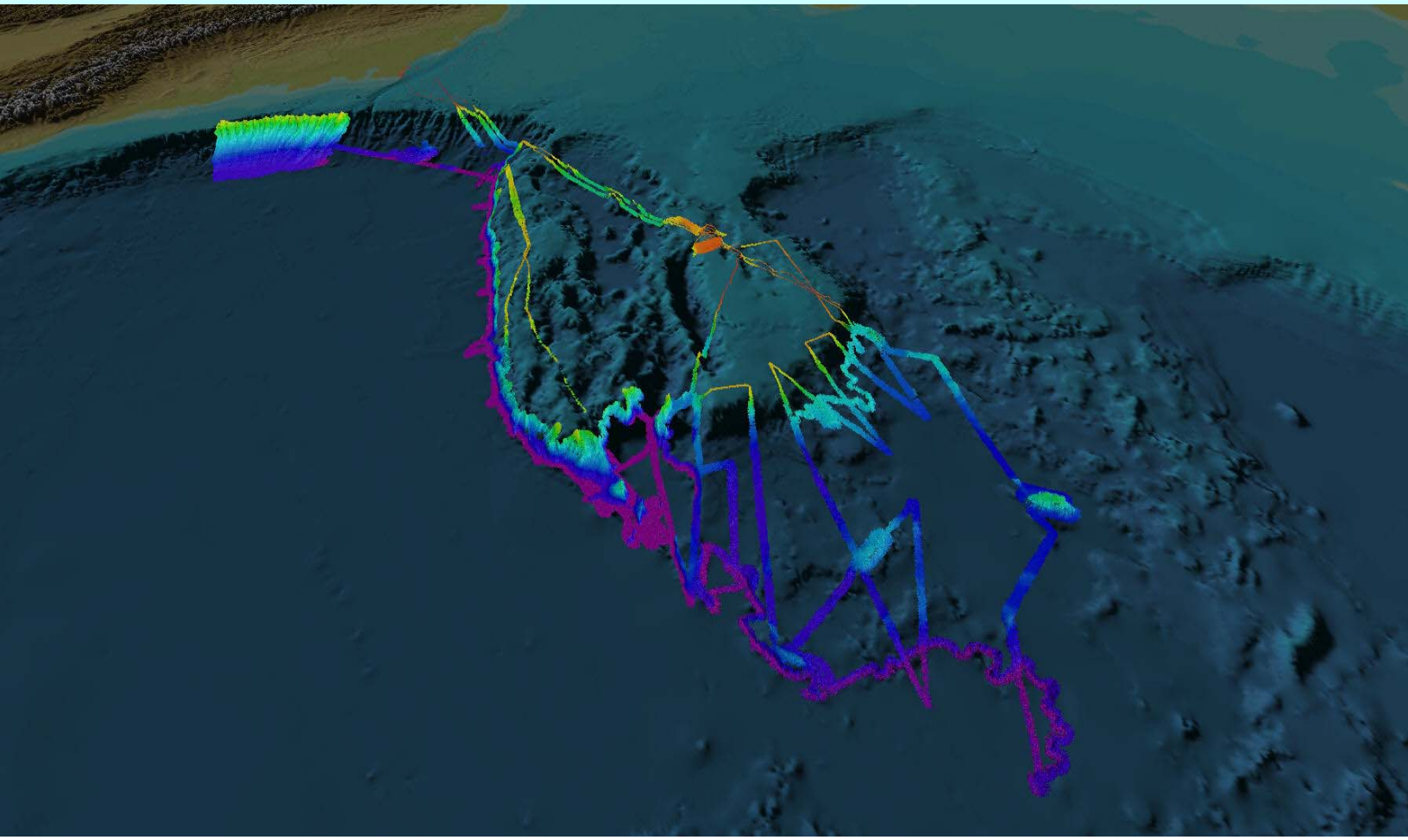
Performance and Progress Report

NOAA Ref No: NA0NOS4001153

Project Title: Joint Hydrographic Center
Report Period: 01/01/2007 – 12/31/2007

Principal Investigator: Larry A. Mayer



CCOM/UNH mapping this past summer of the Chukchi Plateau in the high Arctic (to 82.17 deg N) has redefined the location of the foot of the continental slope and in doing so may greatly impact the potential extension of U.S. sovereign rights over resources in the Arctic.

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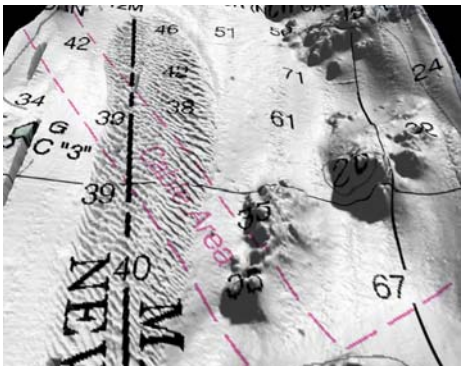
EXECUTIVE SUMMARY

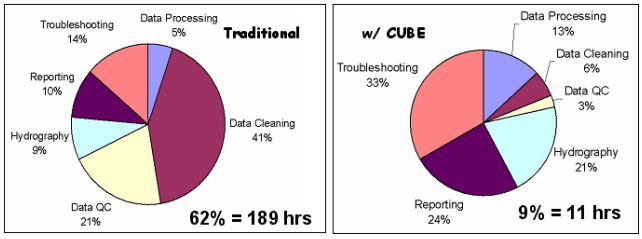
Hydrography has undergone dramatic changes over the past decade. Improved sonar and computer technology have revolutionized the types, quantity and quality of data available to create nautical charts. Until recently, water depths were measured by dropping a lead line at periodic intervals. These data points were sent to an office where contour lines would be painstakingly sketched out. With the arrival of the first single beam sonars, and then ever more effective multibeam sonar technologies, those offices began to receive millions, rather than tens of new data points for every hour of survey work. Instead of connecting the sparse dots of a puzzle, they were presented with a flood of data points that could inundate them, or, if processed properly, present an unprecedented complete and accurate picture of the seafloor.



Traditional chart draped over modern multibeam sonar data – look at what we've been missing.

The NOAA-UNH Joint Hydrographic Center was founded eight years ago to find ways to process the massive amounts of data coming from these new 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. As we begin to achieve this goal, our attention is also turning to the wonderful opportunity to utilize this massive flow of information into products that meet a wide range of needs, such as safer navigation, marine habitat assessments, fisheries management and national security. In this short period of time, 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).

Since our inception, we have worked on the development of automated and statistically robust approaches to multibeam sonar data processing. These efforts have come to fruition. Our automated processing algorithm (CUBE) and our new database approach (The Navigation Surface), have, after careful verification and evaluation, been 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 is *"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).



Data cleaning time saved using CUBE

The acceptance of CUBE and the Navigation Surface has required 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 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.

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. Both CUBE and the Navigation Surface 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.

The usefulness of CUBE has been extended through the development of ways to apply this processing approach to the initial calibration tests performed for multibeam sonar systems at sea (the "patch test"). These are done when new instruments are installed, and again typically when a vessel commences a survey in a new area. When CUBE is applied to patch tests, the overall uncertainty of the survey data is reduced by at least five percent. In another effort to improve survey accuracy, we have developed software that takes advantage of a new timing protocol (IEEE-1588) and allows the components of a sonar system to be synchronized within an absolute time accuracy of approximately 100

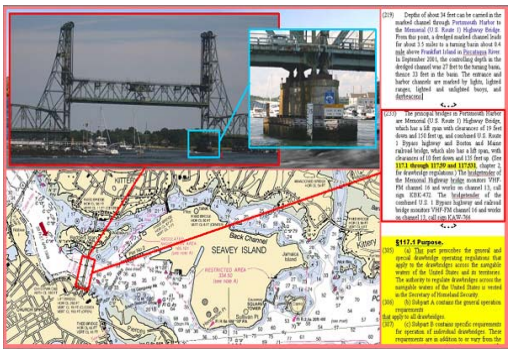
nanoseconds. This level of timing will greatly enhance the accuracy of hydrographic surveys and is already being implemented by our industrial partners. This new timing approach was tested and implemented on the NOAA vessel *Bay Hydrographer* this year with excellent results.

To further increase hydrographic survey efficiency and directly address NOAA's survey backlog, we have developed software and protocols that may allow a high-speed sidescan sonar (Klein 5410) to collect hydrographic-survey-grade bathymetry over swaths as wide as 150 m even in shallow water (depths of 20 m or less). Field trials of this system aboard the NOAA ships *Thomas Jefferson* and *Rude* demonstrated the potential of this approach and we are currently working with NOAA to see how it can best be implemented in the fleet.

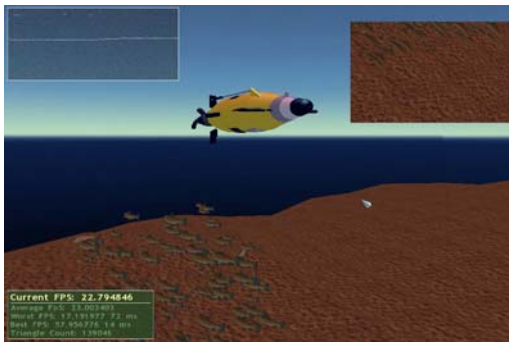
Inherent in the Navigation Surface concept is our long-held belief that the "products" of hydrographic data processing can also serve a variety of applications and constituencies well beyond hydrography. Another long-held tenet of the Center is that the standard navigation charts produced by the world's 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, and our hydrographers and 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 taken roots this year with the successful demonstration of the use of the Automatic Information System (AIS) combined with our visualization tools for verification of compliance with changes in vessel traffic patterns designed to route vessels outside of a known whale migration route. This same capability was used by NOAA and the USCG to quickly view and evaluate the November 2007 collision of the containership Cosco-Buson with the San Francisco Bay Bridge.

Path of containership Cosco-Buson monitored through AIS at CCOM/JHC soon after collision with the San Francisco Bay Bridge

We have also introduced this year a prototype "Digital Coast Pilot" -- a fully digital and interactive version of the commonly used Coastal Pilot books. With the Digital Coast Pilot mariners can explore, through a mouse click, any object identified in the text and see a pictorial representation (in 2-D or 3-D) of the object in geospatial context. Conversely, a click on the picture of an object will link directly to the full description of the object well as other relevant information.



Example of Digital Coast Pilot – a click on the text brings up images that provide 2 or 3-D geospatial context for objects (and vice versa).

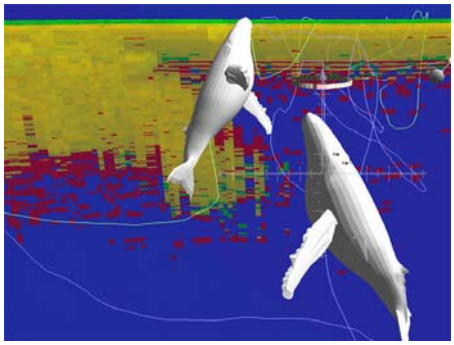


CCOM/JHC AUV simulator with modeled school of fish and seafloor

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 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 developed control, playback and simulation software for a small AUV (FETCH) and are now beginning a project with the South West Fisheries Center to design an adaptive control system for this AUV so that it can autonomously follow and image schools of fish.

In support of our AUV efforts we installed, this year, a fixed acoustic navigation array cabled to the beach (and then wirelessly connected to the lab) in a portion of Portsmouth Harbor. 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.

Working with NOAA Fisheries researchers, we have created 3-D visualizations of the behavior of humpback whales (derived from motion-sensing tags on the whales) that have revealed never-before-seen surface and bottom feeding behaviors. Our development, this year, of portable acoustic pingers, now allows us to also track the whales and their behavior underwater providing unprecedented information on whale swimming speed (up to 12 knots) and feeding behavior. Our visualizations of whale behavior have appeared in numerous media and have been used in hearings on the location of offshore natural-gas terminals.



Visualization of behavior of tagged whales in Stellwagen Bank National Marine Sanctuary

These new tools focus on the visualization of systems that change in both space and time, opening up a world of opportunities for studying many components of ocean systems that are important to NOAA and others. Foremost among these have been our interactive 3-D visualization of the 26 Dec 04 Indian Ocean tsunami that clearly demonstrates the critical role that bathymetry plays in determining run up and inundation, and our efforts to display 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 and will be creating a visualization of global circulation for the Smithsonian's new Hall of the Oceans. This past year we have added the ability to visualize multi-layered atmospheric data and, working with NOAA climate researchers, have produced exciting new visualizations of the ocean/atmosphere interactions leading up to Hurricane Katrina.

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 Atlantic herring and cod during fisheries surveys that also used standard hydroacoustic techniques. The results of these tests clearly indicated the limitations of the standard approaches and the potential benefits of using multibeam sonars for fisheries research. 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. The implications of this capability for the management of pelagic fisheries are immense.

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 from our industrial partners and we have been providing training to NOAA and others in its use. A recent email from one of the trainees (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.*"

Beyond GeoCoder, we have developed an analytical tool (ARA) 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.). This year the approach was extended to include a "theme" mode whereby the backscatter mosaic is segmented (either manually or automatically) and the angular response is calculated for each theme rather than for fixed size patches of the seafloor. The Office of Naval Research initially funded this work (their interest is in remotely identifying seafloor properties for sonar propagation and mine burial models), yet the application of this technique to fisheries habitat studies is

clear and there has been great interest in its use by a number of NOAA labs and researchers. After application of the ARA technique to data from offshore Ireland, Professor Craig Brown of the University of Ulster wrote: *"I personally think that your approach is one of the most exciting developments in the field of seabed habitat mapping. Your approach is unique and I think (with further development) could be just the thing to map seafloor features such as habitats. The combined methods of ARA and theme discrimination from the mosaic offer all the ingredients for accurate and vastly improved delineation of more subtle biological traits (i.e. bioturbation, animal biomass etc.)."* The ARA approach went through careful evaluation at several sites this year where "ground truth" data exists (including the Historic Area Remediation Site off New York) and consistently proved its ability to predict sediment type.

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 1,000,000 sq. km of high-resolution mapping data that have provided an unprecedented new view 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 survey in the high Arctic this past summer 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.

The research highlights outlined above not only represent a few of the successes we have had, but are representative of the clear impact that the lab is having on hydrographic and ocean mapping science. It should also be mentioned that the expertise 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, 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. Of particular note is the remarkable representation by the lab at recent U.S. Hydrographic Conferences -- arguably the premier international venue for the discussion of hydrographic science -- where typically, Center personnel are authors of at least 25% of the papers presented.

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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 twelfth 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 2007. Copies of previous reports can be found on the Center's web site http://www.ccom.unh.edu.

INFRASTRUCTURE
PERSONNEL
The success of any organization will be dependent on the skills and talents of the individuals that make it up. Thus the primary task in establishing the Joint Hydrographic Center was to ensure that an appropriate team of people would be brought to the University of New Hampshire. This has been accomplished, and with the arrival of **Dr. Christian de Moustier** in January 2002, all positions outlined in the original Center proposal have been filled. In 2003, **Dr. James V. Gardner**, a world-renowned marine geologist and leader of the USGS Pacific Mapping Group, retired from the USGS and joined the Center as a research faculty member. In 2004, **Nathan Paquin** began a full-time position as our computer system manager and **Jim Case** joined our staff as a database specialist. Following his retirement from NOAA in 2004, **Dr. Lloyd Huff** joined our research faculty and **David Monahan** joined our faculty as Program Director for the GEBCO Bathymetric Training Program (funded by the Nippon Foundation). In 2005, additions to our staff included **Brian Locke** as a programmer/information technologist, **Briana Sullivan** as a programmer and outreach specialist, **Shachak Pe'eri**

as a post-doctoral scholar focusing on LIDAR issues, and **Will Fessenden** as our assistant system manager. In 2006, **Glenn McGillicuddy** joined the Center in the capacity of a research engineer, **Dr. Tom Weber** joined as a research faculty member specializing in acoustics, and **Dr. Kurt Schwehr** as a research scientist with our data visualization team**.** In 2006, we also saw the re-classification of **Drs. Barbara Kraft** and **Luciano Fonseca** from Research Scientists to Assistant Research Professors. In 2007, **Dr. Larry Ward** joined the Center as an Associate Research Professor specializing in coastal processes, **Dr. Brian Calder** was promoted to Associate Research Professor and **Dr. Kurt Schwehr** was reclassified as an Assistant Research Professor.

