As part of that presentation, we have been looking more into what others have done. Although there are many interesting projects underway, it has become clear that the GeoCoastPilot is still unique in the level and quality of integration.

The Spatially Aware Hand-Held Navigation Aid

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 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 away from other potentially critical tasks. It seems logical that a spatially aware hand-held navigation aid may substantially reduce the difficulty of the task.

Small touch screen devices, such as tablet PCs and newer generation cellphones, can be fed GPS position together with orientation information (and many are now coming with GPS integrated into them). 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 (Fig. 39).

Figure 39. A mockup of a handheld spatially aware navigation aid. Note that precise registration is not needed to make the correspondence between char objects and on-shore objects obvious.

The near-term objective is to carry out human-factors studies of the potential benefits of having a hand-held spatially aware navigation aid. The tasks to be investigated will involve matching an object in the external world (a buoy, another ship, a land-based feature) to one on the digital chart display. This will be done both starting with the chart object and starting with the external object.

We are proceeding by building simplified prototypes and conducting human-factors studies. The chief developer for this project is Roland Arsenault while Colin Ware will design the studies.

Metadata and Google Earth

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.

First, he has begun building UNIX "magic" file definitions for sonar, lidar, seismic, and other types of data used in maritime exploration and research. He hopes to contribute the more robust definitions to the open source UNIX file software and encourage vendors to move towards formats that more readily identifiable by the file contents as file extensions repeatedly prove to be unreliable ways to identify what type of data is in a file. It would be a worthwhile service to the community to start creating an online catalog of sample data file and documentation. Additionally, Kurt has built a SEGY validator that examines SEGY files and reports all fields that appear to be out of compliance with SEGY Rev 1. The hope is that this will provide software developers with a tool that will help them understand the quality of their SEGY output.

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. A tool was created to generate Google Earth KML bounding boxes with placemarks containing the full metadata records (Fig. 40). Based on this work,

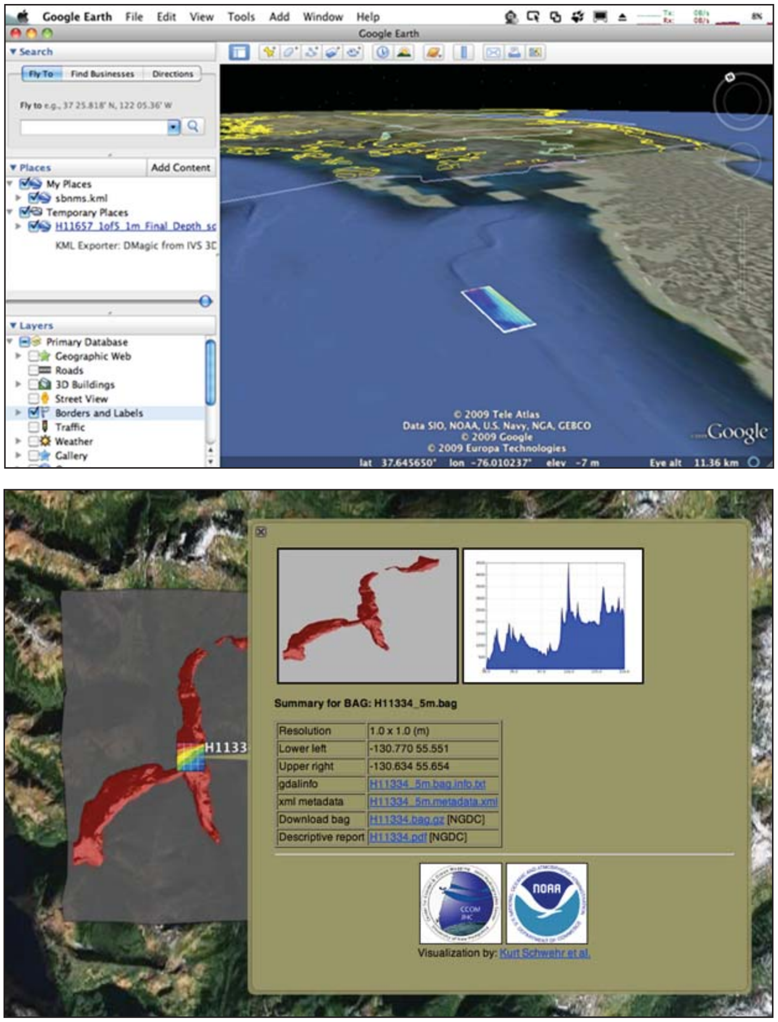


Figure 40. NOAA BAG displayed in Google Earty (top) and metadata provided with the BAG when interrogated in Google Earth (bottom).

Kurt found several rough areas in the BAG creation procedure at NOAA. Most importantly, there needs to be consistent use of the title and abstract fields of the "citation" entry such that automated processing provides results that make sense to the viewer. Currently, the title often contains a MS Windows share path that is a temporary processing location when the bag is created. These have been discussed with Shep Smith and will be passed along to CARIS and the processing team at NOAA. Additionally, this work has reiterated that it is essential for the BAG specification and software to start using the compressed HDF5 option. The uncompressed data require so much disk space that it is hard to work with a suite of bag files all at once.

Finally, Kurt has begun some work on a spider program to explore disks for geospatial content that can be automatically identified. This work depends on the additional magic file definitions and is progressing slowly. The target is to be able to search and identify duplicate data (using a hashing algorithm), file owner, date, and (if possible) spatial extent. The goal is both cataloging what data we have at JHC/CCOM and identifying duplicates and scratch areas that do not need to be archived.

Water Column Mapping

In 2006, we began an exciting new project aimed at exploring the use of the new generation of mid-water sampling-capable multibeam sonars to allow real-time visualization of targets in the water column. Visualization of these mid-water 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.

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 mid-water visualization software has evolved to the point where it is now being transferred to the commercial sector. The Center

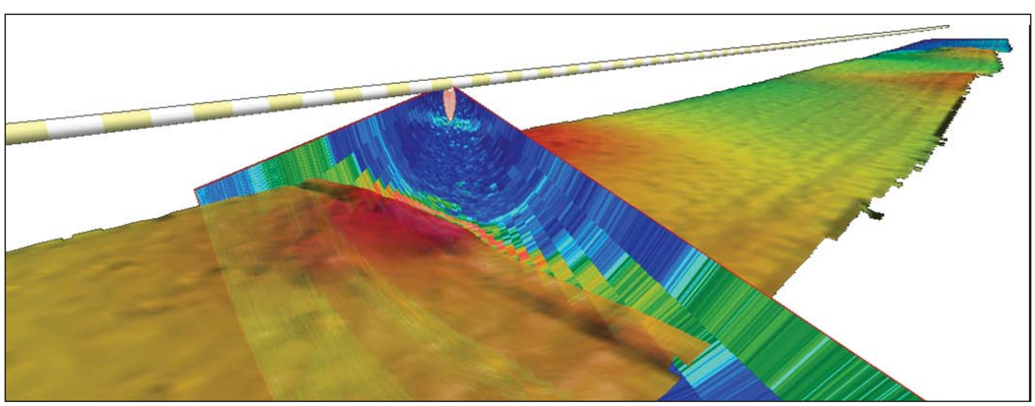


Figure 41. ME70 water column and seafloor bathymetry visualized in the new Fledermaus mid-water tool (bathymetry processed off-line by JHC/CCOM software).

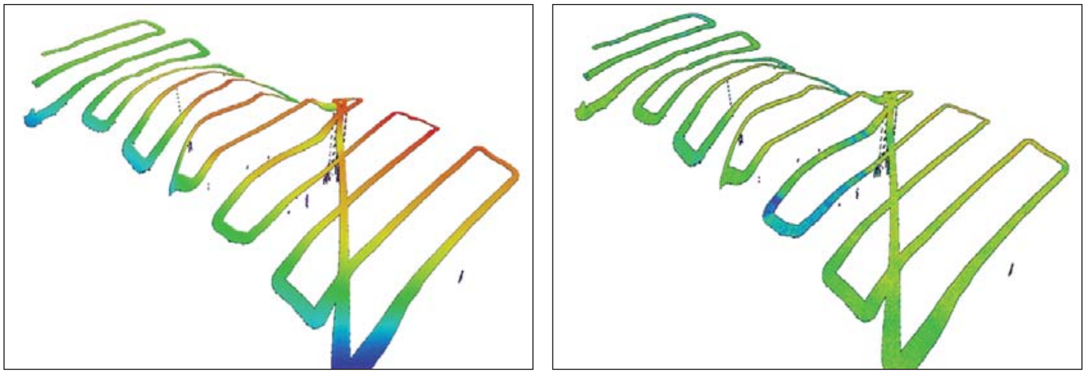


Figure 42. Bathymetry derived from the ME70 data during one of the large scale surveys (red is shallow, blue is deep) is shown on the left. Seafloor backscatter, also derived from the ME70 data (red/yellow indicates higher backscatter, blue indicates lower backscatter) is shown on the right.

and industrial associate IVS-3D have been collaborating on the development of a new multibeam mid-water visualization tool that will be integrated into IVS-3D's Fledermaus software. This project, which has deep roots in GeoZui-4D, is currently at the stage where IVS-3D has a beta version that is being used by researchers at CCOM, NOAA Alaska Fisheries Science Center, and others (Fig. 41). Great potential has been shown for examining wrecks, fish, and gas plumes (including the exciting discovery by Jim Gardner and Mashkoor Malik of the giant gas plumes off Mendocino (see Law of the Sea theme). Weber's role has been to offer technical expertise on multibeam sonars capable of mid-water mapping, including the ME70, and also as an enthusiastic beta tester of this software.

