

UNH/NOAA Joint Hydrographic Center

Performance and Progress Report

Project Title: Joint Hydrographic Center
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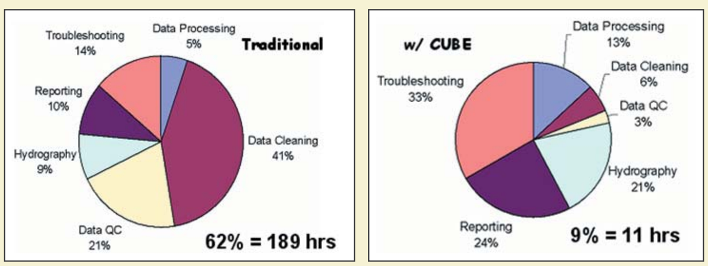
Table of Contents

The NOAA-UNH Joint Hydrographic Center was founded nine 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 massive 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. In the 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).



Data cleaning time saved using CUBE.

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. Almost every hydrographic software manufacturer has, or is, incorporating these approaches into their products. It is not an understatement 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 universally 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:

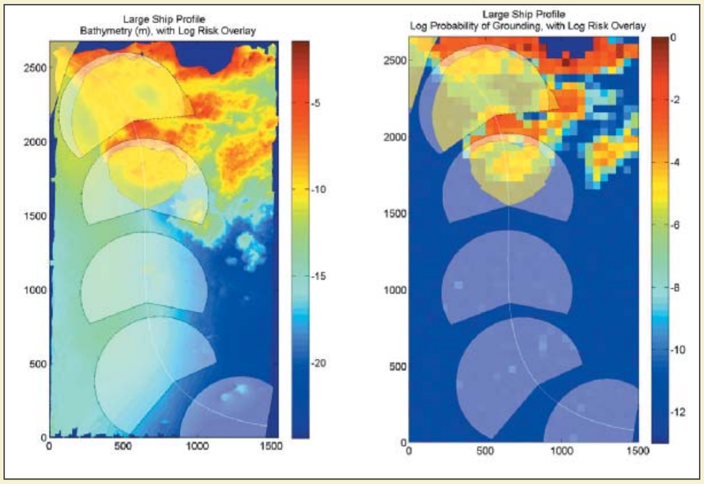
"We are so pleased with GeoCoder! We jumped in with both feet and made some impressive mosaics. Thanks so much for all the support."

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. While we believe we have met the initial goals we set, we will certainly not stop there. CUBE, The Navigation Surface and GeoCoder offer a framework upon which new innovations are being built and new efficiencies gained. Additionally, they provide a starting point for the delivery of a range of non-hydrographic mapping products that set the scene for many future research efforts.

Highlights of Our 2008 Program

Our efforts in 2008 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. Epitomizing our close interaction with, and support of NOAA activities, Dr. Calder spent several days on the *Rainier*, evaluating their approaches to processing and offering valuable suggestions for possible improvements.

A logical outgrowth of CUBE's ability to attribute an uncertainty estimate to hydrographic data is to develop



The probability of grounding along each of these future potential trajectories. We can summarize the information for the user by drawing (white) the maneuvering area, and overlaying (yellow) the accumulated risk along each trajectory.

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 UnderKeel 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 underkeel 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.

The ultimate accuracy achievable from a multibeam survey can often be constrained by our ability to synchronize the time-stamps among the varied sensors (sonar, GPS, motion-sensor, etc.) associated with a survey. Thus we have been investigating the use of the IEEE-1588 'Precision Time Protocol' (PTP) along with a Center-developed algorithm as a solution for low-overhead time synchronization, primarily in survey systems. This year our algorithm was integrated into a Reson 7125 multibeam sonar (to address NOAA needs). The integrated code, interfaced to an Applanix POS/MV timing signal, achieved a remarkable, sub-microsecond rms repeatability, typically on the order of a few tens of nanoseconds, even under heavy processor load. This implementation is now in the process of being adopted by industrial partner Reson for release in all 7000 series systems and will greatly enhance the accuracy of hydrographic surveys.

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. While the potential is great, there are many unknowns associated with airborne bathymetric LIDAR systems and thus we have begun a research program aimed at better understanding the capabilities and limitations of these systems. Studies conducted this past year 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 while 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. We are also exploring the viability of using airborne laser measurement for accurate determination of the shoreline; to better understand just what bathymetric LIDARs are measuring we have acquired our own laser system and have built several "natural" targets for deployment offshore and in our test tanks.

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 Electronic 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 this year with the successful demonstration of the use of the Automatic Information System (AIS) combined with our visualization tools for display of warnings of the presence of acoustically detected right whales in shipping lanes into and out of Boston Harbor. 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, and; 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. This may be extendable to a truly global system through the new USCG LEO satellite that has an AIS receiver on it.

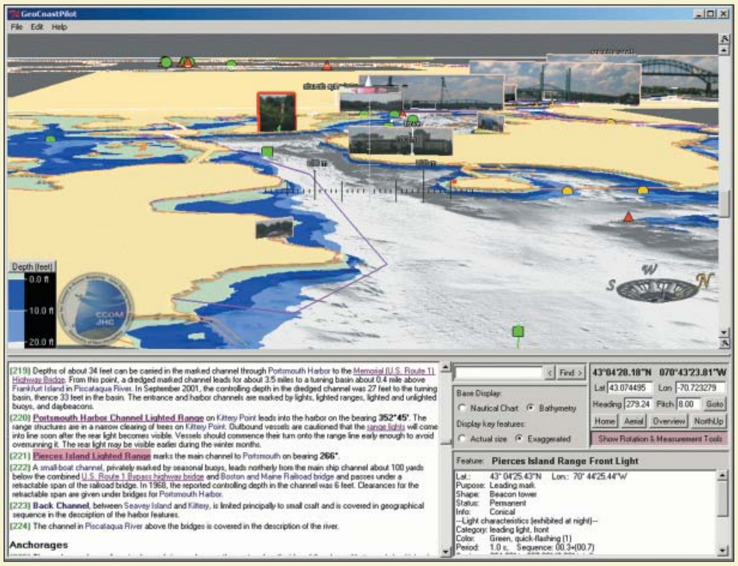
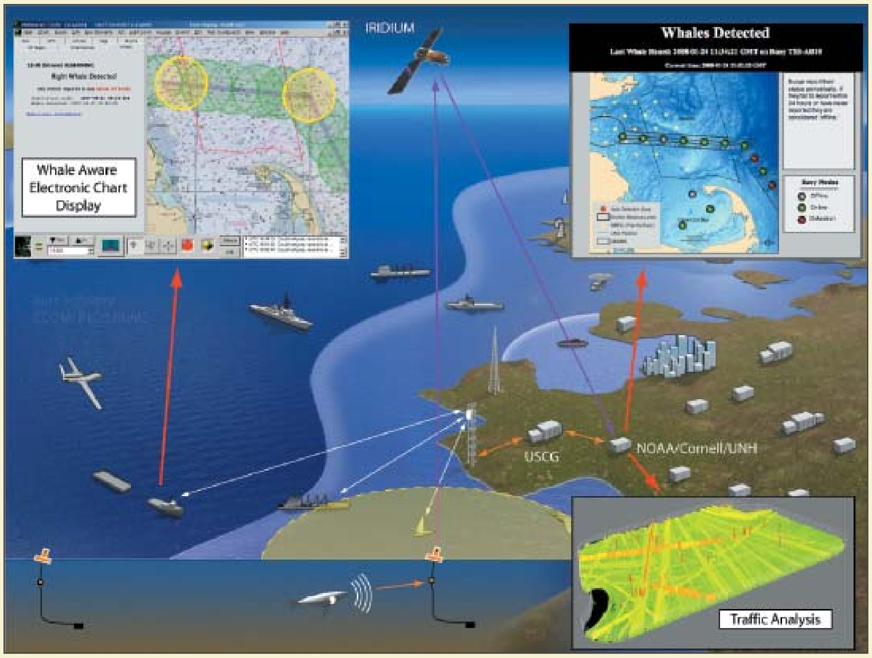


Image captured from the "Digital Coast Pilot" showing approach to bridge in Portsmouth Harbor.

As a transitionary entry into the world of the 'Chart of the Future,' we have developed and released this year a fully digital and interactive version of the commonly used Coast Pilot books (GeoCoastPilot) for Portsmouth, NH. 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 link directly to the full description of the object as well as other relevant information. GeoCoastPilot turns the NOAA Coast Pilot® into an interactive document linked to a 3D map environment, providing links between the written text, 2D and 3D views, web content, and other primary sources such as charts, maps, and related federal regulations. A critical component of this effort has been devising methods and tools to transform the current text of the Coast Pilot into an xml form that allows for integration with other kinds of data, especially georeferencing information. It is this aspect that has generated the greatest interest from both NOAA and the commercial sector. GeoCoast Pilot had its first release on June 6, 2008 with a presentation to the Portsmouth Yacht Club. It is freely available on our website (there have been 227 downloads thus far) and we have conducted phone interviews and web surveys with interested users. We are working on adding Boston Harbor to the system for 2009.

Whereas much of 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. We are developing three-dimensional, interactive interfaces and control systems for Autonomous Underwater Vehicles (AUV's) and



AIS binary message broadcast scheme for Right Whale locations in Stellwagen Bank.

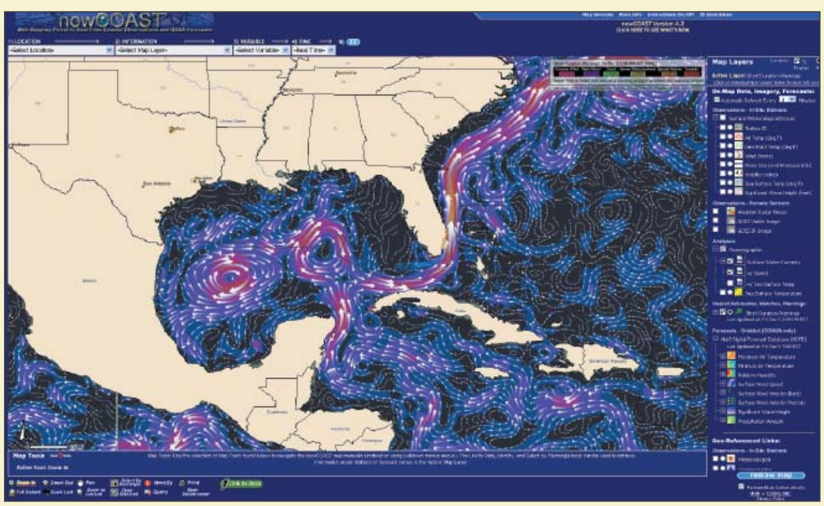
Remotely Operated Vehicles (ROV's) as well as software to visualize the behavior of marine mammals and time-varying oceanographic and atmospheric conditions. This past year we participated in several NOAA cruises that used motion sensing tags and acoustic buoys to track humpback whales. Data from these sensors combined with our visualization tools have allowed us to view, for the first time, the behavior of these remarkable creatures while they are submerged. We have also been able to fuse the visualized whale tracks with other data sets that record the distribution of the fish that the whales are feeding on and thus gain important insight into feeding.

Acoustically tracked position of humpback whale Geometry in context of seafloor bathymetry.

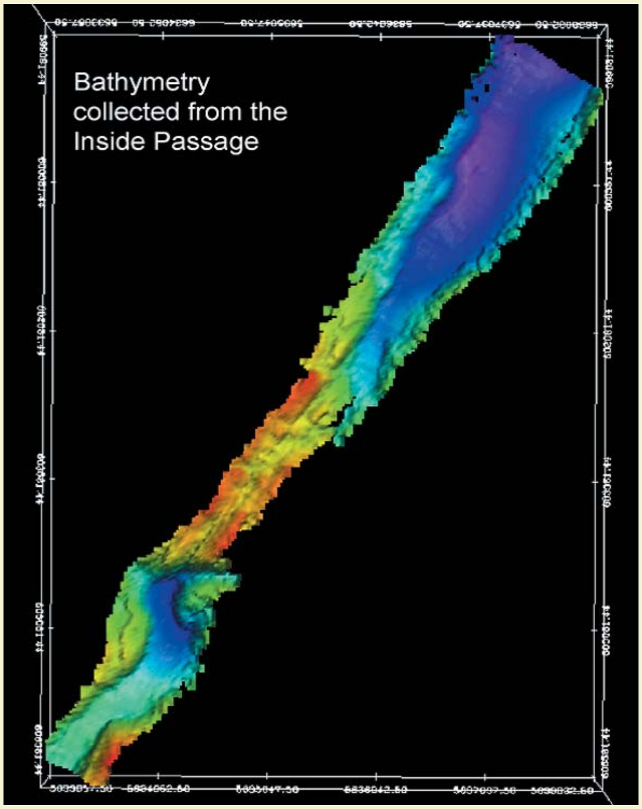
The acoustic buoys that we have used to help track whales were actually developed in support of our efforts to install an acoustic ranging system for AUV's or other platforms in Portsmouth Harbor. The devices are positioned by RTK GPS units (with 2 cm stationary accuracy), contain onboard temperature, 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. An initial buoy was constructed and tested in the fall of 2008; two more will be completed in the coming year. When fully functional, this positioning system will provide the ability to accurately locate any vehicle or device within its range. It may also provide the ability to passively listen to ship-traffic as well as to monitor changes in the physical oceanography of the harbor. This "Harbor Tracking and Observatory" may also have important homeland security applications. As in previous years, we are partnering with the University of Delaware in the operation of an AUV; this year the Fetch AUV and Delta-T multibeam sonar that we worked with in the past have been replaced by a GAVIA AUV and a GeoSwath phase-measuring swath sonar.

The environments we study change in both space and time, and our new 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 3-D visualization of the 26 December 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. A photo of Ware's visualization was featured in the *N.Y. Times* (see image on page 52). Our flow visualization is also now a prime component of NOAA's nowCoast website, presenting complex current patterns in an easily understandable fashion to the general public. The addition of the ability to visualize multi-layered atmospheric data has led to new interactions with NOAA weather modelers and to a Granite State Discovery Grant aimed at developing visualization tools for teaching meteorological concepts.

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. This capability was first demonstrated in a survey of the offshore cages of the Open Ocean Aquaculture Project, imaging the fish cages, anchor lines and fish. This past year we have used these techniques to image walleye pollack off Alaska and juvenile tuna off the east coast. 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



CCOM flow visualization in NOAA's nowCoast.



Bathymetry collected with ME-70 fisheries multibeam sonar.

to see how well they can be used for simultaneous seafloor mapping. The goal is to use 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.

As we seek to extract more than just bathymetric data from seafloor surveys, we 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. Comparisons of the automated techniques with manual segmentation show that the automated procedures are close to those obtained by human interpreters but that the automated procedure is more accurate because it takes into consideration all the available angular information, while human operators are using the backscatter mosaic as a guide. 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. An intriguing offshoot of this work has been the application of the ARA technique to the identification of heavy oil on the seafloor. Initial results indicate that it is easy to acoustically identify oil when spilled on gravelly sand but more difficult as the grain size decreases. More work is planned on this topic in the coming year.

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 has participated in surveys in the Bering Sea, the Gulf of Alaska, and the Atlantic margin, the high, ice-covered Arctic, the Gulf of Mexico and the Marianas, collecting more than 1,060,000 sq. km of high-resolution mapping data that have provided unprecedented new views of the seafloor. This has revolutionized our understanding of many margin processes, and will result in significant additions to a potential U.S. claim under UNCLOS. Our 2007 survey in the high Arctic resulted in a profoundly new view of the location of the "foot of the slope" on the Chukchi Cap, a result that may add substantially to how far the U.S. can extend its sovereign rights over resources in the Arctic and our survey this past summer collected some of the first rock samples from the seafloor in this remote region. Initial analyses of these rocks suggest that earlier notions of the origin of this part of the Arctic Ocean may be wrong and new models will be required to explain the geologic history of the region. Our work in the Arctic this year was highlighted as one of *Discovery Magazine's* 100 top science stories of 2008 (number 5!).

The research highlights outlined above not only represent a few of the successes we have had, but are indicative of the clear impact that the lab is having on hydrographic and ocean mapping science. In October the Center hosted Shallow Survey 2008: The Fifth International Conference on High-Resolution Surveys in Shallow

Water. The conference was remarkably successful with more than 350 attendees and 32 industrial exhibitors. Fifty-two technical papers were delivered highlighting the leading edge of hydrographic science. Interesting spin-offs to the conference were the addition of five new industrial associates to the Center's Industrial Partner Program as well as several job offers to our students. 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, mosaicing 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.). 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, Wired Magazine, National Geographic, PBS-News Hour, Nature, The Boston Globe, Science Daily* and even Steven Colbert.

PERFORMANCE AND PROGRESS REPORT

Introduction

On 4 June 1999, the Administrator of NOAA and the President of the University of New Hampshire signed a cooperative agreement describing 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 providing 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. The activities of the center are focused on two major themes: 1) a research theme aimed at developing and evaluating a wide range of state-of-the-art hydrographic and ocean mapping technologies, and 2) 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 thirteenth 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 2008. 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

2008 saw the arrival of three new researchers to the Center, **Margaret Boettcher**, a geophysicist from MIT and the USGS, **Tom Lippmann**, a coastal process specialist from Ohio State University and **Jim Irish** a well-known physical oceanographer and instrumentation specialist who has recently retired from WHOI. **Val Schmidt** joined the engineering staff after the successful completion of his Master's degree and **Mashkoor Malik** joined the new Integrated Ocean and Coastal Mapping Center as a NOAA-assigned physical scientist. In 2008, we also saw the departure of three members of our IT staff—**Jim Case**, **Brian Locke**, and **Nathan Paquin** who set off on the path of many young IT people—trying their hand in the private sector with the establishment of a new startup specializing in IT security. **Glen McGuillicuddy** also moved on to an engineering management job in Portland, ME. We wish them the best in their new endeavors; we are actively seeking replacements for some of these positions.

The 10,000 square foot addition, completed in 2008.

Faculty

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

Brian Calder has a Ph.D. in Computing and Electrical Engineering, completing his thesis on Bayesian methods in sidescan sonar processing in 1997. Since then he has worked on a number of signal processing problems, including real-time grain size analysis, seismic processing, and wave-field modeling for shallow seismic applications. His research interests include methods for error modeling, propagation and visualization, and adaptive sonar backscatter modeling. His work has focused on developing methods for textural analysis of seafloor sonar data, as well as exploring innovative approaches to target detection and seafloor property extraction. Dr. Calder is an associate research professor with the Center and the Dept. of Electrical Engineering focusing on statistically robust automated data cleaning 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. This year 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 is supported by ONR on a project aimed at understanding how a 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.

Jim Gardner is a world-renowned marine geologist and was leader of the USGS Pacific Mapping Group. He retired from the USGS and joined the Center in the late 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. He was been 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 and illustrious career making important contributions in a number of areas of marine geology and geophysics including leading the U.S. effort to map its EEZ with the GLORIA long-range sidescan sonar. He is leading our field efforts in support of Law of the Sea studies. Jim is a Research Professor in the Center and in the Dept. of Earth Sciences.

Lloyd Huff has over 37 years in the private industry 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 joined the Center's 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; acoustic instrumentation for bottom sediment and bedload transport, for remote observations of sediment and for fish surveys.

Barbara Kraft received a Ph.D. in Mechanical Engineering at the University of New Hampshire. Her dissertation research used optical tomography and interferometry to spatially resolve 3-D density fields of turbulent jets. She has taught several courses including digital signal processing and experimental measurement and data analysis. She also has worked on the demodulation of voice and data transmissions for digital radio communications. At CCOM she is an assistant research professor at the Center and in Ocean Engineering and is working on ONR programs analyzing in situ measurements of seafloor acoustic properties, on upgrading our acoustic tank calibration facilities and analyzing the spatial frequency distribution of features mapped with multibeam sonar.

Tom Lippmann is an associate research professor with affiliation with the Department of Earth Sciences and the Ocean Engineering program. He received a BA in Mathematics and Biology from Linfield College (1985), and a MS (1989) and 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.

Larry Mayer is the 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. He has a background in marine geology and geophysics with an emphasis on seafloor mapping, innovative use of visualization techniques, and the remote identification of seafloor properties from acoustic data. Before coming to New Hampshire he was the NSERC Chair of Ocean Mapping at the University of New Brunswick where he led a team that developed a worldwide reputation for innovative approaches to ocean mapping problems.

Dave Monahan is the program director for the Nippon Foundation's General Bathymetric Chart of the Oceans (GEBCO) training program in oceanic bathymetry. Prior to joining 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 currently the Chair of GEBCO.

Christian de Moustier's faculty position is split between the Departments of Ocean Engineering and Electrical Engineering. 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.

Yuri Rzhanov, with a Ph.D. in Physics and Mathematics, is an associate research professor in the Center and in the Department of Ocean Engineering. He has a very wide range of computing skills and has built a number of applications for higher education that are presently in use at universities around the world. At the Center, Dr. Rzhanov has been developing software for automatic mosaicing of video imagery and sidescan sonar data.

Kurt Schwehr received his Ph.D. from Scripps Institution of Oceanography studying marine geology and geophysics and received a BS from Stanford University. 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 looks forward to participating in the NASA Phoenix Mars Lander project.

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

Colin Ware is the director of the Center's Data Visualization Research Lab and a professor in the Ocean Engineering and Computer Science departments. Dr. Ware has a background in human/computer interaction (HCI) and has been instrumental in developing a number of innovative approaches to the interactive 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 at the Center and in Ocean Engineering. He earned his Ph.D. in acoustics at Penn State University and has BS and MS degrees in Ocean Engineering from the University of Rhode Island. 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.

NOAA Employees

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

Capt. Andrew Armstrong is the co-director of the JHC, retired as an officer in the National Ocean and Atmospheric Administration Commissioned Corps in 2001 and is now assigned to the Center as a civilian NOAA employee. Captain Armstrong has specialized in hydrographic surveying and served on several NOAA hydrographic ships, including the NOAA Ship *Whiting* where he was Commanding Officer and Chief Hydrographer. Before his appointment as co-director of the NOAA/UNH Joint Hydrographic Center, Captain Armstrong was the Chief of NOAA's Hydrographic Surveys Division, directing all of the agency's hydrographic survey activities. Captain Armstrong has a BS, in Geology from Tulane University and a MS 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 is 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 present 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 will be 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.

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. and an MS in meteorology from Penn State Univ. He is involved in the development and implementation of NOS' 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 will be 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.

Jason Greenlaw has been 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 (spring 2006) from UNH with a BS in Computer Science and a minor in French.

Carl Kammerer is an oceanographer with the National Ocean Services' Center for Operational Oceanographic Products and Services (CO-OPS), now seconded to the Center. He is a specialist in estuarine and near-shore currents and presently the project leader or manager for two projects; a traditional current survey in Southeast Alaska, and a more robust survey to ascertain the effects of large bulk cargo ships in Las Mareas, Puerto Rico. Working out of the Joint Hydrographic Center, he acts as a liaison between CO-OPS and the JHC, and provides expertise and assistance in the analysis and collection of tides. He has a BS in Oceanography from the University of Washington and is an MBA candidate at the University of Maryland.

Mashkoor Malik received his MS degree from CCOM/JHC in 2007 has been hired by NOAA (through ERT) as a physical scientist assigned to the new NOAA vessel of exploration *Okeanos Explorer*. In this capacity Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the *Okeanos Explorer*. While not serving on the vessel, Mashkoor is assigned to the Center where he is part of the new Integrated Ocean and Coastal Mapping Center. Mashkoor also continues to be a Ph.D. student at the Center, his research focusing on understanding the uncertainty associated with backscatter measurements.

Other Affiliated Faculty

Dave Wells is world-renowned in hydrographic circles. Dave Wells 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 an other and dissimilar objects to avoid one another.

Ron Boyd (July-December 2003) spent his sabbatical at the Center. Ron is a professor of marine geology at the University of Newcastle in Australia and an internationally recognized expert on coastal geology and processes. 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 – 1974 data collected from Fletcher's Ice Island (T-3).

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

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.

Research Scientists and Staff

Roland Arsenault was an MSc 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-realtime 3-D environments as well as software to support AUV 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 and BS in Geology/Physics-Mathematics from Brown University in 1998. She joined CCOM in 2008 after completing a Mendenhall Postdoctoral Fellowship at the US Geological Survey. While she will continue to collaborate with scientists at CCOM indefinitely, Margaret will also be joining 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's seeks to better understand slip accommodation on oceanic transform faults. And 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.

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

Tianhang Hou was a research associate with the UNB Ocean Mapping for six years before coming to UNH. He has significant experience with the UNB/OMG multibeam processing tools and has taken part in several offshore surveys. In addition to his work as a research associate Mr. Hou has also begun a Ph.D. in which he is looking at the application of wavelets for artifact removal and seafloor classification in multibeam sonar data, as well as developing algorithms for determining the "foot of the slope" for Law of the Sea issues 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 BS in the Department 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, local network administration and assistance with some courses.

Shachak Pe'eri received his Ph.D. and MS from the Tel Aviv University in Geophysics. His Ph.D. research was on monitoring the current uplift and deformation of Mt. Sedom salt diapir using Interferometric Synthetic Aperture Radar (InSAR). The research was done with Stanford University and the Hebrew University of Jerusalem. His MS research was 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 acoustic-LIDAR inter-comparisons.

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 undergraduate degree in Computer Science at the University of Massachusetts, Lowell in 2002 and finished her MS 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 (coming soon), and helping design and build museum exhibits for marine/science centers.

In addition to the academic, research and technical staff, **Abby Pagan-Allis** and **Linda Prescott** are our Program Managers and keepers of order with the able assistance of **Maureen Claussen**.

Figure 1. "The Telepresence Console."