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.

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.

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 in 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.

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 Ocean Engineering and Electrical Engineering Departments. He is a world-renowned expert in the theory and engineering aspects of advanced sonar systems for ocean mapping. Christian came to us

from the Scripps Institution of Oceanography where he was responsible for the installation and operation of a number of multibeam and other sonar systems. His research interests focus on development of innovative sonar processing techniques and acoustic seafloor characterization.

Yuri Rzhanov, with a Ph.D. in Physics and Mathematics, is an Associate Research Professor in the Center and in the Dept. of Ocean Engineering. He has a very wide range of computing skills and has built a number of applications for higher education that are presently in use at universities around the world. At the Center, Dr. Rzhanov has been developing software for automatic 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 in 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 has demonstrated its commitment to the Center by assigning five NOAA employees (or contractors) to the Center:

NOAA EMPLOYEES

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 agencies 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 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 a 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.

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.

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:

VISITING SCHOLARS

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 "Anaytic 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.

James Case is the Database Administrator for the Center for Coastal and Ocean Mapping at the University of New Hampshire with overall responsibility for data management and database infrastructure. Jim's focus project is the maintenance of the U.S. Law of the Sea database. Before coming to the Center, Jim was the Data Services Manager for SAIC's Marine Science and Technology Division. His team was responsible for data management, processing, warehousing and advanced 2-D and 3-D visualizations in support of hydrographic and telecommunications marine survey operations and desktop

studies. Jim received his BS in Ocean Engineering in 1995 from the Florida Institute of Technology, Melbourne, FL. His technical areas of expertise are relational and spatial database development, GIS programming and IT development. Jim is also a part-time Ph.D. student at UNH.

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 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. He is now focusing on applications of single beam sonars for seafloor characterization and fisheries habitat mapping as well as contributing to the teaching of several of our geodesy and ocean mapping courses.

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.

Brian Locke has an MS in Engineering Mechanics, a BS in Physics, and a BS in Computer Science. He started his career as a Materials Engineer at BF Goodrich Aerospace's Aircraft Sensors Division in Burnsville, MN, where he developed and evaluated ceramics, metals, and plastics for use in pressure, temperature, and icing sensors. More recently, he worked as a software engineer at Enterasys Networks in Andover, MA. At Enterasys Networks, Brian developed network management software in C++ and Java, creating innovative user interfaces and network management algorithms. Brian's interests include application and system architecture, software project management, user interface design, and algorithms.

Glenn McGillicuddy received his Bachelor of Science Degree in Mechanical Engineering from the University of New Hampshire in 2001 and his MS in Ocean Engineering from UNH in 2006. His master's thesis dealt with the classification of pre-weakened rope used to reduce marine mammal entanglements. This was achieved through the design and construction of a rope-testing machine in accordance with guidelines set by the Cordage Institute. He is currently employed with the Center as a Research Project Engineer. As a research project engineer, Glenn is involved with the design, construction, and operation of the Acoustic Calibration Facility (ACF) at the Chase Ocean Engineering Laboratory, a calibration facility for underwater transducers and sonar systems. His work involves the integration of hardware and software, experimental design, and the acquisition and processing of acoustic data for internal and external personnel.

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 BSc in the Dept. of Ocean Studies at Maine Maritime. He is finishing his Masters degree in Marine Geology from the University of North Carolina. At UNH, Andy is responsible for maintenance and upgrading of the major laboratory facilities including the test tanks, small boat operations, local network administration and assistance with some courses.

Nathan Paquin joined the Center in 2004 taking responsibility for the daily maintenance and upkeep of our ever-growing computer facilities. Nathan comes from a strong background in computing initially gained while serving in the U.S. Army and being responsible for providing secure servers and clients. This experience was expanded through work in the industrial sector for numerous small and large IT companies.

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 Ineterferometric 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 master's in computer science at UNH in 2004. She is now employed at CCOM full-time with two major responsibilities. The first one is in the Data Visualization Research Lab where she is currently working on human factors research and the Chart of the Future. Her second responsibility is being the CCOM outreach coordinator. In this capacity she is in charge of informing the public of the work going on here at CCOM-JHC. This is done through the design and maintenance of the website, adding an outreach section to the web-site (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**.

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 a new 10,000 square foot addition is currently under construction.

Our computing facilities continue to grow and evolve in order to keep up with our expanding research needs. Center servers are currently in a state of migration with respect to roles and software upgrades. All Linux server operating systems were upgraded from Red Hat 9 to Red Hat Enterprise 4 for security and compatibility reasons, but after additional testing, it was decided that the final operating system would be CentOS Linux, which is identical to Red Hat Enterprise Linux, but freely distributed. All remaining Microsoft Windows 2000 servers were upgraded to Microsoft Windows Server 2003. Our remaining SGI/IRIX server has been decommissioned and replaced with a CentOS server, running on Dell/PC hardware, negating SGI excessive annual maintenance costs.

With new students and staff arriving each semester, the Center continues to grow at an accelerated rate. In the past year the CCOM IT team has completed deploying CCOM's Intranet website. This consists of an online knowledge base and consolidated wiki to encourage collaboration and increase documentation within the Center. In addition, the Intranet also provides web mapping, web mail, web calendar, and a purchase authorization tracking system for CCOM users. Due to compatibility and usability issues, FTP services have been retired in favor of a more secure, easier to use, web-based file transfer application. In order to monitor all of CCOM's servers, we have deployed Microsoft Operations Management Server (MOM). This has allowed us to monitor server and application services 24/7/365. MOM is configured to alert us in the event that servers or services become unavailable. We have completely migrated away from our Linux-based firewall solution to a Windows-based Microsoft Internet Security and Acceleration Server (ISA). ISA has built-in VPN capabilities as a standard feature, and increases network visibility, as it integrates with the Center's Windows Active Directory

infrastructure. This allows one to monitor such things as bandwidth usage, port usage, and desktop application usage across the entire network. For increased speeds on our backup system, we have migrated all direct attached storage (DAS) to our network attached storage (NAS) head server. The DAS storage now benefits from the newer LTO-3 backup array, while freeing up resources on our older SDLT backup array for client workstation backup. This has significantly increased efficiency while reducing the amount of time needed to administer the Center's nightly backups.

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. It provides higher throughput than conventional disk drives, decreasing processing time of research projects and has given CCOM the ability to concentrate all research data in a single location. In addition, CCOM has **12TB** of Legacy DAS which is in the process of being phased out and its data migrated to the SAN. Currently, this process is about 75% complete. Plans are in place to reuse the DAS storage for less critical projects. Ultimately, the Network Appliance FAS960c can be upgraded to house over **300TB** of raw storage.

At the heart of CCOM's infrastructure lies our robust networking equipment. This consists of one Foundry BigIron RX-8 enterprise-level switch, six 3Com 4924 24-port Gigabit Ethernet switches and two enterprise-level Cisco wireless access points. The RX-8 is currently handing the bulk of CCOM's network traffic, and has recently 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, the Geowall, and research vessels. The two Cisco wireless access points are in place to provide wireless Internet connectivity for employees and visitors. The CCOM data/server center is equipped with a FE-227 fire suppression system and dual, redundant air conditioning systems in case of failure. The data center has the physical and power capability to house up to seven full height cabinets.

All CCOM servers are consolidated into four full height cabinets with one Uninterruptible Power Supply (UPS) per cabinet. Currently, there are a total of 17 servers and 5 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 firewall. One of the large projects currently in progress at the Center is the NOAA/Fishpac project, which, due to its compute-intensive needs, requires its own dedicated server with 28TB of DAS, and a cabinet with an uninterruptible power supply. This brings the total number of cabinets in our server room to four. CCOM also currently hosts three dedicated servers for field-related projects (nowCOAST.unh.edu and OpenECDIS.org).

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. CCOM's

computer classroom is populated with ten 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 138 high-end Windows XP and Linux desktops/laptops, as well as several Macintosh G4/G5 computers and one SGI O2 workstation. CCOM continues to operate within a Windows 2003 Active Directory domain environment. It has allowed us to deploy policies to Active Directory objects, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of CCOM to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, CCOM has also upgraded all NOAA laptops with Safeboot encryption software in accordance with OCS standards. This provides the NOAA-based employees located at CCOM 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 fireproof safe, while archived datasets are sent offsite to an Iron Mountain data protection facility where they are stored in an environmentally controlled vault We have a full suite of commercial software packages for both data processing and presentation. In addition, we are developing a great deal of in-house software. For this software development, a cooperative code development environment is in place (Subversion), which allows concurrent development on different platforms with multiple users. A full suite of peripherals (4mm, 8mm, DLT, LTO, CD-R and DVD±R) are available so that we can re-distribute the data on a range of media.

We have a full suite of printers and plotters including both 48 and 60 inch large format color plotters. We have the ability to scan documents and charts up to 54 inches using our wide format, continuous feed, and 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.

We also have built a “Geowall II” a large-format tiled (4 x 3) display consisting of 12 high-resolution Apple monitors. This display has an aggregate resolution of 10240 x 4800 pixels and can easily display images of that size (Figure 1.).

Figure 1. Global circulation model displayed on CCOM/JHC Geowall II

The Center also operates and maintains a "Telepresence Console" that allows high-bandwidth, three high-definition video streams, 16 audio channels, and other data to be transmitted from sea to the lab in real-time (Fig. 2). The Telepresence Console was initially installed for the 2005 NOAA Lost City Expedition. It was used in 2006 for an expedition in the Aegian Sea and in 2007 for work in the Flower Gardens National Marine Sanctuary and in the Black Sea. These projects have been carried out in conjunction with NOAA's Office of Ocean Exploration, The Mystic Aquarium, The University of Rhode Island, and other universities. The master 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 streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints. All equipment is connected to two Powerware uninterruptible power supplies (UPS) to protect against power surges and outages.

Figure 2. "The Telepresence Consol"

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 2007 they operated for eight months (April through November) and have been hauled for maintenance and storage during the hard winter months. 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).

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 two vessels have been moored near Great Bay, at the Jackson Estuarine Lab, approximately one hour (for *Coastal Surveyor*, less for *Cocheco*) from the most common surveying grounds at the entrance to the Portsmouth Harbor. Next year, with the completion of the University/NOAA pier in Newcastle, the vessels will have floating dock berths year-round. Thus, the winter haul-out and the time constraints that it imposes will no longer be an issue. The Center employs a permanent captain and hires hourly help for crew.

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)*

Figure 3. R/V Coastal Surveyor with bow ram

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.

However, the *Coastal Surveyor* is starting to show her age. While the hull remains solid and seaworthy, 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.

The repair and upgrade list for this winter include: autopilot pump replacement, survey instrument communications rewiring, repairs to the fresh water pressure system and head.

R/V COCHECO

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

Figure 4. R/V Cocheco

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. She is still being "broken in". There are items that have yet to be installed for her to be fully functional; the most important of these is the hydraulic winch. She has, however, been very useful as a transport vessel and as a platform for hand-deployed instruments. In the summer of 2007, she was rigged for an over-the-side single beam sonar for use in the CCOM/JHC Summer Hydrography Class.

The only repairs that Cocheco requires are: the autopilot flux gate compass and rudder position sensor, and the air powered signal whistle. This winter (2007-2008), Cocheco is having her hydraulic system installed as well as a UPS-power system wired, 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. She also has already had storage cabinets built for the surveyor's "lab" cabin.

EDUCATIONAL PROGRAM

The Center, under the guidance of Capt. Armstrong, has developed an ocean-mapping-specific curriculum that has been approved by the University. 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 cooperation of the UNH Graduate School and the Foreign Students Office) seven students were selected, admitted, received visas and began their studies. This first class (7) graduated (receiving a "Certificate in Ocean Mapping") in 2005, the second class (5) in 2006, and the third class (6) in 2007. The Nippon Foundation extended the program into 2008 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).

Finally and most importantly, our program was given a Category A certification by the *FIG/IHO International Advisory Board of Standard of Competence for Hydrographic Surveyors* at their annual meeting in May 2001.

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. This past year, 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.

JHC – ORIGINATED COURSES

Course	Instructors
Introduction to Ocean Mapping	Armstrong, de Moustier, Mayer
Ocean Bathymetry	Monahan
Ocean Mapping Tools	Monahan, Gardner, Kraft, and others
Hydrographic Field Course	Armstrong
Marine Geology and Geophysics	Mayer and Gardner
Environmental Acoustics (I & II)	de Moustier, Baldwin
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.
Seminars in Ocean Mapping	All

We have 24 students currently enrolled in the Ocean Mapping program, including the six GEBCO students, one NOAA Corps officer and a NOAA physical scientist and a NOAA surveyor; 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 five more Master's students and one Certificate student (including a NOAA physical scientist and a NOAA surveyor).

Student	Program	Advisor
Roland Arsenault	Ph.D. OE/PT	Undetermined
Robert Bogucki	Ph.D. OE	Ware/Mayer
Daniel Brogan	Ph.D. EE	de Moustier
Chuck Carlise	MS EE	de Moustier
James Case	Ph.D. OE/PT	Undetermined
Janet Felzenberg	MS ESci	Ward/Mayer/Gardner
Nick Forfinski	MS OE *(RECV12/07)*	Armstrong
Bert Franzheim	MS EE	de Moustier
Jim Glynn	MS EE *(RECV 10/07)*	de Moustier/Huff
Fan Gu	MS EE	Rzhanov

Brian Heap	Cert/MS ESci *(RECV 12/07*)	Alexander
Tianhang Hou	Ph.D. OE (PT)	Huff
Mashkoor Malik	Ph.D. ESci	Mayer, Calder
Peter Mitchell	MS CS *(RECV 12/07)*	Ware
Lynn Morgan	MS ESci *(RECV 12/07*)	Armstrong
Mark Moser	MS OE	Armstrong
Brian O'Donnell	MS EE	de Moustier
Daniel Pineo	Ph.D. CS	Ware
Luis Ruis	MS ESci *(RECV 12/07)*	Mayer/Fonseca
Stephan Schaeffer	MS CS *(RECV 12/07*)	Ware
Val Schmidt	MS OE	Weber/Mayer
Ed Sweeney	MS ESci	Gardner, Johnson
Nathan Wardwell	MS ESci	Gardner/Mayer
Michelle Weirathmueller	MS OE	Weber/Mayer
Monica Wolfson	Ph.D. ESci	Mayer/Pe'eri

GEBCO Students: (2007-2008)

Student	**Institution**	**Country**
Daniela Goncalves	Univ. of Aveiro	Portugal
Koji Ito	Coast Guard	Japan
Pryantha Jinadasa	NARA	Sri Lanka
Neil Tinmouth	Univ. of KwaZulu	South Africa
Mohammad Jashim Uddin	Bangladesh Navy	Bangladesh
Rochelle Wigley	Council for Geoscience	South Africa

STATUS OF RESEARCH: JANUARY - DECEMBER 2007

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 (funded in part by NSF), now one of the best of its kind in New England. The facility is now equipped with a rigid x, y positioning system, computer controlled transducer rotor (with resolution of 0.025 degree) and custom built data acquisition system. Barbara Kraft and Glenn McGillicuddy have reworked the software used for calibration. 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. Glenn is also working on the design of a new underwater pitch and roll stepper motor which will add new degrees of freedom to our calibration capability.