Assessing Rockfish in Untrawlable Habitats

Weber has further extended his ME70 mid-water mapping work to the important issue of assessing rockfish habitat. 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 NPRB-funded study is aimed to develope assessment techniques in untrawlable areas using state-of-the-art 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, and are being processed to characterize both fish aggregations and seafloor habitat. Preliminary results describing both bathymetry and seafloor backscatter from one of the large-scale surveys in the study side are shown in Figure 42. These data can be used as an aid to classify the seabed as trawlable or untrawlable, and can also be used to help provide linkages between seabed types and rockfish abundance. Water-column data collected during the large-scale surveys show evidence of several fish aggregations throughout the survey site (Fig. 43), some of which occur off the vessel trackline and thus may not have been observed by standard fisheries single-beam sonars. Where the fish are patchy, the wider field of view of the ME70 may produce a less-variable estimate of relative abundance than the standard fisheries EK60. Observations of fish aggregations collected with both the ME70 and the EK60 during the large-scale surveys were used to select targeted areas for smaller, high-resolution surveys. One of these fine-scale surveys is shown in Figure 43 with several bubble plumes in the region (large ver-

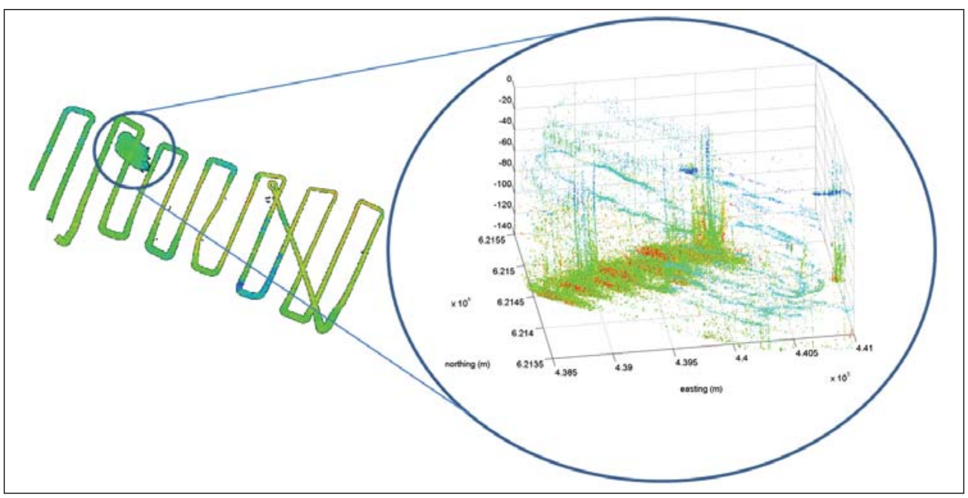


Figure 43. Seafloor backscatter (a proxy for bottom type) from the large scale survey on the left, and the water column backscatter (Sv) from the highlighted area collected during one of the fine scale surveys. In the highlight, apparent bubble plumes appear light blue with a high vertical extent and narrow cross section. Rockfish appear aggregated in a 'carpet' around the base of the plumes (red and green).

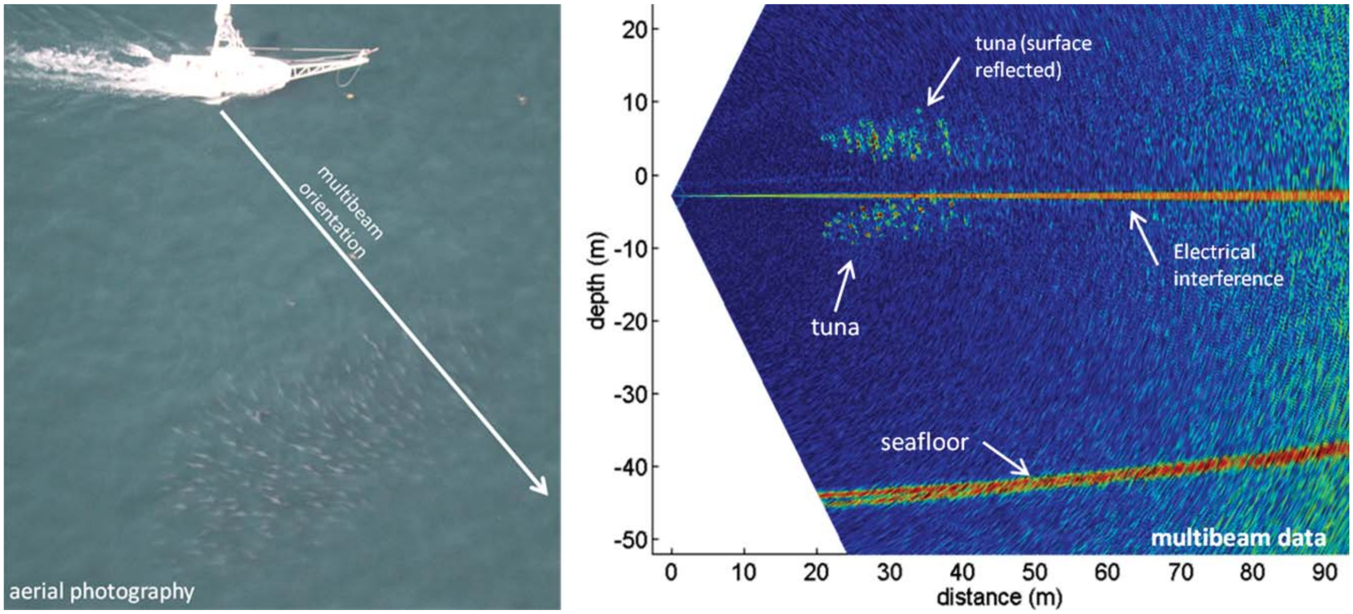


Figure 44. Simultaneous aerial photograph and multibeam data showing a school of juvenile bluefin tuna. The multibeam sonar was located on a side mount on the vessel in the aerial photograph, and oriented in the direction shown.

tical extent and narrow cross section) possibly of methane, and a large number of rockfish aggregated near the bottom. This indicates that there may be a linkage between the bubble plumes and the rockfish, although it is not clear whether this linkage is direct or indirect (i.e., it is possible that there is a linkage between the seabed type and the bubble plumes, and that the fish are present because of the seabed type rather than the bubble plumes; several other possibilities also exist).

Additional mid-water multibeam activities by Weber include an August 2009 experiment using a 400-kHz Reson 7125 multibeam sonar to image juvenile bluefin tuna. In many cases, individuals were resolved, making direct counts and fish-packing densities estimates feasible. These data were collected in collaboration with Molly Lutcavage from the UNH Large Pelagics Research Center on a project funded by the Northeast Consortium. In addition to the multibeam-sonar data, this field effort include aerial photography that is being processed with help from Shachak Pe'eri and Yuri Rzhanov. This adds a second dimension to our data; the multibeam sonar images a vertical slice through the water, but does not detect the entire school in any one ping (nor, realistically, is it possible to estimate the school size from several of these pings because of the mobility of the fish); and the aerial photography gives us the horizontal dimensions and morphology of the fish (when they are near the surface), but not necessarily the vertical spacing of the fish within the school. An example of juvenile bluefin tuna school data are shown in Figure 44. Here, individuals can be detected in both the aerial footage and in the multibeam data.

Yet another project is examining of spatial heterogeneities in fish schools and its impact on volume reverberation for low/mid frequency sonars (funded by ONR). Work has begun on collecting some of the data that will be used for examining fish schools in collaboration with other researchers and other projects. This includes work with Jason Stockwell at GMRI, who is using a combination of the SP90 omni-directional multibeam sonar with multi-frequency EK60 single-beam echosounders to examine Atlantic herring in the Gulf of Maine; work done with Chris Wilson and Sarah Steinesson at the NOAA Alaska Fisheries Science Center, who have data from schooling juvenile pollack in the Gulf of Alaska and the Bering Sea collected with an ME70; and the work with Molly Lutcavage imaging juvenile bluefin tuna described above. Weber will be working with all of these researchers to process the mid-water data in order to examine school structures. These school structures will then be incorporated into an acoustic model for reverberation.

AUV Work and the Harbor Tracking and Observatory Project

In 2006, we 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 DOERRI 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 (Fig. 45). Additional capabilities include sensors for temperature, sound speed, salinity (derived), dissolved oxygen, chlorophyll and turbidity, a downward-looking camera and a Marine Sonics 900 kHz/1800 kHz sidescan sonar. The new system is a much more mature AUV than the FETCH, with imagery, bathymetry, and particularly positioning capabilities far beyond the original vehicle. We have also purchased a WHOI acoustic modem for the new vehicle that will allow enhanced positioning and two-way communication.

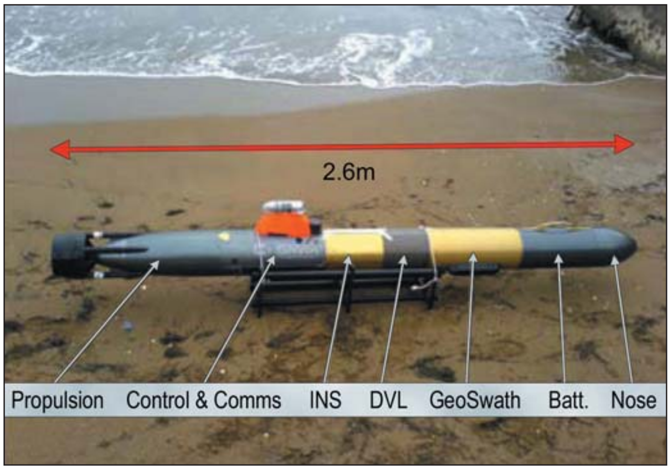


Figure 45. GAVIA AUV with GeoSwath Phase Measuring Bathymetric Sonar.

Val Schmidt is providing support to both the UNH 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.

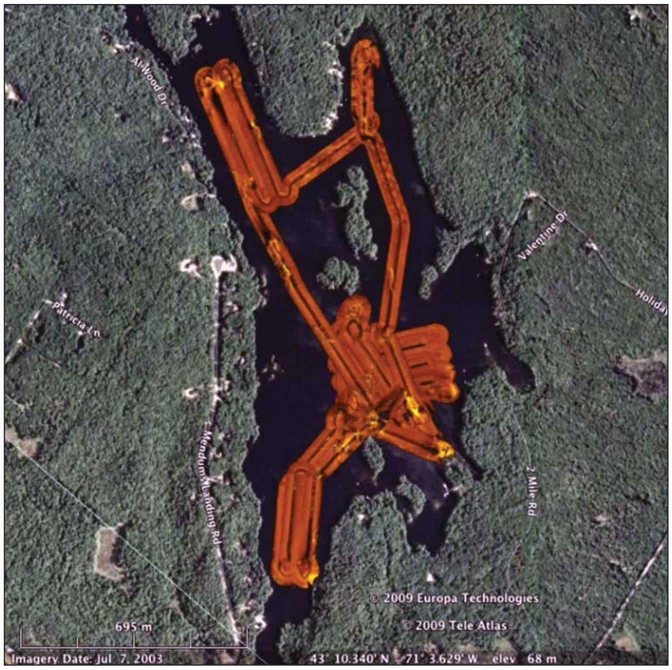


Figure 46. Sidescan coverage of Mendum's Pond from the Gavia AUV during AUV Bootcamp 2009.

In the first week of June 2009, the Center hosted an AUV Bootcamp for both UNH and University of Delaware researchers, graduate students, and engineers. The event consisted of three days of field operations at the UNH recreation center on Mendum's Pond, interleaved with two days of class time. Class time was filled with training on the processing of Geoswath data by Tom Hiller of GeoAcoustics and Fledermaus 7 training by Erin Heffron of IVS-3D. The week's training and missions allowed us to develop and refine operations as well as manage and process data. Sidescan data from a representative mission is shown in Figure 46.
Many other AUV surveys took place in 2009. These included:

- Four benthic habitat mapping missions in Delaware Bay in search of tube worm colonies (Ph.D. work of Univ. of Delaware student Nicole Raineault).
- "AUVs on the Bay"—an AUV operator and educator's workshop hosted by the NOAA Chesapeake Bay Office.
- University of Delaware TIDE program—a science summer camp for high-school students. This event included coverage by the Philadelphia NPR affiliate (WHYY).

- Lake Tahoe survey in search of the invasive Asian Clam. We were collaborators in this event hosted by the Tahoe Environmental Research Center and University of British Columbia.
- ONR-funded seafloor characterization survey off Nantucket and Martha's Vineyard.