Facilities 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 2008 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 new office space, an IT lab, and a new server room. The server room is four times larger than its counterpart in the old wing, and has the capacity to house 14 full-height server racks, bringing the total capacity of the Center to 21 server racks. The room is equipped with redundant air conditioning and each server rack is equipped with a battery backup, helping to ensure that Center network services have as little downtime as possible. Much like the older room, the new facility is also equipped with an FE-227 fire suppression system. With the new server room now in operation, the Center purchased and deployed a new Foundry BigIron RX-8 switch with 8x24-port blades to provide the network backbone for the new facility. With the larger facility and redundant power, nearly all the Center's servers have been moved to the new server room; the rest are scheduled to move to the new wing in 2009. The new lab provides ample workspace for the IT group to carry out its everyday tasks and securely store sensitive computer equipment. Additional offices are located in proximity to the new lab, making room for new faculty and staff in the old offices.

The new wing also includes the addition of the Center's new presentation room, which is now the home of Telepresence Console (Figure 1) as well as the Geowall high-resolution display system (Figure 2). The hardware for the Telepresence Console consists of five Dell PowerEdge servers used for data processing workstations, three Tandberg video decoder devices that decode real-time video streams, three 37" Westinghouse LCD displays through which the video streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints. All server and rack-mounted equipment is now housed in the new server room, located down the hall from the presentation room. As with the Center's other servers, all of the Telepresence Console equipment is now housed in a new Dell server rack and is connected to a Powerware uninterruptible power supplies (UPS) to protect against power surges and outages. The Geowall display system also benefits from the new location, and CCOM has purchased a Powerware UPS system and Dell rack to house the 7 Dell Precision workstations which drive the Geowall display.

Figure 2. Global circulation model displayed on CCOM/JHC Geowall II.

Among the servers moved to the Center's new server room is our new Linux virtualization server. Purchased last year, it has been redeployed to run OpenVZ. With OpenVZ, the Center is able to consolidate multiple services on a single server, with each service running its own virtual server. This allows for the use of fewer physical servers to perform the same tasks while maintaining the same level of security that individual computers can provide. In the event of a virtual server being compromised, the damage is isolated to a single virtual server instance and can be contained. Currently, the Center is using the OpenVZ server to run our new mail server, web file transfer services, the CCOM Wiki, CCOM Web Calendar services, the Shallow Survey 2008 Website, the Open Navigation Surface website, and the MMAP website. The mail server at the Center currently runs Postifx, which was found to perform better than the previous mail server software and is easier to configure.

The Center's storage capabilities rely primarily on the Network Appliance FAS960c iSCSI Storage Area Network (SAN), which provides 34.5TB of raw storage capacity. The SAN provides higher throughput than conventional disk drives, decreasing processing time and providing the ability to concentrate all research data in a single location. In addition, the Center has 12TB of Legacy direct-attached storage (DAS) which is in the process of being phased out and its data migrated to the SAN, freeing the DAS storage for less critical projects. Ultimately, the Network Appliance FAS960c can be upgraded to house over 300TB of raw storage. The SAN is backed up by a Quantum M1500 LTO-3 backup array. Workstations at the Center are currently backed up using a Dell 132T SDLT backup array, however due to the fact that the unit is nearing its end of life, combined with the increasingly demanding backup needs of the SAN, current plans are to add an additional LTO backup system. The New LTO will provide backup for the workstations and provide redundancy in the event of a backup system failure. This upgrade is scheduled to occur in the first half of 2009.

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 handing the bulk of the Center's network traffic, and have replaced our 3Com switches as the Center's primary networking equipment. The 3Com 4924 switches have been repositioned to handle edge applications such as the Center's Electronics Laboratory, Geowall, Telepresence Console, and research vessels. The Cisco and Foundry wireless access points are in place to provide wireless Internet connectivity for employees and visitors.

Currently, All CCOM servers are consolidated into five full height cabinets with one Uninterruptible Power Supply (UPS) per cabinet. At present, there are 25 servers and five storage arrays. Interface between our internal gigabit local area network (LAN) and the Internet is protected by two NitroSecurity Intrusion Prevention Systems (IPS) and a Windows-based ISA firewall. One of the large projects currently in progress at the Center is the NOAA/Fishpac project, which, due to its computer-intensive needs, requires its own dedicated server with 32TB of DAS, and a cabinet with an uninterruptible power supply. The Center also currently hosts three dedicated servers for two field-related projects—NOAA's nowCOAST Web Mapping Portal and OpenECDIS.org. The nowCOAST project recently purchased a new server which, in its current configuration, allows for full mirroring of the nowCOAST website, which is hosted in Silver Spring, MD.

Every office in the Center is wired with gigabit Ethernet and terminated in our data center, which allows us to utilize our own network equipment for enhanced speed, security and management. In addition to enterprise level anti-virus scanners deployed on all computer systems in the Center, all inbound and outbound traffic is routed through our firewall and the two IPS devices where it is interrogated for malicious content. The Center's computer classroom is populated with fifteen small form factor computer systems, and a ceiling-mounted NEC high resolution projector. All training that requires the use of a computer system is conducted there.

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 154 high-end Windows XP and Linux desktops/laptops, as well as several Apple MacOS computers and one SGI O2 workstation. 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 the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, the Center has also upgraded all 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-safe, while archived datasets are sent offsite to an Iron Mountain data protection facility where they are stored in an environmentally controlled vault. The Center has a full suite of commercial software packages for both data processing and presentation. In addition to commercial software, faculty, staff and students are also actively engaged in the development of in-house software. 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 (4mm, 8mm, DLT, LTO, CD-R, DVD±R and Blu-Ray) are available so that we can re-distribute the data on a range of media types.

The Center has a full suite of printers and plotters including both 48 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. With the growth of the center and its increasingly larger need for print media, the Center has added five new HP laser printers this year, bringing the total for network-accessible printers on the Center network to ten.

The Center's IT staff also played an important role in this year's Shallow Survey Conference, which was hosted by UNH/CCOM in October. Center IT staff was responsible for the web hosting for the Shallow Survey website, storage and distribution of the common datasets, coordinating with vendors and staff regarding their IT needs, and the setup and management of the conference's presentation equipment.

Research Vessels

The Center operates two dedicated research vessels (Figs. 3 and 4), 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 2008 the *Coastal Surveyor* operated for nine months (April through December) with much of its operation focused on collecting data in support of the Shallow Survey 2008 conference (see discussion below); the *Cocheco* saw much more limited service as this year saw the installation of a new hydraulic system and winch. This will be the first year that both vessels will be left in the water over the winter – at the new UNH pier facility in New Castle. The vessels are operated primarily in the area of Portsmouth, New Hampshire, but are capable of transiting and operating from Maine to Massachusetts. Neither vessel is designed for offshore operations; however they are ideally suited to near shore and shallow water (down to four meters depth below surface). This past summer the *Coastal Surveyor* traveled to Castine Harbor, Maine which was the site of the "Hydrography Field Course" surveys (see discussions below).

Figure 3. R/V Coastal Surveyor with bow ram.

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

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 on-board navigation system (CBASS—see Coastal Processes discussion below) and has partnered with the Bloggett Foundation to help equip a hovercraft (RH *Sabvabba*) especially equipped to work in the most extreme regions of the Arctic.

The two vessels are different in design, function, and condition.

R/V *Coastal Surveyor*

(40 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed 9 knots)

The *Coastal Surveyor* (Figure 3) 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. She has a bow ram for mounting sonar transducers without hauling the vessel. C&C operated her 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.

This boat continues to be invaluable. Thanks to the improved (in 2005) hydraulic stabilizers, the high precision of boat offset surveys, and the remarkably stable transducer mount, she remains one of the finest shallow water survey vessels in the world. A marine survey was completed in 2008, acknowledging that the vessel is sound but beginning to show her age. The main engine, a 200BHP Caterpillar diesel with over five thousand hours, while 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 will be addressed over the winter.

Figure 4. R/V Cocheco.

R/V *Cocheco*

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

R/V *Cocheco* (Figure 4) is designed for fast transits and for over-the-stern operations from her A-Frame. This vessel, though five years old, has been operated for only a little over one year. This 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 220VAC, instrument bench wiring for 24VDC and 12VDC, and installation of an existing KVH gyro compensated flux gate compass and ship's AIS system were also completed this year.

Figure 4. RH Sabvabba deployed on ice and collecting data near Spitsbergen.

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/V *Sabvabba* was underwritten by the Blodgett Foundation. The vessel has been operated out of UNIS, the University Centre in Svalbard, in Longyearbyen, since June 2008. Through donations from the Blodgett Foundation, The Center for Coastal and Ocean Mapping has provided a Knudsen 12kHz 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, probably the key to unlocking the origin and history of the Arctic Ocean.

The summer of 2008 saw the six 'shake-down' forays (3,500 nmi) of the hovercraft into the icepack over the Yermak Plateau north of Svalbard, to latitudes above 81ºN. These week-long trips took pairs of Norwegian high-school students interested in Arctic geophysical careers, as part of an IPY program called Classroom on the Ice. The various equipment suites were tested; this included the seismic gear, components of one of three planned innovative autonomous drifting seismic buoys, an EM ice thickness probe from AWI, a winch with hydrostatically-boosted corer, multiple CTD lowerings, and the various navigation and communication gear and FLIR night-vision.

Despite the rapid deterioration of the Arctic ice cover, a large area of thick multi-year ice remains north of Greenland and Ellesmere. This is totally inaccessible to icebreakers, and for aircraft for most of the year. This is the area from which the four oldest Arctic cores (~70 my) have been raised, from drifting ice stations several decades ago. The hovercraft can operate at considerably lower cost (~3 liters diesel fuel/km) than other platforms. With an optimal crew of two, it provides a mobile living module capable of seismic work and coring over long periods of time, provided food and fuel are available. It can take advantage of the long open leads for making seismic profiles, or use the strong ice drift motions to do passive profiling. It is also a vehicle for implanting and recovering the three autonomous drifting seismic buoys, as well as the many SSPARR echo-sounding buoys which are now under development in Norway. A website describing the overall program exists at **http://www.polarhovercraft.no**.

The seismic data collected by the CCOM equipment will complement the data acquired at great expense in the annual cruises of the USCG Healy, and should be useful for a future submission of the US UNCLOS claim (see UNCLOS discussion below).

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 the holder of a certification by the *FIG/IHO International Advisory Board of Standard of Competence for Hydrographic Surveyors* since May 2001. We offer both MS and Ph.D. degrees with a specialization in Ocean Mapping through the Dept. of Ocean Engineering, the Dept. of Earth Sciences (now expanded to include the School of Natural Resources), the Dept. of Electrical 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 have also 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 the two years necessary to complete a master's degree a means of upgrading their education and receiving 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 co-operation 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, and the fourth class (6) in 2008. The Nippon Foundation has extended the program into 2009 and six more students are currently enrolled. 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, IBCAO, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, USGS and others). This has proven very useful as our students are allowed to attend 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).

While 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. This past year we have added to our recognition of the importance our educational program by creating 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.

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, Fonseca
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
Seminars in Ocean Mapping	All

We have 25 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 five, Ph.D.'s: Luciano Fonseca (2001); Anthony Hewitt (2002); Matt Plumlee (2004); Randy Cutter (2005); and Matt Quinn (2006). This past year we have graduated four more Master's students.

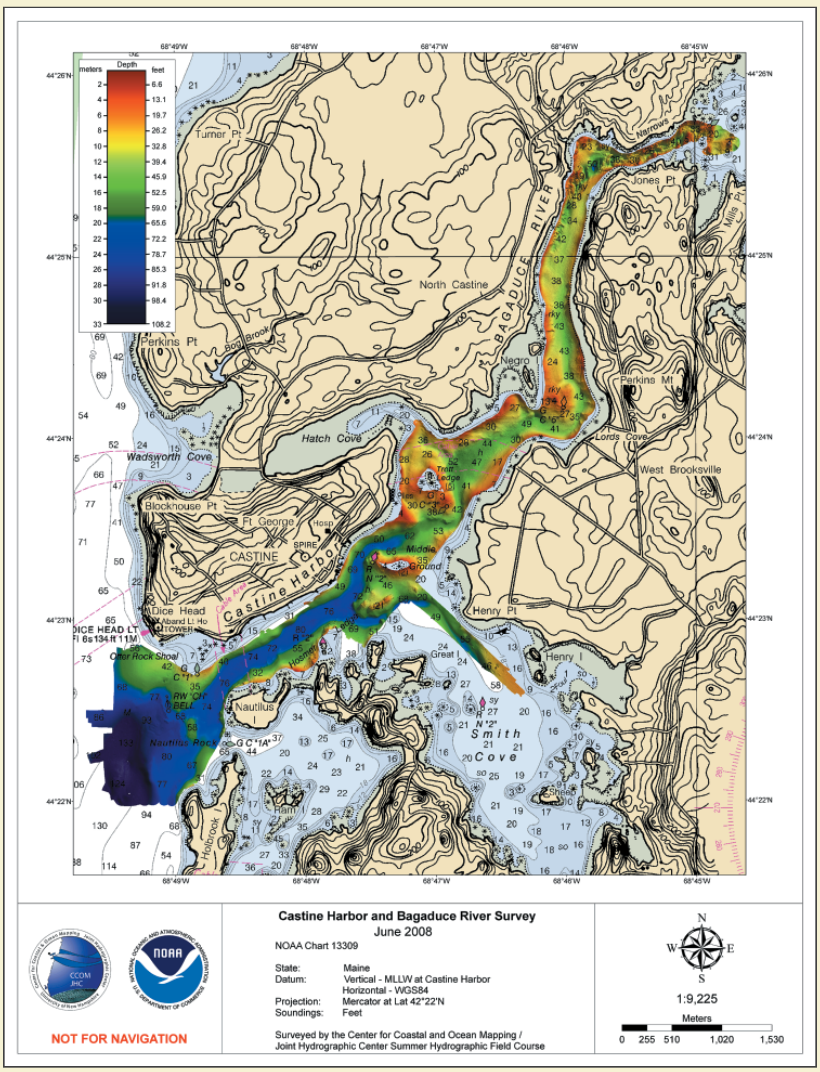
Student	Program	Advisor
Roland Arsenault	Ph.D. OE (PT)	Undetermined
Robert Bogucki	Ph.D. OE	Calder
Daniel Brogan	Ph.D. EE	de Moustier
Tyler Clark	MS ECE	Weber
Janice Felzenberg	MS ESci	Ward/Mayer
Bert Franzheim	MS ECE	de Moustier
Sam Greenaway (NOAA)	MS ESci	Armstrong
Tianhang Hou	Ph.D. OE (PT)	Huff
Nikki Kuenzel	MS ESci	Gardner/Mayer
Carlo Lanzoni	MS OE	Weber/Irish
Mashkoor Malik	Ph.D. NRESS	Mayer/Calder
Marc Moser	MS OE	Armstrong
Venkata Motamarri	Ph.D. ECE	Pe'eri/Calder
Brian O'Donnell	MS EE/Ph.D. ECE	de Moustier/Calder
Daniel Pineo	Ph.D. CS	Ware
Rachel Soraruf (NOAA)	MS ESci	Armstrong
Val Schmidt	MS OE (rec'd., 2008)	Weber
Ed Sweeney	MS ESci (rec'd., 2008)	Gardner/Mayer
Rohit Venugopal	MS CS	Calder
Nathan Wardwell	MS ESci (rec'd., 2008)	Gardner/Huff/Wells
Michelle Weirathmueller	MS OE (rec'd., 2008)	Weber
Monica Wolfson	Ph.D. NRESS	Mayer/Pe'eri

GEBCO Students: (2008-2009)

Student	Institution	Country
Anastasia Abramova	Geol. Inst. RAS	Russia
Felipe Barrios Burnett	Hydro Office	Chile
Guillermo Pena Diaz	Hydro Office	Columbia
Christiana Lacerda	Navy Hydro Center	Brazil
Kentaro Kenada	Coast Guard	Japan
Rachot Osiri	Hydro Office	Thailand

Hydrographic Field Course

This summers' Hydrographic Field Course brought the R/V *Coastal Surveyor* and nine students under the supervision of Andy Armstrong and Semme Dijkstra to Castine Maine where a survey was conducted in the harbor and the Bagaduce River at the invitation of the Maine Maritime Academy. This is the first time that we conducted the field course remote from the lab. The remoteness of the site provided numerous challenges but presented a more realistic work environment. The product of the Hydrographic Field, displayed below, will be a useful product for the Maritime Academy and, if deemed suitable, may be eventually be used to update NOAA charts.



Status of Research: January - December 2008

In our initial proposal (1999), we 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 several 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. Carlo Lanzoni has followed up on the work of Barbara Kraft and Glenn McGuillicuddy, documenting the calibration facility code and adding the ability to visualize processed data in real-time. Additionally code has been written to verify impedance measurements, and to incorporate precise measurements of water temperature into the calibration process.

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

Kongsberg EM3002

In support of Mashkoor Malik's and Chris Gurshin's thesis work. Detailed measurements were made of beam patterns, dource and receive sensitivities, pulse width, pulse length, source levels, etc. at a range of operator settings—see discussion of backscatter processing for more details.

Simrad EK60

Evaluated in support of Chris Gurshin's thesis work and Roland Arsenault's work with whale tagging.

Kongsberg SM2000

(one from DFO Canada and one from NMFS Woods Hole)
In support of Weber work mapping tuna.

Sensortech SX30

In support of whale pinger experiments.

Reson TC213

In support of Mashkoor Malik's backscatter uncertainty research.

MULTIBEAM SONAR ON KLEIN 7180

Brian O'Donnell, under the supervision of Christian de Moustier and Lloyd Huff, collected and evaluated data from the multibeam subsystem which was mounted on the pre-prototype Klein 7180 Long-Range Side Scan Sonar (LRSSS) during its use on the *Fairweather* in the eastern Bering Sea (data collected in August 2006). These data have been subjected to intense scrutiny to study the idiosyncratic behavior of the measured depths. While funded from another NOAA grant (to Huff) this work is very relevant to the overall objectives and research goals of the Center. It is widely recognized that multibeam bathymetry systems often have a specific cross-track pattern in depth measurement uncertainties stemming from the transition from amplitude detection of the seabed location to phase detection of the seabed. However, the cross-track pattern in depth measurement uncertainties in the pre-prototype Klein 7180 was quite different. Detailed investigation revealed that signals from another acoustic subsystem on the 7180 were being "folded" into the pass-band of the multibeam sonar on the 7180. Since the data from the Klein 7180 is only available after it has been subjected to several digital processing steps, it was necessary to develop a scheme of modeling/simulation to unravel the mystery.

O'Donnell's work has indicated that it is the side scan sonar that interferes with the multibeam echo-sounder because the two signals are so closely spaced in frequency. In Figure 5 the echo-sounder signal is the first parabola and the side scan signal is the second parabola. As time of arrival increases, the two echoes completely overlap. The side scan interference causes the weighted mean time detections to be deeper than the seafloor actually is. These deeper detections do not characterize the true shape of the seafloor.

A frequency filter can be used to remove a large portion of the interference. A 10 tap boxcar filter can be used to zero-phase filter the signal and remove most of the interference. In Figure 6 very little of the interference is still visible and it is no longer effecting the weighted mean time detection. There are three locations at which the WMT algorithm is not detecting the seafloor at -22, -15 and -5 degrees because these are the nulls of the transmit beam pattern and there is little acoustic energy scattering from those points on the seafloor. The frequency filtering decreases the resolution from 1.318 meters to 1.873 meters.

Before the field acceptance test in June 2008, L-3 Klein changed a low-pass filter in their signal processing which they claimed would remove SS interference. To quantify the cross-talk into the multibeam echo-sounder, the multibeam receive array listened to the seafloor echo from different sonar waveforms. Analysis of these data show that interference from the side scan sonar becomes indistinguishable from noise at 275 meters slant range and that there is a 10 dB signal to noise ratio until 350 meters slant range. This analysis was carried out for all of the relevant waveforms at multiple towfish depths above the seafloor.

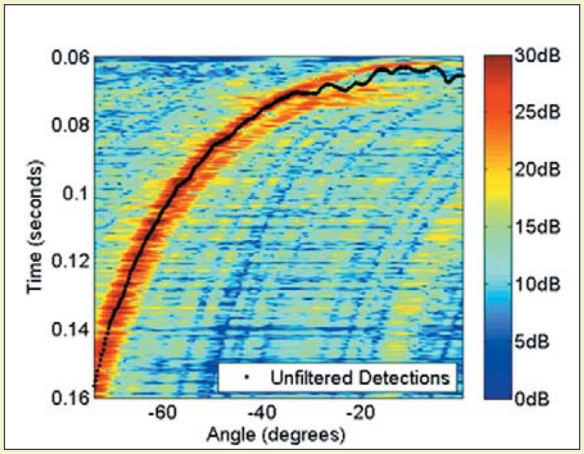


Figure 5. Unfiltered port receive array beamformed image. weighted mean time detections are plotted on top of the beamformed image.

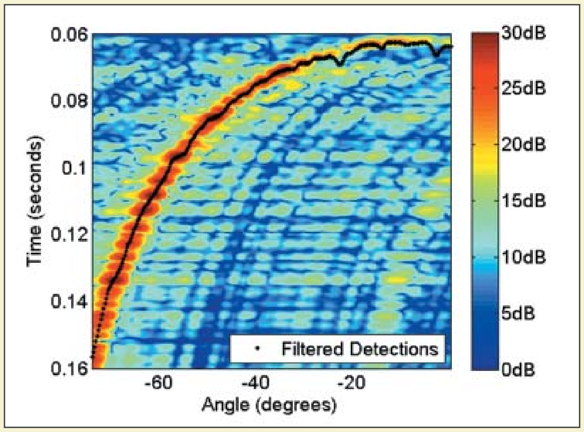


Figure 6. Filtered port receive array beamformed image weighted mean time detections are plotted on top of the beamformed image.

KLEIN 5410 UNCERTAINTY MODEL

Graduate student and NOAA Corps Officer Marc Moser, working under the supervision of Chris de Moustier, has been attempting to understand the uncertainties associated with the bathymetry being collected from the Klein 5410 sonar. Building on the successful implementation of former graduate student Jim Glynn's and Brian Locke's processing and calibration procedures (see last year's progress report), a procedure for the analysis of the resulting bathymetry has been developed in Matlab.

Using exported sounding data and surfaces from Caris and GSF files, data are processed in Matlab. Since Caris has limited export options, GSF data are necessary for the two-way travel time for each sounding. The processing steps include:

a) Process SDF data using Brian Locke C+ processing program.
b) Process GSF data in Caris.
c) Export attributed line sounding data from Caris.
d) Export surfaces created from Klein 5410 and Kongsberg EM 3002 bathymetry
e) Evaluate each sounding against nearest surface node.
f) Ray trace each sounding using raw two-way travel time to calculate total range, horizontal range, depth, absorption loss, and (approximate) grazing angle.
g) Calculate uncertainty for each sounding for all uncertainty sources except for the sonar uncertainty using equations derived by Hare, Godin, and Mayer (1995).
h) Calculate angle of incidence using surface normal of exported EM 3002 surface.
i) De-trend difference data assuming that any non-zero values are the result of tides, draft, refraction, DC bias drift, or interference.
j) Determine the Klein 5410 uncertainty model based on three possible sources of uncertainty including angular uncertainty, SNR, and time resolution (pulse bandwidth).
k) Compare total uncertainty with ocean mapping standards.

Data acquired for Shallow Survey 2008 by Kongsberg are being used for the EM 3002 surface data. The removal of the non-zero mean difference data bias is assumed to encompass those uncertainties associated with draft,

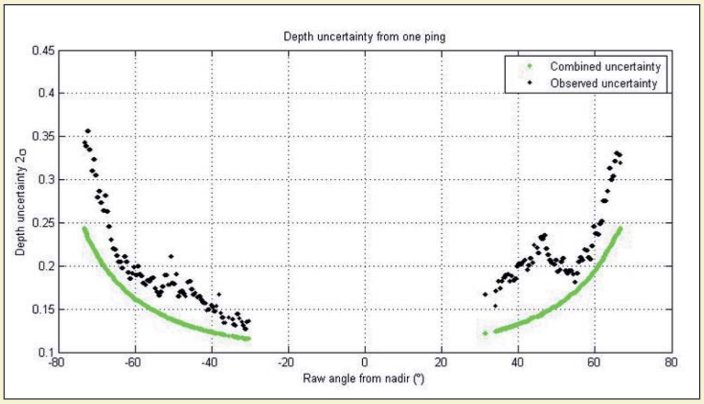


Figure 7. Observed and calculated (ex tide, draft, refraction) uncertainty of Klein 5410 soundings.

tides, and refraction (going on the assumption that any error associated with those uncertainty sources would be relatively constant over course of a single line). The impacts of the two possible additional causes of the non-zero mean difference are not directly calculated. The residual uncertainty is calculated by removing the calculated uncertainty from the observed uncertainty. The residual uncertainty can then be evaluated against three probable sources of sonar uncertainty.

HIGH-PRECISION, HIGH-ACCURACY TIME SYNCHRONIZATION

The ultimate accuracy achievable from a multibeam survey can often be constrained by our ability to synchronize the time-stamps among the varied 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 – 533MHz Pentium III systems – and network – desktop workgroup 100bT Ethernet switches) the National Instruments PCI-1588 cards achieve synchronization and syntonization of clocks within approximate 100ns 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 talking 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 timestamp 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.