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

- **Imagenix Delta T** The Imagenix Delta-T a new compact, low-power multibeam sonar that has been designed specifically for AUV deployment. The Delta-T is specified to form 120, 3 degree beams over a swath width of 120 degrees. Barbara Kraft and Glenn McGillicuddy performed calibration tests on the Imagenex DeltaT multibeam sonar at the UNH Acoustic Calibration Facility in order to verify the operational frequency, the transmit and receive beam patterns, the transmit pulse width and the source level at a range of system settings. Our hope was to integrate the Delta-T with the FETCH/DOERRI AUV (see discussion later in report) to explore the feasibility of collecting hydrographic quality bathymetric data and seafloor

characterization data from an AUV. Calibrations of the Delta-T verified its operational frequency (260 kHz). Imagenex specifies the beam width to be 120° by 3° on both transmit and receive; however, the 3 dB beam width was measured to be approximately 90° while a beam width of 120° corresponded to 6 dB. The transmit beam pattern was measured repeatedly with an NUWC USRD E27 hydrophone to ensure that the it was aligned correctly with the DeltaT transmit transducer and any pitch and roll offsets due to the mounting hardware were resolved. The transmit beam pattern remained unchanged. To determine the receive element spacing and phase offsets, DeltaT native 837 files were recorded while a calibrated pulse was transmitted by the E27 hydrophone and received by the DeltaT in one degree increments while rotating the DeltaT from ±45°. DeltaT 837 files were also recorded for each setting of receive gain (1 dB steps from 0 to 20 dB) and display gain (20% increments from 0 to 100 %). All tests were repeated following repairs and upgrades to the DeltaT and the angular range of the receive tests was extended to ±80°. MatLab scripts were created to read the 837 files and process the raw receive element data for phase difference as a function of rotation angle as well as to simulate the quadrature sampling with digital mixing processes that may be applied by Imagenex during the DeltaT processing. Matlab code was also created (based on code from Christian de Moustier) to perform split aperture beam forming using two and three subarrays.

- **ISSAP Probes** — Kraft and McGillicuddy completed impedance measurements on the 40 and 65 kHz ISSAP probes. These probes are used in the ONR-sponsored In-Situ Sound Speed and Attenuation Probe, a device lowered to the seafloor to make in-situ measurements of seafloor acoustic properties.

- **Env. Acous. Lab** — Impedance measurements were made on five SensComp 40LT10 transmitters and twenty-five 40LTR10 receivers in support of the Environmental Acoustics Course lab exercises.

- **EM3002/7125** — Calder and Malik used the Acoustic Calibration Facility to calibrate the performance of two new Multibeam systems (the Kongsberg EM3002 and the Reson 8125) in order to better understand the long-term instrumental stability so as to help establish base-line uncertainty measurements for

these systems. Included in these calibrations were measurements of transmit and receive beam patterns as well as long-term variance in performance at a range of instrumental settings.

BATHYMETRY FROM THE KLEIN 5410

With the successful completion of his Master's thesis, Jim Glynn, working with Christian de Moustier and Lloyd Huff has demonstrated that when sufficient care is applied to calibrating the Klein 5410 Sidescan sonar system, and with phasor averaging over three baselines, it is possible to obtain hydrographic-survey-grade bathymetry over swaths 150 m wide in 20 m of water depth or less. As a result of this work, Klein has re-wired the sonar arrays to access elements with a wider separation for more accurate phase measurements. The phasors are now obtained with elements spaced at 2.5, 4, and 6 wavelengths apart as compared to the earlier separation of 1.5, 2.5, and 4 wavelengths. The Matlab code developed by Glynn has been converted to C/C++ by Brian Locke so that it can be implemented in real-time. Additionally, the code has been modified to accommodate the new element spacing and make some corrections to the processing chain. A more reliable method of determining the actual element spacing has been devised, tested and implemented. This code; as well as suggested modifications to the array, were tested at sea on three separate cruises, two of these in direct collaboration with NOAA's Office of Coast Survey.

Brian Locke also designed and implemented modifications to the Generic Sensor Format (GSF) format to allow it to handle data from bathymetric sidescan sonars like the Klein 5410 (with separate port and starboard returns). The proposed changes have been submitted to SAIC who maintain the GSF format specifications and should be incorporated into the GSF specification in its next release.

In August, the 5410 with its rewired elements was used to collect data at the entrance to Portsmouth Harbor, NH in support of the thesis work of NOAA Corp officer Marc Moser on the *R/V Coastal Surveyor* under the supervision of Christian de Moustier and Lloyd Huff. For this cruise a "sled-bracket" was designed for the 5410. This sled-bracket has been requested for use on board both of the NOAA vessel *Rude* and *Bay Hydrographer*. The data collected on this cruise suffered from strong refraction-induced caustics, questionable CTD data, dynamic environmental conditions, and an inadequate PC for running the sonar and logging data (many survey lines suffered various instances of data loss because the PC could not keep up) and are still being evaluated.

In September, Jim Glynn and representatives from NOAA's Office of Coast Survey used the newly modified 5410 to resurvey the area south of Seavey Island in Portsmouth Harbor, New Hampshire.

Finally, in October, Jim Glynn and Brian Locke joined the NOAA ship *Rude* in Norfolk, VA to help the shipboard party setup the Klein 5410 and run a survey on the vessel's pole mount modified to accept the UNH "sled-bracket." This was a test of the first release of

the C/C++ code, as well as a test of timing synchronization involving a timeserver and an IRIG-B time card in the sonar's topside unit. Further modifications to Brian's code have been made since this trip to make it more robust under various field conditions.

Based on this work, both Klein and NOAA's Office of Coast Survey have expressed an interest in finding a means of providing OCS with reliable instrumentation for a phase measuring bathymetric Sidescan. A meeting was held at Klein in Salem, NH to discuss possible avenues to go forward on this idea. It is not clear at this time the extent to which Klein is committed to such a system; however, eventually Klein did agree to re-vamp an existing Klein 5000 owned by OCS into a 5410. Consultations were provided to OCS during their negotiations with Klein that ultimately led to the re-vamping.

MULTIBEAM SONAR ON KLEIN 7180

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 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. The modeling/simulation technique was the subject of an abstract submitted to OCEANS'07.

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 amongst 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 (i.e., 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).

The value of this new timing synchronization approach was demonstrated this year when, under the supervision of lab manager, Andy McLeod, it was used to synchronize position, velocity and strain sensor data during tow-tank experiments that took place over a five week period. Over this period the timing synchronization between the motion controller and the data acquisition computer had an RMS error of approximately 620 microseconds over a wireless link.

Also in 2007, Calder demonstrated the value of this approach to NOAA through the integration and support of the SWGM software with a Reson 7-P Operating System, creating an experimental high-precision timing Reson 7125 Multibeam sonar system deployed on NOAA hardware. This system was demonstrated on the NOAA ship *Bay Hydrographer* in April 2007, confirming the performance in the field and providing the ability to measure latencies in other timing schemes.

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 four 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, 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. In particular, work is underway with GeoAcoustics to extend the principles of CUBE to phase comparison bathymetric sonars and to improve the uncertainty propagation equation for very shallow water and ultra-high resolution sonars. NOAA's use of CUBE has been supported through the development of a series of CUBE-related definitions for the NOAA Field Procedures Manual, and Specifications and Deliverables documents, and the development (with Dave Wells) of a "User Guide" for CUBE.

Inherent in the CUBE approach is the need for a robust error model for the sonar being used. This model should be provided by the manufacturer but unfortunately only a few manufacturers publish an error model for their system. In an attempt to develop approaches to extracting an error model from undocumented sonar as well as checking the manufacturer-provided models, Calder and graduate student Mashkoor Malik have been exploring field calibration methods for extracting error models directly from data. This approach has been applied to an EM3002 with POS/MV and the commercial navigation aid C-Nav., both appear to give realistic uncertainties, but further work is required. Within this context, Calder has also developed an "Uncertainty Patch Test" proposal – a methodology for capturing the data required to determine the uncertainties associated with a particular survey system. The proposal consists of a series of survey lines, much like a patch test, designed to isolate (as much as is possible) one component of uncertainty for each line or line-pair.

This year, Calder and Malik have used the acoustic test tank to capture data from the Reson 7125/400 kHz and the EM3002 sonars to confirm/extend the estimates of device-specific uncertainty for these systems and have continued the development of motion-related uncertainty models using time-series decomposition of the on-line measured motion series. Adding to the calibrations of various components of the overall uncertainty budget, Calder has also investigated the performance of the Fugro OmniStar HP/XP GPS positioning correctors and their likely uncertainty as a positioning source. This work has confirmed their advertised static position accuracy (0.03 – 0.04m rms horizontally and 0.04 – 0.05m rms vertically), although a number of problems were observed at higher output rates (5-10 kHz), including bad positions and bad NMEA messages. These problems have been reported to Fugro for further investigation.

Through our close collaboration (and shared field efforts) with NOAA hydrographers, it has become clear that many of the sonar systems (and particularly the Reson systems) used by NOAA survey vessels suffer from a problem when operated in steeply sloping environments due to limitations in the bottom detection algorithm's ability to deal with low signal to noise ratio situations. Calder has made a concerted effort to address this "Downhill Problem" resulting in several component algorithms that have helped mitigate the problem including a Turning Angles algorithm to utilize phase information in beam-to-beam offset vectors (with the ability to run with either GSF or HDCS data). An adaptive fusion system has also been developed to combine the component algorithms' results in order to improve the overall performance of the approach. The fusion algorithm is configured to automatically tune the weighting given to each of the component algorithms in real-time, and then combine them to give a probabilistic estimate of the best solution. In addition to the algorithmic approach to this problem an experiment was developed to determine the consistency of human operator performance on data affected by the downhill problem (so that the performance of the algorithm could be determined). Testing of these approaches on field data has shown that the fused solution is stronger and more robust than the individual component algorithm solutions. The University's Office of Intellectual Property Management has deemed the fusion algorithm (now called MASC'D-Multi-Algorithm Swath Consistency Detector) patentable and has filed an invention disclosure for it. The MASC'D has been packaged

and released to SAIC for implementation in their software and a paper submitted to IHR for publication. This past year Calder has been working with NOAA graduate student Lynn Morgan to re-define CUBE's uncertainty propagation error equation using a more rational analysis of probable propagation distances in order to provide more stable uncertainty estimates in difficult conditions like steep slopes.

THE NAVIGATION SURFACE AND BAG'S

Another aspect of the data processing-related research being conducted at the Center involves rethinking of the final output products of a hydrographic survey. We strongly believe that the standard chart product of selected soundings and contours does not at all do justice to the information content of high-resolution multibeam and sidescan sonar data. We are working on a series of new products that will better serve the mariner as well as many other constituencies. In this context, Lt. Shep Smith developed the concept of the "Navigation Surface" as part of his thesis work. The Navigation Surface is a database that maintains bathymetric data sets at full resolution and a rule base for producing a series of derived products. Thus a single database can be the source for hydrographic (safety of navigation) products as well as products for fisheries habitat or other studies that require full-resolution data. CUBE-processed data can be a component of the Navigation Surface and thus the verification exercise described above also involved the navigation surface and tested (positively) the veracity of the navigation surface as a source of hydrographic products. The combination of CUBE and the Navigation Surface set the stage for a new research effort, "The Chart of the Future" described later.

In support of the new adoption of CUBE and the Navigation Surface into NOAA and NAVO processing protocols, the Center has organized and hosted two workshops with industry, government and academic researchers to define and maintain an open format for Navigation Surface products that will ensure interoperability amongst the various vendors and agencies. The first workshop (in 2004) defined the specifications for the Bathymetric Attributed Grid (BAG) Object, and obtained the commitment of many of those attending (NOAA, NAVO, CARIS, IVS, SAIC, 7C's) to provide source code and adopt the approach. Cross platform libraries for digital signatures have been built and tested and an example certificate construction and management scheme (based on HASP network dongles) has been implemented. In 2005, a DLL version of the Open Navigation Surface (ONS) library was created along with a Visual Basic support application to allow demonstration of the security principles of the ONS project in a graphical context. A second meeting of the Open Navigation Surface Working Group (ONSWG) took place in July 2005 resulting in a build-out of the source tree for the BAG and the linking of stand-alone applications to read and write BAG-format files. In addition this meeting adopted the digital signature system for BAG's (which supports simple XML files) using both private and public keys, with encryption and thus avoiding the need for hardware tokens. The BAG library was demonstrated at the Shallow Survey 2005 Conference in Plymouth, England with trial integrations into IVS Fledermaus, CARIS HIPS, and SAIC SABER software packages. ESRI has now expressed interest in integrating the BAG format into their software (and becoming a member of our Industrial Consortium) and NOAA OCS

has recommended the BAG as the transmission form of data from OCS to NGDC. A website for the ONSWG has been established: http://www.opennavsurf.org.

The Center, under the direction of Calder, has taken the lead in the ONS development, providing code development, documentation and a File Specification Document for the ONS project. Calder has chaired several ONS working group meetings to generate the code-base for a beta-test Candidate Release (CR) and Full Release (FR), established SubVersion software management environment, and updated a project website to support this. The CR/FR process was completed with full source-code being released to the web-site on 14 April 2006 and the initial version 1.0.1 on 2 May 2006. Calder presented work on ONS to the IHO Technical Standards Maintenance and Development (TSMAD) working group; the BAG has been proposed for adoption as part of the IHO S-100 suite of standards for hydrographic products (i.e., the successor to S-57). Calder continues to work with David Parker of the UKHO on the development of the IHO S100 Hydrographic Data Product Standard (HDPS) and on the definition of an initial metadata strawman to be used for the upcoming UKHO bathymetric database and the S100 HDPS.

As a focal point for the broad interest in CUBE and the Navigation Surface amongst government agencies and the private sector, the Center is fulfilling one of its prime mandates of serving as a national center of focus for ocean mapping activities. In bringing these groups together we facilitate efficient and collaborative research efforts aimed at solving a national need.

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 “pretty” 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, i.e. to normalize the backscatter at 45 degrees, (sometimes adding a Lambertian correction). The approach used by GeoCoder calculates the beam pattern as the residual to the modeled angular response of the ensonified seafloor 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 2007 include approaches to better filtering of the Sidescan sonar data collected from towed vehicles. The navigation of towed sonars is normally noisy and not reliable; causing artifacts when the data is georeferenced into a mosaic. Improvements were made to the filtering and correction of navigation files. For that, the navigation is decimated and interpolated with splines, creating an optimal smooth navigation path. The interpolated path can then be used for a better estimation of the "course made good," which is the best option in the absence of reliable measurements of the tow-body heading. A bottom-detection feature has also been added that can extract an estimated tow-body height, so that proper slant-range corrections can still be made when vehicle altitude information is not provided with the data (as is often the case with towed Sidescan sonar systems). Slant range corrections can now also be done using an external bathymetric model, obviating the need to make a flat-seafloor assumption. Finally, several new approaches for removing the angular dependence of backscatter from the mosaic have been implemented (theme based, patch based, sediment type based) as well as correctors designed specifically for correcting nadir irregularities that have been identified in Kongsberg-Simrad low-frequency (12 and 30 kHz) data.

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. A recent 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. Several new systems and formats (Reson 7K, Simrad 2100, EA600, Benthos C3D and Hypack HSX) were added to the support list this year. 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.

This past year Triton, Reson, Hypack, Fugro and CARIS all negotiated licenses for Geocoder, bringing the total list of licensees to:

- IVS
- Caris
- Reson
- Fugro
- Triton
- Hypack
- 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
- Geol 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

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.