As we have evaluated the data from these missions, considerable effort has gone into understanding the sensors and their data quality. Much remains to be done, but one of the more significant findings is the bathymetric data artifact shown in Figure 47, in which 80 cm oscillations are evident in the seafloor bathymetry as across-track bumps.

The artifact was shown to result from pressure fluctuations in the AUVs depth sensor from large surface swell. Artifacts of this magnitude are of great concern because the International Hydrographic Organization specification for total propagated vertical uncertainty for the most stringent "special order" surveys is just 26 cm in 10 m of water depth. After many hours of discussions with the manufacturers of the AUV and the inertial navigation system, it was determined that the AUVs inertial navigation system was not being used appropriately (or at all) for providing the AUVs depth estimate. We corrected this problem and the reprocessed data removed much of the artifact (Fig. 48). Nonetheless, considerable engineering needs to be done to further validate the method and to remove the depth biases that invariably occur in the inertial solution over long periods.

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, we also began a project in 2006 designed to install a fixed acoustic navigation array in a portion of Portsmouth Harbor. 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.

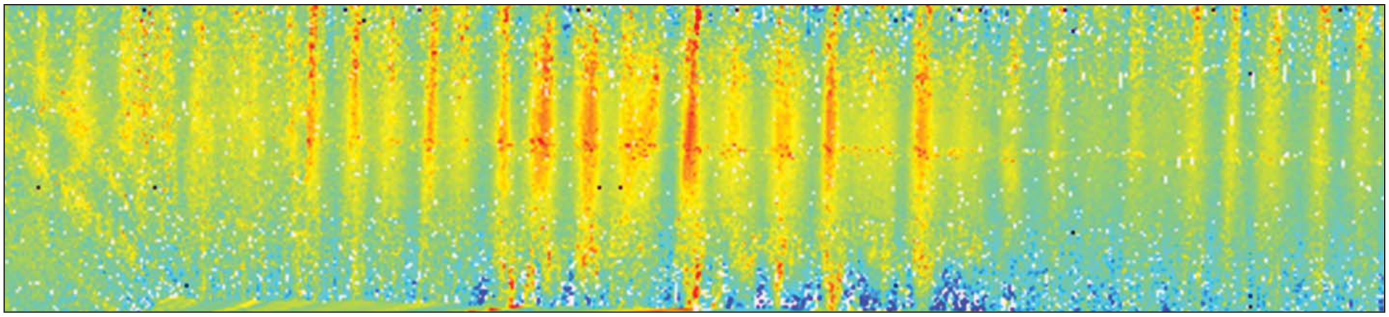


Figure 47. Surface waves (swell) can induce pressure fluctuations in the depth sensor aboard the AUV, which is then imparted to the seafloor measurement shown here.

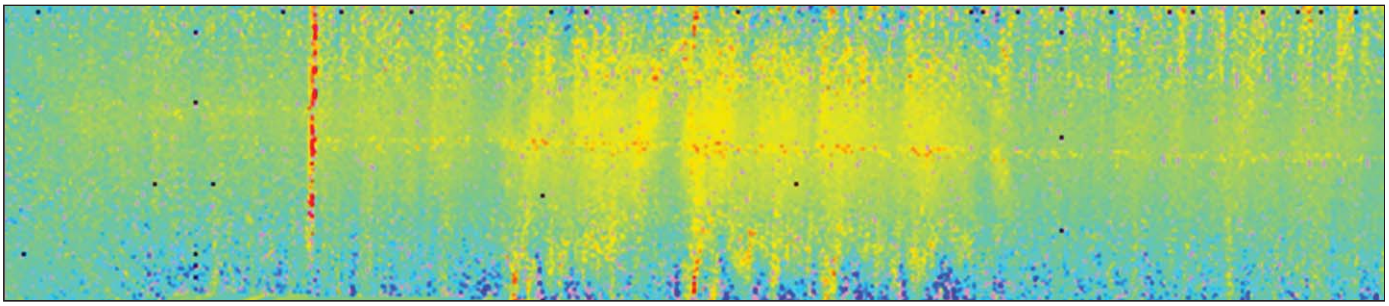


Figure 48. Seafloor bathymetry in which the AUV's depth is taken from the inertial navigation sensor preventing the influence of short duration pressure fluctuations from surface waves.

Figure 49. Upper left: Jim Irish and Tom Weber working on buoy #1 in the lab. Upper right: buoy #1 floating in the acoustic test tank during initial testing. Bottom: the 'guts' of buoy #1.

This past year, the Harbor Tracking project has been in a buoy-construction mode and significant progress has been made. This has been a combined effort principally between Tom Weber, Val Schmidt, Paul Lavoie, Jon Hunt, and Jim Irish. Two buoys have been constructed thus far (Fig. 49) and both buoys were field tested with the Univ. of Delaware GAVIA AUV (Fig. 50). Three modes of operation have been successfully tested with the GAVIA AUV:

1. Round-trip ranging from the buoys to the GAVIA. This is a slow update rate positioning method (~0.25 Hz), but requires no interaction between the AUV mission computer and the AUV modem. The only requirement is that the AUV modem be powered on. This method is not optimal for positioning, but is useful as a fall-back in case of a software problem on the vehicle.
2. One-way ranging between the buoys and the GAVIA (see Fig. 50). A short FM pulse is emitted from the AUV and observed on the buoys. These transmissions are synced on the AUV GPS 1 PPS, giving an update rate of 1 Hz. The modems on the buoys are also synced to GPS 1 PPS, and the time of arrival of each reception is used to calculate the range from each buoy to the AUV.
3. Buoys acting as a communication gateway to the AUV. During a mission, the acoustic modem on the AUV can transmit mission-critical information (e.g., battery power, current position estimate) back to the control center on shore. This traffic can be routed through any buoy, greatly extending the range/coverage at which the AUV can be monitored in real time during a mission.

In addition to acoustic tracking, one of the buoys was deployed as a tide buoy (exploiting the RTK GPS installed on the buoy) during the July survey of Great Bay (see discussion below) for approximately one month (Fig. 51). This served two purposes: it provided the benefit of a reliable tide gauge for the Great Bay survey; and provided the Harbor Tracking team an opportunity for a long-term deployment shakedown.

The combination of testing with the AUV and the long-term tide gauge deployment validated the buoy design. The next several months will see minor architecture changes and a move to a lower-frequency RF link, but the general buoy concept appears to be sound.

Figure 50a. Field trials at Mendums Pond. Upper left: Jon Hunt and Tom Weber deploying the buoys from the sailing dock. Upper right: the RTK base station used for broadcasting corrections to the buoys. Bottom: Jon Hunt and Michele Heller towing the buoys out for deployment.

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

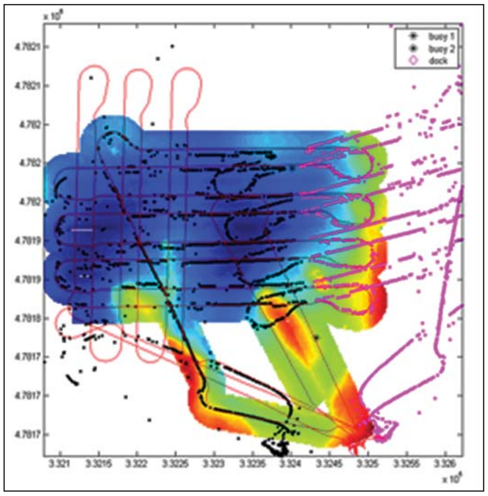


Figure 50b. AUV position estimates derived from buoy data. Note that the position estimates are reflected about the line intersecting both buoy locations. This ambiguity can be broken by working on only one side of the buoys, or by adding additional buoys. The AUV estimate of its track is shown in red, and the position estimates from the bouy are shown as black and magenta dots. The background describes the bathymetry; note that one of the buoys was placed behind a shoal area, causing poor performance in the north-western section of the pond.

it to critical coastal-process questions of relevance to NOAA. Both Larry and Tom have just begun their efforts at the Center, but none-the-less, they are making important contributions and quickly integrating with the work of others (Pe'eri, Rzhanov, etc). 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 Dr. James Irish who provided the MATLAS 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 Tom has developed the Coastal Bathymetry Survey System (CBASS), a personal watercraft equipped with differential GPS, single-beam 192-kHz acoustic altimeter, and onboard navigation system (Fig. 52).

The CBASS has been used extensively within rugged marine environments such as the surf zone where breaking waves are present, in very shallow fresh water bodies around the Great Lakes and inland rivers near bridge piles. Estimated accuracy of the survey system is 0.07 to 0.10 m in the vertical and on the order of 0.1 to 1.0 m horizontally, depending on the water depth and bottom slope. The high maneuverability of the personal watercraft makes very shallow water bathymetric surveys possible, particularly in regions where airborne remote-sensing systems fail because of water-clarity issues or where repeated high-resolution surveys are required (e.g., where an erodable bottom is rapidly evolving). It is particularly useful where shallow hazards prevent the use of vessels with larger drafts. We have used it extensively to survey very shallow regions around Portsmouth Harbor (Fig. 53). Lippmann has been funded to equip the CBASS with a new digital single-beam sonar this year and has a proposal with ONR for upgrading to a multibeam sonar.

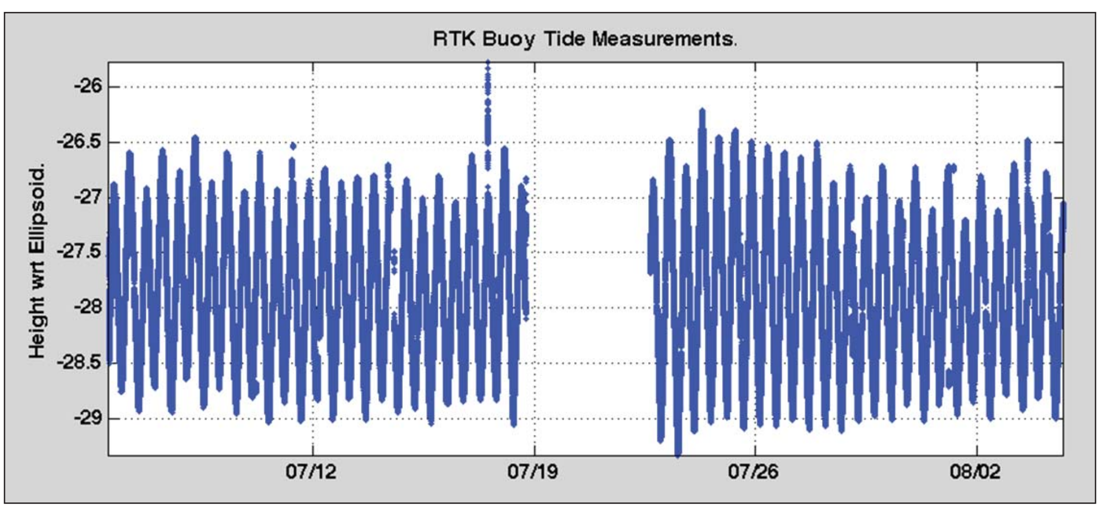


Figure 51: Tide measurements (re: ellipsoidal height) made from RTK-equipped tracking buoy.