Experiments were also done (with Andy McLeod) that demonstrated that an implementation of this approach over commercial wireless is limited in accuracy due to variable latency in the wireless switches, on the order of 1-5ms rms, with some spikes to 10ms. In support of this approach, Calder has developed code, termed the Software Grandmaster (SWGM) Algorithm, to synchronize, syntonize and absolute reference PTP time to a UTC master, in particular the 1PPS and ZDA messages from a GPS or IMU. The short-term accuracy of this system is typically 100-110ns rms from master to slave (slightly better on the master), and the long-term stability is essentially that of the GPS or IMU system itself. That is, SWGM-derived hardware times track UTC time absolutely within 100-110ns rms as long as the system remains in operation. The SWGM algorithm is robust to network packet loss up to ~60% and the a priori uncertainty estimated for timestamps by the SWGM algorithm match the true errors observed in the test environment. The self-timing of software latency is possible using processor register timing and careful control of process priority, but that process priority can significantly affect likely uncertainty in time-stamping (by an order of magnitude or more).

After the trial implementation during the last reporting period, Calder continued to work with Reson on integrating the Software Grandmaster algorithm into their 7kCenter control software for 7000-series systems, focusing particularly on the 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 new tens of nanoseconds, even under heavy processor load with stable, and low predicted uncertainty of timestamps. This implementation is now in the process of being adopted by Reson for release in the Q1/2009 timeframe.

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) and, over the past five years, 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 error-model based, direct DTM generator that estimates the depth plus a confidence interval directly on each node point. 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 automated editing technique fails to make a statistically conclusive decision, it will generate multiple hypotheses, attempt to quantify the relative merit of each hypothesis, as well as 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, Mass., 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 and 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. This past year Dr. Calder has worked closely with NOAA, Fugro, NetSurvey, UKHO and Triton, focusing particularly on the selection of CUBE parameters and their tuning requirements, and supporting NOAA's processing schemes through, *inter alia*, a visit to the *Rainier* to discuss their processing difficulties. It appears that the difficulties were essentially a broken implementation of CUBE incorporated into CARIS's HIPS product, which resulted in a significant loss of confidence among the operators. The team on the *Rainier* is now processing with something more akin to the original intent of CUBE, and are getting back up to speed. This experience has led to an invitation to carry out a full day of CUBE training at the NOAA training classes in 2009-02 (one day each at Norfolk, VA and Seattle, WA).

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 by which to 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 has started this investigation by considering a trial model of underkeel 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 us to predict, at any position and time, the full probability density function (pdf) of the underkeel 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 since it is critical in defining flux of objects potentially encountered by the hull.) The simplest approach is to model the time evolution of the vessel's track which allows us to estimate the instantaneous probability of grounding, and thence 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 are 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. This does not imply, however, 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). We have started investigating this (using analysis of AIS traffic data [collaboration with Schwehr]) and other calibration issues of the modeling. Similarly, although we have shown here area-based estimates of risk, use of gridded products allows them to be easily manipulated for generalization and simplification in order to obtain products that could be used for user-level displays where the contours are now of implied risk to the mariner, rather than depth.

Calder's initial work has only scratched the surface of the models and their complexity. We continue to refine the models, for example by compensating the underkeel clearance adjustment associated with unseen objects as the ship moves based on the argument that the ship's hull acts as a self-wire drag. That is, if the vessel does not run aground at this time instant (even though it is possible according to the current UKC pdf), then we have a new observation about the true depth under the keel, and should factor this in to the UKC pdf that is defined local to the vessel, discounted according to how much exposed hull area is shared by the vessel between time ticks of the simulation model. We have also experimented with the concept of a generalized 'risk' by associating a cost function with the UKC being predicted (which can be, as shown, spatially inhomogeneous and arbitrarily shaped, based on say differences in bottom type), and then computing the expected cost via the predicted UKC pdf (Figure 9).

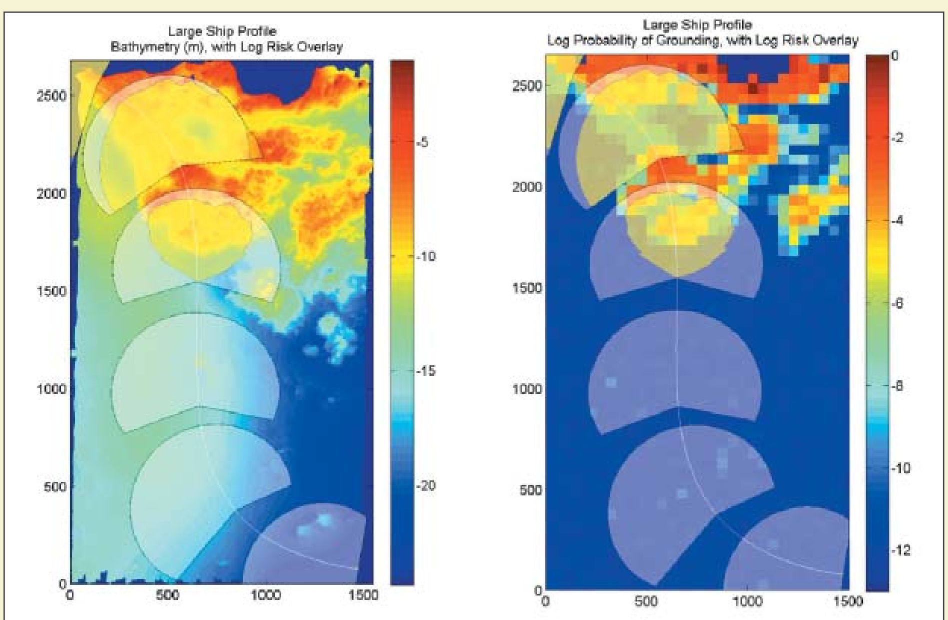


Figure 8. The probability of grounding along each of these future potential trajectories, we can summarize the information for the user by drawing (white) the maneuvering area, and overlaying (yellow) the accumulated risk along each trajectory.

This sort of technique allows the user to emphasize particular features of the costs expected in an area, e.g., to make the system prefer channels, or stay on the right side of a traffic separation scheme, and to factor in non-bathymetric costs (e.g., that going around a buoy on the wrong side has higher costs) in order to provide a fully general risk assessment toolset.

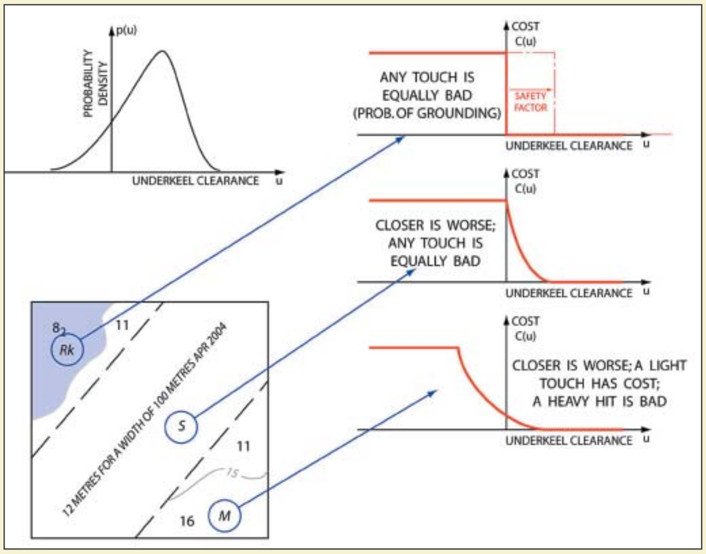


Figure 9. Various "cost functions" associated with the risk of hitting the bottom in different bottom types.

The complete flexibility of modeling and cost assessment that these sorts of techniques provide are clearly powerful, but they also imply a great flexibility that leaves open the question of calibration and stability. We continue to work on these issues, and expect this to be a major theme of next year's research effort.

Dynamic Grid Resolution for Bathymetric Estimation

The efficiency of bathymetric processing varies greatly as data density varies (often associated with a variable depth range). To address this issue, Brian Calder and graduate student Robert Bogucki have been looking at the problem of implementing data-adaptive gridding schemes for multibeam hydrographic data processing. The core effort lies in analytically formulating the optimization criteria and constraints lying at the heart of variable resolution grid adaptation problem, and outlining development of an efficient computational structure for solving this optimization problem, based on the insights gleaned from the statistical exploration of spatial datasets and an understanding of the hydrographic context. The proposed approach uses a hierarchical recursive subdivision scheme which produces a grid hierarchy graph that has the topology of a quadtree. Leaves of this graph are deformed quadrilateral meshes. The expected advantages of this scheme are scalability and relatively low computational footprint. In support of this effort, Bogucki has developed an integrated collection of (primarily) Matlab tools for interactive statistical exploration of bathymetric data over a range of spatial scales, including facilities for online parametric surface fitting to user-specified (and user-deformable) arbitrary quadrilateral regions and analysis of fitting residuals (Figure 10).

Parallel Processing for Hydrographic Data

As data rates increase rapidly, the computational demands for hydrographic processing are becoming ever greater. Many of the computational aspects of hydrographic data processing may lend themselves to a parallel processing approach. Calder has begun to work with Rohit Venugopal (a Computer Science MS student) on understanding how to implement in parallel typical hydrographic data processing algorithms. After discussions with hydrographic systems and technology program (E.J. Van den Ameele), we have also recruited James Hiebert at NOAA Silver Spring to assist in this development and to provide a fleet-support perspective. We have started the project by looking at the basic ingestion and preliminary data processing (tides, navigation, ray tracing, etc.) and have recruited Bill Lamey at CARIS to support this effort through contribution of code libraries and APIs to allow us to use the HIPS algorithms that NOAA use now on the Center's newly acquired parallel processing blade server.

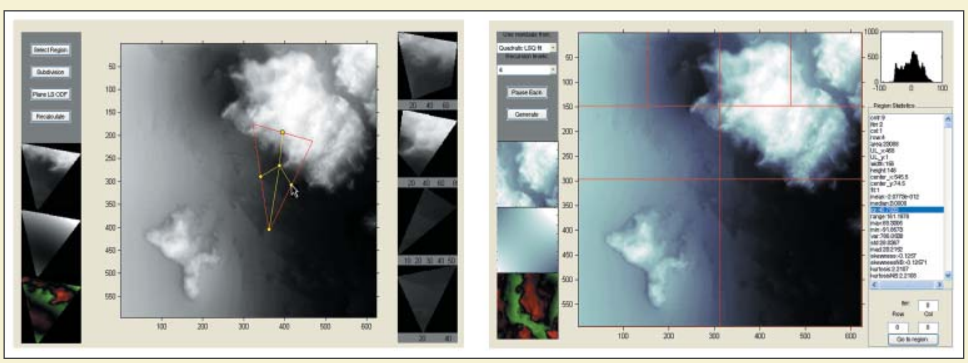


Figure 10. Matlab GUIs for interactive exploration of statistical properties of multibeam-derived data over variable spatial scales.

Automatic Metadata Generation

The provision of metadata for survey data is essential but time-consuming and prone to error due to the extreme repetition that it typically entails. In order to resolve this, Calder developed a collection of programs and scripts that parse the metadata required to adjust the boilerplate background information for each line from the

HIPS/HDCS data and SonarWeb SEGY files typically used in our deep-water UNCLOS mapping cruises. Adaptation of these techniques to support more file types and more flexible structures within the source data files are expected to be required, and we envision a collaboration with Schwehr, Sullivan and the new Data Manager in 2009 to make these more generally useful both at sea and within the Center (for data set mining and recovery).

Sound Speed Profile Uncertainty Estimation and Management

Subsequent to a meeting at Shallow Survey 2008, Calder became involved in a collaborative project with Jonathan Beaudoin (UNB), James Hiebert and Gretchen Imahori (NOAA) and others to investigate ways that Beaudoin's 'uncertainty wedge' method for SSP uncertainty estimation (from an observational model) could be used in the NOAA processing pipeline, and in particular in the TPU modeling used to feed CUBE. This project is a new-start as of 2008-10, but we expect a paper in US Hydro 2009 and subsequent journal article.

IMPROVED SIDESCAN SONAR AND BACKSCATTER PROCESSING

GeoCoder

While our initial data processing efforts focused on improving bathymetric processing, it has become increasingly clear that there is also a great need for improved processing of backscatter data (both from multibeam sonars and sidescan sonars). With this in mind, we began, in 2005, a new effort aimed at improving the suite of backscatter processing tools available to us and NOAA. Our aim was two-fold: 1- to develop easy to use tools that will generate pleasing images of sidescan sonar or multibeam backscatter that will be suitable for small object detection as well as geologic and habitat interpretation, and 2- to develop tools that allow for the quantitative analysis of backscatter data in support of seafloor characterization and small object identification.

In an effort to meet these two objectives, we started a lab-wide effort to develop a new suite of backscatter processing tools. This effort is being led by Luciano Fonseca with input from many others. The goal is to create an integrated suite of tools that will 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 georeferenced mosaic. The result of this 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, 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 which then reveals the actual non-linearity of the transducer angular response. Data is then geocoded 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 that 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 very 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.

Improvements to GeoCoder in 2008 include: 1- support for Simrad EM 710, which include major modification to the code to cope with the new Simrad datagrams and different frequencies for multiple transmit sectors; 2- the addition of processing support for bitmap images. With that, first order and second order statistics can be calculated on standard image processing images, and the output of GeoCoder can be assessed against published results; 3- the ability to display pitch, heave and roll on the mosaic; 4- the option to calculate statistics based on a histogram (1db bin size) and not on the actual samples; the option to visualize and export the histogram for each statistical bin; a generic algorithm for processing snippets (beam time series), which eliminated redundancies in the main code and simplified the inclusion of new systems; the ability to remove the anti-aliasing and speckle-noise filter from final mosaic; and options to apply time exclusion tables and to batch processing a list of files (for the problem of cross-talk in the Klein 7180 sonar described above). Additionally, Fonseca and Malik have been exploring the question of the most appropriate method for calculating statistics from backscatter measurements (e.g., in dB space or amplitude space). Based on these studies; it has been concluded that the most useful statistics are percentiles which do not depend on transformations between dB and amplitude space.

Since its development, GeoCoder has become a simple-to-use tool for generating a sidescan sonar or backscatter "mosaic" which 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 growing quickly. 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 SANCTUARIES
- 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

This past year Luciano Fonseca visited both the *Fairweather* and the *Rainier* during the Hydropalooza event in August 2008. At Hydropalooza Luciano presented seminars about the specific use of GeoCoder for the NOAA-specific systems including the Reson 8111, 8160, and 8101 and 7125 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 this regard, we have completed several experiments 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. The objective of these experiments is to gather a large data set comprising multibeam seafloor backscatter observations accompanied with a detailed observation of the medium. Initial tests involved looking at the stability of backscatter in the controlled environment of our acoustic test tank.

EM 3002 Calibrations in UNH Acoustic Test Tank

EM 3002 (Serial number 372) was calibrated in UNH acoustic test tank during 3-13 June 2008 in collaboration with UNH student Chris Gurshin. The objectives of these calibrations were:

a) Measurement receive and transmit characteristics of the EM 3002 including beam patterns, source level, receive sensitivity etc.
b) Measurement the fluctuations in the sonar characteristics over short period of time in a controlled test tank environment.
c) Calibration using spheres of different sizes (38 mm, 54 mm and 355 mm sphere).
d) Determine the near field - far field transition range of the sonar based on the observed source level variations at different ranges from the sonar.

The analysis of the calibration data is in progress. Preliminary results of the transmit beam patterns at 5 m and 8.5 m range are plotted in Figure 11. These almost identical results show that the errors in the tank calibration due to misalignment are negligible. Backscatter values measured off the wall of the tank appeared to be stable within +/-0.5 dB.

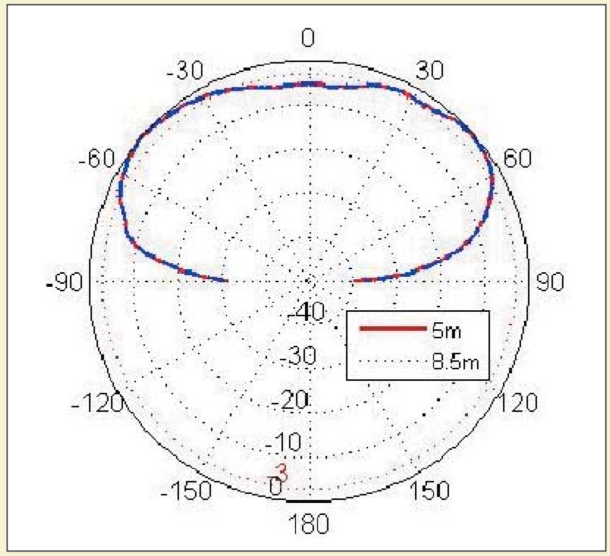


Figure 11. Results of 2 transmit beam pattern measurements on EM3002 in acoustic tank.

UNH Pier Experiment (May 20 – June 2, 2008)

Once the variability of the backscatter measurements made under the controlled conditions of the tank were established (system uncertainty) we then began to look at the influence of the environment on backscatter measurements. This was done with a controlled experiment at the UNH pier in New Castle, N.H. The pier experiment used a 300 kHz (Kongsberg Simrad EM 3002 multibeam sonar borrowed from Mass Div of Marine Fisheries and NOAA Gloria Michelle) multibeam sonar, a 600 mHz ADCP, bottom current meter, optical backscatter sensors, a bottom video camera and an upward looking single-beam Reson TC 2132 sonar. The experiment consisted of two phases. In the first phase, seafloor backscatter data were collected over 7 days (20 May – 27 May) running the multibeam sonar round the clock. In the second phase of the experiment, a 355 mm diameter stainless steel sphere (filled with distilled water) was deployed 1 m above the seafloor in order to isolate seafloor-related changes from the medium-related changes. The changes in the observed backscatter from the sphere were expected to depend exclusively on the medium and the device, thereby isolating the variability in the seafloor backscatter data due to changes on the seafloor. The experimental setup details at the pier are provided in Figure 12.

The detailed analysis of data from pier experiment is in progress. Preliminary results show that the backscatter data is stable with in 0.5 dB for the sphere and about 1 dB for the seafloor during short period of time over a period of 100 seconds. Over longer periods of time, the backscatter from the seafloor fluctuated but it is premature to conclude the magnitude and reasons of the backscatter fluctuations without detailed analysis of all the data including fluctuations observed over the 355 mm sphere.

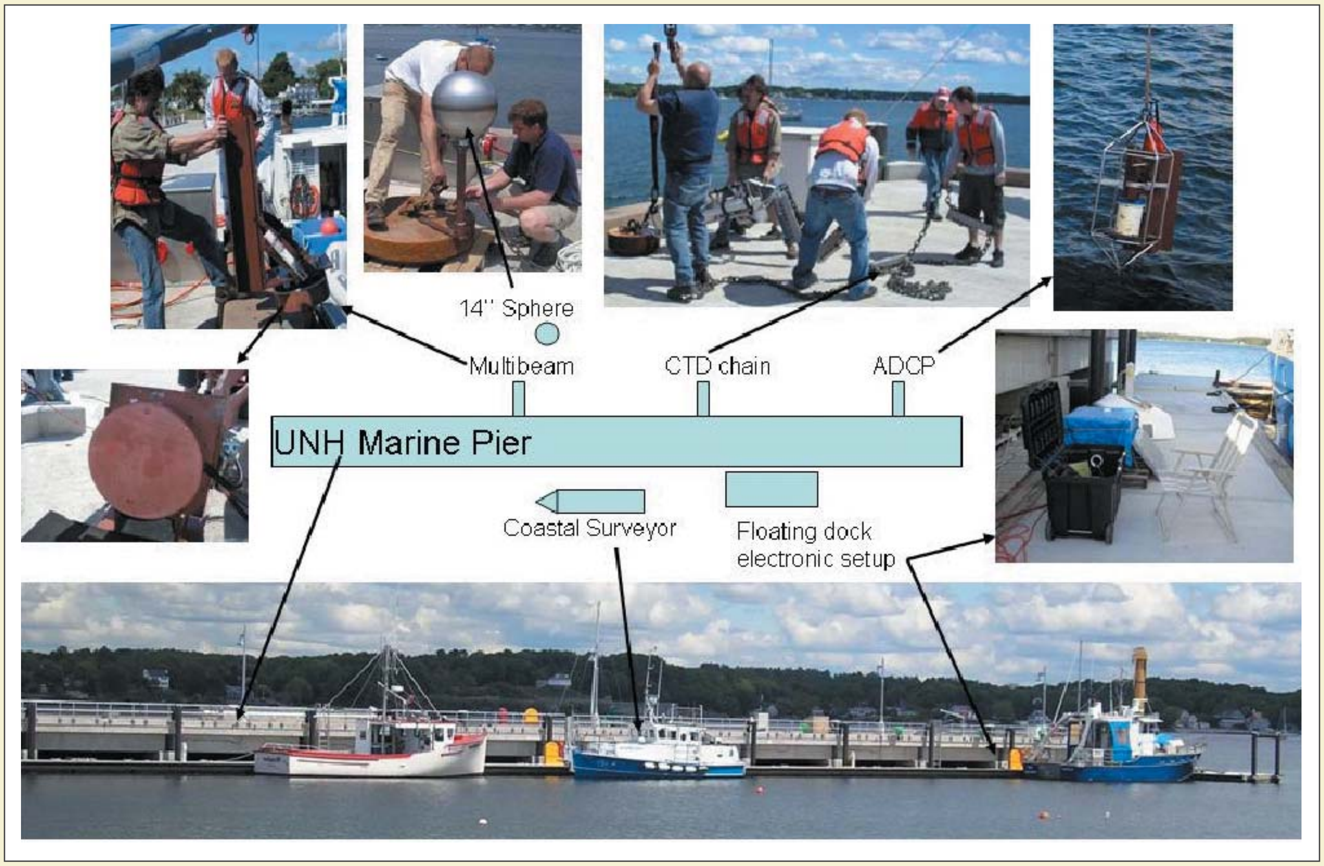


Figure 12. UNH marine pier setup for experiments May 20-June 02. Clockwise from top left: Deployment of Multibeam; 14'' sphere; CTD chain consisting of seabird salinity, temperature and pressure sensors and bottom current meter; ADCP; electronic setup at the pier; location of experimental setup at the pier and the EM 3002 sonar head.

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 (a highly interactive 3-D visualization system designed to support a number of different research projects and ocean mapping applications—see earlier progress reports for details) into GeoZui 4-D which allows the incorporation of time-varying data and opening 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 2008 GeoZui-4D has been interfaced to a number of sonar systems as we explore the possibility of real-time display of both mid-water and seafloor features (see discussions on mid-water visualization below). Specific enhancements include:

- Beam pattern visualization.
- Screen capture capabilities.
- Realtime audio spectrum viewer using sound card inputs.
- Added ability to show AIS data using Kurt's AIS code.
- Added ability to receive binary data through multi-threaded sockets.

Last year, a new, in-house library (libgz4D) was developed to allow much greater functionality and flexibility in the further development of GeoZui-4D and other visualization applications. Enhancements made this year to libgz4D include:

- Support for grib2 data formats for use with FlowVis and nowCoast.
- Enhanced multi-threading support.
- Modularized roughly following the C++ Boost libraries style.
- Added Visual C++ 8.0 as a build target in addition to existing VC 7.0 and gcc targets.
- Switched to boost Python for python bindings.
- Added XML based description of binary file formats and scripts to automatically generate C++ code.
- Added more OpenGL support classes including render to texture and vertex buffer objects.

The GeoZui-4D task is blending more and more with our Chart of the Future (GeoNAV), Midwater Fish, and AUV tasks. Further developments of GeoZui-4D will be discussed under those headings.

WHALE TRACKING

A particularly exciting aspect of GeoZui-4D has been its application to visualizing the underwater behavior of humpback whales supporting both basic science and policy because humpback whales are an endangered species whose decline is attributed to ship collisions and fishing gear entanglement. Understanding humpback whales' underwater behavior is essential to mitigating both of these causes. NOAA and WHOI scientists have developed suction-cup-mounted tags that are attached to a whale and record depth, pitch, roll, and sound for as long as the tag remains on the whale (the record is now 22 hours). Our visualization team has taken these data and created fully georeferenced 4-D display 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 demos of, this technology have been presented at both scientific and policy meetings.

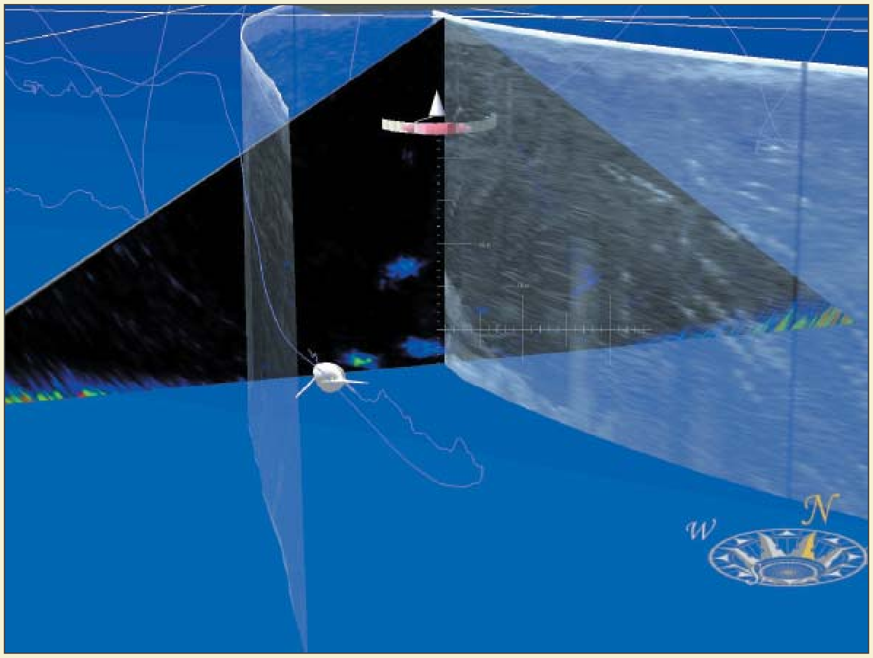


Figure 13. Screen capture from playback of tagged whale track (thin white line), two EK-60 images (whitish curtains) showing whale rising off bottom and Imagenix DeltaT profile (black) with three whales detected (blue spots).