FISHPAC LRSS SONAR

In August 2006, Huff and others participated on a cruise in the eastern Bering Sea on the NOAA ship *Fairweather* and collected acoustic backscatter data at 38 kHz, 40 kHz, 100 kHz, 180 kHz and 455 kHz which were loaded into a new FISHPAC server at the Center in order to provide the basis of numerous studies leading to an improved understanding of acoustic backscatter. A paper was prepared describing the backscatter characteristics of a patch of gastropods that were encountered on one of the eastern Bering Sea survey lines. The preparation of this research paper provided an opportunity to push the applications of GeoCoder. Although sufficient metadata did not exist to determine the actual angular backscatter characteristics of the gastropod patch, it was possible to demonstrate the frequency dependent change in angular backscatter characteristics of the patch, compared to a close by area without the presence of gastropod shells.

The eastern Bering Sea backscatter at 455 kHz was obtained with the Klein 5410 sidescan sonar. The backscatter at 45 deg grazing angle were extracted from the data set and subjected to analyses. The first analysis was the mean backscatter value at 20 sites where NMFS has a 15-18 year record of fish catch. The backscatter generally increased as the sites moved from the SW to NE end of the survey track lines. The second analysis was to conduct spatial spectral estimates. This is an important piece of the puzzle of what spatial resolution of acoustic data are best suited for mapping fish habitat in the eastern Bering Sea. The backscatter generally followed a power law with decreasing energy at smaller spatial scales. However, there appeared to be two break points where the slope of the spectra changed. The preliminary conclusion is that there are two spatial scales that may be important to sample. One is at 50 m and the other is at 250 m.

The backscatter at 38 kHz was processed toward the end of performing spatial spectral estimates. Since the backscatter at the two (38 and 455 kHz) different frequencies are dominated by quite different mechanisms it was thought that such comparisons may be very helpful in developing a strategy to establish a priority plan for analyses of the backscatter observed at 40, 100 and 180 kHz. The analysis of the 38 kHz data led to two important conclusions about the system that was used to collect the data. The first conclusion was the determination that 80 percent of the 38 kHz data were saturated and therefore of no use, even for relative changes in received backscatter levels. The saturation problem was tracked to a coupling between the fixed and time varying gain of the 38 kHz channel and the fixed and time varying gain for the sidescan sonar. When the sonar operator changed the gain to enhance the sidescan imagery, the backscatter data from the vertically looking single beam 38 KHz were driven into saturation. The second finding from the analysis of the 38 kHz data was that the channel was excessively noisy and that the I's & Q's did not have a zero mean. Investigations into the non-zero means led to the "undocumented" fact that the 14-bit A/D samples had been cast into the upper 14 positions of a 16-bit word, while the lower two bits were used as system status bits. The root cause of the excessive noise was traced to a design flaw in the system, whereby the backscatter signals were attenuated then passed through unshielded connectors; as opposed to being attenuated after having passed through unshielded connectors, which would have attenuated any electrical noise that was picked up in the unshielded connectors.

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. The visualization team (Arsenault, Bogucki, Plumlee, Sullivan, Pineo and Schwehr) under the supervision of Lab Director Colin Ware has developed a novel and innovative 3-D visualization environment, GeoZui-3D. GeoZui-3D is a highly interactive 3-D visualization system designed to support a number of different research projects and ocean mapping applications. GeoZui3D was described in detail in previous progress reports. In 2005, GeoZui3D evolved to incorporate time-varying data opening

up a world of new visualization possibilities evolving into what we now call GeoZui-4D. The GeoZui software has been made available to the public and more than 40 groups have downloaded the software.

This past year many important enhancements have been made to GeoZui-4D including:

- The package has been streamlined building on Linux and Windows using SCons.
- Release packages can now be assembled using SCons.
- Enhanced target object have been developed (Arsenault, Calder and Locke) for midwater targets that allow the automatic construction of smoothed point normals from multibeam sonar data. This allows point data to be correctly shaded and for the appropriate design of automatically oriented facets to provide "virtual hull" effects. This approach proved to be very valuable in a repeat survey that documented the degradation of wrecks of the WWI German fleet at Scapa Flow.
- Added support for visualizing acoustically tracked fish or other targets.
- Added for real-time AUV visualization enhancements in support of work with the FETCH/DOERRI AUV.
- File associations: .gzx files can now be associated with GeoZui-4D. This allows GeoZui-4D to launch and load a .gzx file by activating it in a file browser.
- A library has been developed and integrated (libgz4d). GeoZui-4D now uses functionality from libgz4d. This helps eliminate redundancy in code.
- Time referenced ogg file support. Allows compressed sound files to load and play at desired time without an external .gzx file. This is done by embedding the .gzx file in the .ogg file.
- Added capability to visualize mid-water target data (EM3002 and 7125) from real-time sources using network sockets.
- SRTM plus support.
- Added support for visualization clusters (e.g. GeoWall II).
- Added support for Nintendo Wii remote an input device under Linux.
- Added capability to visualize beam pattern of modeled acoustic arrays.
- Support dynamic display of photographs (scaling, priority, etc.).

As mentioned above a new, in-house library (libgz4D) has been developed to allow much greater functionality and flexibility in the further development of GeoZui-4D and other visualization applications. At present libgz4D have the following characteristics**:**

- Incorporates modified GLUT with spaceball support under Windows.
- Uses common SCons based cross platform build system.
- Supports a subset of X3D.
- Supports Wiimote devices
- Includes Swig wrappers which enable Python access to libgz4d.
- Uses gz4d namespace and includes directory subdirectory to help prevent name clashes.
- Includes Doxygen source code documentation.
- Designed to integrate with various frameworks and scene graphs.
- Grib data reader (Grib version 1).
- Offscreen rendering support.

- Option to build as static or shared library.
- Movie recording capabilities.
- Supports socket classes.
- Supports sound recording and playback devices.
- Fourier transform support.
- Threads support.
- Modeling of acoustic response of elements and array of elements.
- Distortion grids that allow display of warped, time changing images.
- Initial support for interfacing with Simrad ME70 multibeam sonar.

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.

AUV Mission Planning and Control and Simulation (Arsenault and Bogucki)

Whereas much of our past visualization efforts have been focused on the 3-D interactive display of static features like the seafloor, with the evolution to GeoZui-4D we have been able to add dynamic, time-varying systems. As part of this effort, and in support of our long-term goal of evaluating the potential of Automous Underwater Vehicles for the collection of hydrographic and seafloor characterization data, the visualization group has been developing 3-D tools for the planning, monitoring and review of AUV missions. In the past year much of this work focused on our close collaboration with Dr. Art Trembanis at the University of Delaware and his FETCH 3 AUV (called DOERRI). With our initial access to the DOERRI AUV we quickly learned that it suffered from serious problems with its control and operation software (e.g. it had difficulty flying a straight path, maintaining constant depth, etc.). To address these issues graduate student Robert Bogucki and Roland Arsenault worked in collaboration with University of Delaware and the AUV manufacturer (PRISM) to build new control software as well as a simulator to test their developments. As part of this effort Arsenault implemented a navigation module for DOERRI that reads serial sensors (GPS, DVL, Attitude, etc.) and provides integrated navigation fixes to AUV control modules and sensors. Real-time visualization tools were developed using GeoZui-4D for tracking DOERRI on the surface as well as for providing submerged navigation from a Linkquest Tracklink system (Figure 5.).

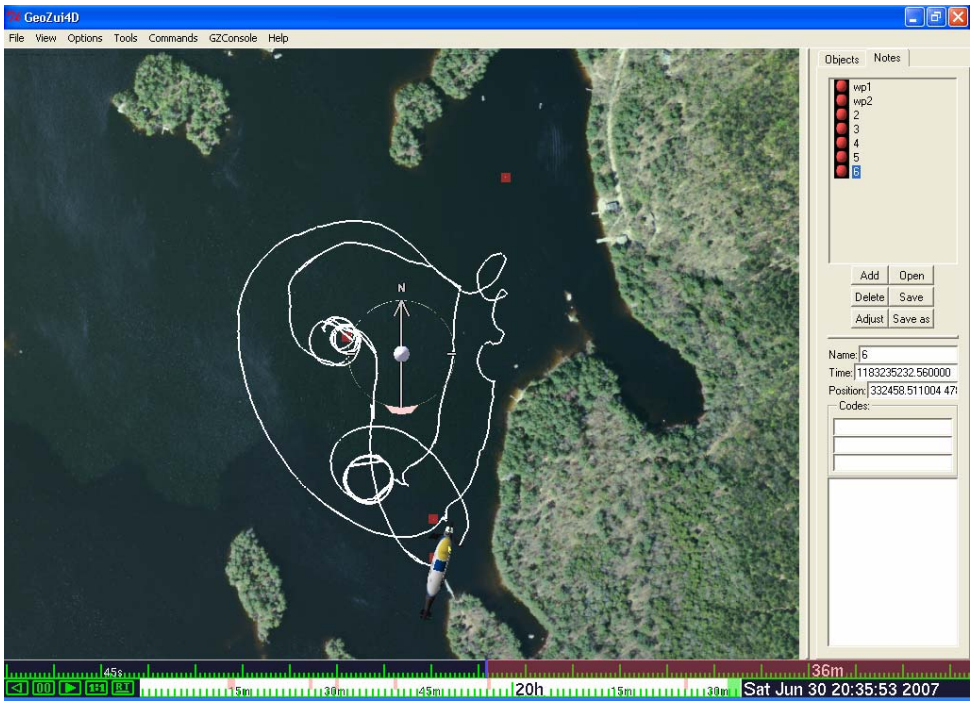

Figure 5. Example of real-time display of AUV navigation in GeoZui-4D

As the DOERRI vehicle was being tested it quickly became clear that it has severe problems with its control software. Addressing these issues, Bogucki developed and tested new C++ and LabView code and modified the existing software and operating system configuration. The vehicle was reconfigured to allow for a multiple codebase branch development with an independent operating system configuration used for each individual branch using a 'multi-boot' partition setup. The DOERRI LabView-based software was restructured for greater modularity, testability and understandability. Given the limited access to the vehicle as well as the danger of testing new control software on an AUV that is out of visible or communication range, a simulation module was developed based on a third party visualization library. This allowed for initial testing of the AUV's control code separately from the vehicle's hardware, using a simple kinematic model of the vehicle.

The approach fixed problems with the vehicle's actuator control thus improving the AUV's responsiveness to operator or control system originated commands. Joystick control of rudder, elevators and throttle were implemented and code was modified to streamline communications with a topside computer. These improvements translated to safer launch/recovery in real deployment conditions. Additionally data logging subroutines were developed for individual onboard instruments and modules created for new AUV behaviors such as multi-stage descent, waypoint seeking, station keeping and surface autopilot.

Software was also developed to better control the AUV while on the surface by providing visualization and telemetry to the AUV pilot. This visualization was integrated into a wireless AUV pilot setup based on a head mounted display and an ultra-portable computer. These software developments and implementations have been tested in a

number of environments including the Center's test tank, Mendums Pond, NH; Pepper Creek, DE, and the mouth of Delaware Bay at Lewes, DE. A deep-sea deployment of the vehicle took place in the Black Sea, Ukraine as part of Byzantium 2007 underwater archaeological expedition in conjunction with Bob Ballard, Dwight Coleman, National Geographic and the NOAA Office of Ocean Exploration. Unfortunately the vehicle catastrophically failed during this expedition. This will be discussed later on in the report.

A particularly useful result of our AUV efforts has been the development of the AUV simulator toolkit which allows the testing of software changes on the behavior of the vehicle without risk to the AUV. This code has now been ported to Python, while integrating the visualization with a third-party physics engine library. Within the new framework, the vehicle's mass distribution and geometrical extents can be approximated with a collection of geometrical primitives - independently of the more complex 3D meshes used to present the vehicle to the user visually. The simulated AUV can be placed in a virtual environment alongside fish models and arbitrary bathymetry. Vehicles, fish and other objects can be assigned masses and moments of inertia, and subjected to the influence of specified forces and torques. Newtonian physics solutions and collision detection are provided by the physics engine, allowing for a more realistic specification of the simulated vehicle's behavior. The physics based approach is much more flexible and vehicle-agnostic, potentially allowing us to use the toolkit for vehicles with diametrically different propulsion and actuation schemes as long as some information about the physical forcing is available.

Deformable geometry objects have also been implemented in the simulator, with the purpose of modeling configurations of marine organisms with dynamically changing spatial extents (Figure 6.). The position of vertices specifying the geometry is tied to node objects with “physical” properties, allowing for their repositioning through user interactions (utilizing ray-casting techniques for picking objects and applying forces to them) or algorithmically (custom callback functions for position or force/torque application). The toolkit can generate a real-time simulated output of a simple single-beam echosounder based on the scene geometry and the vehicle's position and orientation relative to other objects in the environment. A virtual AUV-mounted camera provides imagery of the fish school as “seen” by the vehicle. User interaction with the simulation in real-time is now supported through mouse-picking and support for 3DConnexion Space Navigator six degree of freedom input device simultaneously.

Figure 6. AUV Simulator with seafloor and physics-based fish

The above innovations will ultimately allow for developing a suite of simulated AUV instruments of greater sophistication-incorporating more realistic models (sonar, water medium, and sound propagation) as well as more realistic vehicle and fish school models. Rapid development of new functionality and integration with other solutions are now feasible due to the transition to a high level scripting language. Increased degree of simulation realism through physics computation will allow the verification of the validity and robustness of simplified models used within the vehicle's onboard control code. While the loss of the DOERRI Fetch was a setback, NOAA's Southwest Fisheries Center in La Jolla owns another FETCH vehicle designed for fisheries research and operated under the supervision of David Demar and Center graduate Randy Cutter. Robert Bogucki is now working with this group to continue with these developments and to produce further developments focused specifically on their research needs and in particular, the adaptive mapping of fish schools.

WHALE TRACKING

Another particularly exciting aspect of GeoZui-4D has been its application to visualizing the underwater behavior of humpback whales supporting both basic science and policy as humpback whales are an endangered species whose decline are attributed to ship collisions and fishing gear entanglement. Understanding their 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 (Fig. 7). 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.

This past year, improvements made to the whale tracking software include:

1) Obtained calibration files and .dtg files. This allows a deeper look into the raw data instead of relying only on processed Matlab files. l sequences.
2) libDTAG: A library was built to directly access .dtg files. This allowed converters to be built to convert DTAG data to ogg, flac and other formats.

Ware, Arsenault, Weber and Schmidt participated in another Stellwagen Marine National Sanctuary organized whale tagging cruise in July of 2007. During this cruise acoustic pingers developed at the Center were deployed to allow the tracking of the tagged whales while submerged (see discussion of the work of Val Schmidt and Tom Weber later in the report) and exploring the behavior of multiple animals (tagged with hydrophones) in the same foraging group. This work, being developed by Schmidt into a Master's Thesis, is showing very promising initial results, having provided underwater whale tracks and important whale energetic metrics such as swimming speed (which in the past could only be estimated). We have preliminary but credible evidence of humpback whale speeds up to 12 knots. In addition we can corroborate whale feeding methods that have previously been hypothesized and can place them in the context of the local bathymetry and seafloor type. The results from these tags are being analyzed and incorporated into Trackplot – the software developed at the lab for the analysis of whale behavior. The development of improved hardware mounts for the pingers have turned into a senior project for a group of undergraduate mechanical engineering students (Tom Weber, advisor).

FLOW VISUALIZATION

The incorporation of flow visualization models into the GeoZui-4D environment has opened of a range of applications and interest from ocean and current 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 working closely with NOAA (and other) 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 this year 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. The file loader of the flow visualization software has also been enhanced to allow time-varying, multi-layered atmospheric data, and internal data structures have been optimized resulting in significant improvements in performance.

There are now four 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 another museum-based effort, work with Kate Raisz of Northern Lights continues on the Smithsonian Science-on-a-Sphere visualization of global flow patterns for the new Smithsonian Oceans Hall. The design for this exhibit is near completion and will be released in 2008. The same code will be used with SkyScan to visualize ocean processes in planetaria through a recently acquired Granite State Technology Innovation Grant.