Figure 52. The Coastal Bathymetry Survey System (CBASS) operating in an energetic surf zone. The CBASS is equipped with single-beam echo-sounder and differential GPS, and is capable of measuring the bathymetry in shallow water with accuracies on the order of 0.10 m.

Great Bay Survey and Data Compilation

Larry Ward began a research project during this reporting period 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 (that will be stored on a server at JHC/CCOM); creating bathymetric maps from several survey periods (1898-1913, 1950-1955, and 2001-2007); and conducting a bathymetric comparison to assess depth changes (change analysis). This project was recently completed with the bathymetric archives created, the methodology for conducting comparisons between bathymetric surveys developed and tested, and comparisons between two NOS surveys (1913 and 1953-1955) for the upper estuary. Interestingly, the major finding of this study was 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.

During this analysis, it became clear that many of the historic datums that were used have been either lost or were unreliable, creating a clear need for a new comprehensive baseline survey. Given historical datum issues, it was decided that new data would be collected with respect to a reference ellipsoid (WGS84). For hydrographic purposes, we also need to refer the data 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 (Fig. 54). The CBASS was used to survey the entire bay region at 100 m line spacing utilizing its single-beam echosounder. A portion of the southeast part of the estuary was surveyed at higher resolution (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.

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 we define the depth based on consolidated sediment. The data collected and processed so far give a fairly good indication of where the 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.

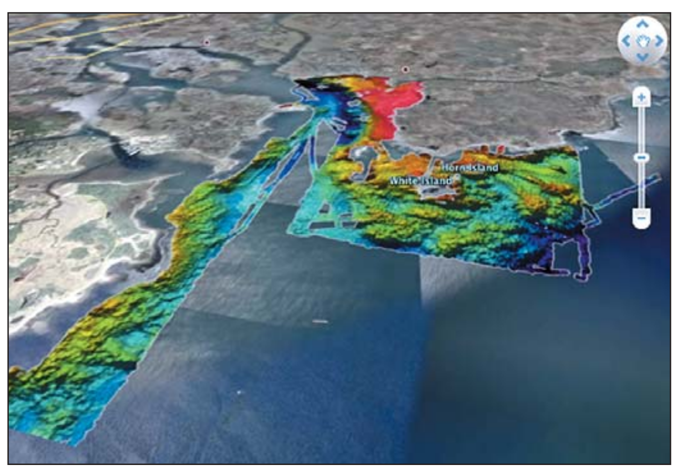


Figure 53. Oblique image showing the bathymetry measured with the CBASS around Portsmouth Inlet overlaid on satellite imagery from Google Earth. The depths range from 0.5-25 m.

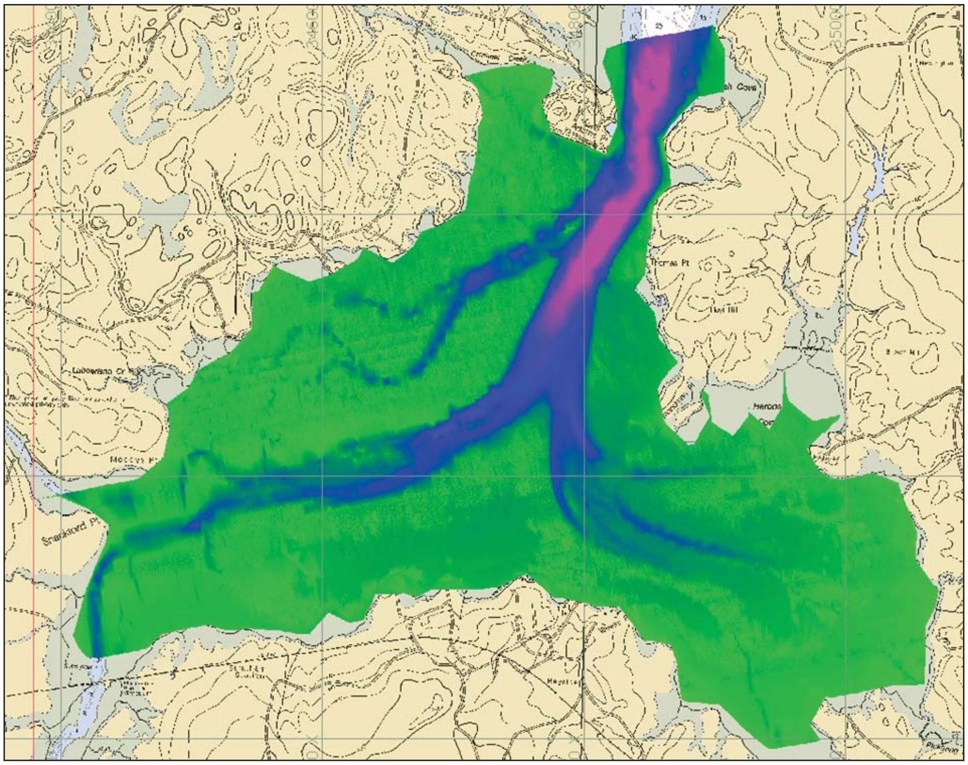


Figure 54. Results of the 2009 Great Bay survey. Note that the presence of eelgrass can be observed by an increased noise level. This data has great potential for post processing with the TracEd tool.

IOCM Processing Center

One of the major events of this past year was the completion of an addition to our 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 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.

The first NOAA employees to arrive have been from OAR's Ocean Exploration Program (Mashkoor Malik and Meme Lobecker). We have been working 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 a workshop specifically designed to address the question of data production on board *Okeanos Explorer*. We have put the "telepresence console" to good use as we have provided technical support to the vessel from the Center. In addition, Jim Gardner took part in the sea acceptance trials for the multibeam sonar for *Okeanos Explorer*, during which important contributions to the U.S. Law of the Sea program were also made (see Law of the Sea theme). The Center is also hosting employees of NOS's Marine Modeling and Development Office who are working with our visualization group developing visualization tools for NOAA's nowCOAST. The most recent arrivals to the IOCM Processing Center are Glen Rice and Megan Greenaway from the Office of Coast Survey. Glen is a NOAA Corps officer who will be specifically looking at bathymetric issues related to the Office of Coast Survey and Megan is a physical scientist who will be developing protocols for backscatter data collection.

Outreach

We have formalized and increased our outreach activities with the addition of Colleen Mitchell (graphic design—part-time) and David Sims (scientific writing—part-time) in addition to Briana Sullivan (web-based outreach) to our outreach staff. 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. This year, our work has been featured in numerous articles, from sources such as *Science*, *National Geographic*, National Public Radio's *Earth and Sky*, *The New York Times*, the Associated Press, and the CBC. Some highlights are:

DATE	TITLE	SOURCE
2009-10-26	Indiana School Welcomes Home NOAA 'Teacher at Sea' from Arctic Voyage Teacher Discovers New Seamount	NOAA
2009-10-06	Technology shows local ocean maps outdated	*SeacoastOnline.com*
2009-09-24	Fledermaus Technology Used in 1400 Meter Plume Discovery Off the Northern California Coast	*PR-USA.net*
2009-09-22	Healy makes stop in Kodiak	*Kodiak Daily Mirror*
2009-09-16	Scientists collaborate in exploring continent's extended continental shelf	Media-Newswire
2009-09-10	Welcome to Earth's "New" Ocean: The Arctic	*The New York Times - DOT EARTH*
2009-08-12	NOAA Joins Other U.S. Agencies and Canada to Survey the Arctic Continental Shelf	NOAA
2009-07-29	Canada and U.S. to Conduct Second Joint Survey of Extended Continental Shelf in the Arctic	*Foreign Affairs and International Trade Canada*
2009-07-29	US, Canada Arctic expedition to start	Associated Press
2009-07-29	U.S. Pushes for Law of the Sea Ratification as New Arctic Mapping Project Begins	*The New York Times*
2009-06-19	Law of the Sea: A Final Push to Divvy Up the Sea by All the Rules	*Science*
2009-04-15	Healy Mapping Mission - Arctic Landgrab	*National Geographic*
2009-02-09	Arctic Melt: Reopening a Naval Frontier	*Proceedings Magazine*
2009-01-29	Battle for the Arctic	CBC
2009-01-26	Video Update on Tussle Over Unfreezing Arctic	*The New York Times*

Other outreach activities for this year have included tours for Alton High School students, a career day hosted by Andy Armstrong, a tour for visitors from Poland to the Durham Rotary Club and representation of JHC/CCOM at the 1st annual New Hampshire Technology Festival at Pinkerton Academy in Derry, NH.

Website Upgrades

In an effort to maximize the website's usefulness, Briana Sullivan has been working to make all JHC/CCOM-related publications and activities easily accessible. This includes user options to display publications by topic (related to each of the major research themes as outlined in the annual progress report). Each research section of the website now has a list of related publications to make them more accessible to visitors of our site. A major effort in 2009 has been undertaken to update the Law of the Sea web pages. With the establishment of a web database, it is relatively effortless to add current publications and cruise reports and display them on the Law of the Sea publications page. Now, all publications related to the Law of the Sea work are displayed, and a filter allows the web user to narrow their results to types of papers for the Law of the Sea, such as all cruise reports or published articles.

One of the Law of the Sea webpages showing data from mapping expeditions in the Atlantic Ocean.

Part of the "make-over" for the Law of the Sea website was also to aggregate all relevant data into one page and to have a "dash-board" view of what is happening with each cruise area. All images for each area are displayed in context with any related reports and zipped data files. Specific zipped data files and their associated metadata files are displayed concurrently with each rendered image of the related data set. The data page is also more succinct and makes all of the data for all of the cruises available on one page. The image page for the Law of the Sea will also follow this single page idea, making it easier for our web visitors to see everything that is available to them in a glance without having to search different pages or tabs.

Partnerships and Ancillary Programs

One of the goals of the JHC is to establish, through its partner organization the Center for Coastal and Ocean Mapping, 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 BV
- C&C Techologies, Inc.
- CARIS, Inc.
- Chesapeake Technologies
- EdgeTech
- Electronic Navigation Ltd.
- Environmental Systems Research Institute, Inc. (ESRI)
- Fugro Pelagos, Inc.
- GeoAcoustics, Ltd.
- Geocap
- HYPACK, Inc.

- ICAN, Inc.
- IFREMER
- Instituto Hidrografico
- Interactive Visualization Systems Inc. (IVS)
- IXSEA Inc.
- Knudsen Engineering Limited
- Kongsberg Underwater Technology, Inc. (KUTI)
- L-3 Communications Klein Associates
- Marport Canada Inc.
- ODIM Brooke Ocean Ltd. (ODIM)
- Odom Hydrographic Systems, Inc. (Odom)
- Ohmex
- QinetiQ
- Quality Positioning Services B.V. (QPS)
- Quester Tangent
- RESON, Inc.
- Science Applications International Corporation (SAIC)
- SevenCs GmbH
- Substructure Inc.
- Teledyne Benthos, Inc.
- Triton Elics International, Inc.