In June/July 2008, Ware and Arsenault participated in another Stellwagen Marine National Sanctuary organized whale tagging cruise. During this cruise, whales were tagged, and imaged with several EK-60 fisheries sounders, and an Imagenix DeltaT multibeam sonar. On this cruise, Arsenault used GeoZui-4D to display, in real-time imagery of the whales from several EK-60's simultaneously. In post-processing, data from the tags, the EK-60's and the Imagenix multibeam sonar were fused to reveal a remarkable interactive 4-dimensional image of the behavior of several (three) whales in time and space (Figure 13).

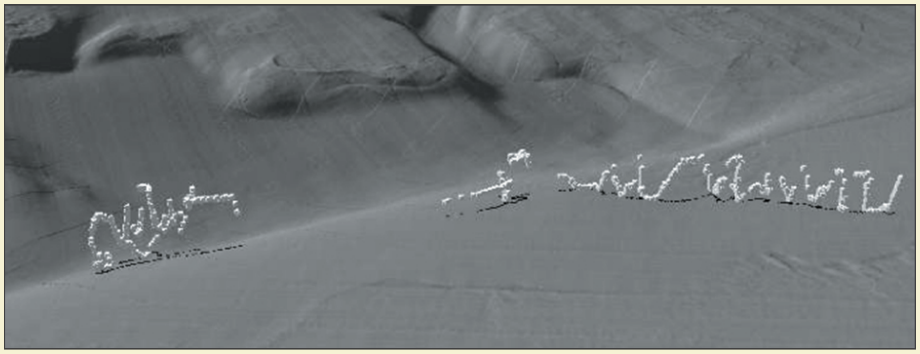


Figure 14. Acoustically tracked position of humpback whale Geometry in context of seafloor bathymetry.

While the ability to play back the underwater behavior of tagged whales has led to important advances in understanding the behavior of whales, once the whales submerge the position of the whale must be estimated through a process of dead-reckoning between surface appearances. This leads to distortions in the whale track and uncertainties in the quantitative analysis of whale behavior. To address this issue, Val Schmidt (as part of his MS thesis) and Tom Weber have developed acoustic "pingers" which can be deployed from small vessels and used to acoustically track the position of the whales underwater while submerged. These, in turn can be used for exploring the behavior of multiple animals (tagged with hydrophones) in the same foraging group

The pingers operate at 25-31 kHz, above the estimated threshold of whale hearing. Signals from each pinger are GPS triggered and are recorded on the whale tag with other whale vocalizations and ambient noise. A calibration of the whale tag's time reference allows timing of the pulses from each pinger, calculation of range to the whale and a final least-squares estimation of the whale's position. The humpback whale 'Geometry' was tagged and tracked on July 21, 2007 and has provided a proof-of-concept data set. Results from the effort are shown in Figure 14, in which the whale track is shown over gray-scale shaded bathymetry. A shadow of the track has been cast for clarity and the vertical exaggeration in the image is x 10. The horizontal whale track shown is approximately 2 km in length and the track covers approximately 80 minutes of time.

Geometry's movement is from left to right in this plot. After several bubble net feeding dives shortly after tagging, Geometry transited some distance to join another group of whales. The Rigid Hull Inflatable Boats were unable to keep up with the pingers deployed over the side and had to secure the pingers, reposition and redeploy them, hence the break in the track in the left-center of the plot. An improved pinger design was deployed in the July 2008 whale tagging experiment described above. A project to combine the Track Plot interface for analyzing whale behavior with acoustic data has now been funded by ONR.

FLOW VISUALIZATION

Ware's work on flow visualization has opened of a range of applications and interest from ocean and 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, understanding weather and climate prediction. The flow visualization work is being carried out by Ware and graduate student Daniel Pineo; partial funding for this work has also been provided by NSF. Ware is also building the beginnings of a new flow visualization package to deal with sigma coordinate models. He is

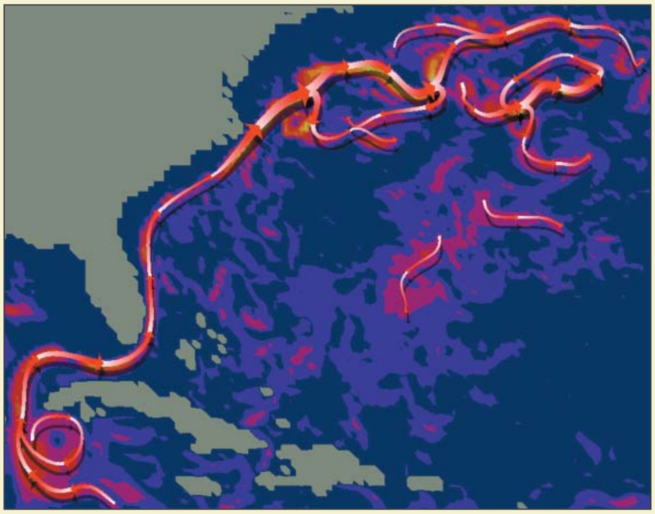


Figure 15. Automated illustration of coherent flow.

working closely with NOAA (and others) modelers and currently the new visualization package can load data from the following models:

- Cbofs (Chesapeake Bay)
- Gbofs (Galveston Harbor)
- Nyofs (New York Harbor)
- Gulf of Mexico

The flow visualization package can display salinity or temperature profiles and supports an exciting array of particle tracing methods. It also allows for 2D or 3D viewing. Significant enhancements include the transformation from a desktop to server application and the development by Pineo of a method of automatic flow illustration using a biased advection technique. This method produces a simplified flow visualization that enhances the major flow features within the viewing area. The result is a visualization of complex flow in a form previously only achievable by human illustrators (Figure 15).

THERE ARE THREE SUB-PROJECTS WITHIN THE FLOW VISUALIZATION INITIATIVE:

Museum Displays/Smithsonian Global Flow Visualization

Following on our successful development of a kiosk-based interactive 3-D museum exhibit for Seacoast Science Center (GeoExplorer) which allows an interactive tour through an immersive 3-D environment up and under the Piscataqua River, stopping at interesting sights along the way, Ware has developed a prototype touch-screen display that incorporates flow models for the Pisquataqua River, Great Bay and Little Bay Estuary. The display shows the flow of water in the estuary as a function of tides and currents. Wherever the screen is touched a bright dye is injected into the system and the observer can see the fate of the injected particles over several current and tidal cycles. In October of this year, after three years of preparation, Ware's representation of global ocean circulation using particle fields has finally opened 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. A photo of Ware's visualization was featured in the N.Y. Times as part of their report on the new exhibit (see page 52).

FlowVis2D/NOAA nowCoast

Colin Ware and NOAA employee John Kelley continue to work on a project using the FlowVis2D software to create innovative and more effective ways of presenting NOAA flow model output (from the HYCOM system of models) to the general public. Our optimized 2D flow visualization package is transitioning from a research project to an operational visualization tool. It is scheduled to be used in nowCoast for both Ocean Flow patterns and for the Operational Forecast System Models (ofs) of the Great Lakes and estuaries of the United States. FlowVis2D has proved to be robust and capable of generating quality visualizations of 2D flows at many scales and for different kinds of flow model data including ocean and basin circulation, operational forecast models of estuaries and the great lakes, as well as atmospheric models on both global regional and local scales (Figure 16).

Interacting With the Latest Global Weather Patterns

Modern computers have the capability of loading large amounts of data output from weather forecast models (both atmospheric and oceanographic). This enables the

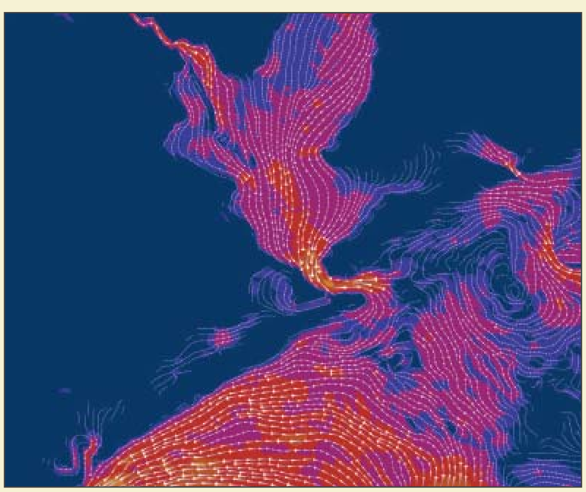
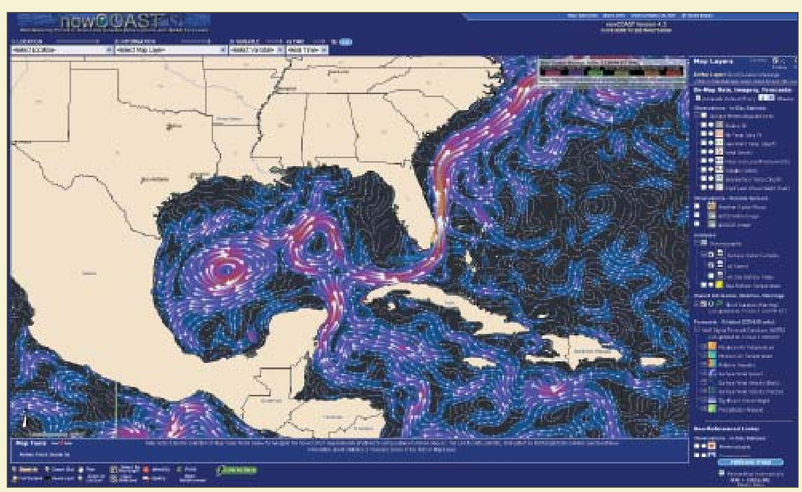


Figure 16. FlowVis2D with data input from the Galveston Bay Operational Forecast Model.



FlowVis2D in nowCoast

flow model to be treated like a kind of virtual wind tunnel. Ware has been developing interfaces to explore the possibilities of interactively seeding tens of thousands of particles into a flow model playback. This allows people to almost literally get their hands into the wind or ocean flow model and deposit virtual dye streams to reveal the flow patterns. One application for this is the potential for interactive data exploration. A second is in education. With the aid of a Granite State Discovery Grant we have been exploring the potential for the method for teaching meteorological concepts.

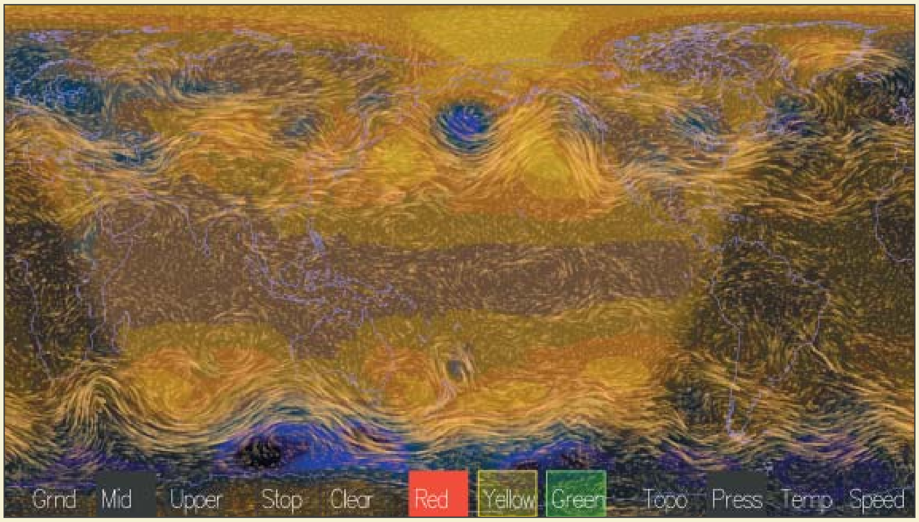


Figure 17. Ground level Pressure and Global Wind patterns are shown based on the latest NOAA weather forecast.

SkySkan is a company that makes both digital projector systems and content for planetaria. They are interested increasing the amount of earth science that can be shown in planetaria and on their GaiaSphere system. We have been working with them on an interactive exhibit that uses up-to-date NOAA weather forecast models to make it possible to see the global pattern of winds at different levels in the atmosphere (Figure 17). The system currently has the following features.

- Different levels of the atmosphere can be selectively highlighted. Selecting the upper atmosphere illustrates the how the northern and southern jet streams encircle the globe. Selecting ground level winds can be used to highlight individual storm events.
- Virtual "dye pots" can be added to events, showing how a windstorm in the Sahara or Gobi Desert can cause dust to be carried around the world via the jet stream.
- Either surface pressure, surface temperature, or wind speed can be color coded and provided as background information.
- Features can be interactively highlighted and automatically tracked. For example, a low pressure area can be selected revealing the counterclockwise wind circulation pattern.

The system has had a number of demonstrations by SkySkan at planetarium trade shows and also at the IEEE visualization conference.

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 make-up 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 INTERFEROMETRIC SONARS

We have made substantial progress in developing approaches to multibeam seafloor characterization on a number of fronts. These developments have been made using EM 120, 121, 300, 1000, 1002, 3000, 3002 302, and Reson 8101, 8111, 8160, 8125 and 7125, as well as GeoAcoustics GeoSwath, Klein 5000 and 5410 data collected in support of the 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 in 2007 and 2008, a new "Common Data Set" was collected in support of the Shallow Survey 2008 Conference hosted by the Center in October. 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 our sonars (through better processing and modeling) and improving our ground-truthing abilities.

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. While 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 they were applied (see discussion of Backscatter Processing above). 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 should be much more representative of true sea floor variability and thus be an important contributor to efforts to remotely characterize the seafloor.

ARA (FORMERLY AVO) ANALYSIS

The GeoCoder software (which is designed to make fully corrected backscatter mosaics and calculate a number of backscatter statistics) has now been integrated with the ARA software package – also developed by Luciano Fonseca – which is designed to analyze the angular response of the backscatter as an approach to remote seafloor characterization. The ARA software has now implemented 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, the enhanced 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. Another benefit is that, with a certain number of assumptions mainly relating to backscatter offsets and beam pattern, the same ARA seafloor characterization can be applied to different sonar systems.

In 2006, the concept of "theme analysis" was added to GeoCoder and the ARA software. With that, average backscatter angular responses can now 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. For that, the theme areas are segmented and clustered directly in the angular response space, and not in the image textural space.

This past year, the "theme analysis" has been enhanced significantly. Luciano has joined forces with Yuri Rzhanov to apply sophisticated image processing techniques that will allow the automatic segmentation of the mosaic into regions of common response before determining the angular response of those regions. These techniques take advantage of both the spatial resolution of the mosaic, and the angular resolution derived from the angular response analysis. Initially, the backscatter mosaic undergoes an over-segmentation (excessive segmentation) which produces a set of the smallest possible segments which still preserve some spatial similarity. These segments are now considered the smallest spatial units for classification (as opposed to mosaic pixels, which represent the smallest possible units and are determined by the specifics of a sensing device (sonar) and survey conditions). The mosaic reflects only a narrow range of angular responses (typically around angle of 45 degrees), but at this stage we need it only to indicate boundaries between spatially homogeneous areas (that are detected in the segmentation process). These small segments do not normally have a complete angular response, as they may be (and usually are) smaller than the swath width. So, the segments need to be joined (coagulated) with similar adjacent segments in order to generate areas on the seafloor with a more complete angular response. This task is achieved using a combinatorial optimization technique (specifically, graph cut). The optimal solution is determined by minimizing some energy functional, consisting of "data" and "smoothness" parts. This approach requires the choice of a set of predetermined labels (in this particular case, angular response curves). Each segment has certain "data" cost associated with assigning it a certain label. Graph cut and a number of other combinatorial techniques are being explored to join the data.

The "coagulation" process joins the small segments in larger areas on the seafloor that we call themes. We then calculate one average angular response per theme, rather than across the sonar swath. With that, the angular response is not limited to the swath width of one acquisition line, but rather is related to all beams from all acquisition lines that intersect the theme polygon the seafloor. The ARA inversion technique is then applied to this average angular response of the theme, which generates estimates of the acoustic impedance, acoustic roughness and mean grain size of the seafloor delimited by the theme (Figure 18).

Rzhanov has recently developed an alternative method for over-segmentation of acoustic backscatter mosaics based on LANL approach. In this approach the image is hierarchically segmented with a gradually increasing number of segments. The output (in the form of an SVG file) is parsed and converted in a sequence of greyscale images that GeoCoder can deal with.

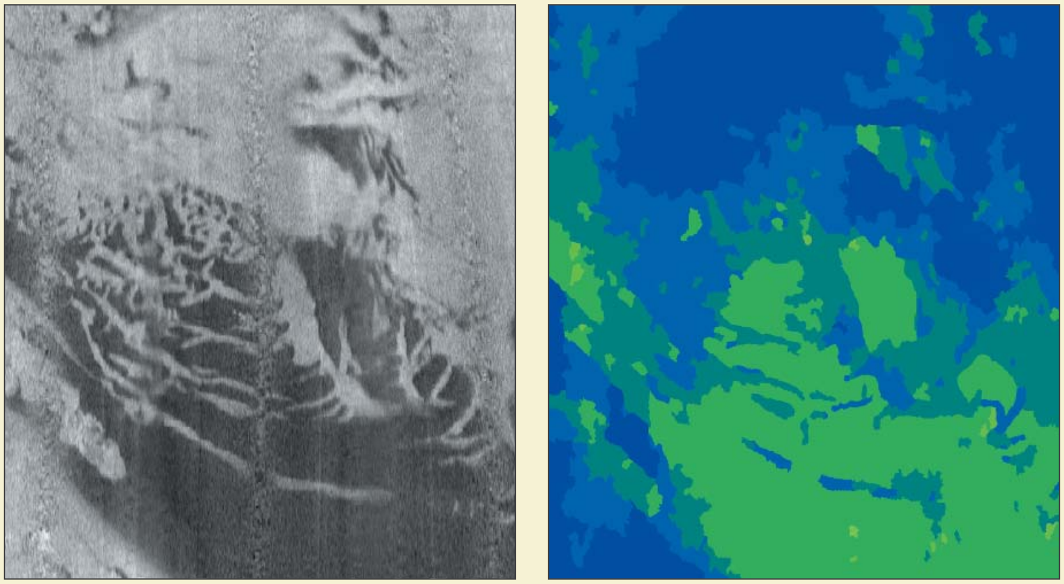


Figure 18. Backscatter mosaic (left) from Stanton Banks, Ireland and grain-size map resulting from theme analysis described above. Note the level of spatial detail achievable.

Fonseca and Rzhanov have compared results of automated delineation with manual delineation performed by several individuals – professionals and amateurs. The results of these studies show that the automatic procedures are close to all of those obtained by human interpreters. Some areas where the interpretation was drastically different were investigated more closely and the general conclusion was that the automated procedure is more accurate because it takes into consideration all the available angular information, while human operators are judging only on the basis of the backscatter mosaic.

ACOUSTIC DETECTION OF HEAVY OIL WITH MULTIBEAM SONAR

In 2008 Fonseca began a collaborative project with Reson Denmark and Reson California aiming to assess the use of multibeam echosounders for the detection of heavy oil on the seafloor in estuaries and riverbeds. The U.S. Coast Guard is very concerned with this matter, because the transportation of very heavy crude oil, which at the moment is highly under priced, has increased considerably. The reason for the concern relies on the fact that the density of heavy crude is higher than the density of the water, so in case of an accident or spill, the oil will sink to the seafloor and eventually be mixed with surficial sediments by currents and wave action. Our first hypothesis is that the oil that rests on seafloor would have a clear acoustic backscatter signature, because the oil has very low acoustic impedance and reduces the surface roughness. An experiment was conducted in the Ohmsett testing facility in New Jersey were patches of oil were spilled on the top of gravelly sand, and the backscatter angular response of this assembly was measured with a Reson 7125 multibeam echosounder at 400 kHz. The result showed that the backscattering strength of the sediment with oil was systematically 10 dB below the backscattering strength of the sediment alone. Consequently, it was a trivial problem to detect oil over gravelly sand.

An additional experiment was conducted using silt, fine sand, coarse sand, very coarse sand with a film of oil of them. The main results from the experiments were that sediments with oil have angular signatures very similar to oil, approximately 10 dB below the sediment without oil. The only exception is oil over silt, which is only 3 dB below the angular response of silt, but has a very particular angular signature. So our final technique for detection starts with a backscatter mosaic. Then areas with very low backscatter are extracted with a simple threshold. The areas separated by this threshold define polygons, and the partial angular responses of these segments are extracted, by theme ARA analysis (as described above). This partial angular response is then tested against the library of measured angular responses and a voting algorithm will define the presence of oil. This work is on-going.

LIDAR Studies

Given the potential advantages (speed of coverage safely above any potential hydrographic hazard) of LIDAR as a means for addressing a number of critical problems facing NOAA (safety of navigation, habitat characterization, shoreline identification, etc.), the Center has been increasing its focus on trying to understand the benefits and limitations of airborne (mostly bathymetric) laser measurements in the context of NOAA and national needs.

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 (Tennix LADS and Optech SHOALS) collected in an area of Portsmouth Harbor, NH and offshore Gerrish Island, ME for which we also have high-resolution multibeam sonar data (EM3002). The two LIDAR data sets showed a remarkable correlation in terms of where bottoms were 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, state of the tide, etc., the properties of the water column which have been traditionally thought to control the success or failure of bottom detection with LIDAR (particularly the diffuse attenuation coefficient) were vastly different. Comparisons of the acoustic measurements and underwater video imagery showed that at depths greater than 7 m, the factor controlling the success or failure of the bottom detection was the nature (composition) of the bottom. Bottoms were consistently detected in regions of sand but were not detected in 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, rocky targets may be systematically missed.

Following up on these exciting results, in 2008 Pe'eri, with help from Jim Gardner, Larry Ward and Ru Morrison (UNH-EOS), collected underwater imagery and bottom samples from Gerish Island survey area. The results of this ground-truthing is currently being analyzed and will help in further understanding the reason for the failure of the airborne bathymetric LIDAR systems (ALB) to detect the bottom.

LIDAR FOR SHORELINE MAPPING

Presently, shoreline mapping is a manual process constrained by the limitations of passive-optical imaging. Two major problems with this process 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 in the current process leads to the creation of shoreline products with results that cannot be reproduced. Recent studies published in the literature have investigated the use of high-resolution Digital Elevation Models (DEM) for to determine 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 and the morphological evidence is not always clear in relation to the tide cycle.

In an attempt to address these limitations, in 2007, 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 1) manual digitization of a reference shoreline from aerial imagery, 2) configuring a shoreline procedure based on a commercial-of-the-shelf (COTS) software (ArcMap), and 3) performance analysis of the different land-water 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 started a collaborative extension of this work with Chris Parrish and Stephen White of NGS/ RSD in NOAA. The goal of this project will be to produce mean high water (MHW) and mean lower low water (MLLW) shorelines and as well as an associated uncertainty estimate.

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 Amarish Motamrri, a new Ph.D. student, Pe'eri is developing an optical configuration for the LIDAR system that can be deployed in our tanks as a waveform recording capability. 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.

Another unresolved uncertainty associated with ALB is the ability of airborne lasers to resolve small, but hydrographically significant targets. To better address this issue we have developed a "natural target" (rock) and that can be considered a suitable target for both for sonar and LIDAR surveys. With the help of Lloyd Huff, James Gardner and Glenn McGillicuddy, a design was developed for a concrete target. The design includes considerations such as target-surface detection in both the optical range and the acoustic range (200 kHz - 400 kHz), ease of deployment and retrieval of the target, and the ability to control positioning of the target. With the help of David Gress (Civil Engineering, UNH), Andy McLeod, Paul Lavoie, and Glenn McGillicuddy, two concrete targets were produced (known as "Even" and "Sela"; rock and boulder in Hebrew) (see figures above).

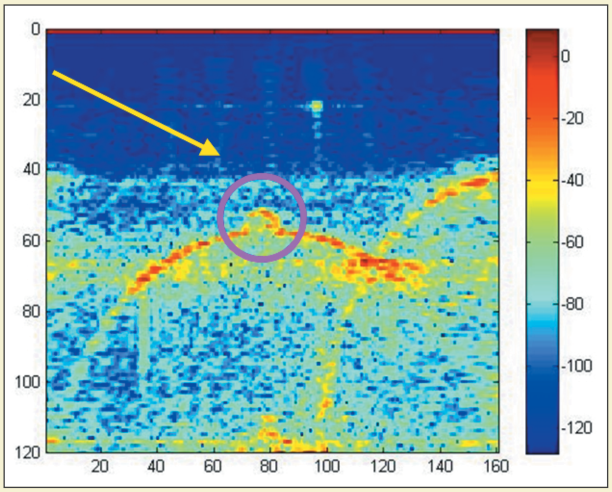


Figure 19. Artificial targets constructed for LIDAR and sonar studies (top) – EM3002 response to target (bottom).

Preliminary tank measurements with a Simrad EM3002 acoustic echosounder was conducted with the help of Malik Mashkoor and Andy McLeod show that the "rocks" are clearly detectable with sonar. The next stage in the experiments will involve deployment of the targets in the ocean to investigate the target's performance under acoustic and LIDAR surveying conditions.