FLOWVIS2D/NOAA NOWCOAST

Colin Ware and NOAA employee John Kelley continue to work on a project that will use 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. Briana Sullivan will be helping with evaluation and technology transfer. This effort has attracted some attention within NOAA. Carlos Lozano at NOAA's National Center for Environmental Prediction (NCEP) is also evaluating the FlowVis2D software as a tool for visualizing their models.

VISUALIZATION OF COUPLED ATMOSPHERE AND OCEAN MODEL OUTPUT FOR HURRICANE FORECASTING

There is considerable interest in being able to visualize the atmosphere and the ocean data in a single visualization. While this project is just beginning, it has the support of Naomi Surgi who is in charge of hurricane modeling for forecasting at NCEP. Hurricane Katrina data has been obtained. The package being developed is being called FlowVis-4D. The SkyScan project (mentioned above) will also involve a visualization of Hurricane Katrina based on the same data.

INTEGRATING MARINE MAMMAL DATA WITH FLOW MODEL OUTPUT

This project is just beginning. The idea is to integrate the mammal tracking visualization capabilities with flow visualization capabilities using sigma coordinate models. This tool should be able to evaluate the behavior of tagged targets within the context of oceanographic processes and may be ideally suited for exploring time series data from ocean observatories.

MID-WATER FISH

One of the most exciting recent advances has been our adaptation of a new generation of multibeam sonars to allow the real-time visualization of targets in the water column. While aspects of this fall under our visualization theme, we will discuss this activity in detail under "New Projects".

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.

SINGLE BEAM SONAR AND MAPPING AND CHARACTERIZATION

In general support of our seafloor characterization efforts, Semme Dijkstra has continued the development of several software tools. The TracEd tool provides a robust means of tracking, editing and parsing returns from single beam echosounders. This tool, which has the potential to be a very useful aid to single-beam hydrographic data processing, has now been ported to the Windows environment. Upgrades to TracEd this year include the extended ability to display of LIDAR data, as well as interfaces for the ODOM Echotrac MKIII, cvc2 and cv3 systems, and revised snippet editing. The Lassoo tool which is used for comparing multivariate data sets to imagery data sets in both geographic and

multivariate feature space has also undergone a number of upgrades including the development of a generalized AI classification scheme that is designed to automatically identify benthic organism grazing haloes that have been shown to be associated with the location of underwater ordinance in certain locations (e.g. Vieques).

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, 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 Icelandic-sponsored 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*. This year we have also begun the collection of a new "Common Data Set" in support of the upcoming Shallow Survey 2008 Conference. 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. Theme segmentation can now be done visually by an interpreter or automatically with the aid of image processing algorithms. Fonseca and Yuri Rzhanov are working together to develop segmentation algorithms that take into account the acquisition geometry of the sidescan or multibeam sonar and analyze, simultaneously, parameters extracted from the backscatter mosaic (image-distribution space) and from the angular response (angular-response space). In addition a tool has been added this year that allows the editing and interpretation of the ARA parameters that describe the angular response curve in slope-intercept space. The results of this editing can then be used directly in the model inversion. Finally a capability has been added that allows the simultaneous adjustment of the inversion parameters when information is available at multiple frequencies from the same piece of seafloor. While these situations are rare, the potential for obtaining a more robust solution of seafloor character is quite exciting.

A "blind" test of the ARA technique was done this year as part of a symposium on seafloor characterization held in Northern Ireland. Acoustic backscatter from a Simrad EM1002 survey of the Stanton Bank, Northern Ireland was analyzed using the ARA tools with no knowledge of the actual bottom type. The results were then compared to bottom photographs acquired in the same area last summer. The results were compiled in a GIS and showed very good correlation between the bottom type predicted by the ARA and that shown in photos and by other analyses. The organizer of the symposium, Professor Craig Brown at the University of Ulster wrote to Fonseca:
"I personally think that your approach is one of the most exciting developments in the field of seabed habitat mapping. Your approach is unique and I think (with further development) could be just the thing to map seafloor features such as habitats. The combined methods of ARA and theme discrimination from the mosaic offer all the ingredients for accurate and vastly improved delineation of more subtle biological traits (i.e. bioturbation, animal biomass etc.)."

GROUND-TRUTH STUDIES

In order to better understand the relationship between remotely measured sonar backscatter and the physical properties of the seafloor, we have also developed (with ONR funding) an instrument system designed to make in situ measurements of sound-speed, sound attenuation, and resistivity (along with video of the seafloor -- ISSAP). In the past year, Barbara Kraft and Glenn McGillicuddy have calibrated the ISSAP transducers (to better understand the measurements made with them). In the case of the Geoclutter work, ISSAP measurements have been compared with the ARA model predictions of Fonseca with very encouraging results (reported in previous annual reports).

The most recent ground-truthing study involves the Master's thesis work of graduate student Luis Soares-Rosa. Luis focused his research on the Historic Area Remediation Site (HARS), a well-studied region of controlled disposal of hazardous waste and capping. This dataset is important because it provides a wide variety of sediment types ranging from clays to gravel in a relatively small area along with a large amount of ground-truth and sonar (single beam, multibeam, side scan sonar, sub-bottom profiling, grab samples, corers, plan view and profile images) collected over an eight year period. This extended dataset allows understanding the sedimentary dynamics of this area and its evolution, which in turn influences the strategy for determining the need for new sediment sampling to fill existing gaps.

Comparisons of the ARA results with ground-truth measurements (Sediment Profile Imaging (SPI) camera, grain size analyses on grab samples and bottom photos) proved very encouraging. When the sediment sampled was both laterally and vertically homogeneous (within the uncertainty of the relative positioning of the sample and the acoustic data), the ARA used in the "patch" (averaging over a swath width) mode proved to be a very effective predictor of the mean grain size of the sediment ($R2 = 0.90$); when there was substantial lateral variability, the "theme" mode of the ARA proved to be a better approach. The difference in the ARA predicted mean grain size and the measured mean grain size was $\pm$ 0.4 phi at 1 sigma.

LIDAR

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, Shachack 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 3 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 and shoal areas. This is a very important result as it indicates that the failure to detect the bottom may not simply indicate that the water is deeper than the attenuation depth of the laser and that in these situations, shoal or rocky targets may be systematically missed. This frightening result will be further investigated in the coming months.

In support of our LIDAR investigations McLeod has modified a rosette system for the real-time measurement of the optical properties of seawater during LIDAR surveys. A new cage was designed for this instrument suite and successfully tested offshore. We also have purchased a 532 nannometer green laser so that we can work with it in our large tanks to better understand the behavior of the LIDAR pulse in water and as a function of different water conditions (sea state, clarity, etc.). *More on this effort next year.*

LIDAR FOR SHORELINE MAPPING

This past year Pe'eri worked with NOAA graduate student Lynn Morgan to look at potential enhancements in the use of LIDAR for defining the shoreline. Previous algorithms for defining the land–water interface have used either the presence of a saturated peak in the infrared-channel waveforms, or the ratio between the green-channel, red-channel and infrared-channel waveforms to make a shoreline determination. Both of these approaches were investigated using SHOALS-400 LIDAR data (from Lake Michigan) and SHOALS-3000 LIDAR data from the Portsmouth Harbor area. Observations of the red-channel waveforms show a strong dependence between the waveform and the presence of water. Different waveform characteristics were found from water and land returns (bare earth and vegetation coverage). Procedures were developed to contour the algorithm results into shorelines and then to compare the results between the different algorithms. The analyses of these comparisons showed good delimitation of the shoreline that are within NOAA shoreline standards.

VIDEO/PHOTO IMAGE MOSAICKING AND QUANTIFICATION

THE HUBBARD CAMERA

Lloyd Huff continues to be active with the development of the "Hubbard Camera" a towed video camera system with a diesel-powered stand-alone winch, which has become a vital part of seabed studies conducted by the UNH Marine Programs, including the Joint Hydrographic Center. The system was given a thorough check out in the laboratory prior to the spring 2007 field season, passed all tests and was deemed fit for service. The first application of the camera this reporting period was to conduct a survey at the Open Ocean Aquaculture Site. The plans to utilize the Hubbard Camera winch and cable for towing the Klein 5410 were abandoned when the immediate need for such a configuration dissipated. The materials are on hand to complete the underwater 6 to 8 pin jumper cable, if the need were to arise again.

The Hubbard camera was also used in the fall of 2007 in support of LIDAR research being lead by Shachak Pe`eri. The videos of the seabed supported the conjecture that success of LIDAR is dependant on the seabed, in addition to the well recognized factors of water depth and water clarity.

VIDEO MOSAICS AND IMAGE PROCESSING AND HABITAT GROUND TRUTH

Yuri Rzhanov has continued the development and application of automated mosaicking algorithms for underwater video, laser line-scanner and still images. The effectiveness and efficiency of Yuri's mosaicking software is gaining wider and wider recognition and it is becoming increasingly in demand. This past year the mosaicking projects completed included:

1) Construction of a photomosaic of the Monitor in collaboration with Dwight Coleman of the University of Rhode Island and Institute for Exploration and James Moore of the Monitor National Marine Sanctuary.

2) Re-processing of ultra-high resolution (1 cm per pixel) laser line-scanner data collected near Hawaii by SAIC/NOAA Pacific Fisheries (NOAA Fisheries, Pacific Islands Fisheries Science Center: John Rooney, Scott Ferguson).

3) Semi-automated mosaicking of video from Olympic Coast Sanctuary (Steve Intelmann).

4) Processing of Gulf of Mexico seafloor imagery acquired from NR-1 in collaboration with the University of Mississippi. Constructed long single-swath transects mosaics (with imagery from one or two cameras). Swaths from different transects did not have any overlap (due to relatively narrow horizontal field of view (around 50 degrees). This precludes the construction of a multi-swath mosaic.

5) Processing deep-sea imagery data in collaboration with Viram Unnithan of Jacobs University, Bremen, Germany. A collaborative project is being planned with Jacobs University and StatOil.

In addition to the processing of mosaics, a number of new capabilities have been added to the mosaicking tool suite. These include:

1) The development of "DirectShow" filters for the capture of specified video frames from high-definition video.

2) The modification of video mosaicking tools for the automatic registration of hyperspectral imagery with optical ortho-rectified imagery. This approach has been used in the aid of shoreline determination from LIDAR (see LIDAR studies section).

3) The development of an algorithm and implementation for automatic determination of camera tilt from imagery (FindAttSequence.exe). This algorithm has been applied to a sequence of ice images taken from helicopter. It found an almost constant pitch bias (3-5 degrees) that allowed the production of a much higher quality (less distorted) mosaic of the ice surface.

4) The development of a prototype application for accurate object counting in image sequences with substantial sequential overlap.

5) In collaboration with Norman Vine (WHOI) an image registration method using polygonal primitives generated in the process of image vectorization was developed. Images saved in SVG format (Scalable Vector Graphics) are parsed, and each path primitive (closed contour associated with some almost constant color) is processed, generating a set of features invariant to translation, rotation and scaling. Feature vectors obtained from two images are compared pair-wise, establishing matches between contours.

6) Evaluation (by Fan Gu under supervision of Rzhanov with input from de Moustier) of five blending techniques used for underwater mosaics (illumination correction based on the median mosaic; thin-plate spline warping; perspective warping; graph-cut applied in the gradient domain; and in the wavelet domain. A combination of the first two methods yields globally homogeneous underwater photomosaics with preserved continuous features. Further improvements are obtained with the graph-cut technique applied in the spatial domain.

7) Two new feature-matching approaches have been implemented: an algorithm for the search of approximate nearest neighbor and a fast feature matching routine (SURF – Speeded Up Robust Features).

8) Working with Fonseca, Rzhanov is applying his image processing skills to Fonseca's work on GeoCoder and seafloor characterization by developing automated techniques to segment the data for "theme" analysis (see above). The backscatter mosaic generated by GeoCoder is over-segmented under the assumption that each segment represents an area with homogeneous sediment. Most segments are too small to have a complete angular response curve (ARC) and have to be joined with other segments for characterization. Segments are characterized by vectors of features constructed from moments of backscatter intensity distributions. Agglomerative clustering of these vectors is used to divide segments into maximum number of clusters with complete ARC's. For each cluster of segments the complete ARC is recalculated that allows for model inversion and determination of sediment properties.

TWO NEW PROJECTS (FUNDED SEPARATELY, BUT COMPLEMENTARY TO OUR ONGOING WORK) BEGAN THIS YEAR

The first project is aimed at using stereo cameras to improve the accuracy of optically-assisted acoustic rockfish abundance measurements and habitat surveys. This project is funded by NOAA's Southwest Fisheries Science Center, with J. Butler, G. Cutter, D. Pinkard, D., Demer collaborating with Rzhanov at the Center.

The second project, funded through IOOS, is for the development in cooperation with Scott Gallager and others at Woods Hole Oceanographic Institution, of a mobile benthopelagic observatory to support fisheries and ecosystem management (NEBO). Our role in this effort will be to create video mosaics from the high-resolution photographic and video data collected by the WHOI benthic sled and to compare the habitat-relevant analyses of this imagery to acoustic data collected by multibeam and sidescan sonar.

DATA MANAGEMENT

With the arrival of Jim Case as our full-time data manager, we have begun a serious effort at organizing our data holdings and making them accessible both to internal and external users. Since his arrival Jim has evaluated the hardware and software data infrastructure at the Center. A data management scheme has been designed and in support of this restructure, several new data servers have been purchased. In concert with the data management restructuring, Case and Calder are working on a "Knowledge Repository" database concept that will attempt to capture "expert opinion" from Center domain experts on relevant information in any particular field.

The primary focus this past year has been developing code and procedures to support the mass migration of data from various locally-attached storage servers to a new Storage Attached Network (SAN). The key features of the system are automatic discovery and cataloging of data files by project, the harvesting of metadata whenever possible from well-known data files and the storage of all of the above in a data management schema within Oracle. All new code written for this project is either in C, C++ or C#. C# is being used as the wrapper for all legacy code and the language for all new code related to data management, metadata or Oracle I/O.

A full multibeam data and FGDC-compliant metadata delivery was made to the National Geophysical Data Center (NGDC) of all Law of the Sea data collected by the Center through January 2007. This was accomplished through automation of the collection of metadata from each and every data file and subsequent integration in to the metadata database. The metadata for each file was then automatically merged with a universal metadata XML template for delivery. It is important to note that each multibeam data file has a corresponding metadata file, which added up to 1600+ for this delivery.

A new development has occurred in early 2007. The next-generation metadata and data warehouse system developed by LDEO will be configured to accommodate our Center's metadata holdings. This will effectively standardize our data archives between LDEO and UNH. NGDC has full interoperability with this system. The tools developed for data and metadata discovery already created for UNH use will be incorporated in to the

new system along side an already extensive arsenal of discovery tools. This system comes with a complete backend database, file management and data discovery tools. A web front-end with metadata search and web mapping are also included. Case is currently working directly LEDO with (Bob Arko) on this implementation.

The Center's database manager, Jim Case has been asked by the Integrated Ocean and Coastal Mapping Working Group (IOCMWG) to lead the Metadata Working Group of this important new program. This is a great recognition of Jim's talent as well as the important role that the Center can, and will continue to play, in helping the nation better organize the collection, processing and distribution of its offshore mapping data.

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 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 6 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 325 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 38,000 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 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 ~22,500 nmi2. 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 47,586 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 27,000 nmi2 of MBES data were collected representing approximately half of the area to be mapped in this region.

This past year, 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 82.17^{o}N. 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.

To date, the Center has collected more than 1,000,000 nmi^2 of new, high-resolution multibeam sonar data in regions that have never before been mapped in detail. 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. One of these efforts is that of Ed Sweeney who is working with Jim Gardner to understand a large anomalous (low) backscatter anomaly that was found in the Law of the Sea multibeam data off the U.S. mid-Atlantic margin. Several hypotheses have been proposed for this large low-backscatter anomaly (erosion, non-deposition, deposition, presence of gas) and hopefully by the time of completion of Sweeney's thesis we will have a much better understanding of its significance.