In addition, grants are in place with:

- ConocoPhillips Company
- Cornell University
- IVS-3D Inc.
- N.H. Sea Grant
- National Science Foundation
- Nippon Foundation
- North Pacific Research Board
- Office of Naval Research
- 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 $1.4 M from a total commitment from other sources of approximately $4.6 M (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		Credits
Required Courses:		
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	GIS 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

Tower of Power, (TOP); 1 January–30 June, the USACE Field Research Facility in Duck, NC, Ongoing daily video data collection from automated, remote land-based system in Duck, NC. (Lippmann)

Oceanic Transform Faulting: Foreshocks, Seismic and Aseismic Slip on the Quebrada, Discovery and Gofar Transforms 7 January – 5 February, R/V *Atlantis*, Recover the forty ocean bottom seismometers and seven geodetic instruments that we deployed in 2007/2008 and complete multibeam mapping of the area. (Boettcher)

Oscar Dyson gear trials, 19-22 January, R/V *Oscar Dyson*, Assist in ME70 set-up. (Clark)

Nearshore Bathymetric Estimation from LIDAR-based Airborne Imagery, 1 March-30 June, Cessna 172/182 aircraft, Develop new digital airborne video system for remote bathymetric measurements in shallow water. (Lippmann)

NOAA Ship *Okeanos Explorer* Field trials, 29 March-4 April, R/V *Okeanos Explorer*, Mapping Lead. (Malik)

Larry Ward's and Jim Irish's Nearshore class, 9 April, Beach deployment at Hampton Beach, Deploy and recover ADCP at Hampton Beach; Survey beach topography with differential GPS; As part of Nearshore Classroom field exercises. (Lippmann)

Multi-scale Interdisciplinary Study of Humpbacks and Prey (MISHAP), 18 April-12 June, R/V *Laurence M. Gould,* Visualization and interpretation tools for developing a multi-scale trophic level model encompassing the food chain: meso-scale zooplankton→krill→Humpbacks; Emphasis on Humpback feeding behaviors. (Ware)

Multi-scale Study of Humpbacks and Their Prey (MISHAP) 2009, 18 April-12 June, R/V *Laurence M. Gould*, Improved tools for adaptive prey sampling. Integrated various data into GeoZui4D; Assisted with krill sampling. (Arsenault)

Seafloor Characterization-Optical Imagery, 4 May, R/V *Gulf Challenger*, Operate Benthos ROV to obtain video footage of offshore wreck. (Huff)

EX09-03, 5-26 May, NOAA Ship *Okeanos Explorer*, Map the bathymetry and acoustic backscatter of the eastern Mendocino Ridge. (Gardner)

NOAA Ship *Okeanos Explorer* Field trials, 5-26 May, NOAA Ship *Okeanos Explorer*, Expedition coordinator. (Malik)

Keku Strait, 18-29 May, NOAA Ship *Rainer*, Bottom samples and underwater video imagery in a LIDAR-survey area. (Pe'eri)

Shallow Water Bottom Characterization from Single-beam Echoshounders 1-30 June, CBASS; Coastal Bathymetry Survey System; Develop new capability to digitize single-beam echo-sounder signal for seafloor bottom characterization. (Lippmann)

Great Bay Mapping Project, 1 June-15 August, R/V *Limnulus*, R/V *Raw Deal* and R/V *Coastal Surveyor*, Positioning; Acoustic data collection and processing bathymetry data. (Dijkstra)

Hydrographic Field Course, 1 June-1 July, R/V *Cocheco*, R/V *Coastal Surveyor*, and R/V *Galen J.*, Co-teacher of the OE/ESCI 972 course. Bathymetry, backscatter and sound speed and temperature data collection south of the Isles of Shoals, as well as sound speed and temperature collection in the Piscataqua river. (Dijkstra)

CSHEL (University of Delaware) / CCOM (UNH) AUV Boot camp 2009, 1-5 June 2009, GAVIA AUV, Shore and small-boat operations from the UNH Recreation Facility at Mendum's Pond. Testing and training operations with the

GAVIA-model AUV. Ancillary programs included operations with the CCOM Harbor Tracking Buoys (Weber, Hunt, Schmidt), Geoswath training by Tom Hiller of GeoAcoustics, Fledermaus Training by Erin Heffllron of IVS and AIS message for AUV experimentation (Alexander, Schmidt, Schwehr)

DY0909: Summer Pollock, 7-19 June, NOAA Ship *Oscar Dyson*, Collect, analyze ME70 data. (Weber)

Benthic Habitat Mapping via AUV, 6-12 June, GAVIA AUV, Seafloor mapping for Sabalaria Tubeworm nodules - Ph.D. work of Nicole Raineault, University of Delaware. (Schmidt)

Great Bay Survey, 11 June-9 July, AUV *Iver* and Jackson Lab Skiff, Single beam depths and side scan sonar in lower section of the Great Bay. (Huff)

CUBE V2 Development, 15 June-1 July, NOAA Ship *Fairweather*, Start development of multi-resolution, data-driven, density-controlled bathymetric grids. (Calder)

Autonomous Vehicle Applications in Estuaries, 16-18 June, GAVIA AUV, Four AUV operator groups surveyed similar areas and compared techniques and data. Educators observed and commented on methods for integration into classroom work. Shore operations from NOAA Chesapeake Bay Office, Annapolis, MD. (Schmidt)

NOAA Ship *Okeanos Explorer* Field trials, 17-27 June, NOAA Ship *Okeanos Explorer*, Expedition coordinator. (Malik)

Great Bay Survey, 25 June-25 November, Coastal Bathymetry Survey System (CBASS), Collaborative Survey the Great Bay Bathymetry with single beam echosounders. (Lippmann)

SBNMS Whale Tagging, 28 June, R/V *Auk*, Demonstrated adaptive prey mapping by using GeoZui4D to visualize real-time EK60 echosounder data. (Arsenault)

Great Bay Survey, 9-11 July, AUV *Iver* and Jackson Lab skiff, single beam depths and side scan sonar in lower section of the Great Bay. (Huff)

Bathymetric Survey 2009 of Great Bay, New Hampshire, 10 July-15 August, R/V *Coastal Surveyor*, Single beam bathymetric survey of Great Bay, New Hampshire. (Ward)

NOAA Ship *Okeanos Explorer* Field trials, 14-24 July, NOAA Ship *Okeanos Explorer*, Expedition coordinator. (Malik)

ONR Sholte Wave Study, 24 July, R/V *Tioga*, Observation of ONR Sholte wave study by Jim Lynch and Art Newhall. (Schmidt)

ONR Seafloor Characterization from an AUV - Martha's Vineyard, 26-30 July, R/V *Tioga*, Seafloor characterization from an AUV - surveys near Nantucket and Martha's Vineyard. (Schmidt)

NE seafloor characterization, 30 July-30 September, R/V *Cocheco*, Bottom samples and underwater video imagery in a LIDAR-survey area (6 field days). (Pe'eri)

US UNCLOS Mapping: Arctic, 7 August-17 September, *USCGC Healy*, UNCLOS Mapping and Seismics in the Arctic. (Armstrong, Calder, Mayer, Fessenden, Lacerda, Kuenzel, Soraruf)

Juvenile Bluefin Tuna, 11-21 August, F/V *Lilly*, Chief Scientist. (Weber)

Lake Tahoe Asian Clam Survey, 14-21 August, GAVIA AUV, Lake Tahoe Asian Clam Survey—in conjunction with the Tahoe Environmental Research Center and the University of British Columbia. (Schmidt)

NOAA Ship *Okeanos Explorer* Field trials, 21 August-3 September, NOAA Ship *Okeanos Explorer*, Expedition coordinator. (Malik)

Terrestrial laser scanner, 7-11 September, Mapping different coastal environment using a camera, terrestrial laser scanner, and RTK GPS. (Pe'eri)

DY0912: Untrawlable Rockfish, 1-14 October, *Oscar Dyson*, Collect, Analyze ME70 data. (Weber)

NOAA Ship *Okeanos Explorer* Field trials, 1-21 October, NOAA Ship *Okeanos Explorer*, Expedition coordinator. (Malik)

Delaware Bay Benthic Habitat Mapping, 7-9 October, R/V *Donna M* – GAVIA AUV, Seafloor mapping for Sabalaria Tubeworm nodules - Ph.D. work of Nicole Raineault, University of Delaware. (Schmidt)

Carbonate Migration Study Survey for Kansas University, 16-28 October, GAVIA AUV, Contract bathymetric surveys to support KU research efforts on Bahamas Platform. Grand Cay, Bahamas. (Schmidt)

AUV Post repair shakedown and Delaware Bay Benthic Habitat Survey, 16-17 November, R/V *Donna M.* and GAVIA AUV, AUV testing and post-repair shakedown. Plus benthic habitat mapping in Delaware Bay to support Ph.D. work of Nicole Raineault, University of Delaware. (Schmidt)

Harbor Tracking Buoy Project, R/V *Cocheco*, Engineering and testing of the UNH Harbor Tracking buoy over various dates throughout the year. (Schmidt)

Appendix C: Other Funding

Name	PI	Grantor	FY Award	Total Award	Length
AIS of Broadcast for USCG	Alexander, L	U.S. Coast Guard	41,959	41,959	1 year
Inland Electronic	Alexander, L	U.S. Army Corp of Engineers	50,536	50,536	1 year
Mapping Seafloor Uncertaininty	Calder, B.	Office of Naval Research	19,109	96,593	3.5 years
Africa Partnership Station: "Video Imaging Workshop"	Lippmann, T.	Office of Naval Research	35,247	35,247	1 year
Shallow Water Bottom Characterization from single-beam Echosounders	Lippmann, T.	NH Sea Grant	6,535	6,535	5 months
Evaluate Methods for Shallow Water Marine Habitat Mapping in National Park Service Lands of the Gulf of Maine and Vicinity: Convene a Workshop and Prepare Workshop Proceedings	Lippmann, T.	National Park Service	15,000	15,000	8 months
Africa Partnership Station	Lippmann, T.	Office of Naval Research	49,052	91,476	1.5 years
Nearshore Bathymetirc Estimation	Lippmann, T.	3001, Inc.	197,733	197,733	1.5 years
GEBCO Gift Fund	Mayer, L.	Blodgett Foundation	46,000	46,000	-
Tyco Endowment Interest from perpetuity	Mayer, L.	TYCO	23,442	-	Perpetuity
A Mobile Bentho-Pelagic	Mayer, L.	Woods Hole Oceanographic Institution	-	76,984	1.5 years
GEBCO Sixth Year	Mayer, L.	GEBCO Foundation	525,000	3,154,467	6 year
NH IRC:IVS Multi-Beam	Weber, T.	IVS 3D Inc.	-	40,066	1.5 years
NHIRC: IVS 3D Multi-Beam (NSF)	Weber, T.	National Science Foundation	-	35,364	1.5 years
Remote Identification of Marine Lithofacies Distribution Using Seabed Mapping Techniques	Mayer, L. Garder, J.	Conocophillips Company	92,882	92,882	2 years
AIS Notification for Right Whales	Schwehr, K.	Cornell University	87,432	251,000	3 years
Tools to Compare Diving-Animals Kinematics with Acoustic Behavior and Exposure	Ware, C.	Office of Naval Research	143,862	143,862	1.5 years
Rockfish Assessment	Weber, T.	North Pacific Research Board	-	64,152	1.5 years
ME70 Multibeam Sounder	Weber, T.	US DOC NOAA	58,197	58,197	1.5 years
The Effect of Clustered Scatterers on Volume Reverberation	Weber, T.	Office of Naval Research	46,917	89,693	2.5 years
Total			**1,438,903**	**4,587,746**	

Appendix D: Publications

Journal Articles

Alexander, L., 2009, "e-Navigation: Concept and Reality," *Sea Technology*, Vol. 50, No. 3, pp. 7-7.