DATA FUSION FOR LIDAR SURVEYING—HYPERSPECTRAL

Looking at the suite of sensors typically carried along with airborne LIDAR, Shachak Pe'eri and Yuri Rzhanov are looking at approaches for registering hyperspectral, LIDAR and imagery data. The US Army Corps of Engineers (USACE) CHARTS system is an airborne LIDAR bathymetry (ALB) sensor suite that includes a RGB DuncanTech DT-4000 camera and a hyperspectral CASI-1500 sensor. Hyperspectral imagery is usually used independently for geographical application. The use of numerous bands (30-300) at small spectral resolution (< 10 nm) allows a chemical characterization following the spectral response of the different wavelengths. A common application is geological and vegetation classification

In earlier work, a semi-automatic procedure was developed for generating a continuous and visually consistent photographic map using the individual frames from the RGB DuncanTech DT-4000 camera. This is now being extended to provide the ability to register the hyperspectral data to the produced map of the RGB camera. This process involves spectral analysis for finding the best channel for both systems to be matched, defining the hyperspectral instantaneous field of view (IFOV) and the pitch angle with respect to the RGB camera, configuring a correlation functions between each line of the hyperspectral imagery to the RGB map, and defining a skip mode to advance to the next line-to-map correlation.

Also, we have begun the investigation for registering LIDAR measurements. Registration of this system adds another parameter of complexity where the footprint size and the scanning patterns are geometrically more complex. If perfected, these techniques can be applied to a number of critical environmental issues including the mapping of eelgrass/macroalgae and measurements spatial water clarity. Pe'eri is currently involved with projects that are exploring the use hyperspectral, LIDAR and optical imagery to evaluate these environmental issues in the Great Bay of New Hampshire. These projects are funded by the Environmental Protection Agency and the N.H. Dept. of Environmental Services.

NEW PROJECTS

The Center tries to be as responsive as possible to national needs and thus we begin new projects that go beyond the scope of our initial program themes as the need demands. Several of these "new" efforts have evolved over the years and are currently underway:

Law of the Sea

Growing recognition that implementation of United Nations Convention on the Law of the Sea Article 76 could confer sovereign rights of resources over large (and potentially resource-rich) areas of the seabed beyond our current 200 nautical mile (nmi). Exclusive Economic Zone has renewed interest in the potential for a 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 assuring 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 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. Summaries of these cruises were presented in the 2003 progress report. In 2004 we returned to the Chukchi Cap and, under very difficult ice conditions, mapped another 100 nmi of the 2500 m contour as well as a 3250 sq. nmi region of the margin off Barrow, Alaska. That year we also began mapping of the continental margin off the east coast of the U.S., covering approximately 98,500 sq nmi in about 60 days of surveying.

In 2005, we conducted two more Law of the Sea cruises, one representing the completion of our initial work off the east coast of the U.S. (two legs) and the other in the Gulf of Alaska (two legs). The survey work off the U.S. east coast took place on the NAVO vessel USNS *Pathfinder*, a 329-ft, 5000 ton vessel equipped with a hull-mounted Kongsberg Simrad EM121A multibeam sonar, under the supervision of Dr. Jim Gardner. In addition to the multibeam sonar, the *Pathfinder* also carried an ODEC Bathy2000 3.5-kHz chirp sub-bottom profiler and a BGM-5 Bell Gravity Meter. The first leg of the 2005 Atlantic work mapped a total area of 57,500 nmi^2. Data collected on the second leg have been classified by the U.S. Navy and are not publicly available at this time.

Also in 2005, we mapped the Gulf of Alaska on 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 3.5-kHz chirp sub-bottom profiler and a Carson gravimeter. This cruise was divided into two legs, the first leg mapped an area of 35,500 nmi^2 and the second an additional 46,138 nmi^2 for a total of 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 tragic diving accident on board the USCG *Healy* led to her return to Seattle and cancellation of her mission before the completion of the 2006 field season leading to the cancellation of our 2006 Arctic Law of the Sea cruise. This cruise was rescheduled for the summer of 2007. Additional equipment problems with the vessel scheduled to do the Gulf of Mexico work led to the postponement of that cruise to April 2007. We did, however, 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 multibeam sonar, under the supervision of Dr. Jim Gardner. In addition, to the multibeam sonar, the USNS *Bowditch* also carried a Knudsen 3.5-kHz chirp sub-bottom profiler and a BGM-5 Bell Gravity Meter. In the course of 30 days at sea, approximately 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 completion of the Marianas area. The Chukchi Cap mapping was conducted using the Seabeam 2112, 12 kHz MBES on board the USCG *Healy* from August 17 to September 17. The *Healy* cruise collected approximately line 10,000 km (5400 nmi) of multibeam echosounder and Knudsen 320 B/R 3.5 kHz chirp sub-bottom profiles reaching as far north as 82.17oN. Using a nominal swath width of approximately 7 km, the total area surveyed during the cruise (Healy0703) was approximately 70,000 sq. km (20,400 nmi^2). The combination of multibeam bathymetry and high-resolution subbottom profiles on this leg have radically changed our view of where the "foot of slope" on the northern margin of the Chukchi Cap is located, 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 Escarpments 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 mapping and 5 days of transits and collected a total of 2357 line nmi of data and mapped 12,000 nm^2 of area.

The 2007 Marianas cruise, under the supervision of Dr. James Gardner, completed the mapping of the Marianas area 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 multibeam sonar and a Knudsen 320 B/R 3.5-kHz 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 sq nmi of MBES data were collected to complete the mapping in this region.

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 multibeam echosounder. Dr. Brian Calder, CCOM-JHC, was the Chief Scientist in charge of the cruise. The cruise was plagued by bad weather and equipment problems. Even though the cruise was scheduled to be conducted a month before the official start of the Atlantic hurricane season, the first week of the cruise encountered gales that generated seas in excess of 25 ft. The excessive ship motion rendered the data considerably less than high quality, although they are useable. The second circumstance involves the performance of the multibeam installed on the *Revelle*. Contrary to all the assurances we were given at the pre-cruise meeting at Scripps Institution of Oceanography (the operator of RV *Revelle*), the *Revelle* EM120 multibeam was not performing anywhere close to Simrad specifications when we boarded the ship. There were numerous technical problems encountered with the performance of the multibeam and the motion sensor discovered during the transit to the patch-test site. As many as 11 multibeam transmit-receive boards could not pass the Simrad built-in self test, rendering many channels of the multibeam inoperable. Perhaps worse than that, there were very few spares aboard (only one spare transmit-receive board) to allow trouble-shooting, let alone replacement. The lack of spares ultimately required the mapping to be suspended for three days for a round-trip transit to Norfolk, VA to collect one additional circuit board. It was also found that even a modest pitch of 3˚ produced worthless data because of cavitation of the transducers from bubble sweep past the transducers. This last circumstance meant that the ship's course greatly affected the performance of the multibeam; going with the current and sea generated less pitch than going against the current and sea. The bottom line is that because of all of the problems, the area mapped during the 30 days at sea was reduced to about 50% of the plan. However, even with the bad weather and the malfunctioning multibeam system, the cruise collected 48,000 km^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 Coast Guard Icebreaker *Healy* (*Healy* 08-05) designed to map the seafloor on the northern Chukchi Cap in order to explore this poorly known region and better understand its morphology and its potential for an extended continental shelf under UNCLOS. The multibeam echo sounder on board the Healy was the primary tool, supplemented by the Knudsen subbottom profiler and deep-sea dredging operations. The primary targets for the mapping were the delineation of the 2500 m depth contour and the "foot" of the continental slope—the area where the continental margin transitions into the deep sea. In addition to its usefulness for Law of the Sea, the seafloor mapping data we collect is also valuable for better understanding seafloor processes, fisheries habitat, and as input into climate and circulation models that will help us predict future conditions in the Arctic. Three ancillary programs also took place during the cruise: 1- 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; 2- the deployment of several different types of ice-monitoring buoys by personnel from the National Ice Center (NIC), and; 3- the daily observation by a specialist from the Fish and Wildlife Service of both bird and marine mammal sightings.

Healy 08-05 departed Barrow on 14 Sept and commenced operations with both mapping and the successful recovery of two HARP hydrophones that had been deployed on *Healy* 07-03. From the HARP sites, we steamed north to pick up mapping of the region thought to represent the base of the slope in the vicinity of 82°N 162°W. Surveying continued east following the morphologic expression of the base of the slope until approximately 150°W where the character of the morphological expression of the base of the slope changed and we switched to a reconnaissance mode of surveying. This mode of survey continued until we reached the easternmost extent of our survey at approximately 139°W. From this point we traveled westward mapping several regions that we suspected shoaled above 2500 m (they did) and then began dredging operations (on 30 August). A total of 3114 linear nautical miles were surveyed (5767 km) on HLY08-05 covering an area of approximately 34,600 sq. km (assuming an average swath width of 6 km).

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. Dredge 1 yielded samples from an outcrop of layered sedimentary rock. Dredge 2 contained over 200 pounds of mud and ice-rafted debris (IRD). Dredge 3 also brought back only mud and IRD. Dredge 4 was predominantly mud and IRD; however, there were interesting iron concretions and manganese crusts along with one sample of a possible altered ash deposit. Dredge 5 recovered over 1000 pounds of mud with about 10 pounds of IRD of various rock types. Dredge 6 was mud free and contained over 200 pounds of what appear to be pillow basalts. Dredge 7 had very little mud but over 700 pounds of rock that probably represented both outcrop and angular tallus from the foot of the steep slope from which it was dredged. Samples from Dredge 7 were of various rock types including sedimentary, metamorphic, and basaltic.

All data collected on the 2008 *Revelle* and *Healy* cruises were archived with the NOAA National Geophysical Data Center, LDEO's GeoMAPAPP server as well as on the CCOM/JHC website (**http://www.ccom.unh.edu/law_of_the_sea.html**) soon after the completion of the cruises. The data are made available in ASCII xyz, ArcGIS, and IVS3D formats as well as various map and perspective image views.

To date, the Center has collected more than 1,060,000 km² (409,268 nmi²) of new, high-resolution multibeam sonar data in regions that have never before been mapped in detail (Figure 20). 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 student theses.

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

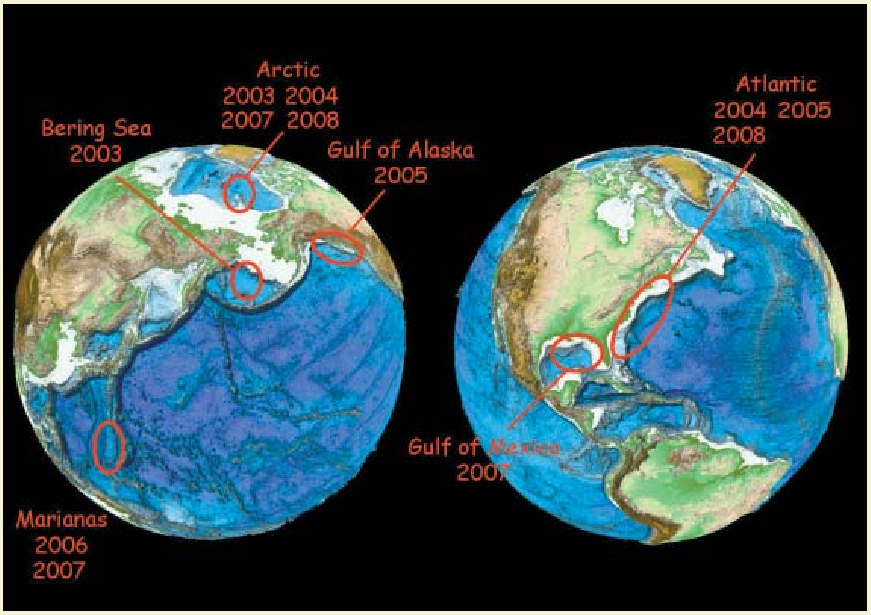


Figure 20. JHC Law of the Sea surveys.

With the formal establishment, under the direction of the State Dept., of a joint agency task force to explore the U.S. position with respect to and 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. Should the U.S. accede to the Law of the Sea Treaty in 2009, the activities of the Center in support of this task may increase.

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 at trying to define the electronic chart of the future. One track 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 very 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), our experienced NOAA mariners are playing a key role, ensuring that everything that is developed will be useful and functional.

EVOLUTIONARY

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 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 ENC's with new data layers through his work with three of CCOM's Industrial Consortium partners (*CARIS*, *SevenCs*, and *ICAN*) on a prototype "Tide Aware" ENC. The ENC contains decimeter contours/depth areas produced from a *Navigation Surface/BAG*, where dynamic/time-varying water level information is applied. To date, this involved water level information from NOAA's *PORTS* and the Canadian Hydrographic Service *SINICO* on the St. Lawrence River between Quebec City and Montreal. Other time-varying information also being investigated includes current flow, sea ice coverage, and weather information. When used with ENCs in ECDIS, this supplemental information is regarded as Marine Information Overlays (MIOs). In the near term, the results of this research can be applied to the use S-57 ENC datasets, while a longer term goal is to contribute to the development of the "Next Generation ENC" under the future IHO Geospatial Data Standard (S-100).

The "Tide Aware" ENC was demonstrated at the U.S. Hydro Conference in 2007. Feedback at the conference was extremely positive and has led to advances in the process of establishing an AIS binary message and procedure for NOAA CO-OPS/PORTS and the USCG to deliver real-time water level messages. The USCG RDC and NOAA have begun a testbed project in Tampa, FL for the NOAA Ports data. The system will use the new environmental message that Schwehr and Alexander helped to design. The USCG RDC has started a testbed project in Tampa, FL with NOAA PORTS to broadcast met-hydro messages over AIS. Lee Alexander is participating in the project. Raven has provided the first implementation of decoding the messages. ICAN Marine is currently developing their software to handle the message.

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. Dr. Schwehr's work on this has reached the point where the work is being discussed by NOAA CO-OPS/PORTS, USCG, the U.S. Army Corps of Engineers, and the Radio Technical Commission for Maritime Services.

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. The data content is based on a refinement of IMO SN/Circ. 236 ("Guidance on the Development of AIS Binary Messages"). This effort is being coordinated with the USCG R&D Center, NOAA *PORTS*, and the RTCM SC121 – AIS within VTS Working Group. In addition to Darrin Wright (PORTS), they are also working with John Kelley to determine an appropriate means/process to convert selected NOAA *nowCoast* data into AIS binary messages that can be broadcast to mariners via AIS. They have 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) and 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. Once completed, the Register will be hosted by the International Association of Lighthouse Authorities (IALA) in Paris. This effort is also associated with Alexander's association with the USCG in the IALA e-Navigation Committee and IALA AIS Technical Working Group.

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 (Figure 21). To date, 10 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, Kurt 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. Kurt and Lee have been collaborating with the USCG Research and Development Center (RDC) to create an official AIS Binary Message for the US authority.

Presently, only liquefied natural gas (LNG) vessels using the North-East Gateway (NEG) deep-water port are required to use these notices. The agreement is that these LNG vessels must slow to less than 10 knots and maintain heightened alertness within a 5 nm radius of any buoy with a detection for 24 hours after the most recent call. Many other mariners have expressed interest in having their electronic chart systems upgraded to understand and display right whale notices.

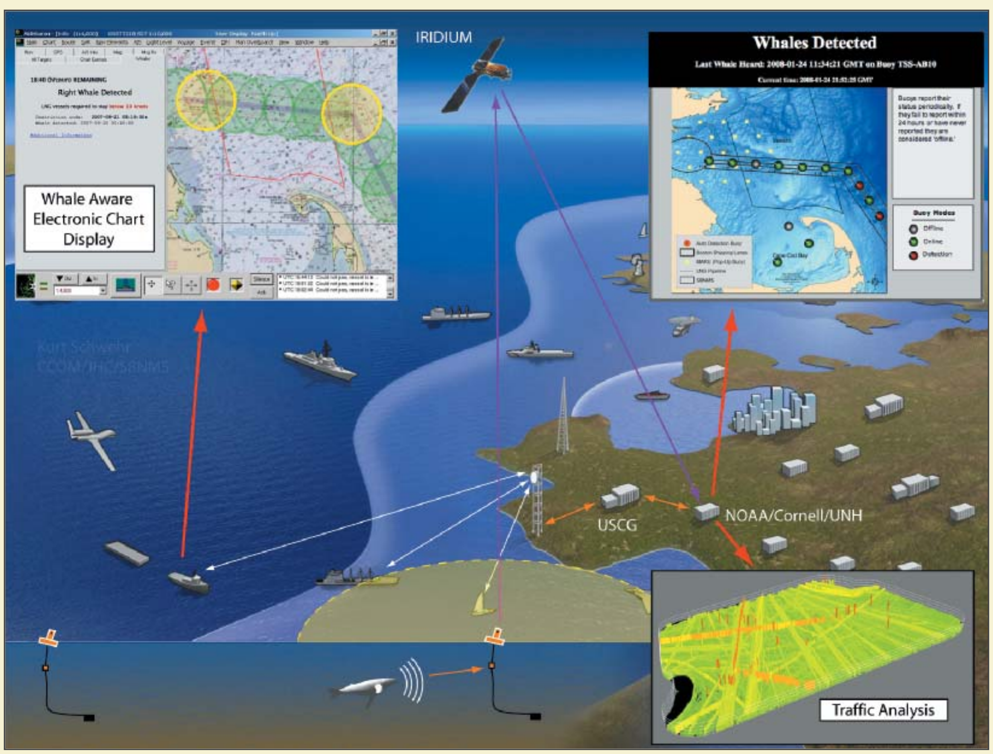


Figure 21. AIS binary message broadcast scheme for Right Whale locations in Stellwagen Bank National Marine Sanctuary.

CCOM is working with ICAN Marine to get the first version of an Electronic Chart Display system working for initial deployment on board the LNG vessels coming to the NEG terminal. The first draft of the message was successfully displayed on Aldebaran II software at the RTCM annual meeting in San Diego during May 2008 (Figure 22). Kurt presented the system to the Boston Port Operators Group (POG) and the New England Passenger Vessel Association (PVA). Lee Alexander will be providing guidelines and suggestions for how best to display these messages under operational conditions.

The Center is currently working with the USCG and NOAA to establish agreements for

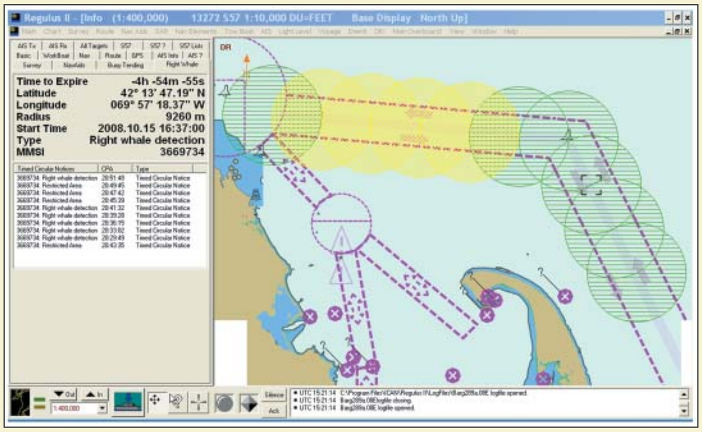


Figure 22. Whale Aware Electronic Chart Display. Pictured here is the initial version of the timed circular notice messages being displayed in Aldebaran II by ICAN Marine.

deploying the system. This project is helping to define best practices, policies, and procedures for regional AIS system implementations. These dynamic aids to navigation (ATONs) are very different than the traditional aids to navigation and will require much research in how to best provide these tools to mariners. Kurt is working with the SBNMS staff to analyze the systems range, effectiveness, and compliance. Work continues on AIS message analysis techniques to reduce the workload for staff monitoring the Boston TSS. Kurt will be producing a VHF load analysis for the region around Cape Cod.

Vessel Types are Distributed Differently in Space

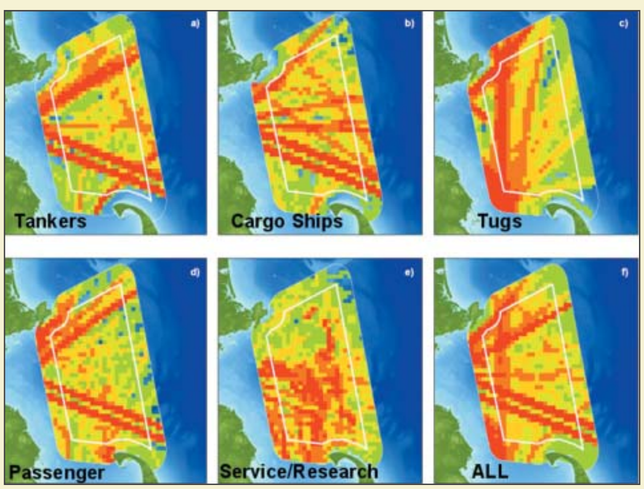


Figure 23. Vessel traffic separated by general class of vessel type for the SBNMS. Each vessel class uses different routes through the SBNMS. AIS data was gridded by Kurt Schwehr and visualized by Mike Thompson.

AIS for Sanctuary Management

Kurt is continuing to work with the SBNMS on techniques for processing AIS data to support management of marine sanctuaries (Figure 23). The first journal paper details the acoustic impacts of vessels transiting the sanctuary has been accepted for publication. In the next few months, the team will begin writing the second journal paper detailing AIS analysis techniques.

AIS Vessel Traffic for Hydrographic Survey Planning

Kurt is assisting Kyle Ward, Lorraine Robidoux, and James Hiebert in adopting NOAA data for AIS processing to provide input to planning for hydrographic surveys. They

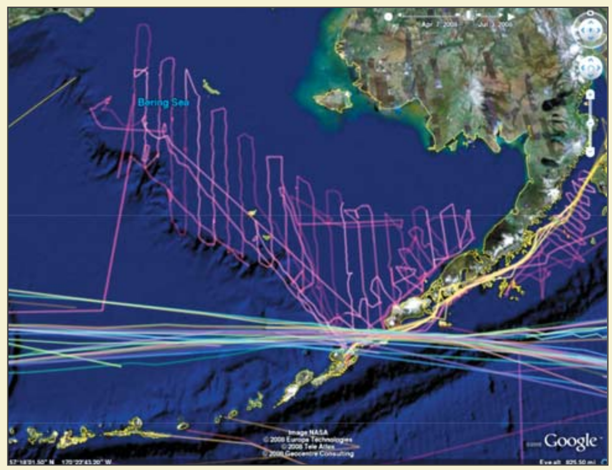


Figure 24. Google Earth map with parsed VOS observation reports showing shiptracks and identifiers.

have provided Kurt with bug reports to help improve NOAA data. The NOAA team is close to being able to integrate AIS data into their GIS systems. The recent release of ArcGIS 9.3 has the potential for making this process easier because this new version provides the ability to connect to PostGIS databases such as that created by NOAA data.

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 has done 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

(Figure 24). ORBCOM has just launched a LEO satellite for the USCG that has an AIS receiver. This may be able to provide occasional coverage in areas with few vessels such as in the open ocean. If we are able to get some sample data from this system, Kurt will do some sample processing. Potentially more valuable is the Long Range Information and Tracking (LRIT), but getting access to the data may be much more difficult.

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.
- Pseudo-photo realistic renderings with billboards and 360 disk panorama models.
- Basic ship position decoding from AIS messages.
- Tide based flow modeling.
- Multi-ship and marine mammal coordinated displays.
- Multiple view coordination.
- Analysis of a predictor for ship behavior to assist novice ship drivers.

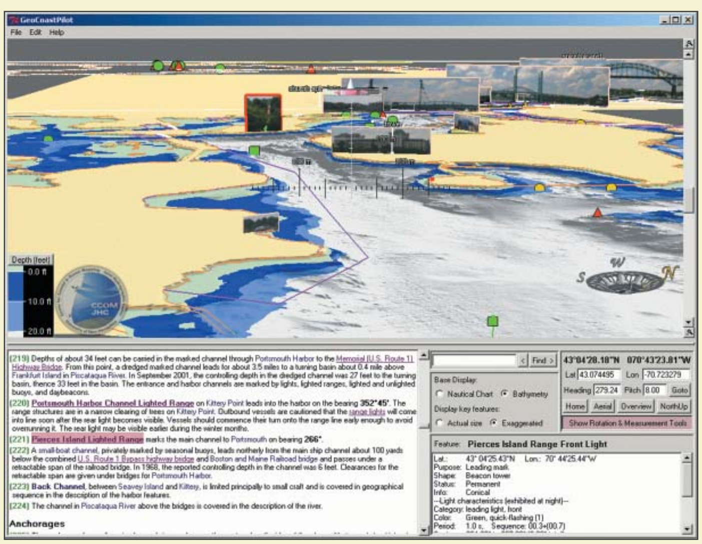


Figure 25. Image captured from the "Digital Coast Pilot" showing approach to bridge in Portsmouth Harbor.

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. 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 (Figure 25). GeoCoastPilot turns the NOAA Coast Pilot 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 has a number of innovative features:

- It links NOAA Coast Pilot information (Chapter 9 of Book 1) with an interactive 3D map and S-57 information, including USCG light list information.
- Wherever some shore feature is mentioned, it is linked with a feature on the 3D map. Clicking on the text links centers the 3D view on the corresponding feature. Where possible, there is a photo of that feature placed in the correct geographic location.
- Links go both ways: when you click on a photo, buoy, or other navigation mark in the 3D view, you are taken to the first corresponding reference in the Coast Pilot text, and other references are highlighted. Additional information is listed to the side.

A significant part of the work (done primarily by Matt Plumlee with assistance from Kurt Schwehr, Colin Ware, Roland Arsenault and Briana Sullivan) has been devising methods and tools to transform the current text of the GeoCoastPilot 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.

GeoCoastPilot had its first release on June 6, 2008 with a presentation to the Portsmouth Yacht Club. It is freely available on our website and we have conducted phone interviews and web surveys with interested users. The first test site is Portsmouth Harbor and the Piscataqua estuary including the entrance to Portsmouth Harbor from near Kitts Rocks Lighted Buoy 2KR, up to the I-95 Bridge. This may be extended to Great Bay Marine as newer versions are released. We are working on adding Boston Harbor to the system for 2009.