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/
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 2008, the activities of the Center in support of this task may increase.

ELECTRONIC CHART OF THE FUTURE

In FY 2003, we began our "Chart of the Future" 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 (i.e. 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 two ENC production software companies (CARIS and SevenCs). The development process involves three phases: 1) incorporation of high-density depth information (based on Navigation Surface – discussed above) into existing IHO S-57 ENC data; 2) development of a "Tide Aware" ENC Product Specification," and; 3) integration of predicted, forecast, and real-time water level information services transmitted via a shore-based AIS communications broadcast. Based on Kurt Schwehr's work (see below), tidal information is provided in XML format and transmitted via AIS Base Stations operated by USCG. This includes water level information from NOAA's Physical Oceanographic Real-time System (PORTS) and the Tidal Constituent and Residual Interpolation (TCARI) method. Other time-varying information also being investigated includes current flow, sea ice coverage, and weather information. The results

of this research are being implemented into S-57 ENC datasets, and will help define the new ENC Product Specification under the future IHO Geospatial Data Standard (S-100.)

This past year, the Center participated in the Elizabeth River Demonstration Project held in conjunction with the 2007 US Hydro Conference in Norfolk, VA. At the U.S. Hydro 2007 Conference Kurt Schwehr demonstrated the "Tide Aware ENC" project. The software combines the Pydro hydrographic software with TCARI for finite element modeling of water surfaces. Real time water levels are delivered via internet based automatic identification system (I-AIS) messages pulled from the NOAA CO-OPS/PORTS database. Schwehr also worked with NOAA/OCS-employees Barry Gallagher, Jack Riley, and Rick Brennan on the integration of the AIS messages and tuning of the Pydro and TCARI software for real-time water level calculations and display. TCARI was sped up by an order of magnitude by Schwehr and Gallagher by converting the dispatch and looping of the finite element modeler from Python to C-Python. Schwehr implemented the real-time I-AIS using his noaadata-py software. Feedback at the conference was extremely positive and has lead 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. Work continues with Darren Wright of NOAA and Irene Gonin of the USCG RDC on evaluating what needs to be done to bring PORTS data to ships via AIS. AIS binary messages are being discussed in the RTCM SC121 working group.

Also under the "evolutionary" track of our Chart of the Future effort is Lee Alexander's work with the Office of Coast Survey on a project to convert existing coral reef habitat data into a suitable format for use as Marine Information Objects (MIOs) with ENCs in ECDIS and ECS. A key focus is to develop new IHO S-57/S-100 objects/attributes for biological and regulatory criteria associated with coral reef designation and management. Additionally, Lee's work with numerous committees (IHO Committee on Hydrographic Resource and Information Systems – CHRIS; IHO Transfer Standard Maintenance and Application Development Working Group – TSMAD; IEC Technical Committee 80/Working Group 13 – Display of Navigation Related Information, and; IHO-IEC Harmonization Group on Marine Information Objects – HGMIO) ensures that the lab stays on the forefront of standards issues.

Another aspect of our "evolutionary" track of the Chart of the Future has been our effort to develop efficient and robust approaches for the "generalization" of the dense bathymetric data sets such as those collected by modern multibeam sonars into products that are appropriate for display on current-day paper or electronic charts using standard cartographic protocols. For this effort, the Center brought in a visiting scholar, Lysandros Tsoulos, an internationally-known expert in electronic cartographic techniques from the National Technical University of Athens. Lysandros worked with NOAA physical scientist Nick Forfinski on Nick's Master's project entitled "An Algorithm for Assessing the Horizontal Displacement Resulting from Bathymetric Generalization." While techniques to assess the vertical displacement resulting from raster-based generalization (and thus assess the validity of the generalization approach) are well-established, there has been much less work done on approaches to assessing the

horizontal displacements associated with raster-based generalization. Nick and Lysandros developed a hybrid (raster/vector) method to visually and quantitatively characterize the horizontal displacement resulting from generalization. The hybrid approach proved very useful as it produces a comprehensive assessment of vertical displacements by incorporating the depth differences associated with every node of both the original and generalized surface. With the establishment of a robust approach for the assessment of horizontal as well as vertical displacements, we are now in a much better position to test a range of approaches for generalization.

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.

DIGITAL COAST PILOT

This past year 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 (Fig. 8). Schwehr and Plumlee have been working on the initial design and development of a Digital Coast Pilot system for Portsmouth Harbor. The goal is to develop an XML format to represent the contents of the existing Coast Pilot books such that the contents can be geocoded and converted with style sheets (XSLT) to a range of end products that include a PDF of the book, an HTML web format, and 3D model files for use for 3D modeling with libgz4d, Google Earth, and other software. The style sheet system will automate the process of collecting and integrating the range of additional resources that are included with the Coast Pilot. For example, the style sheet processing can pull the

text of the Code of Federal Regulations (CFR) for each referenced regulation and attach the text to the reference within the Coast Pilot.

We have created an initial version of a XML file format for storing the Digital Coast Pilot and ancillary data. We obtained the initial concept XML format and stylesheets from Tucker and Nyberg, at NOAA (Tucker and Nyberg, 2005). The initial concept by Tucker and Nyberg is focused on PDF and HTML output. Therefore, we have worked to alter their form into a prototype that can meet the additional requirements of being input to 3D graphics software. The system is designed around two core XML files for one Coast Pilot book. The first is the "CoastPilot" document that closely follows the text of the traditional Coast Pilot main chapters. References to legal documents, geographic names, and other references are tagged with unique identifiers. The geographic names are also contained in a second XML document. This "features" file contains the details of every geographic name contained in the CoastPilot. For each feature, a block of XML gives the textual name, geometry, GNIS (USGS name identifier) if available, references to S57 (or S100) ENC data, images, and feature classification (e.g. "Bay", "River", "Buoy"). For the geometry, we evaluated GML, but decided to avoid it as GML 3.0 is a set of schemas that must be instantiated into specific schemas. This makes GML reasonably undefined. We will try out the Open Geospatial Consortium's Well Known Text (WKT) as our initial representation of geometry.

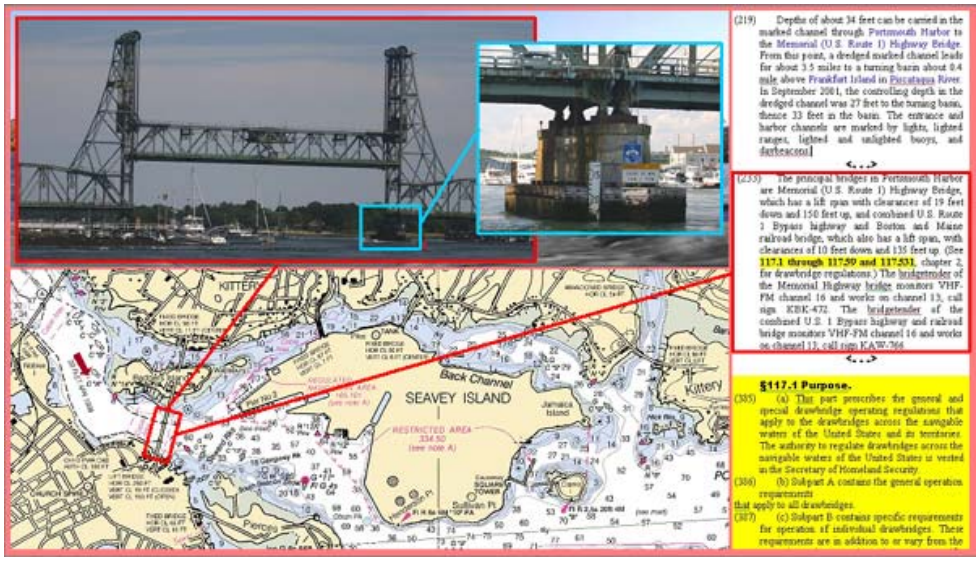

Figure 8. Image captured from the "Digital Coast Pilot" showing approach to bridge in Portsmouth Harbor

In the next few months, once the Coast Pilot and Features XML files have been defined for a test subset of a Coast Pilot book, we will be working on style sheets and software to convert these files into 3D representations for a displayable 3D Digital Coast Pilot. The target platform is libgz4d with OpenSceneGraph (osg) using X3D as the file format to represent the geometry. In addition, we will create a prototype of a Google Earth representation to evaluate how off-the-shelf virtual world's software might be utilized. The plan is to make this prototype available to mariners for testing in the spring of 2008.

SPECIFICATION FORMAT FOR AIS BINARY MESSAGES AND REAL-TIME VESSEL MONITORING

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. Lee Alexander attended a coordination meeting in June between many of these parties and Lockheed Martin to discuss the path for deploying AIS Binary Messages. Schwehr attended the second meeting in November. As discussed above the concept of using AIS to send real-time water level data for "tide-aware" charts was presented at the Hydro 2007 by Brennan et al. and is now being evaluated by NOAA CO-OPS/PORTS.

Schwehr has received an AIS base station for testing and development from ICAN Marine. Initial work has begun on understanding how to correctly send VHF AIS binary messages and Schwehr met with ICAN Marine and the staff of the Stellwagen Bank National Marine Sanctuary (SBNMS) to discuss the needs for AIS infrastructure and testing. The SBNMS will be a prototype/demonstration of the AIS broadcast capability for the USCG. An earlier demonstration of the power of AIS to track vessel traffic approaching Boston Harbor using the AIS system and monitor compliance with the change in shipping lanes prescribed by NOAA to avoid a whale migration route in SBNMS was very successful.

The success of this effort has led to a much more sophisticated whale monitoring/vessel notification project that is funded by North East Gateway (LNG carriers) and is being carried out in collaboration with researchers at Cornell University. Schwehr has been continuing to talk to North East Gateway and Cornell on how to best implement a right whale notification system using AIS to meet the environmental mitigation requirements created by NOAA and the USCG.

Finally, the AIS system has been used for collision and oil spill analysis. Schwehr and Dr. Phil McGillivary, from the USCG PACREA-Icebreaker liaison, published a concept paper at the September 2007 IEEE/MTS meeting that described how investigators might use AIS for selecting vessels, and to investigate how that might be the source of the mystery oil spills**.** During November 2007, the USCG New York Detachment began using this technique for an investigation of 500 gallons of oil that washed ashore in New York. Using this technique Schwehr was able to create a visualization of the containership Cosco Busan's collision with the San Francisco Bay Bridge in Google Earth. This visualization was provided to NOAA PORTS and USCG VTS personnel at their request. Schwehr has also aided in the development of the Emergency Response Mapping Application, a web-based tool developed by the Coastal Response Research Center at UNH to instantly and interactively provide emergency response workers with a range of critical situational awareness information so that they can best respond to an oil-spill or other emergency.

GOOGLE EARTH FOR MARINE USERS

Google Earth is becoming a ubiquitous tool for visualizing geospatial data. Taking advantage of this, Schwehr has started working on tools for processing marine data into usable Google Earth visualizations to support planning and data processing tasks at NOAA, CCOM, and elsewhere. Demonstration visualization has been created that shows acoustic tracking of whales in the Gulf of Maine (see discussion below). Additionally visualizations that combine S57 electronic navigation charts (ENC) and ship tracks from AIS position reports have been generated. Both GDAL's S57 conversion tools and the EarthNC chart products from Destin Shark have been evaluated in this context. While these charts are visually appealing, they do not comply with any display standard. Schwehr continues to have discussions about the maritime communities' requirements directly with engineers from Google Earth, and Google is now aware of the limitations of their time format for large datasets. Finally, work towards a "Google Oceans" continues; the recent agreement between NOAA and Google bodes well for the creation of an official ocean product.

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 development by Weber, Brian Locke and Roland Arsenault.

While last year's effort involved our first exposure to the remarkably dense data rates produced by these new sonars when collecting mid-water data (up to 1 Gigabyte per minute), this year's effort has been multi-pronged. This has included analysis of data collected in the fall of 2006 on Georges Bank, where schools of Atlantic herring were imaged with both a Reson 7125 SeaBat multibeam sonar and an EK60 split-beam scientific echo-sounder (the standard system used in fisheries research) at 38, 120, and 200 kHz. The results of the analysis to date clearly indicate some of the advantages of using multibeam sonar in fisheries work (i.e., school volume calculation, identification of school fragmentation, general school morphology). In the figure below (Fig. 9), data representing six passes over Atlantic herring are shown. The red volumes are iso-surfaces of constant volumetric scattering strength (a first-order proxy for school density) extracted from the raw multibeam data. The vertical surface in each image is co-located raw scattering strength data collected from the single-beam echo sounder. Analysis of these results (performed with colleagues from the Institute for Marine Research, Bergen, Norway; Northeast Fisheries Science Center, Woods Hole, MA; MIT, Cambridge, MA; and Northeastern University, Boston, MA) is on-going, but will include comparing the multibeam data with low-frequency, wide coverage (50 km) towed array data collected from the same fish schools (using the MIT Ocean Acoustic Waveguide Remote Sensing technique).

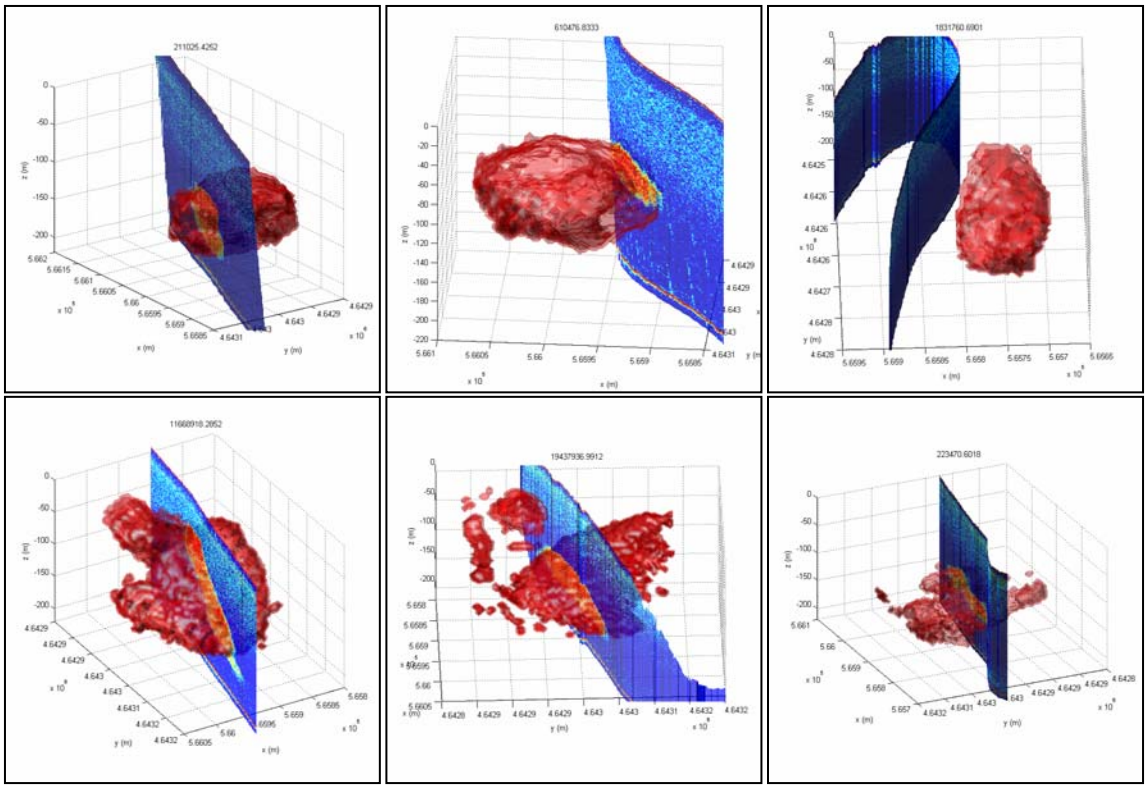

Figure 9. Comparison of standard fisheries echo-sounder (blue curtain) with results of multibeam sonar (red blobs) over same school of fish. Note how much is missed by standard sonar.