Beaudoin, J.D., Calder, B.R., Hiebert, J., Imahori, G., 2009, "Estimation of Sounding Uncertainty from Measurements of Water Mass Variability," *International Hydrographic Review*, No. 2, pp. 20 - 38.

Boettcher, M.S., McGarr, A., Johnston, M.J., 2009, "Extension of Gutenberg-Richter Distribution to MW −1.3, No Lower Limit in Sight," *Geophysical Research Letters*, Vol. 36, No. 10.

Calder, B.R. Brennan, R.T., Hill, R., Lear, R., 2009 "Precise Distributed Timekeeping in Hydrographic Survey," *Systems Professional Surveyor Magazine*, August 2009, Vol.29 No.8.

Fonseca, L., Brown, C., Calder, B.R., Mayer, L.A., Rzhanov, Y., 2009, "Angular Range Analysis of Acoustic Themes from Stanton Banks Ireland: A Link between Visual Interpretation and Multibeam Echosounder Angular Signatures," *Applied Acoustics*, Vol. 70, pp. 1298-1304.

Friedlaender, A.S., Hazen, E.L., Nowacek, D.P., Halpin, P.N., Ware, C., Weinrich, M.T., Hurst, T. , Wiley, D.N., 2009, "Diel Changes in Humpback Whale (Megaptera Novaeangliae) Feeding Behavior in Response to Sand Lance (Ammodytes SPP.) Behavior and Distribution," *Marine Ecology Progress Series*, Vol. 395, pp. 91-100.

Gardner, J.V., Malik, M.A., Walker, S., 2009, "Plume 1400 Meters High Discovered at the Seafloor off the Northern California Margin," *EOS Transactions, American Geophysical Union,* Vol. 90, No. 32, pp. 275-275.

Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A., Rosenberg, A.A., 2009, "Effects of a Large Fishing Closure on Benthic Communities in the Western Gulf of Maine: Recovery from the Effects of Gillnets and Otter Trawls," *Fisheries Bulletin*, Vol. 107, pp. 308-317.

Gurshin, C.W., Jech, J.M., Howell, W.H., Weber, T.C., Mayer, L.A., 2009, "Measurements of Acoustic Backscatter and Density of Captive Atlantic Cod with Synchronized 300-kHz Multibeam and 120-kHz Split-Beam Echo Sounders," *ICES Journal of Marine Science*, Vol. 66, pp. 1303-1309.

Hazen, E.L., Friedlaender, A.S., Thompson, M.A., Ware, C., Weinrich, M.T., Halpin, P. N., Wiley, D.N., 2009, "Fine-scale Prey Aggregations and Foraging Ecology of Humpback Whales (Megaptera Novaeangliae)," *Marine Ecology Progress Series*, Vol. 395, pp. 75-89.

McGarr, A., Boettcher, M.S., Fletcher, J.B., 2009, "A Deployment of Broadband Seismic Stations in Two Deep Gold Mines," Rockburts and Seismicity in Mines. In press.

McGarr, A., Boettcher, M.S., Fletcher, J.B., Sell, R., Johnston, M.J., Durrheim, R., Spottiswoode, S., Milev, A., 2009, "Broadband Records of Earthquakes in Deep Gold Mines and a Comparison with Results from SAFOD, California," *Bulletin of the Seismological Society of America*, Vol. 99, No. 5, pp. 2815-2824.

Ward, R.W., Alexander, L., Greenslade, B., 2009, "The New IHO Hydrographic Geospatial Standard for Marine Data and Information," *International Hydrographic Review*, Vol. 5, No. 1, pp. 44-55.

Ware, C., 2009, "Quantitative Texton Sequences for Legible Bivariate Maps," *IEEE Transactions on Visualization and Computer Graphics*, Vol. 15, No. 6, pp. 1523-1529.

Weber, T.C., Peña, H., Jech, J.M., 2009, "Consecutive Acoustic Observations of an Atlantic Herring School in the Northwest Atlantic," *ICES Journal of Marine Science*, Vol. 66, pp. 1270-1277.

Book

Hecht, H.B., Berking, M.J., and Alexander, L., 2009, The Electronic Chart: Functions, Potential and Limitations of New Navigation System: Lemmer, The Netherlands, GeoMares Publishing.

Book Chapter

Dartnell, P., Gardner, J.V., 2009, "Seafloor Terrain Analysis and Geomorphology of the Greater Los Angeles Margin and San Pedro Basin, Southern California," in Lee, H.J. and Normark, W.R. (eds.), Earth Science in the Urban Ocean: The Southern California Continental Borderland, Geological Society of America, Special paper 454, pp. 9 - 28.

Symonds, G., Lippmann, T.C., 2009, "Surf on Tropical Islands," in Gillespie, R.G. and Clague, D.A., (eds.), Encyclopedia of Islands, in Encyclopedias of the Natural World, Univ. of Calif. Press, Vol. 2 pp. 879-883.

Conference Proceedings

Alexander, L., 2009, "e-Navigation and Electronic Charting: Implications for Hydrographic Community," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Alexander, L., 2009, "e-Navigation: Challenges and Opportunities," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Alexander, L., Seefeldt, D., 2009, "Development of Port ENC Standard," Smart Rivers '21, Vienna, Austria, 6-9 September.

Beaudoin, J.D., Hiebert, J., Calder, B.R., Imahori, G., 2009, "Uncertainty Wedge Analysis: Quantifying the Impact of Sparse Sound Speed Profiling Regimes on Sounding Uncertainty," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Boyd, R., Keene, J., Hubble, T., Gardner, J.V., Glenn, K., Ruming, K., Exon, N., 2009, "Southeast Australia: A Cenozoic Continental Margin Dominated by Mass Transport," 4th International Symposium Submarine Mass Movements and Their Consequences, Austin, TX, USA, 7-12 November, pp. 491-502.

Calder, B.R., Schwehr, K., 2009, "Traffic Analysis for the Calibration of Risk Assessment Models," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Calderon, H., Alexander, L., 2009, "Marine Spatial Data Infrastructure Challenges and Opportunities: The Cuban Experience," GEOMATICA, Havana, Cuba, 9-13 February.

Doucet, M., Gee, L. , Weber, T.C., Arsenault, R. , Mayer, L.A., Ware, C. , Malik, M.A., 2009, "Advanced Mid-Water Tools for 4D Marine Data Fusion and Visualization," IEEE Oceans, Biloxi, MS, USA, 26-29 October.

Fonseca, L., Rzhanov, Y., McGonigle, C., Brown, C., 2009, "Automatic Construction of Acoustic Themes for Benthic Habitat Mapping at Stanton Banks, UK," GeoHab, Trondheim, Norway, 5-8 May.

Gonin, I., Johnson, G., Shalaev, R., Tetreault, B., Alexander, L., 2009, "USCG Development, Test and Evaluation of AIS Binary Messages for Enhanced VTS Operations," Institute of Navigation, Anaheim, CA, USA, 26-28 January.

Grizzle, R.E., Malik, M.A., Ward, L.G., 2009, "High-resolution Seafloor Mapping and an Assessment of the Effectiveness of the Western Gulf of Maine Closure Area ," Workshop on Integrating Seafloor Mapping and an Assessment of the Effectiveness of the Western Gulf of Maine, Portland, ME, USA, 15-16 April.

Huff, L.C., Fonseca, L., Hou, T., McConnaughey, R., 2009, "Comparison Between Physical Sediment Samples and Grain-size Estimates from GeoCoder," International Hydrographic Conference , Cape Town, Western Cape, South Africa, 10-12 November.

Lippmann, T.C., Smith, G. M., 2009, "Shallow Surveying in Hazardous Waters," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Mayer, L.A., Armstrong, A. A., Gardner, J. V., 2009, "Mapping in the Arctic Ocean in Support of a Potential Extended Continental Shelf," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

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Plumlee, M.D., Schwehr, K., Alexander, L., Sullivan, B. M., Ware, C., 2009, "GeoCoastPilot: A Better Way of Organizing and Displaying Information in Support of Port Familiarization," IEEE Oceans, Biloxi, MS, USA, 27-29 October.

Rice, G.A., Calder, B.R., 2009, "Data Density and Grid Resolution," U.S. Hydrographic Conference, Norfolk, VA, USA, 11-14 May.

Rzhanov, Y., Fonseca, L., Mayer, L.A., 2009, "High-resolution Delineation of Acoustically Homogeneous Areas in Multibeam Backscatter Maps," Gulf of Maine Symposium.

Abstracts

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Alexander, L., 2009, "e-Navigation: Challenges and Opportunities," Inland Navigation Technology, Vicksburg, MS, USA, 3-4 February.

Alexander, L. , Schwehr, K. , 2009, "Concept: IALA AIS Binary Messages Web Site for Message Catalog and Register," International Association of Aids to Navigation and Lighthouse Authorities AIS Working Group, Key West, FL, USA, 15 January.

Boettcher, M.S., 2009, "A Synoptic Model of Slip on Mid Ocean Ridge Transform Faults - Insights from Earthquakes and Laboratory Experiments," Marine Geoscience Leadership Symposium, Washington DC, USA, 23-27 March.

Boettcher, M.S., McGuire, J., 2009, "Oceanic Transform Fault Seismicity-Earthquakes of a Different Kind," 6th International Workshop on Statistical Seismology, Lake Tahoe, CA, USA, 12-16 April.

Gardner, J.V., Malik, M. A., 2009, "Physiography of the Eastern Mendocino Ridge, NE Pacific Ocean," American Geophysical Union, San Fransisco, CA, USA, 14-18 December.

Jacobi, M. , Braswell, R., Merten, A. A., Kinner, N. E., Schwehr, K., 2009, "Environmental Response Management Application—Web-based GIS Data Display and Management System for Oil Spill Planning and Environmental Response," Coastal Geotools, Myrtle Beach, SC, USA, 2-5 March.

Malik, M.A., Weirich, J., Russel, C., Stuart, E., Peters, C., Mayer, L. A., Armstrong, A. A., 2009, "*Okeanos Explorer*—Aligning Today's Technology to a New Paradigm of Ocean Exploration," FEMME (Kongsberg Maritimes forum for all users of our Multibeam Echo Sounder Systems), Lisbon, Portugal, 21-24 April.

Monfort, C. , Lippmann, T.C., 2009, "Assimilation of Airborne Imagery with LIDAR for Bathymetric Estimation," 2nd FUDOTERAM Workshop Reminder on LIDAR Bathymetric Studies, Montreal, Quebec, Canada, 27-28 March.