Mid-Water 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 hope to also be able to extract quantitative information from these returns that can then be used in fisheries and other applications. The focus of this project, led by Tom Weber, has been the visualization of four dimensional data (3 spatial dimensions plus time) in GeoZui and through software being developed by Weber and Roland Arsenault.

Roland's development have been on the visualization side, developing a software system that is designed to insulate the sonar specific details from the visualization systems. This system supports multiple sonars (EK60, Imagenex DeltaT, ME70, so far, others are easily added) and provides a generic real-time sonar visualization framework. This framework will easily allow the addition of many processing modules (like CUBE). The framework also uses multi-threaded pipelining to allow more intensive processing and/or data rates while maintaining real-time performance.

A prototype pipeline for handling raw Simrad ME70 data has been developed using this framework. Very crude bottom detection and target detection algorithms have been implemented and generic data is sent to GeoZui4D at a rate that allows real-time viewing. The result shown in Figure 26 demonstrates the working framework that is totally independent of Simrad specifics. Also noteworthy is the fact that the bottom and target detection algorithms work on generic ranges of samples, so are not tied to Simrad specific details.

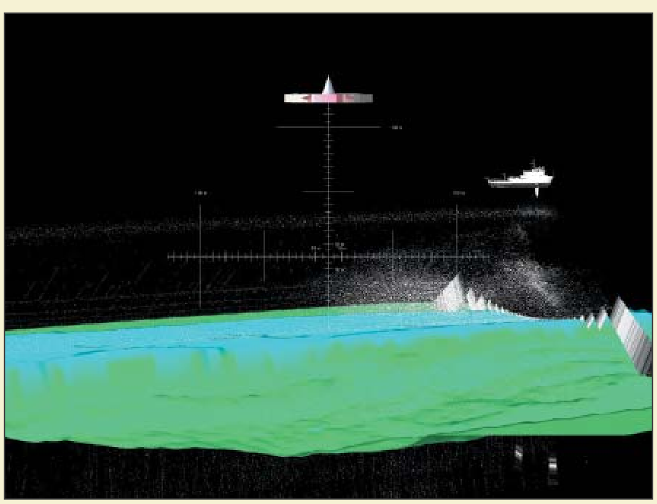


Figure 26. ME70 data in GeoZui4D with simple bottom and target detection.

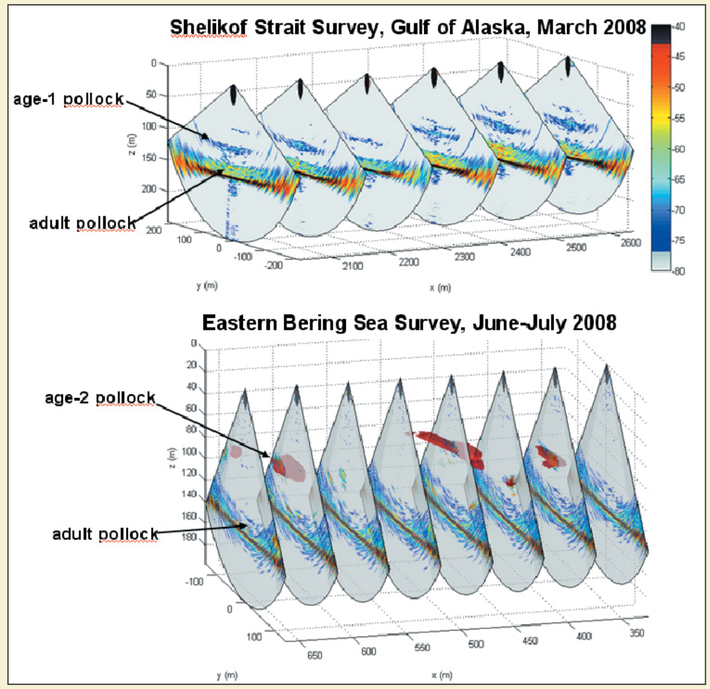


Figure 27. ME70 data (every 5th ping) collected in the Sheliokof Strait in 2008. The returns are from walleye Pollock.

In parallel with Arsenault's work, Weber has been working on the analytical aspects of mid-water data. Analysis of Reson 7125 data from Atlantic herring in the Gulf of Maine has been largely completed with a poster presented at the ICES SEAFACTS conference in Norway (presented by NOAA fisheries colleague Mike Jech). This conference paper explores using both a multibeam sonar and a multi-frequency echo sounder for fisheries research, and has been selected for peer-review submission into a special issue of ICES Journal of Marine Science.

Weber's efforts pertaining to the Simrad ME70 (Figure 27) have intensified. He has been working closely with the Alaska Fisheries Science Center (AFSC), one of the main users of the NOAA fisheries research vessel *Oscar Dyson*. This has included transiting with the ship between Seattle and Kodiak, Alaska in February 2008, during which time a general investigation into the capabilities of the ME70 was conducted, and an engineering cruise in October 2008 where the goal was to conduct an initial assessment of the ME70 water column modes for bathymetric mapping. This has led to funding (5 months over the next two years, plus travel) to investigate the ability of the ME70 to survey rockfish near the seafloor in untrawlable habitats. We have also have been highly rated on a full proposal to NOAA's Advanced Sampling Technology Working Group for work that will explore the use of the ME70 for simultaneously collecting seafloor and water column mapping (funding is dependent on the FY09 NOAA budget). This work will be a collaborative effort with AFSC and SWFSC. Preliminary work along these lines is under way, both with the *Oscar Dyson* and the *Henry Bigelow* (the two ME70 equipped ships currently in use in the U.S.). Although

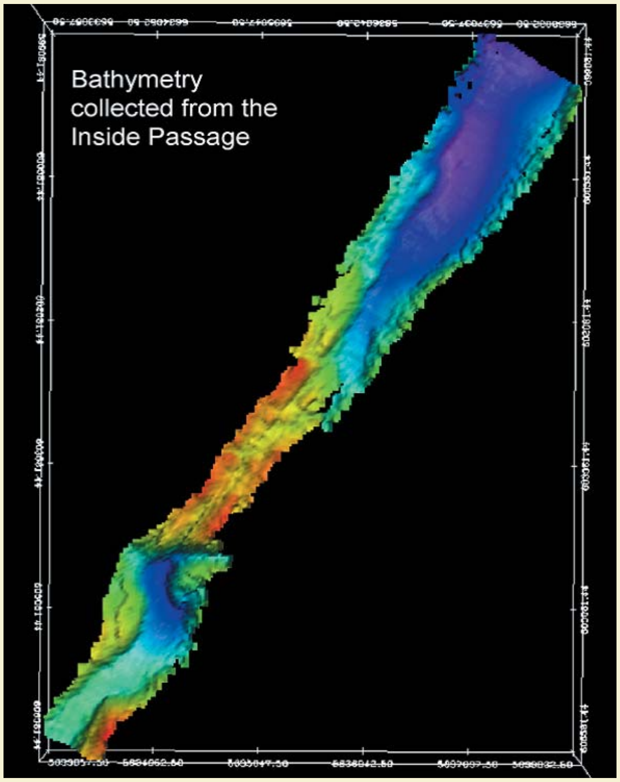


Figure 28. Bathymetry data collected from the ME70 using a water column mode. Depths range from 50 m (red) to 450 m (purple).

the ME70 does not have the resolution of a hydrographic multibeam sonar, an initial analysis of its capabilities shows that it can provide useful data for activities such as seafloor characterization without sacrificing the ability to collect water column data. An example of bathymetry collected with the ME70 is shown in Figure 28 (data collected during the transit from Seattle, WA to Kodiak, AK). It is important to note that Simrad is expected to release a bathymetry option for the ME70 soon, and that these efforts are aimed at complementing this option rather than replacing it. A new student (Tyler Clark, MS EE) has recently been recruited to help with these efforts.

Additional mid-water multibeam activities (Weber) include 1) the analysis of bubble clustering in the ocean and studies of their acoustic implications (funded by ONR Ocean Acoustics with data collected with a Reson 7125 multibeam sonar; 2) investigations of the efficacy of multibeam sonar (SM2000) for juvenile tuna stock assessments (funded by NH Sea Grant); work with the Gulf of Maine Research Institute investigating the effect of mid-water trawling on schools of Atlantic herring (again using an SM2000 MBES as well as an Simrad SP90 omni-directional sonar); and work with Chris Gurshin, a Ph.D. candidate in Zoology who has been using an EM3002 MBES to insonify cod held in a fish cage in an effort to extend the use of MBES to the assessment of benthic fish.

AUV Work and the Harbor Tracking and Observatory Project

Also begun in 2006 was our effort to explore the applicability of using a small Autonomous Underwater Vehicle (AUV) for collecting 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, however, the system was fully insured and a replacement vehicle (this time a GAVIA AUV with a GeoAcoustics Geoswath bathymetric sidescan and a Kerfot Inertial Nav system) was ordered and has already been tested in the tanks at the Center. The new system is a much more mature AUV with imagery, bathymetry, and particularly positioning capabilities far beyond the original Fetch vehicle. We have also purchased a WHOI acoustic modem for the new vehicle that will allow enhanced positioning and two-way communication. The WHOI modem has just been integrated into the system and the GAVIA is expected back in New Hampshire at the end of January 2009. We are very excited about the enhanced possibilities offered by this system and look forward to working with it in the coming year.

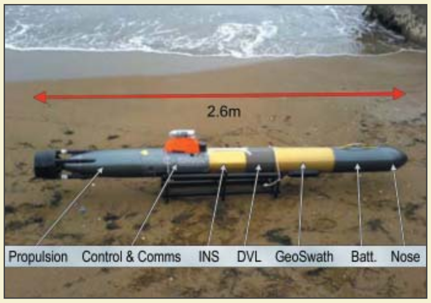


Figure 29. GAVIA AUV with GeoSwath Phase Measuring Bathymetric Sonar.

In support of our AUV effort, as well as to provide a permanent ability to accurately position this (or any other) vehicle, samplers 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."

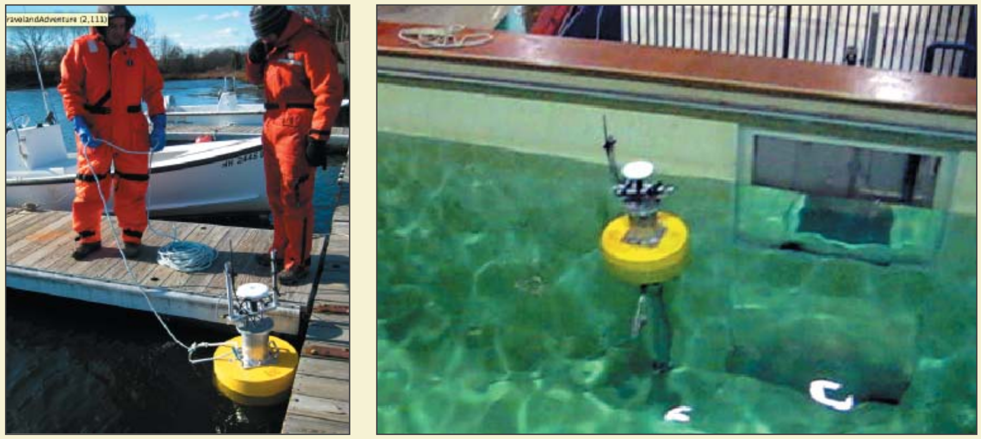


Figure 30. Harbor Tracking Buoys being tested in the tank (right) and in the Bay (left).

In October 2007, graduate student Michelle Weirathmueller and the Harbor Tracking Team (Schmidt, McGuillicuddy, Irish and Lavoie and under the guidance of Weber) conducted a series of experiments to measure the environmental effects on the acoustic path across Portsmouth Harbor. Both a static and roving acoustic sources were deployed for the duration of a tidal cycle each day for several consecutive days. Environmental data including CTD casts, a CTD chain measurement, tide levels and weather measurements were collected as well. The analysis of the data set were the focus of Michelle Weirathmueller's Master's thesis work (completed December 2008) and will be used to better understand the limitations of the time-of-arrival and phase-tracking underwater acoustic tracking systems.

The results of Michelle's work have been incorporated into the design of an AUV tracking buoy system. The buoys will serve the dual purpose of communicating 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 will be telemetered from each unit via a WiFi link to shore for data monitoring and processing. An initial buoy has been constructed and tested in the fall of 2008 (Figure 30), and a second buoy is currently under construction (two additional buoys – which will complete the system – are expected to be built in 2009). Weber has taken the lead investigator role in this project, which also involves Val Schmidt, Jim Irish, Paul Lavoie, Glenn McGillicuddy (who departed in July 2008), and Michelle Weirathmueller (who departed in September 2008). In addition to guiding the technical efforts, Weber has been the primary person responsible for assembling the prototype buoy and field testing. Next steps include communications testing with the Univ. of Delaware GAVIA AUV (the buoys are ready—we are simply awaiting delivery of the vehicle), further testing of the buoy mooring system, continued software development, and assembly of the remainder of the buoys.

Coastal Process Studies

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 start to build an expertise base that can both collect data and apply it to critical coastal-process questions of relevance to NOAA. Both Larry and Tom have just begun their efforts at the Center, but nonetheless, they are making important contributions.

VERY SHALLOW WATER MAPPING

Tom has focused on mapping bathymetry around harbor entrances or inlets which is of particular interest to mariners because this is often a region of 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, and thus plays an important role in contaminant transport and in determining the rate of organic carbon transmitted to the continental shelf by rivers. Unfortunately, difficulties working within shallow hazardous water often precludes accurate measurement of water depth both within the

Figure 31. The Coastal Bathymetry Survey System (CBASS) operating in an energetic surf zone. The CBASS is equipped with single-beam echosounder and differential GPS, and is capable of measuring the bathymetry in shallow water with accuracies on the order of 0.10 m.

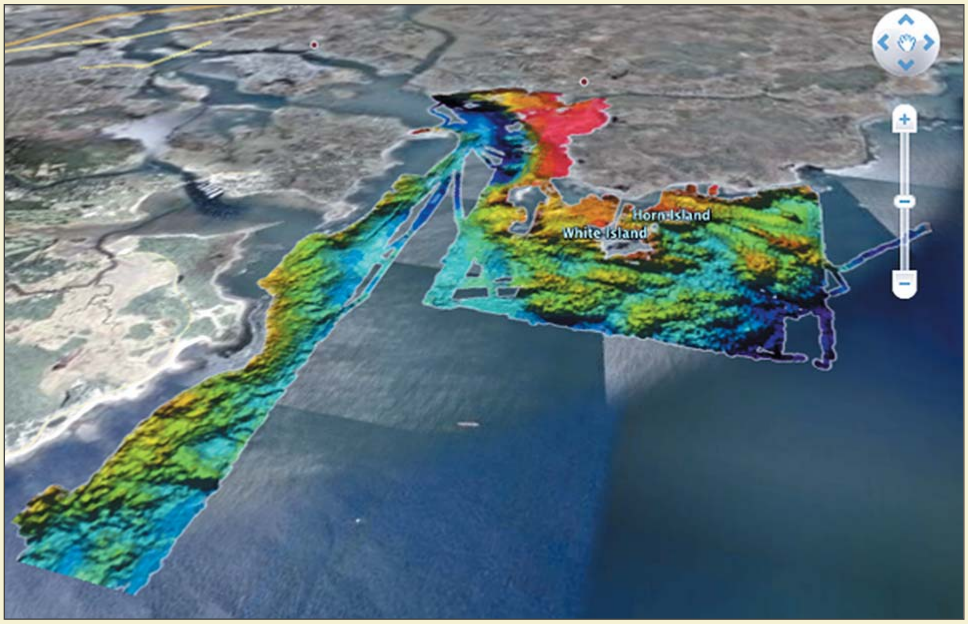


Figure 32. Oblique image showing the bathymetry measured with the CBASS around Portsmouth Inlet overlaid on satellite imagery from Google Earth. The depths range from 0.5-25 m.

river channel where high flows rapidly change the location of the channel, ebb tidal shoals, or 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 (Figure 31).

The CBASS has been used extensively within rugged marine environments such as the surf zone where breaking waves are present, and along fresh water bodies in the Great Lakes and inland rivers near bridge piles. Estimated accuracies of the survey system is 0.07-0.10 m in the vertical, and on the order of 0.1-1 m horizontally depending on the water depth and bottom slope. The high maneuverability of the personal watercraft makes very shallow water bathymetric surveys possible with acoustic altimeters, particularly in regions where airborne remote sensing systems fail (owing to 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 such as in the shallow coastal waters off of Portsmouth.

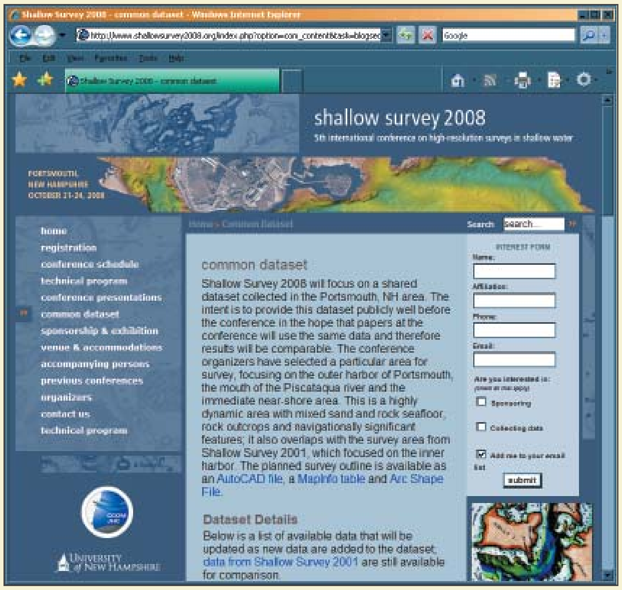
Three regions were surveyed near the Piscataqua river mouth (Figures 32). The first region covers Pepperell Cove; the second along the rocky outcrop to the north of the inlet near Garrish Island; and the third to the south of the inlet near Odiorne Point. Observed water depths range from 0.5 m near the shoreline and over rocky outcrops to over 25 m in the river channel. A total of 421 cross-shore transect lines (ranging 1-2 km in length) separated at 20 m alongshore spacing were surveyed on 10 days and covered a regional area approximately 10 km^2.

QUANTIFYING SEDIMENT TRANSPORT

Graduate student Janice Felzenberg, under the supervision of Larry Ward and in collaboration with Yuri Rzhanov, has been exploring quantitative ways to document sediment transport through repeat MBES surveys. A major result of her work has been to develop a new approach to quantify bedform migration on short temporal and spatial scales. While existing methods of quantifying bedform migration utilize the bathymetric surface or representations of spatial gradient, our novel approach determines bedform migration length from a binary-labeled map of bedform crests derived from the bathymetric surface by adapting an algorithm originally developed for fingerprint recognition. Bedform migration length is determined by quantifying local migration of ridge-crest centroids, which works well on short time-scales where the migration distance is short relative to the bedform wavelength. This novel approach is producing clear and quantifiable evidence of the migration of seafloor bedforms over various time-scales.

DEVELOPMENT OF DEVELOPING A NH SHELF AND ESTUARY DIGITAL DATA ARCHIVE

Over the last few years, Larry Ward has undertaken to locate, evaluate, and recover all appropriate sedimentological and stratigraphic data for the New Hampshire shelf and estuaries. The focus of this work was to recover geophysical records obtained by various investigators at UNH during surveys in 1981, 1982, 1985, 1992, and 1999. The original surveys were funded by a number of agencies including NSF, MMS, the Navy, and NOAA. In total, the seismic records include various levels of coverage and quality for ~1800 km of the New Hampshire and vicinity seafloor. Unfortunately, all of the records are analog requiring electronic scanning. In addition, the available databases also included the results of detailed analysis and interpretation of the 1981 and 1982 sub-bottom seismic surveys by Dr. Frank Birch (UNH Department of Earth Sciences). Birch had developed a series of maps that crudely displayed (by today's standards) the interpretation of the seismic records based on four seismic units (1-4) that represented glacial tills, glacial marine sediments, Holocene sediments (mud and sands), and Holocene sand and gravel deposits. This information essentially was presented as isopach maps showing unit thickness or depth to pre-Quaternary reflectors in a xyz format. Unfortunately, the electronic records of this work were stored on magnetic tapes which had become contaminated over the years and unusable, leaving only hard copies of the original records. Therefore, the data had to be reentered into an electronic database. Recovery of the seismic records (scanning all of the analog seismic records and inputting the data from the seismic interpretations back into a digital format) was a substantial effort. A major product of the digital data is a GIS that includes all of the data and records from previous studies in easily viewed form. The GIS includes seismic records for the ~1800 km of seafloor, grain size information for over 1200 bottom sediment samples, 24 vibracore logs, and sediment maps for a section of the nearshore shelf off Hampton Beach and Seabrook Beach and for Portsmouth Harbor. This database and GIS projects, which will be stored in the CCOM network, represents most of the known sediment and stratigraphic data (Quaternary) for the New Hampshire and vicinity shelf that was previously collected (prior to the establishment of CCOM). It does not include at this time the more recent seismic and high resolution bathymetry databases. Nevertheless, it provides important background information and, in many cases, is the only information available.



The website for Shallow Survey 2008, http://www.shallowsurvey2008.org.

Shallow Survey 2008

In October of 2008, the Center hosted Shallow Survey 2008: The Fifth International Conference on High-Resolution Surveys in Shallow Water. This unique conference series combines the collection of a "common data set" from Portsmouth Harbor with an international forum where different approaches to collecting and processing the common data set and other topics are discussed in an open forum. The Center hosted the second shallow survey conference in 2001 and the data sets collected by various manufacturers and organizations provided a wealth of information for students and researchers. With the addition of Shallow Survey 2008 data sets, Portsmouth Harbor is unquestionably the most surveyed harbor in the world. Data for Shallow Survey 2008 was collected with the following systems:

- EchoScan
- Kongsberg EM3000D
- Kongsberg EM3002D
- Atlas Fansweep 20
- GeoAcoustics 125/250kHz
- Atlas HydroSweep
- IXSEA Shadows SAS
- Reson 7125 200/400 kHz
- Reson 8101, 8125
- SEA SwathPlus
- NOAA RSD Topo LIDAR
- CBASS Single Beam (see Coastal Processes Report above).

The common data set provides the ability to see the same piece of seafloor as imaged by different systems as well as the ability to compare the same system's data processed in different ways. Comparison of the 2001 common data set with the 2008 common data set also allows a direct measure of improvements (hopefully) in technology as well as documenting changes in the seafloor.

The conference was remarkably successful with more than 350 attendees and 32 industrial exhibitors. Fifty-two technical papers were delivered highlighting the leading edge of hydrographic science. Interesting spin-offs to the conference were the addition of five new industrial associates to the Center's Industrial Partner Program as well as several job offers to our students. Details of the conference and the common data set can be found at: **http://shallowsurvey2008.org/**.

Outreach

We have formalized our outreach activities with the addition of Briana Sullivan to the staff and are actively working to increase the usefulness of our website (**http://www.ccom.unh.edu**) as well as develop museum displays (see visualization section above), and materials and programs that will help share the results of our efforts with the broader community. 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 33 articles, from sources such as *Nature Journal, PBS – News Hour, Wired Magazine, New York Times, Boston Globe* and even *NY Arts*. Images created at the Center have been requested by various organizations such as *National Geographic*, *The History Channel*, the *Canadian Geographic Magazine*, and have recently appeared in the new *National Geographic Atlas of the Oceans*. Some highlights are:

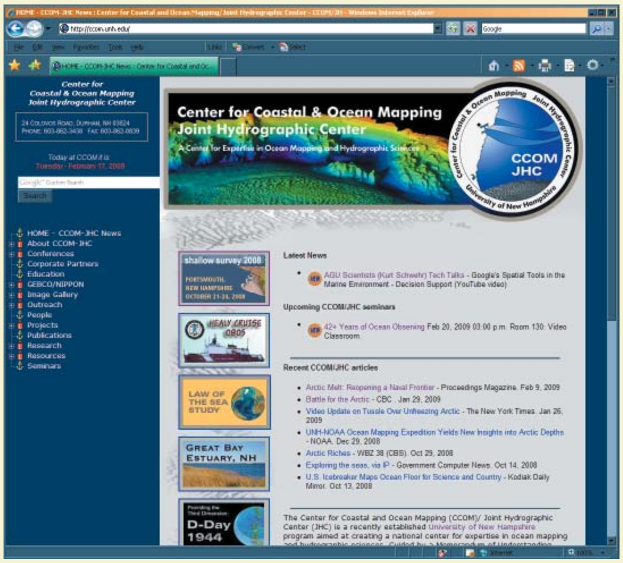
DATE	TITLE	SOURCE
2008-01-03	Geology: The Next Land Rush	*Nature Journal*
2008-01-18	Russia Contests Borders With Canada, Denmark, and The United States	*Wired Magazine*
2008-01-18	The Last Great Landgrab	*Wired Magazine*
2008-01-18	Foreigners Keep Out! High Tech Mapping Starts to Redefine International Borders	*Wired Magazine*
2008-02-06	Tools of Polar Research	*PBS - Newshour*
2008-02-11	Arctic Mapping May Bolster Us Claims	Associated Press
2008-02-11	Alaska Continental Slope 100 Miles Farther Out Than Thought	Environment News Service
2008-02-11	UNH-NOAA Ocean Mapping Expedition Yields New Insights Into Arctic Depths	UNH Media Relations
2008-02-12	Arctic Melt Yields Hints of Bigger U.S. Seabed Claim	*The New York Times*
2008-02-12	Continental Slope Off Alaska 100 Nautical Miles Further Off Coast Than Assumed	*Science Daily*
2008-02-15	Arctic Mapping Redraws Borders	*Nature*
2008-02-22	UNH Discovery May Lead to More Sea Floor Resources	*The New Hampshire*
2008-04-02	U.S. Could Grab More Arctic Seafloor	*Geotimes*
2008-04-18	Alaska Continental Slope 100 Miles Farther Out Than Thought	*SitNews*
2008-04-28	Whale-Watching Boats Are Putting Whales in Jeopardy, Study Says; Skippers Ignoring Speed Limits in Effort to Wow Passengers	*The Boston Globe*
2008-05-13	U.S. Pursues Arctic Claim	*The Washington Times*

2008-06-01	The Race to Own The Arctic	*Parade*
2008-06-19	Castine: Bagaduce River Study Key to Energy Plan	*Bangor Daily News*
2008-06-20	Maine Maritime Academy Hosts Marine Research Group	Maritime Global Net
2008-08-11	A Cartographer of The Unseen	*NY Arts*
2008-08-12	Two Scientific Cruises to Map Arctic Seafloor	U.S. Department of State
2008-08-12	U.S. Ship Heads for Arctic to Define Territory	Reuters
2008-08-20	Countries Map Arctic Boundaries to Build Cases for Resource Rights	*PBS - News Hour*
2008-09-03	Unknown UNH	*New Hampshire Magazine*
2008-09-08	GeoCoastPilot, Early Adopters Needed!	*Panbo*
2008-09-29	Diving Into a New World	*New York Times*
2008-10-06	Oil Survey Says Arctic Has Riches	*AAPG Explorer*
2008-10-07	Sant Ocean Hall Now Open	*OCS News*
2008-10-13	U.S. Icebreaker Maps Ocean Floor for Science and Country	*Kodiak Daily Mirror*
2008-10-14	Exploring the Seas, Via IP	Government Computer News
2008-10-29	Arctic Riches	WBZ 38 (CBS)
2008-12-29	UNH-NOAA Ocean Mapping Expedition Yields New Insights Into Arctic Depths	NOAA

Ocean currents displayed in the Museum of Natural History's Sant Ocean Hall in Washington, DC.