A new mid-water mapping focus has been on the Kongsberg ME70, which is a new multibeam sonar specifically designed for mid-water column fisheries applications. This sonar is currently installed on two NOAA fisheries survey vessels – the Bigelow and the Dyson – and is slated to be installed on two more NOAA vessels. Weber participated in the acceptance trials for the ME70 installed on the Dyson in an observer/technical advisor role. The current work with regard to this sonar is focused on understanding its capabilities and limitations, and trying to understand how it can be best used in a multi-mission sense. This includes exploring its current capabilities with regard to habitat mapping, surveying benthic fish (Weber is the Co-PI along with NOAA scientists Chris Wilson and Chris Rooper on a proposal to the North Pacific Research Board to study rockfish), and surveying pelagic species.

The ME70 has also become the focus of an effort to develop a real-time geo-referenced display of midwater multibeam sonar data by taking advantage of the GeoZui 4-D software environment developed by our Visualization Lab. This type of system is expected to provide valuable information for fisheries scientists who must make real-time adaptive survey decisions in moving/fragmenting fish schools. Other target sonars for this activity are the Reson Seabat 7125 and the Kongsberg EM3002. This capability is nearing a demonstration.

In an effort to provide "ground truth" for our midwater sonar efforts Weber and Mayer have been working with UNH zoology graduate student Chris Gurshin. Chris is at the

beginning of a multi-year project where he catches cod, places them in a fish pen, and images them with both multibeam (EM3002) and single beam (EK60) sonars. This exciting experiment which also takes advantage of UNH's unique open ocean aquaculture capabilities will provide an excellent testing ground for mid-water multibeam sonar systems. The initial fish cage experiments took place in June 2007 and the initial results look promising.

Additional mid-water multibeam activities include 1) the analysis of bubble clustering in the ocean and studies of their acoustic implications (funded by ONR Ocean Acoustics with data collected in October 2006 with a Reson 7125 multibeam sonar, and; 2) continuing investigation into kelp coverage/density/height on Cashes Ledge critical cod habitat in the Gulf of Maine, using data collected in June 2006 also with a Reson 7125 multibeam sonar.

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 batyhymetric 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. As described under the Visualization theme, in support of this effort, the Visualization group has developed mission planning and control software as well as an AUV simulator. 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 Submetrix Geoswath bathymetric sidescan and a Kerfot Inertial Nav system) has already been ordered (with delivery expected in April 2008). The new system is a much more mature AUV with imagery, bathymetry, and particularly positioning capabilities far beyond the original Fetch vehicle. We are thus very excited about the enhanced possibilities offered by this system and look forward to working with it in the coming year.

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."

During the past year, Tom Weber, Glenn McGillicuddy, Val Schmidt, Michelle Wierathmueller, Andy Mcleod, Lloyd Huff, and others have built and installed a semi-permanent installation of acoustic gear at Portsmouth Harbor Light. This is essentially a cable-to-shore acoustic tracking node that we are using for high frequency (30-40 kHz) acoustic research. This installation currently consists of a set of four hydrophones, signal

conditioning electronics, and a small computer on a submerged mount located approximately 100 m from Portsmouth Harbor Light on New Castle Island. This hardware has been largely developed in-house. Power and data communications utilize a multi-conductor underwater cable connecting the submerged hydrophone system with a 'topside' computer housed inside the lighthouse. A wireless Ethernet system provides connectivity with the outside world, enabling the complete system to be controlled from any convenient location (e.g., on a research vessel or in project team member's offices). The analysis of data collected in late 2006 showed that for high signal to noise ratios (> 20 dB), the standard deviation of the acoustic phase detecting bearing sensor developed as part of this project was between 0.3-0.5°. However, there is some concern that there is an angle dependent bias in this measurement methodology that could be difficult to correct.

Further system testing in February 2007 focused on determining the useful range for this system by pinging at the hydrophones from various locations around the harbor entrance. The initial results look promising for ranges up to 1.5 km. We are currently conducting research on the various acoustic tracking methodologies in this challenging, shallow water (<50m water depths) environment. This research is being developed as a Master's degree thesis by Michelle Weirathmueller. At this time, the deployed system is being upgraded with new preamplifiers and the addition of a conductivity/temperature sensor. Acoustic pingers are also being developed in-house (with Val Schmidt, Andy Mcleod, Glenn McGillicuddy) as part of this research in order to help test time-of-flight ranging accuracies. The "UNH Pingers" are battery operated and are packaged in either a small Pelican case or buoy. Each pinger is GPS positioned and able to send both CW and stepped chirp signals from 1-100kHz at roughly 175dB. GPS 1PPS signals provide unified triggering to better than 200 nanoseconds. As described under the Visualization theme, the devices have already been used with great success for acoustically tracking tagged humpback whales in collaboration with the Stellwagen Bank National Marine Sanctuary. Preliminary results from this work were presented at the Acoustical Society of America conference in November. It is expected that these devices will be of great utility for many future studies.

In October 2007, Weirathmueller and the Harbor Tracking Team (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 a 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 will be the focus of Michelle Weirathmueller's Master's thesis work and will be used to better understand the limitations of the time-of-arrival and phase-tracking underwater acoustic tracking systems. This data should help provide a fundamental understanding of the limitations of each of these approaches.

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. Some of these articles are listed below:

2007-10-25 Coast Guard Plans to Set Up Arctic Base Associated Press
2007-10-19 New Coast Guard Task in Arctic's Warming Seas The New York Times
2007-10-19 U.S. Coast Guard seeks base in Arctic International Herald Tribune
2007-08-31 U.S. Draws Map of Rich Arctic Floor Ahead of Big Melt The Wall Street Journal
2007-08-20 Scientists Take Underwater Robot on Black Sea Expedition Science Daily
2007-08-19 U.S. Coast Guard joins in Arctic oil rush Christian Science Monitor
2007-08-19 CG Icebreaker to Map Arctic Sea Floor Evening Colors
2007-08-15 Americans Launch Another Arctic Expedition Kommersant
2007-08-14 U.S., too, pursues Arctic ambitions Marine Log
2007-08-13 After Russia and Canada, U.S. ship headed for Arctic Reuters
2007-08-13 NOAA coast survey contiues sea floor mapping expedition in the Arctic NOAA News
2007-08-11 U.S. Icebreaker to Map Arctic Sea Floor Guardian Unlimited
2007-08-10 Canada announces new army base, navy International Herald Tribune
2007-08-08 Russia´s Deep-Sea Flag-Planting at North Pole Strikes a Chill in Canada Washington Post
2007-08-08 Icebreaker deploys on Arctic mapping mission Navy Times
2007-08-01 The Evolution of Telepresence Techonology NOAA Office of Ocean Exploration
2007-07-29 Wireless whales The Patriot Ledger
2007-07-20 A species tagged for survival Boston.com
2007-05-01 Crossing Thresholds in Seafloor Mapping Hydro International
2007-03-11 UNH aids undersea archaeology expedition Foster´s Online

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.
- ENL
- EdgeTech
- Fugro
- GeoAcoustics
- HyPACK
- IFREMER
- IVS-3D Inc.
- Knudsen
- Kongsberg Simrad
- L3/Klein Associates
- ODOM
- Reson
- SAIC
- Sonartech Atlas
- SevenC's
- QPS
- QinetiQ
- Quester Tangent
- QinSy
- SonarTech Atlas
- TENIX/LADS
- Triton-Elics
- 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 C). 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 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

CCOM Fort Point, Piscataqua River, 16-18 January**,** R/V Gulf Challenger**,** Harbor Tracking / Observatory node performance evaluation. (McGillicuddy, Weber & Weirathmueller)

Harbor Tracking Source Level Measurements and Propagation Testing, Piscataqua River 2 February, R/V Gulf Challenger. (McGillicuddy, Schmidt, Weber & Weirathmueller)

Klein 5410 transducer acceptance testing, Isles of Shoals, NH, 13 February, R/V Gulf Challenger, acceptance testing of two candidates for warranty replacement of port transducer. (Glynn & Huff)

High-Precision Timing (with Reson, NOAA), 2-6 April, R/V Bay Hydrographer, Solomon's Island. (Calder)

Doerri AUV, 3-4 April, R/V Hugh Sharp, DOERRI engineering. (Arsenault)

Vessel Offset Survey, 11 April, R/V Coastal Surveyor, total station survey and fieldwork. (Morgan, Schmidt & Weirathmueller)

NOAA CO-OPS ADCP deployment PIR07, 9 May, R/V Meriel B, ADCP deployment in Portsmouth Harbor, NH. (Felzenberg)

LOMROG Test Cruise, 16-25 May, R/V Icebreaker Oden, EM120 Sea Acceptance Test. (Jakobsson & Weber)

New Hampshire Inner Shelf, May to October *(one day per month water quality cruises)*, R/V Gulf Challenger, UNH/NOAA AMAC OOA Project. (Ward)

New Hampshire Inner Shelf, one day in May and October, R/V Gulf Challenger, UNH/NOAA AMAC OOA Project. (Ward)

UNH-CCOM Summer Hydrographic Field Course, 8-15 June, R/V Coastal Surveyor, Kongsberg EM3002 survey of Portsmouth Harbor, NH. (Felzenberg & Moser)

ONR Gulf of Mexico, 18-26 June, R/V Pelican, Multi-system time series cruise leg 2. (Sweeney, Orange & Garcia-Garcia)

Gulf of Mexico UNCLOS Mapping, 21 June – 8 July, R/V Northern Resolution. (Gardner)

NOAA Hydrographic Survey, 25 June – 13 July, R/V Gloria Michelle, H11636. (Moser & Forfinski)

Bay of Firth Submerged Landscapes, 4-13 July, M/V Girl Kilda, Orkney, Scotland. (Calder, Hogarth (GeoAcoustics), Hiller (GeoAcoustics), Forbes (SULA Diving), *Note: not technically a CCOM survey (no resources committed), but used CCOM's GeoSwath ICA loan time.*

ME70 Fisheries Sonar Assessment 9-13 July, R/V Bigelow. (de Moustier & Schmidt)

CCOM Hampton Harbor, Entrance Jetty, 10 July, R/V Gulf Challenger, Retrieve MET sensors from topside of day marker. (McGillicuddy, Ward & Irish)

Digital Coast Pilot prototype data collection, 12 July, R/V Cocheco. (Plumlee & Schwehr)

Stellwagen Bank Whale Tagging, and Tracking, 15-21 July, NOAA R/V Auk, track subsurface movements of tagged whales using UNH pingers. (Arsenault, Ware, Wiley & Weber*)*

IKB-Seistec Profiling System Survey, 17-20 July, R/V Cocheco, IKB-Seistec sub-bottom profiler survey of Portsmouth Harbor, NH. (Felzenberg, Mayer & Ward)

CCOM vicinity of 2KR, Entrance to Piscataqua River, 23 July, R/V Gulf Challenger, Shallow water 2008 field program – deploy navy objects. (McGillicuddy, Boduch &GC crew)

LIDAR feature detection, 25 July, R/V Cocheco, off Gerrish Island, ME to Water optical properties measurement – preparation for a planned USACE LIDAR survey. (Pe'eri, Gardner, Morrison, Novak, McLeod, & Smith).

Klein 5410 data acquisition for Marc Moser's MS thesis, 30 July – 7 August, R/V Coastal Surveyor. (Glynn, de Moustier & Moser)

Klein5410 data acquisition, August 2007, R/V Coastal Surveyor. (de Moustier& Moser)

Byzantium2007, 9-25 August, M/V Flamingo and R/V Alliance, AUV operations. (Arsenault)

Black Sea Archaeological Mapping, 5-22 August, R/V Alliance, Black Sea, Ukraine and Turkey. (CCOM's cast of thousands)

NOAA Hudson Canyon, New Jersey Margin, 8-24 August, R/V Ronald H. Brown, Eagle Ray AUV multibeam mapping cruise. (Rona & Sweeney)

Law of the Sea Mapping**,** 15 August- 17 September, USCGC R/V Healy, Barrow, AK. (Ware, Calder, Felzenberg, Fonseca, Mayer & Wardwell)

WHOI Bermuda Rise, 28 August – 14 September, R/V Knorr, WHOI Long Piston Core Test Cruise. (Broda, Curry & Sweeney)

Kongsberg EM 3002 data collection at State pier, Portsmouth NH, 23-28 September, R/V Coastal Surveyor, to assess the repeatability of the Multibeam backscatter data. (Malik)

Harbor Tracking Environmental Impact Study Portsmouth Harbor, October, R/V Coastal Surveyor. (Weber, Weirathmueller & Schmidt)

Hubbard Camera bottom videography survey, October, R/V Gulf Challenger, Continuation of long-term bottom videography survey of Open Ocean Aquaculture site. (Felzenberg)

NOAA Klein 5410 Bathy Training, 1-4 October, R/V Coastal Surveyor, training of NOAA personnel for setup and use of Klein 5410 in bathymetric survey. (Glynn)

CCOM Fort Point, Piscataqua River, 9-12 October, R/V Coastal Survey Harbor tracking field deployment node calibration. (McGillicuddy, Weber, Weirathmueller & Coastal Surveyor Crew)

Shallow Survey 2008 mapping (iXSea), 10 October, R/V Gulf Challenger, Portsmouth Harbor Approaches, Portsmouth NH. (Calder & McGillicuddy)

Dyson ME70 HAT/SAT, 15-20 October, NOAA R/V Oscar Dyson, ME70 Harbor Acceptance Test and Sea Acceptance Test. (Ressler & Weber)

CCOM Approaches to Portsmouth Harbor, Piscataqua River, 15-21 October, R/V Gulf Challenger, IXSEA SHADOWS demonstration and survey. (McGillicuddy)

Acceptance trials of EM 120 onboard University of Columbia, 20-27 October, R/V Marcus G. Langseth, Gulf of Mexico. (Malik)

CCOM Fort Point, Piscataqua River, 22-26 October, R/V Coastal Surveyor, Harbor tracking field deployment node calibration. (McGillicuddy, Weber, Weirathmueller & Coastal Surveyor Crew)

NOAA Klein 5410 Testing, 22-24 October, NOAA R/V Rude, Klein 5410 deployment and survey conducted under NOAA supervision. (Glynn & Locke)

Shallow Survey 2008 Mapping (Reson), 5-14 November, R/V Coastal Surveyor, Portsmouth Harbor Approaches, Portsmouth NH. (Calder, Smith, & Mutschler (Reson)).

Northern Marianas UNCLOS mapping, 15 November – 17 December, R/V USNS Bowditch. (Gardner)

Hubbard Camera bottom videography survey, 5 December, R/V Gulf Challenger, Bottom videography of White Island, NH for Mashkoor Malik dissertation. (Felzenberg & Malik)

APPENDIX C: OTHER FUNDING

Name	PI	Grantor	FY Award	Total Award	Length
AIS Broadcast for VTS	Alexander, L	US Coast Guard	51,547	51,547	11 months
Inland Elec. Navigational Chart	Alexander, L	US DOD Army	30,024	80,072	20 months
QPE Uncertainty	Calder, B	ONR	30,015	30,015	1 year
A Mobile Bentho-Pelagic	Mayer, L	Woods Hole Oceanographic Institution	65,722	200,471	2 years
Ocean Mapping Student Training 4th year	Mayer, L	GEBCO Foundation	510,000	2,080,961	4 years
Data Recovery	Mayer, L	Blodgett Foundation	20,000	20,000	1 year
Remote Identification	Mayer, L	ONR	84,491	216,387	1.5 years
Seafloor Mosaic Research	Mayer, L	USGS	10,000	30,000	3 years
Tyco Endowment	N/A	TYCO	38,088	Perpetuity	
Solar System Visualization	Schwehr, K	Jet Propulsion Laboratory	23,032	23,032	6 months
NHIRC- SkySkan Climate and Change	Ware, C	New Hampshire Industrial Research Center	25,975	25,975	1 year
EPSCOR-SkySkan	Ware, C	National Science Foundation	14,459	14,459	1 year
Bubble Clustering	Weber, T	Office of Naval Research	21,954	21,954	10 months
Cashes Ledge	Weber, T	Gulf of Maine Research Institute	4,500	4,500	6 months
GEBCO Gift Fund	Mayer, L	Blodgett Foundation	30,000	30,000	-
Graduate Fellowship		Anonymous donor	10,000	10,000	-
Total			969,807	2,839,373	

APPENDIX D: PAPERS, BOOKS, CONFERENCE PROCEEDINGS, ABSTRACTS, THESES, DIRECT RESEARCH PROJECTS, REPORTS, AND TALKS

JOURNAL ARTICLES

Alexander, L., Brown, M., Greenslad, B., and Pharaoh, A., 2007, Development of IHO S-100: The New IHO Geospatial Standard for Hydrographic Data: International Hydrographic Review, v. 8, p. 56-62.