Morrison, J.R., Pe'eri, S., Trowbridge, P., Frederick, S., 2009, "Using Moored Arrays and Hyperspectral Aerial Imagery to Develop Eelgrass-Based Nutrient Criteria for New Hampshire's Great Bay Estuary," Coastal Geotools, Myrtle Beach, SC, USA, 2-5 March.

Pe'eri, S., 2009, "Evaluation of Airborne LIDAR Bathymetry in Sub Tidal Coastal Environments," GeoTech, Silver Spring, MD, USA, 5-6 October.

Pe'eri, S., Gardner, J.V., 2009, "Evaluation of Airborne LIDAR Bathymetry (in Sub-Tidal Coastal Environments," 10th Annual Joint Airborne LIDAR Bathymetry Technical Center of Expertise Coastal Mapping and Charting Workshop (JALBTCX), Portland, OR, USA, 16-18 June.

Pe'eri, S., Gardner, J.V., 2009, "Evaluation of Airborne LIDAR Bathymetry (ALB) in Sub-tidal Coastal Environments," NE Airborne LIDAR Workshop for the Coastal Zone, Woods Hole, MA, USA, 6 May.

Pe'eri, S., Morgan, L.V., Armstrong, A. A., 2009, "Current Research on Airborne LIDAR Bathymetry (ALB) Shoreline Mapping," 2nd FUDOTERAM Workshop Reminder on LIDAR Bathymetric Studies, Montreal, Quebec, Canada, 27-28 March.

Pe'eri, S., Morrison, J.R., Frederick, S., Mathieson, A., Trowbridge, P., 2009, "Macroalgae and Eelgrass Mapping in Great Bay Estuary Using AISA Hyperspectral Imagery," Coastal Geotools, Myrtle Beach, SC, USA, 2-5 March, pp. 110-111.

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Schwehr, K., Alexander, L., 2009, "Right Whale AIS Project (RAP): Acoustic Detections in the Boston Approaches," Inland Navigation Technology, Vicksburg, MS, USA, 3-4 February.

Schwehr, K., Brennan, R.T., Sellars, J., Smith, S. M., 2009, "Discovery of Marine Datasets and Geospatial Metadata Visualization," American Geophysical Union (AGU), San Francisco, CA, USA, 14-18 December.

Ware, C., Mitchell, J., Arsenault, R., Kelley, J.G., 2009, "Optimally Displaying 2D Vector Fields of Meteorology and Oceanography," American Meteorological Society, Phoenix, AZ, USA, 11-16 January.

Weber, T.C., Bradley, D.L., Lyons, A.P., 2009, "Multiple Scattering Through Clouds of Gas Bubbles in Liquids: Accounting for Clustering in the Higher-order Moments," 158th Meeting of the Acoustical Society of America, San Antonio, TX, USA, 26-30 October.

Weber, T.C., Clark, T.J., Doucet, M., 2009, "ME70 Seafloor Characterization and 4D Water Column Visualization," ICES Working Group on Fisheries Acoustic Science and Technology, Ancona, Italy, 19-22 May.

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Wiley, D.N., Brown, M.W., Clark, C., Hatch, L., Johnson, L., Koyama, K., Merrick, R. , Schwehr, K., Siber, G., Tetreault, B., Thompson, M. A., 2009, "Minimizing Vessel Strikes to Endangered Whales: A Crash Course in Conservation Science and Policy," Beyond the Obituaries: Success Stories in Ocean Conservation Smithsonian's National Museum of Natural History, Washington DC, USA, 20 May.

Conference Presentation Only

Alexander, L., 2009, "e-Navigation: Implications for Electronic Charts," International ECDIS Conference, Singapore, 19-21 October.

Calder, B.R., 2009, "Bathymetric Processing with PMBS," International Seminar on the Latest Hydrographic Survey Technology, Tokyo, Japan, 12-13 November.

Calder, B.R., 2009, "CUBE: Uncertainty, Resolution and Speed," Reson User Group Conference, Houston, TX, USA, 15-16 October.

Calder, B.R., 2009, "Uncertainty and Risk Models in Hydrographic Surveys," NOAA Field Procedures Workshop, Norfolk, VA, USA, 27-29 January.

Lippmann, T. C., Rzhanov, Y., 2009, "Nearshore Bathymetric Estimation from LIDAR-based Airborne Imagery," 10th Annual Joint Airborne LIDAR Bathymetry Technical Center of Expertise Coastal Mapping and Charting Workshop, Portland, OR, USA, 16-18 June.

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Ward, L.G., Dijkstra, S. J., Armstrong, A. A., Irish, J. D., McLeod, A., 2009, "Overview of 2009 Bathymetric Mapping of Great Bay, NH," Survey Methods for Shallow Water Habitat Mapping in Northeast Department of the Interior Holdings & Estuarine Research Reserves, Durham, NH, USA, 30 September.

Wigley, R., Monahan, D., 2009, "The Nippon Foundation/GEBCO Postgraduate Certificate in Ocean Bathymetry Scholarship Program at the University of New Hampshire," International Hydrographic Conference , Cape Town, Western Cape, South Africa, 10-12 November.

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Felzenberg, J., 2009. "Detecting Bedform Migration from High Resolution Multibeam Bathymetry in Portsmouth Harbor," Masters Thesis, University of New Hampshire, Durham, NH, 97 pp.

Moser, M.S., 2009, "Bathymetric Uncertainty Model for the L-3 Klein 5410 Sidescan Sonar," Masters Thesis, University of New Hampshire, Durham, NH, 91 pp.

O'Donnell, B.N., 2009, "Modeling the Signal Processing of a Multi-Sonar System to Determine Interference Solutions," Master of Science Thesis, University of New Hampshire, Durham, NH, 67 pp.

Direct Research

Soraruf, R.E., 2009. "Geomorphologic Inputs for the Determination of Hydrographic Survey Prioritization," Direct Research Project, University of New Hampshire, Durham, 97 pp.

Reports

Alexander, L., 2009, "Inland Navigation Technology '09 - Digital Technology Impact on Safety and Efficiency," U.S. Army Engineer Research and Development Center - Coastal and Hydrologic Laboratory, Vicksburg, MS, 5 pp.

Alexander, L., 2009, "Port ECDIS Evaluation Report for EFFORTS Project Work Package 1.3," ISSUS/Hamburg Port Authority, EC Contract No FP6-031486, Hamburg, Germany, 5 pp.

Cormier, M.H., Vogt, P. R., Monahan, D., Smith, W. H., 2009, "A Proposal to Completely Chart the World's Oceans," National Oceanographic Partnership Program (NOPP), Ocean Research and Resources Advisory Panel, Washington DC, 41 pp.

Gardner, J.V., Malik, M. A., 2009, "U.S. Law of the Sea Cruise to Map the Eastern Mendocino Ridge, Eastern Pacific Ocean," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, 35 pp.

Lippmann, T.C., 2009, "The Vertical Structure of Shallow Water Flow in the Surf Zone," Department of Defense, Office of Naval Research, Washington DC.

Lippmann, T.C., 2009, "Observations of River Topography and Flow Around Bridges," The Ohio State University, USGS Water Resources Research Institute, Columbus, OH, 18 pp.

Kinner, N.E., Lippmann, T.C., Ravens, T., Zufeldt, J, 2009, "Climate Change Impacts and Research Needs for DoD Assets in Alaska's Coastal Regions," U.S. Army, Cold Regions Research and Engineering Laboratory, Fairbanks, AK, 23 pp.

Lippmann, T.C., 2009, "Daily Surface Currents from Argus Video at Benson Beach, WA," U.S. Army, U.S. Army Corps of Engineers, Portland, OR, 20 pp.

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Morrison, J.R., Gregory, T. K., Pe'eri, S., McDowell, W., Trowbridge, P., 2009, "Using Moored Arrays and Hyperspectral Aerial Imagery to Develop Nutrient Criteria for New Hampshire's Estuaries," The New Hampshire Estuaries Project, Piscataqua Regional Estuary Program, Portsmouth, NH, 65 pp.

Pe'eri, S., Morrison, J. R., Frederick, S., Mathieson, A., Brook, A., Trowbridge, P., 2009, "Macroalgae and eelgrass mapping in Great Bay Estuary using AISA Hyperspectral Imagery.," The New Hampshire Estuaries Project, Piscataqua Regional Estuary Program, Portsmouth, NH, 45 pp.

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Ward, L.G., 2009, "Development and Analysis of a Bathymetric Database for Great Bay Estuary, New Hampshire," New Hampshire Department of Environmental Services , New Hampshire Coastal Program , Portsmouth, NH, 34 pp.

Conference Poster

Arsenault, R., Friedlaender, A. , Hazen, E. L., Ware, C. , Wiley, D. N., 2009, "Advances in the study of marine mammal predator-prey interactions: a novel real-time visualization of independently collected Echo Sounder data using GeoZui4D," 18th Biennial Conference Society for Marine Mammalogy, Quebec City, Quebec, Canada, 12-16 October.

Poster

Boettcher, M. S., 2009, "Mid-Ocean Ridge Transform Faults."

Talks

Alexander, L., "e-Navigation: Challenges and Opportunities," 2009 Mariner's Workshop-Port of Montreal/Shipping Federation of Canada, Montreal, QE, Canada, 11 February 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," 2009 US Hydro Conf.- e-Navigation Workshop, Norfolk, VA, USA, 11 May 2009.

Alexander, L., "Joint Germany - Canada - USA e-Navigation User Needs Study," US Navigation Safety Advisory Council (NAVSAC), Savannah, GA, USA, 20 May 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Canadian Coast Guard Halifax, NS, Canada, 25 May 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Canadian Coast Guard St. John's, NFLD, Canada, 27 May 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Canadian Coast Guard Montreal, QE, Canada, 8 June 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Canadian Coast Guard, Quebec City, QE, Canada, 9 June 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Canadian Coast Guard Burlington, ON, Canada, 17 June 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Korean Maritime and Ocean Engineering Research Institute, Daejeon, South Korea, 23 July 2009.

Alexander, L., "e-Navigation: Challenges and Opportunities," Pacific Region Maritime Safety Council (Canada), Vancouver, BC, Canada, 30 September 2009.

Alexander, L., "Use of Portable Piloting Units (PPUs) by Maritime Pilots and e-Navigation: Challenges and Opportunities," Maritime Institute for Training and Graduate Studies (MITAGS), Linthicum, MD, USA, 9 December 2009.

Boettcher, M.S., "Near Source Observations of Very Small Earthquakes in Deep Gold Mines," Brown University, Providence, RI, USA, 2 April 2009.

Boettcher, M.S., "Near Source Observations of Very Small Earthquakes in Deep Gold Mines," Boston University, Boston, MA, USA, 8 October 2009.

Calder, B.R., "Data Processing with CUBE," NOAA, Seattle, WA, USA, 17 February 2009 [Invited Talk].

Calder, B.R., "Data Processing with CUBE" NOAA, Norfolk, VA, USA, 20 February 2009 [Invited Talk].