Website Upgrades

It has taken some time to get content for the outreach section of the website, but in a combined effort Shachak Pe'eri and Briana Sullivan were able to create the sites' first flash animation in the K-12 section, giving an introduction to LIDAR (**http://ccom.unh.edu/index.php?p=31|37&page=outreach/lidarIntro.php**). There are many exciting things that can be done with flash content which Briana plans to explore over the next year.



Homepage of the CCOM/JHC website, http://ccom.unh.edu.

In an effort to maximize the website's usefulness, Briana has been working to make all CCOM/JHC related publications and activities easily accessible. This includes adding a database to organize and keep track of publications and activities and working on giving the user options in how the data is displayed on the website (by year, author and category). In the future this will include displaying by topic as there has been a major effort to try to tag all publications according to specific topics that correspond to areas of research. There has also been an effort to update the research section of the website. This year the research section has been organized according to 8 main areas of research that follow the format of the annual reports. The goal is to make sure that every year each section has been updated so that current research will always be easy to find and available to those interested.

Partnerships and Ancillary Programs

One of the goals of the JHC is, through its partner organization, the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a 5 million dollar endowment; 1 million dollars 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:

- Benthos
- C&C Technologies
- CARIS Inc.
- Chesapeake Technology Inc.
- EdgeTech
- ESRI
- Fugro
- GeoAcoustics
- HyPACK
- IFREMER
- IVS-3D Inc.
- Knudsen
- Kongsberg Simrad
- L3/Klein Associates
- ODOM Hydrographic
- QinetiQ
- QinSy
- QPS
- Quester Tangent
- Reson
- SAIC
- SevenC's
- Sonartech Atlas
- Tyco

In addition, grants are in place with the Office of Naval Research, the Naval Research Lab, the Naval Oceanographic Office, IEEE, the National Science Foundation, Fugro, the Nippon Foundation, CICEET and the U.S. Geological Survey (see Appendix E). The USGS supports collaborative projects involving multibeam sonar mapping as well as a post-doctoral fellow at the Center. Funding beyond this grant this past year is on the order of $1.0 M from a total commitment from other sources of approximately $11M (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 6 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 895,6 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 6 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 895,6 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 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	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

Sediment Dynamics: Janice Felzenberg M.S. Thesis, 5-6 February, R/V *Gulf Challenger*, Acquired bottom videography and sediment samples from 20 stations in Portsmouth Harbor. (Felzenberg)

Ground truth collection for LIDAR capabilities (seafloor detection), 25-26 February, R/V *Gulf Challenger,* off Gerrish Island, ME: Conducted bottom videography and sediment sampling in support of ALB research and bottom sediment transport. (Bogucki, Felzenberg, Pe'eri & Ward)

Dyson Transit, February 2008, R/V *Oscar Dyson*, Investigate ME70 capabilities. (Weber)

Long Range Side Scan Sonar: Full Functional Demonstration, 3-6 March, M/V *3 Aces*, Technical observer/advisor. (Huff)

Automatic Identification System, 12 March, East Point Light House, Site visit and AIS test, Cape Ann, MA. (Schwehr)

Automatic Identification System, 17 March, Highland Light, Site visit and AIS test, Cape Cod, MA. (Schwehr)

Stellwagen Bank National Marine Sanctuary, 24 March, R/V *Auk*, AIS transmission testing, pop-up deployment, Auto-buoy inspection. (Schwehr)

Software Grandmaster Integration with Reson 7-P Processors, 14-18 April, R/V *Minotaur*, Tested PTP/SWGM code in Reson 7kCenter production software prior to supported release. (Calder)

Phoenix Mars Lander Operational Readiness Test 10, 28 April-1 May, Jet Propulsion Laboratory Solar System Visualization group. (Schwehr)

Klein 5500 survey, 15 April, Coast Guard Vessel, to provide positioning support. (Dijkstra)

US United Nations Convention on the Law Atlantic Mapping, 2008, 1-31 May, R/V *Roger R. Revelle* (AGOR-24), mapped Hatteras Transverse Canyon System and Hatteras Outer Ridge. (Calder & Gardner)

Estimation of uncertainty in the measurement of seafloor acoustic backscatter, 20 May, to collect redundant data with Multibeam sonar attached to the UNH marine pier. (Malik)

Phoenix Mars Lander Science Operations, 20 May-14 July, Jet Propulsion Laboratory Solar System Visualization group. (Schwehr)

Pet Rock, June 2008, R/V *Gulf Challenger*, deploy pet rock in Portsmouth harbor. (Gardner)

NOAA Ocean Exploration-Blue Hill Bay, 1-10 June, R/V *IraC*, Assist/supervise SAIC in system installation/integration, data acquisition and QA/QC of the daily data products. (Huff)

Multibeam sonar in-tank calibration, 3-13 June, to calibrate EM 3002 (Serial Number 372). (Malik)

Summer Hydrographic Field Course, 10 June-3 July, R/V *Coastal Surveyor*, to teach the hydrographic field course and support various graduate students by collecting useful data; to repeat a segment of the 2006 Hydrographic Field Course area near Gerrish area as close in time to the collection of LIDAR data in the same region as possible; map the Bagaduce river for tidal generating stations. (Dijkstra & Smith)

LIDAR target rock, 16 June, R/V *Gulf Challenger*, Deployment of the Target Rock, Cod Rock, and Portsmouth Harbor. (Pe'eri)

Performance of Reson 7125/200 kHz, 21 June-4 July, NOAA Ship R/V *Rainier*, Investigate performance of new launches and Reson 7125s; examine data processing paths and methods. (Calder)

Investigation of capabilities of Reson 7125, 23 June-3 July, NOAA Ship R/V *Rainier*, investigation of Reson 7125, participation in hydrographic survey operations. (Bogucki)

Cod spawning area survey, 26 June-7 July, R/V *Coastal Surveyor*, coordinating, planning, and implementation of a combined bathymetry, backscatter and water column survey. (Bogucki)

Humpback Whale foraging behavior, 2008, 29 June-15 July, R/V *Nancy Foster*, visualization, data fusions and analysis of data from tagged Humpback Whales. (Ware & Arsenault)

Pet rock, July 2008, R/V *Coastal Surveyor*, locate pet rock by mapping area with EM3002 Multibeam system. (Gardner)

LIDAR target rock, 2 July, R/V *Coastal Surveyor*, MBES EM 3000 survey of Cod Rock and the target rock. (Pe'eri)

Sediment Dynamics: Janice Felzenberg MS Thesis, 2-16 July, R/V *Gulf Challenger*, Deployed a pair of acoustic current meters (MAVS and ADCP) in Fort Point bedform field, Portsmouth Harbor, NH, USA to determine near-bottom current velocities during repetitive MBES survey period. (Felzenberg)

Sediment Dynamics: Janice Felzenberg's MS Thesis, 3-9 July, R/V *Coastal Surveyor*, Acquired a pair of repetitive MBES surveys of Fort Point bedform field, Portsmouth Harbor, NH, USA to determine dune migration rates over a spring-neap tidal cycle. (Felzenberg)

Stellwagen Bank National Marine Sanctuary Whale Tagging and Tracking Expedition, 7-17 July, R/V *Nancy Foster*, Tagging and tracking of humpback whales. (Schmidt)

LIDAR target rock, 8 July, R/V *Coastal Surveyor*, First attempt to retrieve the target rock with a grapnel. (Pe'eri)

Sediment Dynamics: Janice Felzenberg MS Thesis, 9 July, R/V *Coastal Surveyor*, acquisition assistance for one survey day of Fort Point sandwave field. (Bogucki)

LIDAR target rock, 16 July, R/V *Coastal Surveyor*, Second attempt to retrieve the target rock with divers. (Pe'eri)

Automated Underwater Vehicle (AUV), 21-23 July, AUV Gavia, Test the acquisition of Geoswath sidescan with the *Gavia* AUV in Little Bay, New Hampshire. (Fonseca)

FISHPAC 2008; Essential Fish Habitat Survey in the eastern Bering Sea, 22 July-12 August, NOAA Ship R/V *Fairweather*, Principle QA/QC for Navigation, BOT-FFCPT, Sound Speed data and Reson Multibeam Sonars (8111 and 8160). (Huff)

Habitat Mapping Cruise HB0503-leg 3, 31 July-11 August, R/V *Henry Bigelow*, Develop real time ME70 visualization. (Arsenault)

Aquaculture Program, 13 August, R/V *Gulf Challenger*, Videography cruise to UNH Open Ocean Aquaculture site ~7 km off Portsmouth Harbor to monitor bottom conditions for aquaculture program and obtain bottom video; analyze for benthic organisms and sediment conditions. (Ward)

US United Nations Convention on the Law of the Sea Mapping, 14 August-5 September, R/V *Healy*, Law of Sea Survey off Chukchi Cap, Arctic Sea; data processing for the MBES/subbottom survey, GIS data processing, Seafloor mapping. (Armstrong, Bogucki, Calder, Mayer, Pe'eri & Schmidt)

GeoCoastPilot, 20 August, R/V *Auk*, Photomapping of the harbor for GeoCoastPilot. (Schwehr & Plumlee)

Hydropalooza meeting, 21-23 August, R/V *Fairweather*, Discussing techniques for process acoustics backscatter acquired by Reson 8111, 8160, and 8101 Multibeam echosounders. (Fonseca)

Hydropalooza meeting, 23-25 August, R/V *Rainer*, Discussing technique for processing acoustic backscatter acquired by Reson 712 Multibeam echosounder. (Fonseca)

Coastal Bathymetry Survey System (CBASS), 25 August-31 December, transition vessel to CCOM. (Lippmann)

Sonar Capabilities - Sonar Calibration, 3-27 September, NOAA R/V *Okeanos Explorer*, Mapping shake down including calibration and SAT of EM 302. (Malik)

Tampa Bay AIS Binary Broadcast Test-bed, 15 September 2008-30 June 2009, Develop/administer Survey Questionnaire on use of AIS Binary Broadcast. (Alexander)

Platt's Bank Wreck Investigation, 28 September, R/V *Gulf Challenger*, Survey planning, sonar operator, Iver2 AUV deployment and processing of side scan data from towed Klein 5410 and AUV mounted side scan sonar. (Huff)

Tuna stock assessment feasibility study, September 2008, F/V *Lily*, Investigate the use of Multibeam sonar for assessing juvenile Bluefin tuna. (Weber)

Dyson Bottom Mapping and Calibration Study, 9-14 October, NOAA Ship R/V *Oscar Dyson*, Investigate ME70 bottom mapping capabilities and conduct calibration. (Clark & Weber)

Right whale Automatic Identification System Project, October 2008, transponder installation Cape Cod, MA. (Schwehr)

Right whale Automatic Identification System Project: SBNMS, R/V *Auk*, October 2008, reception testing. (Schwehr)

Submarine Landslides and Sedimentation Model for the SE Australian Margin, 4-24 November, R/V *Southern Surveyor*, (1) Conducted regional survey of SE Australian Margin between northern New South Wales and southern Queensland, concentrating on the continental slope between 100-4500 m water depth, using Kongsberg EM300 MBES and Topas high-resolution seismic systems; (2) Identified locations of major landslides from the MBES and seismic data, and investigated sediment distribution in these regions by means of cores and grab samples; (3) Ground-truthed the MBES and seismic data with regional sediment grab samples to determine sediment composition and dispersal mechanisms on the margin, followed by dredging of canyons and other significant features to determine the makeup of the margin stratigraphy. (Felzenberg & Gardner)

Long Range Side Scan Sonar: Full Functional Demonstration, 1-5 December, M/V *3 Aces*, Technical observer/advisor. (Huff)

Harbor Tracking Buoy, various dates, R/V *Cocheco* and R/V *Coastal Surveyor*, Engineering and testing of the UNH Harbor Tracking buoy. (Schmidt)

APPENDIX C: OTHER FUNDING

Name	PI	Grantor	FY Award	Total Award	Length
Inland Electronic Charting	Alexander, L	U.S. Army Corp of Engineers	79,627	79,627	1.5 years
Us pf AIS Broadcast for US Coast Guard VTS	Alexander, L	U.S. Coast Guard	41,602	41,602	1 year
ECS Uncertainty Modeling	Calder, B.	Office of Naval Research	23,211	23,211	2 years
Mapping Seafloor Uncertaininty	Calder, B.	Office of Naval Research	55,504	96,593	3.5 years
Volume Search Sonar	de Moustier, C.	Scripps	11,000	11,000	1 year
Africa Partnership Station	Lippmann, T.	Office of Naval Research	17,162	17,162	4 months
Surface Currents from Argus	Lippmann, T.	USACE	11,501	11,501	1 month
Vertical Structure of Shallow	Lippmann, T.	Office of Naval Research	41,027	41,027	4 months
2008 Network Projects	Mayer, L.	GEBCO Foundation	38,000	38,000	3 months
A Mobile Bentho-Pelagic	Mayer, L.	Woods Hole Oceanographic Institution	11,262	76,984	1.5 years
GEBCO Gift Fund	Mayer, L.	Blodgett Foundation	46,000	46,000	-
Government of Bangladesh Desktop Study	Mayer, L.	Government of Bangladesh	119,771	119,771	5 months
Ocean Mapping Student Training 5th year	Mayer, L.	GEBCO Foundation	510,000	2,629,467	5 years
Remote Identification	Mayer, L.	Office of Naval Research	131,895	216,387	2.5 years
Tyco Endowment interest from perpetuity	N/A	TYCO	23,469	-	Perpetuity
Stereo Image Measurement	Rzhanov, Y.	NOAA Fisheries	9,000	9,000	1 year
AIS Notification for Right Whales	Schwehr, K.	Cornell University	83,668	251,100	3 years
Development and Analyses of a Bathymetric Database for Great bay Estuary New Hampshire	Ward, L.	NH Coastal Program	30,000	30,000	1 year
Humpback Whale Tagging	Ware, C.	University of Delaware	20,000	20,000	1 month
NH IRC:IVS Multi-Beam	Weber, T.	IVS 3D Inc.	40,066	40,066	1.5 years
NHIRC: IVS 3D Multi-Beam (NSF)	Weber, T.	National Science Foundation	35,364	35,364	1.5 years
Rockfish Assessment	Weber, T.	North Pacific Research Board	64,152	64,152	1.5 years
Total			1,443,281	3,898,014	

APPENDIX D: PUBLICATIONS

Journal Articles

Alexander, L., 2008, MIOs: The What, Why, and How: Seaways, the Nautical Institute *(October issue)*, p.13-15.

Alexander, L., Brown, M., Greenslade, B., and Pharaoh, A., 2008, S-100: A New Standard for the Future Electronic Navigational Charts: Canadian Maritime Magazine, v. 44, p. 7-8.

Alexander, L., and Casey, M.J., 2008, Use of Portable Piloting Units: Digital Ship, v. 8 (9), p. 54-55.

Calder, B.R., LCDR Brennan, R.T., Marcus, J., Malzone, C., and Canter, P., 2008, High-Precision, High-Accuracy Time-keeping in Distributed Survey Systems: International Hydrographic Review, v. 9 (1), p. 9-24.

Fonseca, L., Brown, C., Calder, B.R., Mayer, L.A., and Rzhanov, Y., 2008, Angular Range Analysis of Acoustic Themes from Stanton Banks Ireland: A Link between Visual Interpretation and Multibeam Echosounder Angular Signature: Journal of Applied Acoustics *(special issue)*, URL: **http://doi:10.1016/j.apacoust.2008.09.008**.

Fonseca, L., Gardner, J.V., Calder, B.R., Mayer, L.A., and Armstrong, A.A., 2008, US UNCLOS Multibeam Data: The Processing of Multibeam Bathymetry and Backscatter: Hydro International, v. 8 (9), p. 14-17.

Hatch, L., Clark, C., Merrick, R., Van Parijs, S., Ponirakis, D., Schwehr, K., Thompson, M., and Wiley, D., 2008, Characterizing the Relative Contributions of Large Vessels to Total Ocean Noise Fields: A Case Study Using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary, Acoustical Society of America: Acoustical Society of America, Paris, France, 30 June-4 July.

Jakobsson, M., Macnab, R., Mayer, L.A., Anderson, R., Edwards, M., Hatzky, J., Schenke, H.W., and Johnson, P., 2008, An Improved Bathymetric Portrayal of the Arctic Ocean: Implications for Ocean Modeling and Geological, Geophysical and Oceanographic Analyses: Geophysical Research Letters, v. 35, (L07602), URL: **http://doi:10.1029/2008GL033520**.

Monahan, D., 2008, Application of the General Bathymetric Chart of the Oceans (GEBCO) Digital Atlas in the Delineation of Continental Shelves under Article 76: Journal of Ocean Technology, v. 3 (1), p. 24-29.

Pe'eri, S., and Rzhanov, Y., 2008, Mosaicking Tools for Aerial Imagery from a LIDAR Bathymetry Survey: International Hydrographic Review, v. 9 (1), p. 35-44.

Perkovic, D., Lippmann, T.C., and Frasier, S., 2008, Longshore Surface Currents Measured by Doppler Radar and Video PIV Techniques: IEEE Transactions on Geoscience and Remote Sensing, p. 1-42.

Schwehr, K., 2008, Seismic-py: Reading Seismic Data with Python: The Python Papers, v. 3 (2), p. 1-8.

Ward, L.G., Zaprowski, B. J., Trainer, K. D., and Davis, P. T., 2008, Stratigraphy, Pollen History and Geochronology of Tidal Marshes In A Gulf of Maine Estuarine System: climatic and relative sea level impacts: Marine Geology, v. 256 (1), p. 1-17.

Ware, C., 2008, Towards a Perceptual Theory of Flow Visualization: IEEE Computer Graphics and Application, v. 8 (2), p. 6-11.

Ware, C., Gilman, A.T., and Bobrow, R. J., 2008, Visual Thinking with Interactive Diagram: Lecture Notes on Artificial Intelligence, v. 5223, p. 118-126.

Ware, C., and Mitchell, P., 2008, Visualizing Graphs In Three Dimensions: ACM Transactions on Applied Perception, v. 5 (1), p. 1-15.

Weber, T. C., 2008, Observations of Clustering Inside Oceanic Bubble Clouds And the Effect on Short-range Acoustic Propagation: Journal of the Acoustical Society of America, v. 124 (5), p. 2783-2792.

Book

Ware, C., 2008, Visual Thinking: for Design, Morgan Kaufmann Series: Elsevier Science & Technology: Burlington, MA, Morgan Kaufmann, p.1-197

Book Section

Ware, C., 2008, Why Do We Keep Turning Time into Space? Understanding Dynamics of Geographic Domains, University Consortium for Geographic Information Science: Boca Raton, CRC Press, p. 3-12.

Conference Proceedings

Alexander, L., 2008, e-Navigation, ECDIS and MIOs: At Present and in the Future, e- Navigation 2008 Conference: Seattle, WA, USA, 18-19 November.

Alexander, L., 2008, e-Navigation, ECDIS and PPUs: Challenges and Opportunities, XIXth IMPA Congress 2008: Bangkok, Thailand, 4-8 August.

Alexander, L., 2008, Marine Electronic Chart Highway Project: The MIO Component CARIS: Bath, UK, 22-26 September.

Alexander, L., 2008, Portable Piloting Units (PPUs): Current Use, Future Trends, and Annual Assembly Meeting the Radio Technical Commission for Maritime Services: San Diego, CA, USA, 4-10 May.

Alexander, L., 2008, Use of Portable Piloting Units (PPUs) by Maritime Pilots: Study Findings and Implications, American Pilot's Association Biennial Convention: Kauai, HI, USA, 20-24 October.

Alexander, L., 2008, Use of Portable Piloting Units by Maritime Pilots, Canadian Maritime Pilots Association 2nd Biennial Congress: Vancouver, British Columbia, Canada, 21-25 April, p. 1-9.

Alexander, L., and Casey, M.J., 2008, Use of Portable Piloting Units by Maritime Pilots 2008, Canadian Hydrographic Conference: Victoria, British Columbia, Canada, 5-8 May.

Braswell, B., Schwehr, K., Milliman, T., and Fisk, J., 2008, Open Geoscience: Using Free and Open Source Software for Research and Education, Association of American Geographers: Boston, MA, USA, 2-7 March.

Gardner, J.V., Mayer, L.A., and Armstrong, A. A., 2008, From the Arctic to the Tropics: The U.S. UNCLOS Bathymetric Mapping Program, Canadian Hydrographic Conference: Victoria, British Columbia, Canada, 5-8 May, p. 1-11.

Jacobi, M., Kinner, N.E., Braswell, B., Schwehr, K., Newman, K.S., and Merten, A.A., 2008, Environmental Response Management Application, International Oil Spill Conference: Savannah, GA, USA, 4-8 May.

Lippmann, T.C., 2008, Analytic Solution for the Forced Mean Cross-shore Flow in the Surf Zone, 31st International Conference on Coastal Engineering: Hamburg, Germany, 2 - 5 September, p. 1-9.

McGillivary, P.A., Schwehr, K., Curcio, J., Hine, R., Terrill, E., Wiggins, S., Roth, E., and Fall, K., 2008, Marine Technology Advances to Reduce Incidence of Whale Ship Strikes, Oceans '08 MTS/IEEE Kobe-Techno: Kobe, Japan, 8-11 April.

McLean, C., and Alexander, L., 2008, Production of Marine Information Overlays (MIOs) for Marine Environmental Protection, Global Ecology and Oceanography of Harmful Algal Blooms: Sitka, AK, USA, 29 April-2 May, p. 1-18.

Monahan, D., 2008, International Research and Law of the Sea, Navigating A Course Toward Ocean Renewable Energy, A Colloquium to Enhance North American Research Collaborations: Narragansett, RI, USA, 28-29 October.

Morrison, J.R., Trowbridge, P., Pe'eri, S., Gregory, T., and Novak, M., 2008, Hyperspectral Airborne Remote Sensing for Assessing Water Quality and Clarity in the Great Bay Estuary of New Hampshire, Ocean Sciences Meeting: Orlando, FL, USA, 2-7 March.

Pe'eri, S., Gardner, J.V., and Ward, L.G., 2008, Validating Coastal Flooding Models using ALB-drived Shorelines, Canadian Hydrographic Conference: Victoria, British Columbia, Canada, 5-8 May.

Pineo, D., and Ware, C., 2008, Neural Modeling of Flow Rendering Effectiveness, Applied Perception in Graphics and Visualization 08 Symposium: Los Angeles, CA, USA, 9-10 August.

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Boettcher, M., 2008, The Natural Earthquake Laboratory in South Africa Gold Mines Project, Rapid Response Drilling Workshop: Tokyo, Japan, 17-19 November.

Brumley, K., Mayer, L.A., Miller, E.L., and Coakley, B., 2008, Dredged Rock Samples from the Alpha Ridge, Arctic Ocean: Implications for the Tectonic History and Origin of the Amerasian Basin, American Geophysical Union, Fall Meeting USA, Eos Trans AGU, 89(53), Fall Meet, Abstract T43B-2013: San Francisco, CA, USA, 15-19 December.

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Monahan, D., 2008, The Impacts of a Non-accepted Boundary Claim: Russia's frontier in the Arctic Ocean, Association of American Geographers: Boston, MA, USA, 15-19 April.

Monahan, D., 2008, New Geopolitics of the Arctic Region: Panel, Association of American Geographers: Boston, MA, USA, 15-19 April.

Monahan, D., Schwehr, K., Wigley, R., Uddin, M. J., Tinmouth, N., Jinadasa, P., Ito, K., Goncalves, D., 2008, *"GEBCO Visual Library, Proof of Concept."* International Bathymetric Science Day, Tokyo, Japan, 27 May 2008, p. 1.