Calder, B.R., "Use of Telepresence in Ocean Mapping," National Academy Panel, Woods Hole, MA, USA, 17 March 2009 [Invited Talk].

Calder, B.R., "Multibeam Data Processing," United States Hydrographic Conference 2009, Norfolk, VA, USA, 13 May 2009 [Invited Talk].

Calder, B.R., "HLY0905 Data Processing," Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, Durham, NH, USA, 9 October 2009.

Calder, B.R., "CUBE Data Processing," RESON, Inc., Houston, TX, USA, 15 October 2009 [Invited Talk].

Dijkstra, S.J., "Survey Methods for Shallow Water Habitat Mapping in Northeast Department of the Interior Holdings & Estuarine Research Reserves," The Gulf of Maine Mapping Initiative (GOMMI), Durham, NH, USA, 30 September 2009.

Gardner, J.V., "The East Australian Margin, or At Least What's Left of It," Center for Coastal and Ocean Mapping/ NOAA-Joint Hydrographic Center Seminar Series, Durham, NH, USA, 29 March 2009.

Lippmann, T.C., "Shallow Surveying in Hazardous Waters," Department of Oceanography and Fisheries, University of Ghana, Legon, Ghana, 24 August 2009.

Lippmann, T.C., "Video Image Processing with Nearshore Applications," Department of Oceanography and Fisheries, University of Ghana, Legon, Ghana, 25 August 2009.

Lippmann, T.C., "Surface Wave Observations from Directional Waverider Buoys," Department of Oceanography and Fisheries, University of Ghana, Legon, Ghana, 28 August 2009.

Malik, M.A., "Backscatter Measurement Uncertainty: Estimation and Validation," Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, Durham, NH, USA, 4 February 2009.

Malik, M.A., Weirich, J., Russel, C., Stuart, E., Peters, C., Mayer, L. A., Armstrong, A. A.,"*Okeanos Explorer*– Aligning Today's Technology to a New Paradigm of Ocean Exploration," FEMME 2009, Lisbon, Portugal, 22 April 2009 [Presented by Mayer-Invited Talk].

Malik, M.A., "Ocean Exploration: A Working Model," Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, Durham, NH, USA, 11 December 2009.

Mayer, L.A., "Continental Shelf Issues: Mounting Tensions and Melting Ice: Exploring the Legal and Political Future of the Arctic" Vanderbilt University School of Law, Memphis, Tennessee, USA, 6 February 2009 [Invited Talk].

Mayer, L.A., "Arctic ECS Issues," 22nd Annual United States Pacific Command International Military Operations and Law Conference, Auckland, New Zealand, 2 April 2009 [Invited Talk].

Mayer, L.A., "Center for Coastal and Ocean Mapping Activities – A National Center for Ocean Mapping Activities," Portuguese Hydrographic Institute, Lisbon, Portugal, 23 April 2009 [Invited Talk].

Mayer, L.A., "Changing Perspectives of the Seafloor: New Approaches to Seafloor Mapping and Data Visualization," Geosciences Symposium, Texas A&M University, College Station, TX, 27 April 2009 [Invited Talk].

Mayer, L.A., Armstrong, A.A. and Gardner, J.V., "Mapping in the Arctic in Support of a Potential U.S. Extended Continental Shelf," U.S. Hydrographic Conference, Norfolk, VA, USA, 14 May 2009 [Invited Talk].

Mayer, L.A., "New Tools and Approaches for Ocean (and Atmospheric) Mapping," NOAA Corps. Dining Out, Washington, DC, USA, 16 May 2009 [Keynote Address].

Mayer, L.A., "Mapping and Exploring in a Changing Sea Ice Environment," 33rd Center for Ocean Law and Policy Conference "Changes in the Arctic and the Law of the Sea," Seward, AK, 21 May 2009 [Invited Talk].

Mayer, L.A., "New Tools for Seafloor Mapping: Lifting the Veil," Capitol Hill Ocean Week, Washington, DC, USA, 10 June 2009 [Invited Talk].

Mayer, L.A., U.S. "Mapping of the Extended Continental Shelf in the Arctic," 3rd Symposium on the Impacts of an Ice-Diminishing Arctic on Naval and Maritime Operations, Annapolis, MD, USA, 11 June 2009 [Invited Talk].

Mayer, L.A., "Program, Mobilize, Deploy & Retrieve AUV," Autonomous Vehicle Applications in Estuaries: Sponsored by NCBO's Environmental Science Training Center, Annapolis, MD, USA, 16 June 2009 [Keynote].

Mayer, L.A., "Mapping Activities in the Arctic," Presentation for Asst. Secretary of State Kerri-Ann Jones, Washington, DC, USA, 30 September 2009 [Invited Presentation].

Mayer, L.A., "New Views of the Chukchi Borderland and Alpha/Mendeleev Ridge Complex," Penrose Conference on Tectonic Development of the Amerasian Basin, Banff, AL, Canada, 5 October 2009 [Invited Presentation].

Mayer, L.A., "Mapping in the Arctic," Presentation to National Geographic Society Advisory Board for OCEANUS TV Series, Silver Spring, MD, USA, 27 October 2009 [Invited Presentation].

Mayer, L.A., "U.S. ECS Activities in the Arctic, Canadian, U.S., Russian and Danish Joint Meeting on Arctic ECS Activities," Halifax, NS, Canada, 17 November 2009 [Invited Presentation].

Mayer, L.A., "Requirements for UNCLOS Article 76," U.S. ECS Task Force Data Management Workshop, Durham, NH, USA, 8 December 2009 [Invited Presentation].

Monahan, D., "Who Owns the Arctic Ocean: Myths, Media and Median Lines," Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Seminar Series, Durham, NH, USA, 30 January 2009.

O'Donnell, B., "UNH Thesis Templates and LaTeX Resources," University of New Hampshire Center for Coastal and Ocean Mapping, Durham, NH, USA, 24 February 2009.

Pe'eri, S., "Eelgrass and Microalgae Detection using Hyperspectral Remote Sensing," US EPA Atlantic Ecology Division, Narragansett, RI, USA, 19 February 2009.

Pineo, D., "The Applicability of Computational Modeling to Data Visualization," University of New Hampshire: Computer Science Department, Durham, NH, USA, 12 November 2009.

Schwehr, K., "Right Whale AIS Project (RAP) - Initial Presentation to LNG Companies," Northeast Gateway and Neptune LNG, Gloucester, MA, USA, 9 January 2009.

Schwehr, K., Calder, B.R., "Traffic Analysis for Calibration of Risk Assessment Methods," Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center Seminar Series, Durham, NH, USA, 14 April 2009.

Schwehr, K., "Visualization at CCOM using Google Earth, GeoZui4D," and FlowViz, Methods for Shallow Water Habitat Mapping in New England Department of the Interior Holdings & Estuarine Research Reserves, Durham, NH, USA, 30 September 2009.

Schwehr, K., "Landing Robots on Another Planet," University of New Hampshire's Speakers Bureau, Colby-Sawyer College, New London, NH, USA, 4 November 2009.

Schwehr, K., "Visualizing Mars Exploration," University of New Hampshire: CS900 Seminar Series, Computer Science Department, Durham, NH, USA, 5 November 2009.

Schwehr, K., "Center for Coastal and Ocean Mapping Visualization Lab," University of New Hampshire, Computer Science Class, Durham, NH, USA, 9 November 2009.

Schwehr, K., "Update on Testbed and Demonstrations: Stellwagen Bank NMS Right Whale Location," RTCM SC121 Working Group on Expanded Use of AIS in VTS, Seattle, WA, USA, 19 November 2009.

Schwehr, K., "The Right Whale Listening Network in Cape Cod and Efforts to Improve Metadata Standards for NOAA Hydrographic Survey Data and Other Data Sources," NOAA PHB, Seattle, WA, USA, 20 November 2009.

Ware, C., "Visual Language – An Opportunity or an Oxymoron," VizThink'09 San Jose, CA, USA, 23 February 2009 [Plenary Speaker].

Ware, C., "Space, Time, Whales and First Order Cognitive Modeling for Data Visualization," Rochester Institute of Technology, Rochester, NY, USA, 25 March 2009.

Ware, C., "First Order Cognitive Modeling for Data Visualization," Rutgers University, Princeton, NJ, USA, 3 April 2009.

Ware, C., "Perception and the Process of Visual Thinking," University of Toronto, Department of Information, Toronto, Ontario, Canada, 18 June 2009.

Ware, C., "Space, Time, Whales and First Order Cognitive Modeling for Data Visualization" Gordon Research Conference, Oxford, England, 25 July 2009.

Ware, C., "Visual Thinking and Visual Thinking Tools," IEEE Visualization, IEEE Information Visualization and IEEE Visual Analytic, Atlantic City, NJ, USA, 14 October 2009 [Keynote Speaker].

Ware, C., "Visual Thinking and Visual Thinking Tools," University of Calgary, Calgary, AL, Canada, 20 November 2009.

Appendix E: Meetings And Conferences Attended

Dijkstra, S., Lilly-East Conference on College and University Teaching, Newark, DE, USA, 15-17 April 2009.

Dijkstra, S., 2009 New England Surveying Societies Conference, Nashua, NH, USA, 10-12 December 2009.

Lippmann, T.C., Survey Methods in Shallow Water Habitat Mapping, Durham, NH, USA, 30 September 2009.

Monahan, D., International Bathymetric Science Day, Brest, France, 30 September 2009.

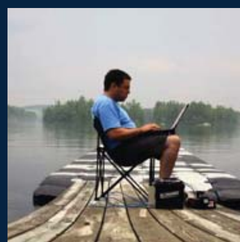
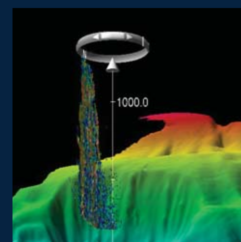
Schwehr, K., e-Navigation 2009, Seattle, WA, USA, 17-18 December 2009.

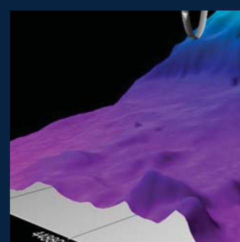
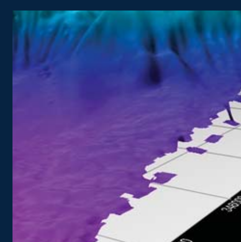
Schmidt, V.E., Unmanned Untethered Submersible Technology, Durham, NH, USA, 23-26 August 2009.

Sullivan, B.M., "Webinar—Using PHP and Flash for Developing Rich Internet Applications," Adobe systems, Durham, NH, USA, 2 December 2009.

Ward, L.G., Northeastern Section of the Geological Society of America Annual Meeting, Portland, ME, USA, 22-24 March 2009.

Ward, L.G., Integrating Seafloor Mapping and Benthic Ecology Into Fisheries Management in the Gulf of Maine, Portland, ME, USA, 15-16 April 2009.

The Center for Coastal and Ocean Mapping
The NOAA-UNH Joint Hydrographic Center

Jere A. Chase Ocean Engineering Lab
24 Colovos Road
Durham, NH 03824

603-862-3438 tel
603-862-0839 fax

www.ccom.unh.edu