Monahan, D., Vogt, P.R., and Cormier, M. H., 2008, A Proposal to Complete Mapping of the World Ocean Floors, American Geophysical Union: San Francisco, CA, USA, 15-19 December.

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Morgan, L.V., Pe'eri, S., and Armstrong, A.A., 2008, Development and Assessment of Airborne LIDAR Bathymetry Products for Shoreline Mapping, Canadian Hydrographic Conference: Victoria, British Columbia, Canada, 5-8 May.

Morrison, J.R., Trowbridge, P., Pe'eri, S., Gregory, T., and Novak, M., 2008, Hyperspectral Airborne Remote Sensing for Assessing Water Quality and Clarity in the Great Bay Estuary of New Hampshire, Ocean Sciences Meeting: Orlando, FL, USA, 2-7 March.

Pe'eri, S., Gardner, J.V., Morrison, J.R., and Ward, L.G., 2008, Ground-truth Results of Comparison or Airborne LIDAR Bathymetry in Subtidal Coastal Environments, American Geophysical Union, Fall Meeting: San Francisco, CA, USA, 15-19 December.

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Rzhanov, Y., and Pe'eri, S., 2008, Registration of the Hyperspectral Data to Aerial Photography (USACE's CHARTS system), Joint Airborne LIDAR Bathymetry Technical Center of Expertise Coastal Mapping and Charting Workshop: San Francisco, CA, USA, 12-18 June.

Schmidt, V.E., 2008, Arctic Sound Speed: A Desktop Study for Single Beam Echo Sounding, American Geophysical Union, Eos Trans. AGU, 89 (53) Fall Meeting Supplement, Abstract OS51C-1269.

Trembanis, A., Hiller, T., Fonseca, L., and Mayer, L.A., 2008, Going Autonomous-Seafloor Mapping from an AUV, Recent Results and Challenges, 5th International Shallow Water Survey Conference: Portsmouth, NH, USA, 21-24 October.

Trusel, L.D., Willems, B.A., Powell, R.D., and Mayer, L. A., 2008, Quantification of Glacimarine Sediment Yields Using Multibeam Sonar in Alaskan Fjords, American Geophysical Union, Eos Trans. AGU, 89(53), Fall Meeting Supplement, Abstract C11B-0508.: San Francisco, CA, USA, 15-19 December.

Wigley, R., Pe'eri, S., and Ward, L.G., 2008, Analysis of Coastal Morphology for Crescent and Sea Point Beaches, MaineGround-truthing Airborne LIDAR Bathymetry Digital Elevation Models, 5th International Shallow Water Survey Conference: Portsmouth, NH, USA, 21-24 October.

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Wardwell, N., 2008, Establishing Chart Datum Across the Bay of Fundy Using Virtual Tide Gauges. [MS thesis]: Durham, University of New Hampshire.

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Reports

Alexander, L., 2008, Electronic Chart System-related Findings Pertaining to the Queen of the North Sinking Draft Report: Surry, BC, Canada, Royal Canadian Mounted Police, 20 April, p. 1-20.

Alexander, L.,, 2008, e-Navigation Workshop: Compiled Results and Findings: Ottawa, ON, Canada, Canadian Coast Guard, 10-11 June, p. 1-24.

Alexander, L., 2008, M/T Cap Diamant ENC Non-Availability Incident Analysis Report: Montreal, QC, Canada, Marine Press of Canada and IHO WEND Committee, 26 August, p. 1-5.

Calder, B.R., 2008, Comments on "Data Representation and Griding in CARIS": Durham, NH, USA, Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, 4 November, p. 1-9.

Calder, B.R., Gardner, J.V., 2008, U.S. Law of the Sea Cruise to Map the Foot of the Slope of the Northeast U.S. Atlantic Continental Margin Leg 6: Durham, NH, USA, Center for Coastal and Ocean Mapping/ Joint Hydrographic Center, 31 May, p. 1-147.

Lippmann, T.C., 2008, ONR Annual Report: Africa Partnership Station: Washington, DC, USA, Office of Naval Research, 30 September, p. 1-5.

Lippmann, T.C., 2008, ONR Annual Report: The Vertical Structure of Shallow Water Flow in the Surf Zone and Inner Shelf: Washington, DC, USA, Office of Naval Research, 30 September, p. 1-8.

Lippmann, T.C., 2008, Daily Surface Currents from Argus Video at Benson Beach, WA: Portland, OR, USA, US Army Corps of Engineers, 22 December, p. 1-10.

Lippmann, T.C., 2008, Observations of River Topology and Flow around Bridges: Columbus, OH, USA, USGS Water Resources Research Institute and Ohio State University, 30 October, p. 1-3.

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Lippmann, T.C., and Monfort, C., 2008, Assimilation of Airborne Imagery with LIDAR for Surf Zone Bathymetric Estimation: San Diego, CA, USA, Furgro Pelagos, Inc., 22 December, p. 1-10.

Malik, M.A., 2008, Ph.D. Proposal titled Estimation of Uncertainty in the Measurement of the Seafloor Acoustic Backscatter: Durham, NH, USA, University of New Hampshire, Center for Coastal and Ocean Mapping, 10 March, p. 1-73.

Monahan, D., 2008, Adoption of Rule of Procedure 21.2c: Paris, France, Intergovernmental Oceanographic Commission, 25 June.

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Ward, L.G., Grizzle, R. G., and Irish, J.D., 2008, UNH OOA Environmental Monitoring Program Final Report for 2004-2008: Durham, NH, USA, University of New Hampshire, AMAC OOA, December.

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Alexander, L., *"e-Navigation: Challenges and Opportunities."* Shipping Federation of Canada, Montreal, QE, Canada, 6 February 2008.

Alexander, L., *"e-Navigation: Challenges and Opportunities."* US Merchant Marine Academy, Kings Point, NY, USA, 14 May 2008.

Alexander, L., *"e-Navigation: Challenges and Opportunities."* Canadian Coast Guard, Ottawa, ON, Canada, 10 June 2008.

Alexander, L., *"e-Navigation, ECDIS and MIOs: At Present and in the Future."* International Hydrographic Organization Regional Seminar, Niteroi, Brazil, 5 November 2008.

Alexander, L., *"e-Navigation and Electronic Charting: Challenges and Opportunities."* Canadian Hydrographic Service, Ottawa, ON, Canada, 18 December 2008.

Boettcher, M., *"A Synoptic Model of Slip on Mid-Ocean Ridge Transform Faults-Insights from Earthquakes and Laboratory Experiments."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, 14 November 2008.

Boettcher, M., *"The Natural Earthquake Laboratory in South African Gold Mines Project."* GeoForchungsZentrum, Potsdam, Brandenburg, Germany, 12 December 2008.

Calder, B.R., *"CUBE Processing in HyPack Expert Session."* HyPack Inc. User Conference, Savannah, GA, USA, 7 January 2008.

Calder, B.R., *"Mapping History: The Scapa Flow Marine Archaeology Project 1999-2006."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, 7 November 2008.

Calder, B.R., *"Sonar Data Processing for Map Making."* Doosan-Babcock Energy Ltd, Glasgow, Scotland, United Kingdom, 18 December 2008.

Gardner, J.V, *"Western insular margins of the Northern Mariana Islands & Guam - 2006 & 2007."* U.S. State Department ECS Task Force, Washington, DC, USA, 15 January 2008.

Dijkstra, S.J., *"Tides and Water Levels for Surveying and Mapping."* Center for Coastal and Ocean Mapping/Joint Hydrographic, Durham, NH, USA, 19 November 2008.

De Jong, E., Andres, P., Levoe, S., Suzuki, S., Schwehr, K., *"Visualizations for the Phoenix Mars Lander."* NASA JPL and University of Arizona Science Operations Center (SOC), Tuscan, AZ, USA, May and June 2008.

De Jong, E., Suzuki, S., Schwehr, K. *"Solar System Visualization for the Phoenix Mars Lander,"* Presented to Charles Elachi (director of JPL) and Gentry Lee, Tucson, AZ., 29 May 2008.

Gardner, J.V., *"Proposed ECS Mapping in Kingman Reef and Palmyra Atoll."* U.S. State Department ECS Task Force, Washington, DC, USA, 15 January 2008.

Gardner, J.V., *"U.S. Law of the Sea Bathymetry Mapping."* U.S. Geological Survey, Santa Cruz, CA, USA, 21 March 2008.

Gardner, J.V., *"Bathymetry of Western Insular Margins of the CNMI & Guam - 2006 & 2007 MBES Mapping."* U.S. Department Pacific ECS workshop, Honolulu, HI, USA, 22-23 April 2008. [Invited Talk]

Gardner, J.V., *"Proposed ECS Mapping in Kingman Reef and Palmyra Atoll."* U.S. Department Pacific ECS workshop, Honolulu, HI, USA, 22-23 April 2008. [Invited Talk]

Lippmann, T.C., 2008, *"Analytic Solution for the Forced Mean Cross-shore Flow in the Surf Zone."* 31st International Conference on Coastal Engineering: Hamburg, Germany, 2 - 5 September, p. 1-9.

Lippmann, T.C., and Smith, G., 2008, *"Shallow Surveying in Hazardous Water."* 5th International Shallow Water Survey Conference: Portsmouth, NH, USA, 21-24 October, p. 118.

Malik, M.A., *"Hydrographic Data Processing: Caris Processing of Bathymetric and Backscatter Data Derived from Multibeam Sonars."* Matlab Developer visit, Center for Coastal and Ocean Mapping/Joint Hydrographic Center, Durham, NH, USA, 8 February 2008.

Mayer, L.A., *"UNH Desktop Study and Bathymetric Data Collection in the Arctic Ocean."* U.S. State Department, ECS Taskforce Arctic Geology Workshop, Arlington, VA, USA, 31 January 2008. [Invited Talk]

Mayer, L.A., *"Integrated Ocean Mapping?"* Interagency Working Group on Ocean and Coastal Mapping, National Ocean and Coastal Mapping, Strategic Action Plan Workshop, Dania Beach, Florida, USA, 26 February 2008. [Keynote Speaker]

Mayer, L.A., *"Initial Assessment of Pacific Areas in UNH Desktop Study and Why Foot of the Slope Is the Critical Factor."* ECS Taskforce Pacific Geology Workshop, Honolulu, HI, USA, 22 April 2008.

Mayer, L.A., *"Seafloor Characterization."* Geoscience Australia, Canberra, Australia, 30 April 2008. [Invited Talk]

Mayer, L.A., *"Mapping the Uncharted Arctic."* National Defense University, National War College Symposium on National Security, Climate Change and the Arctic Frontier, Washington, D.C, USA, 13 May 2008. [Invited Talk]

Mayer, L.A., Gardner, J.V. and Armstrong, A.A., *"U.S. Efforts to Delineate its Extended Continental."* International Geological Congress, Oslo, Norway, 6 August 2008. [Invited Talk]

Mayer, L.A., *"Arctic Mapping in Support of Law of the Sea."* Southwest School of Law, Los Angeles, California, USA, 3 October 2008. [Invited Lecture]

Mayer, L.A., *"Recovering the TRIFFID and Other Sailboat Adventures."* Mark Wimbush Symposium, University of Rhode Island, Kingston, Rhode Island, USA, 17 October 2008. [Invited Lecture]

Mayer, L.A., *"Initial Assessment Bering Sea and Gulf of Alaska in UNH Desktop Study and Potential Implications of the Statement of Understanding."* ECS Taskforce Pacific Geology Workshop, Menlo Park, CA, USA, 3 December 2008. [Invited Talk]

Mayer, L.A. and Jakobsson, M., *"Seafloor Mapping in the High Arctic: The Challenges and the Joys."* Arctic Change 2008, Quebec City, Canada, 11 December 2008. [Plenary Talk]

Mayer, L.A., *"Mapping the Arctic Ocean for Science and Country: Recent Results and Availability of Bathymetric Data from the Chukchi and Beaufort Seas, Arctic Research: Goals, Updates and Opportunities."* Arctic Research Commission Town Hall Meeting, American Geophysical Union,, San Francisco, CA, USA, 13 December 2008. [Invited Talk]

Monahan, D., *"New Marine Boundaries Arising from UNCLOS."* University of New Brunswick, Fredericton, NB, Canada, 28 November 2008.

Monahan, D., *"Who Owns the Arctic Ocean?"* Sterling College, Craftsbury Common, VT, USA, 30 October 2008.

Monahan, D., *"New Geopolitics of the Arctic Region."* Association of American Geographers, Boston, MA, USA, 15 - 19 April 2008.

Monahan, D., *"Combining Multibeam from Many Sources – Challenges and Promises."* International Bathymetric Science Day, Tokyo, Japan, 27 May 2008, p. 1 - 34.

Pe'eri, S., *"The Airborne LIDAR Bathymetry Products for Shoreline Mapping."* UNB/OMG seminar, Fredericton, NB, Canada, 28 April 2008.

Pe'eri, S., *"Current LIDAR Research in CCOM."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, 9 May 2008.

Pe'eri, S., *"Analysis of Hyperspectral Imagery for Light Attenuation."* New Hampshire Department of Environmental Services, Portsmouth, NH, USA, November 2008.

Plumlee, M., *"Some Applications of Computer Science at the CCOM Vislab."* CS 416 Class, University of New Hampshire, Durham, NH, USA, 5 May 2008.

Plumlee, M., Ware, C., Schwehr, K., *"GeoCoastPilot."* NOAA CoastPilot team, Durham, NH, USA, August 2008.

Plumlee, M., *"Developing New User Interface Design Principles."* CS900 class, University of New Hampshire, Durham, NH, USA, October 2008.

Plumlee, M., *"Interactive 3D Interfaces."* CS770/870 class, University of New Hampshire, Durham, NH, USA, December 2008.

Schmidt, V.E., *"Center for Coastal and Ocean Mapping / Joint Hydrographic Center Seminar Presentation."* U.S. Navy SUBTECH Program, Center for Coastal and Ocean Mapping/Joint Hydrographic Center, Durham, NH, USA, 17 October 2008.

Schwehr, K., *"Whale Detection Buoys That Have Just Been Placed in the Boston TSS."* Port Operations Group Meeting, Boston, MA, USA, 16 January 2008.

Schwehr, K., *"Web Mapping-Environmental Response Management Application."* Math Works Visit, Durham, NH, USA, 8 February 2008.

Schwehr, K., *"AIS for Right Whale Notifications."* Bioacoustics Research Program, Cornell, NY, USA, 2 April 2008.

Schwehr, K., *"The CCOM Wiki and Automatic Identification System for Real-time Right Whale Notices."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, 11 April 2008.

Schwehr, K., *"IALA AIS Binary Message Registry Version 0.1."* RTCM SC121 AIS Binary Messages for VTS Working Group, San Diego, CA, USA, 8 May 2008.

Schwehr, K., De Jong, E., Andres, P., Levoe, S., *"Using the Image Products Release Website (IPRW."* Pre-Landing Phoenix Science Operations Center Software Training, Tucson, AZ, 21 May 2008.

Schwehr, K., Smith, P., Lee, G., *"Phoenix Mars Lander Update for Sol 23 – Visualizations."* Phoenix Mars Lander, Tucson AZ, USA, 18 June 2008.

Schwehr, K., Smith, P., Lee, G.,*"Mars Surface Exploration Visualization on the 50 ft. Panorama Screen: Pathfinder through Phoenix."* Phoenix Mars Landing Science Operation Team, Tucson, AZ, USA, 24 June 2008.

Schwehr, K., Alexander, L., *"Right Whale AIS Project Update."* RTCM SC121 Working Group, Arlington, VA, USA, September 2008.

Schwehr, K., *"Phoenix Mars Lander-Visualization of the Surface of Another Planet."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, October 2008.

Schwehr, K., *"Applications of Coastal Science to Today's Issues."* Geological Sciences Seminar Class, University of Delaware, Delaware, USA, November 2008.

Schwehr, K., "Phoenix Mars Lander-Visualization of the Surface of Another Planet (and collaborations across the globe)." Earth Sciences Department, University of Delaware, Delaware, USA, November 2008. [Invited Talk]

Schwehr, K., Alexander, L., *"Right Whale AIS Program Update-Initial Transponder Deployment."* RTCM SC121 Working Group on Expanded Use of AIS with VTS, Seattle, WA, USA, November 2008.

Schwehr, K., *"Scripting Languages in Science."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, November 2008.

Schwehr, K., *"Spatial Tools in the Marine Environment: Decision Support."* NASA Ames, Intelligent Robotics Group, Moffett Field, CA, USA, December 2008.

Ward, L.G., *"Sedimentologic and Stratigraphic Studies on the New Hampshire Shelf."* University of New Hampshire, Center for Coastal and Ocean Mapping/Joint Hydrographic Center Seminar Series, Durham, NH, USA, 25 April 2008.

Ware, C., *"Cognitive Systems Design Patterns."* New Directions in Cognitive Science Conference, Vancouver, BC, Canada, 2 February 2008.

Ware, C., *"Visual Thinking and Geospatial Visualization."* Macalister College, Minneapolis, MN, USA, 29 March 2008.

Ware, C., *"Integrating Space and Time in an Interactive 3-D Environment."* University of Rhode Island, Kingston, RI, USA, 15 April 2008.

Ware, C., Plumlee, M., and Schwehr, K., *"The GeoCoastPilot."* Center for Coastal and Ocean Mapping/Joint Hydrographic Center, Durham, NH, USA, 2 May 2008.

Weber, T.C., *"Clustered Scatterers: The Effect on the Mean Acoustic Field."* 155th Meeting of the Acoustical Society of America, Paris, France, 29 June - 4 July 2008. [Invited Talk]

Weber, T.C., Weirathmueller, M., Mayer, L.A., *"High-Frequency One-Way Propagation Experiments in Portsmouth Harbor, NH."* Meeting of the Acoustical Society of America, Miami, FL, USA, 10 - 14 November 2008. [Invited Talk]

Wiley, D., Schwehr, K., Baker, Box, J., Hatch, L., 2008, *"Right Whale AIS Project Initial Demonstration."* Boston Port Operators Group, Boston, MA, USA, October 2008.

APPENDIX E: MEETINGS AND CONFERENCES ATTENDED

Alexander, L., International Hydrographic Organization Meeting, Monaco, 14-17 January 2008.

Alexander, L., International Association of Lighthouse Authorities Meeting, St. Germain en Laye, France, 18-19 January 2008.

Alexander, L., HYPAC, Inc. Software Development Meeting, Middletown, CT, USA, 23 January 2008.

Alexander, L., Shipping Federation of Canada Workshop, Montreal, QC, Canada, 2-6 February 2008.

Alexander, L., Maritime Safety Administration of P.R. China Meeting, Shanghai: Inland Electronic Charting International Standards, China, 28 February 2008.

Alexander, L., Tampa Bay Port Authority Project Planning Meeting, Tampa Bay, FL, USA,17-18 March 2008.

Alexander, L., U.S. Coast Guard District One HQ Project Planning Meeting, Boston, MA, USA, 10 April 2008.

Alexander, L., U.S. Coast Guard R&D Center Project Planning Meeting, Groton, CT, USA, 17 April 2008.

Alexander, L., Frazier River Pilotage Authority site visit, Vancouver, BC, Canada, 24 April 2008.

Alexander, L., ESRI Software Development Meeting, Redlands, CA, USA, 7 May 2008.

Alexander, L., U.S. Coast Guard District One HQ Briefing Meeting, Boston, MA, USA, 13 May 2008.

Alexander, L., U.S. Merchant Marine Academy: Ship Simulator Facility Visit, Kings Point, NY, USA, 14 May 2008.

Alexander, L., Marine Press of Canada Planning Meeting, Montreal, Canada, 11 June 2008.

Alexander, L., Department of Fisheries and Oceans - Science Branch, St. Johns, Newfoundland, Canada, 24 June 2008.

Alexander, L., ICAN, Ltd. Project Planning Meeting, St. Johns, Newfoundland, Canada, 25 June 2008.

Alexander, L., NAVSIM, Ltd. Project Planning Meeting, ST. Johns, Newfoundland, Canada, 26 June 2008.

Alexander, L., Canadian Coast Guard/Department of Fisheries and Oceans Project Planning Meeting, St. Johns, Newfoundland, Canada, 26-27 June 2008.

Alexander, L., U.S. Coast Guard/Tampa Bay Port Authority/Tampa Bay Pilots Association: AIS Binary Message Project, Tampa, FL, USA, 10-11 September 2008.

Alexander, L., International Association of Lighthouse Authorities Meeting: AIS Regional AIS Binary Message Register, St. Germain en Laye, France, 19 September 2008.

Alexander, L., Port of Montreal: Project Planning Meeting - e-Navigation & Ice Coverage MIO Testbed, Montreal, Canada, 13 November 2008.

Alexander, L., Directorate of Navigation and Hydrography – Brazil meeting, Inland ENCs and River Information Overlays (RIOs), Niteroi, Brazil, 13-14 November 2008.

Alexander, L., Canadian Coast Guard VTS Centre Project Planning Meeting, Quebec City, QC, Canada, 14 November 2008.

Alexander, L., U.S. Coast Guard VTC Center Project Planning Meeting: - e-Navigation User Needs Study, Seattle, WA, USA, 17 November 2008.

Alexander, L., Shipping Federation of Canada Planning Meeting for the 2009 Mariners Workshop, Montreal, QC, Canada, 17 December 2008.

Alexander, L., Canadian Coast Guard planning meeting on e-Navigation, Ottawa, ON, Canada, 18 December 2008.

Alexander, L., Canadian Ice Service planning meeting on Ice Coverage Testbed Project, Ottawa, ON, Canada, 18 December 2008.

Boettcher, M., U.S. Geological Survey Meeting, Menlo Park, CA, USA, 1-8 October 2008.

Bogucki, R., Shallow Survey Conference, Portsmouth, NH, USA, 20-24 October 2008.

Calder, B.R., Taiwan National Ocean University Planning Meeting for ONR QPE field experiment, Taipei, Taiwan, 11-15 March 2008.

Calder, B.R., SAIC Pre-Cruise for UNCLOS Atlantic Mapping 2008, Newport, RI, USA, 28 March 2008.

Calder, B.R., Gardner, J.V., Scripps Institute of Oceanography Pre-Cruise Meeting for UNCLOS Atlantic Mapping 2008, San Diego, CA, USA, 3-5 April 2008.

Calder, B.R., Reson Inc. Development and testing of PTP/SWGM Integration with Reson 7-P Processor; Discussions on Uncertainty, Golta, CA, USA, 14-18 April 2008.

Calder, B.R., MIT/WHOI Planning of ONR Quantifying, Predicting and Exploiting Uncertainty program field exercise 2009 (Pre-meeting), Cambridge, MA, USA, 8 December 2008.

Calder, B.R., Doosan Babcock Energy Ltd meeting: discussion of data processing techniques used in MBES surveys, Glasglow, Scotland, United Kingdom, 18 December 2008.

Dijkstra, S., All Seas Mapping Meeting, Delft, Netherlands, 28 November 2008.

Felzenberg, J., L-3 Klein Associates Inc. Data Meeting, Salem, NH, USA, 1 May 2008.

Huff, L.C., Hydro 08, Liverpool, UK, 4-6 November 2008.

Lippmann, T.C., National Science Foundation Research Program Meeting, Washington, DC, USA, 15 August 2008.

Monahan, D., Nippon Foundation Selection Meeting, New York, NY, USA, 9 March 2008.

Monahan, D., Nippon Foundation Training Program Meeting, Tokyo, Japan, 27 May 2008.

Pe'eri, S., University of New Brunswick, Dept. of Geodesy and Geomatics Engineering Master Thesis Meeting, Fredericton, NB, Canada, 28 April 2008.

Pineo, D., Brown University Collaboration Meeting, Providence, RI, USA, 10 June 2008.

Pineo, D., Sky-Scan, Inc. Development Meeting, Nashua, NH, USA, 12 June 2008.

Pineo, D., Sky-Scan, Inc. Development Meeting, Nashua, NH, USA, 17 June 2008.

Rzhanov, Y., NOAA South Pacific Fisheries Software Meeting, San Diego, CA, USA, 10-14 November 2008.

Schmidt, V.E., Shallow Water Survey Conference, Portsmouth, NH, USA, 20-24 October, 2008.

Schmidt, V.E., Ocean Platform Workshop: High Precision GNSS Observations from Ocean Platforms, Boulder, CO, USA, 27-28, October 2008.

Schwehr, K., RTCM SC121 AIS for Expanded VTS Services, USCG RDC, Groton, CT, USA, 22 January 2008.

Schwehr, K., Opening the Arctic Seas: Envisioning Disaster & Framing Solutions, Coastal Response Research Center, University of New Hampshire, Durham, NH, USA, 18-21 March 2008.

Schwehr, K., RTCM Annual Meeting, San Diego, CA., USA, 4-7 May 2008.

Schwehr, K., e-Navigation 2008, Seattle, WA, USA, 18-19 November 2008.

Sullivan, B.M., an Event Apart, Boston, MA, USA, 23-24 June 2008.

Sullivan, B.M., ArcGIS 9.3 Seminar Series, Durham, NH, USA, 6-9 October 2008.

Ware, C., Stockholm University Visualization Work Meeting, Stockholm, Sweden, 12-19 February 2008.

Ware, C., SBNMS Meeting, Scituate, MA, USA, 21 March 2008.

Ware, C., NCEP Cyber Informatics Forum Meeting, Boulder, CO, USA, 4-7 May 2008.

Ware, C., Duke University Marine Lab Meeting, Beaufort, NC, USA, 14 December 2008.

Ward, L.G., American Quaternary Association Biannual Meeting, State College, PA, USA, 4-7 June 2008.

Ward, L.G., EPA New England Climate Change Forum, Durham, NH, USA, 19 June 2008.

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