Alexander, L., and Huet, M., 2007, Relationship of Marine Information Overlays (MIOs) to Current/Future IHO Standards: International Hydrographic Review, v. 8, p. 80-82.

Bekins, B., Spivak, A., Davis, E., and Mayer, L.A., 2007, Dissolution of Biogenic ooze over Basement Edifices in the Equatorial Pacific with Implications for Hydrothermal Ventilation of the Oceanic crust: Geology, v. 35, p. 679-682.

Calder, B.R., 2007, Multi-Algorithm Swath Consistency Detection for Multibeam Echosounder Data: International Hydrographic Review, v. 8, p. 5-22

Calder, B.R., and McLeod, M., 2007, High Precision Absolute Time Synchronization in Distributed Data Capture Systems: IEEE J. Oceanic Eng., v. 32, n. 4

Fonseca, L., and Mayer, L.A., 2007, Remote Estimation of Surficial Seafloor Properties through the Application Angular Range Analysis to Multibeam Sonar Data: Marine Geophysical Researches, v. 28, p. 119-126.

Gardner, J.V., Calder, B.R., Hughes Clarke, J.E., Mayer, L.A., Elston, G., and Rzhanov, Y., 2007, Drowned shelf-edge delta complexes and barrier islands and related features along the outer continental shelf north of the head of De Sotot Canyon, NE Gulf of Mexico: Geomorphology, v. 89, p. 370-390.

Gulick, S.P.S., Lowe, L.A., Pavlis, T., Mayer, L.A., and Gardner, J.V., 2007, New insights into the Transition Fault debate: Propagating strike-slip in response to stalled subduction in the Gulf of Alaska: Geology, v. 35 (8), p. 763-766.

Hecht, H., Kampfer, A., and Alexander, L., 2007, the WEND Concept for Worldwide ENC Database - Past or Future: A Review of Progress and a Look to the Future: International Hydrographic Review, v. 8, p. 73-79.

Jakobsson, M., Backman, J., Rudels, J., Nycander, J., Frank, M., Mayer, L. A., Jokat, W., Sangiorgi, F., O'Regan, M., Brinkhuis, H., King, J., and Moran, K., 2007, The Early Miocene onset of a Ventilated Circulation Regime in the Arctic Ocean: Nature, v. 447, p. 986-990.

Malik, M.A., and Mayer, L.A., 2007, Investigation of Seabed Fishing Impacts on Benthic Structure using Multi-beam Sonar, Sidescan Sonar, and Video: ICES Journal of Marine Science, v. 64, p. 1053-1065.

Mayer, L.A., Raymond, R., Glang, G., Richardson, M.D., Traykovski, P., and Trembanis, A., 2007, High Resolution Mapping of Mines and Ripples at the Martha's Vineyard Coastal Observatory: IEEE J. Oceanic Eng., v. 32, p. 133-149.

Monahan, D., 2007, GEBCO and Deep Water: data assembler, converter, interpreter and disseminator: Hydro International, v. 11, p. 7-9.

Pe'eri, S., and Philpot, W.D., 2007, Increasing the Existence of Very Shallow-Water LIDAR Measurements Using the Red-Channel Waveforms: IEEE Trans. Geo. Rem. Sens., v. 75 (5), p. 1217-1223.

Schwehr, K., and Alexander, L., 2007, Encoding AIS Binary Messages in CML Format for Providing Hydrographic-related Information: International Hydrographic Review, v. 8, p. 37-57.

Schwehr, K., Driscoll, N., and Tauxe, L., 2007, Origin of continental margin morphology: submarine-slide or downslope current-controlled bedforms, a rock magnetic approach: Marine Geology, v. 240, p. 19-41.

Stimpert, A.K., Wiley, D.N., Au, W.W.L., Johnson, M.P., and Arsenault, R., 2007, "Megapclicks": Acoustic Click Trains and Buzzes produced during night-time Foraging of Humpback Whales (Megaptera novaeangliae): Biol. Lett, v. 3 (5), p. 467-470.

Traykovski, P., Richardson, M.D., Mayer, L.A., and Irish, J.D., 2007, Mine Burial Experiments at the Martha's Vineyard Coastal Observatory: IEEE J. Oceanic Eng, v. 32, p. 150 -166.

Vorosmarty, C.J., Ericson, J.P., Dingman, S.L. and Ward, L.G., 2007. Future impacts of fresh water resource management: sensitivity of coastal deltas. International Association of Hydrological Sciences, v. 314, p. 231-238.

Weber, T.C., Lyons, A.P., and Bradley, D.L., 2007, Acoustic Propagation in Bubble Clouds Exhibiting Spatial Structure in the Fluctuating Number Density: IEEE J. Oceanic Eng, v. 32 (2), p. 513-523.

Wolfson, M.L., Naar, D.L., Howd, P.A., Locker, S.D., Donahue, B.T., Friedrichs, C.T., Trembanis, A., Richardson, M.D., and Wever, T.F., 2007, Multibeam Observations of Mine Burial near Clearwater, FL, including Comparisons to Predictions of Wave-Induced Burial: IEEE J. Oceanic Eng, v. 32 (1), p. 103-118.

BOOK SECTION

Monahan, D., 2007, Marine Charting by Canada, 1900-2000., in Monmonier, M., ed., History of Cartography Volume Six (Twentieth Century): Chicago, University of Chicago Press.

CONFERENCE PROCEEDINGS

Alexander, L., 2007, Electronic Navigational Charts and Marine Information Objects for Navigation Safety and Marine Environmental Protection, Pan American Institute for Geography and Hydrography, 12th Commission on Hydrography Conference: Veracruz, Mexico.

Alexander, L., 2007, Status Report on International Inland ENC Development and Standardization, 2007 RTCM Conference: St. Petersburg Beach, FL.

Braswell, R., Jacobi, M., and Schwehr, K., 2007, Portsmouth Harbor Response Initiative Web Interface, Coastal Response Research Center Workshop: Durham, NH.

Brennan, R., Gallagher, B., Riley, J., Schwehr, K., and Alexander, L., 2007, Tide-Aware ENC: Demonstration of an Operational Concept, US Hydrographic Society Conference: Norfolk, VA.

Calder, B.R., 2007, CCOM Research Brief 2006, NOAA Field Procedures Workshop: Virginia Beach, VA.

Calder, B.R., Forbes, B., and Mallace, D., 2007, Marine Heritage Monitoring with High Resolution Survey Tools: ScapaMAP 2001-2006, US Hydrographic Society Conference: Norfolk, VA.

Calder, B.R., LCDR Brennan, R.T., Malzone, C., Marcus, J., and Canter, P., 2007, Application of High-Precision Timing Systems to Distributed Survey Systems, US Hydrographic Society Conference: Norfolk, VA.

Calder, B.R., and McLeod, M., 2007, High-Precision Absolute Time Synchronization in Distributed Data Capture Systems, NOAA Field Procedures Workshop: Virginia Beach, VA.

Fonseca, L., and Calder, B.R., 2007, Clustering Acoustic Backscatter in the Angular Response Space, US Hydrographic Society Conference: Norfolk, VA.

Gardner, J.V., 2007, Bathymetry of West Mariana Ridge and Eastern Parece Vela Basin: a lot of surprises, Subduction factory studies in the Izu-Bonin-Mariana Arc System: Results and Future Plans Conference: Honolulu, HI.

Gardner, J.V., Mayer, L.A., and Armstrong, A.A., 2007, High Resolution Mapping in support of UNCLOS Article 76: Seeing the seafloor with new eyes. US Hydrographic Society Conference: Norfolk, VA, p. 12.

Huff, L.C., and Fonseca, L., 2007, A Surprise Occurrence in Acoustic Bottom Backscatter Measurements Conducted in the Eastern Bering Sea, US Hydrographic Society Conference: Norfolk, VA.

Lyons, A.P., and Weber, T.C., 2007, A Multibeam Sonar Survey for Benthic Lake Habitat: Assessing the Impact of Invasive Mussels in Seneca Lake, NY, 2nd International Conference Underwater Acoustic Measurements: Technologies and Results: Crete, Greece.

Lyons, A.P., Weber, T.C., and Gustafson, M.J., 2007, An Experimental Study on the Causes of Non-Rayleigh Scattered Envelope Statistics, 2nd International Conference Underwater Acoustic Measurements: Technologies and Results: Crete, Greece.

Malik, M.A., and Mayer, L.A., 2007, Assessing Bottom Gear Impact in the WGOM Closure Area: A Multifaceted Approach, Western Gulf of Maine Closure Area Symposium: Durham, New Hampshire.

Monahan, D., 2007, %? 5%? 10%? How much of the seafloor has ever been ensonified?, Bathymetric Science Day: Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York.

Monahan, D., 2007, five years of the General Bathymetric Chart of the Oceans, International Hydrographic Organization: Monaco, p. 1-18.

Monahan, D., and Jacob, C., 2007, History and Activities of GEBCO Guiding Committee, International Symposium on Application of Marine Geophysical Data and Undersea Features: Incheon, Korea.

Morgan, L.V., and Pe'eri, S., 2007, Quality Assurance of Airborne LIDAR Bathymetry Products for Shoreline Mapping, American Geophysical Union Fall Meeting: San Francisco, CA.

Niles, A., Birklhuber, L., Alexander, L., Kluytenaar, P., and Sekachev, V., 2007, European North American-Russian Federation Inland ENC Harmonization Group, US Hydrographic Society Conference: Norfolk, VA.

Pe'eri, S., Gardner, J.V., Ward, L.G., Morrison, R., and Lillycrop, J., 2007, Identifying Subtidal Coastal Environments using Airborne LIDAR Bathymetry (ALB), American Geophysical Union Fall Meeting: San Francisco, CA.

Pe'eri, S., Morgan, L., Philpot, W.D., and Guenther, G., 2007, LIDAR as a Shoreline Mapping Tool, U.S. Hydrographic Society Conference: Norfolk, VA.

Pohner, F., Ove Bakke, J., Eckholt Nilsen, K., Kjaer, T., and Fonseca, L., 2007,

Integrating Imagery from Hull Mounted Sidescan Sonars Multibeam Bathymetry, US Hydrographic Society Conference: Norfolk, VA.

Rzhanov, Y. and Gu, F., 2007. Enhancement of underwater video mosaics for post-processing, OCEANS 2007: Vancouver, Canada.

Schmidt, V., Weber, T.C., Ware, C., Arsenault, R., Wiley, D., Johnson, M., Dawe, E., and Friedlaender, A., 2007, Whale Tracking Underwater: High Frequency Acoustic Pingers and the Instrumented Tag (DTAG), 154th Meeting of the Acoustical Society of America: New Orleans, LA.

Schwehr, K., 2007, AIS Binary Messages, Domain Examples and A Case for a XML Message Definition Language, RTCM SC121 Working Group on Expanded use of AIS with VTS, USCG Puget Sound VTS: Seattle, WA.

Schwehr, K., and Alexander, L., 2007, Proposed AIS Binary Message Format Using XML for Providing Hydrographic-related Information, US Hydrographic Society Conference: Norfolk, VA.

Schwehr, K., 2007, Specification Format for AIS Binary Messages for Providing Hydrographic-related Information, US Hydrographic Society Conference: Norfolk, VA, p. 21.

Schwehr, K., and McGillivary, P., 2007, Marine Ship Automatic Identification (AIS) for Enhance Coastal Security Capabilities: An Oil Spill Tracking Application, Oceans 2007 MTS/IEEE Conference: Vancouver, B.C.

Weber, T.C., 2007, Multibeam Sonar Observations of Near-Surface Bubbles during a Storm, 154th Meeting of the Acoustical Society of America: New Orleans, LA.

Weber, T.C., Pena, H., and Bradley, D.L., 2007, Identifying Bubble Clustering: Comparisons of the Coherent and Incoherent Fields, 2nd International Conference Underwater Acoustic Measurements: Technologies and Results: Crete, Greece.

Weber, T.C., Pena, H., and Jech, M., 2007, Combining Single Frequency Multibeam with Multifrequency Single beam Sonars: an example with Atlantic Herring, 2nd International Conference Underwater Acoustic Measurements: Technologies and Results: Crete, Greece.

Weber, T.C., 2007, Multibeam and Single-Beam Sonar Observations of Atlantic Herring in the Gulf of Maine, 154th Meeting of the Acoustical Society of America: New Orleans, LA.

ABSTRACTS

Fonseca, L., Mayer, L.A., and Brown, G., 2007, Angular Range Analysis of the acoustic Backscatter from Stanton Banks, Ireland, Femme 2007 EM Multibeam Experience Conference: Amsterdam, Netherlands.

Gardner, J.V., Mayer, L.A., and Armstrong, A.A., 2007, Bathymetry Mapping for U.S. UNCLOS concerns: A Gold Mine for Marine Geology, American Geophysical Union Fall Meeting: San Francisco, CA.

Glynn Jr., J.M., de Moustier, C., and Huff, L., 2007, Clearance of Harbor Navigation Channels with High-Resolution Bottom Surveys, 153rd Meeting of the Acoustical Society of America: Salt Lake City, Utah.

Hazen, E.L., Friedlaender, A., Wiley, D., Thompson, M., Ware, C., and Weinrich, M., 2007, Oceanographic structuring of fish distribution and fine scale foraging of Humpback whales (Megaptera novaeangliae), Stellwagen Bank Marine Sanctuary, Society of Marine Mammalogy Conference: Scituate, MA.

Hazen, E.L., Friedlaender, A., Wiley, D., Thompson, M., Ware, C., and Weinrich, M., 2007, Three dimensional prey aggregations and fine scale foraging patterns of Humpback whales (Megaptera novaengliae), Stellwagen Bank Marine Sanctuary, ICES Annual Meeting: Scituate, MA.

Hou, T., Huff, L., and McConnaughey, R., 2007, Toward Quantitative Approach: Evaluating Impact of Bottom Trawls by Enhancing High-Resolution Side Scan Sonar Data Process, Marine Habitat Mapping Technology Workshop: Anchorage, AK.

Malik, M.A., Licciardi, J.M., Ward, L.G., and Mayer, L.A., 2007, Glacial Features in the Western Gulf of Maine Inferred from High Resolution Bathymetric Data, American Geophysical Union Fall Meeting: San Francisco, CA.

McGillicuddy, G., Huff, L., and McConnaughey, B., 2007, Brooke Ocean Technology's Free Fall Cone Penetrometer: Deployment Experience aboard the NOAA Ship Fairweather, US Hydrographic Society Conference: Norfolk, VA.

Pe'eri, S., Gardner, J.V., Ward, L.G., Morrison, R., and Lillycrop, J., 2007, The Seafloor as key Component for the Success of LIDAR in Bottom Detection, JALBTCX 8th Annual Workshop: Seattle, WA.

Pe'eri, S., and Mayer, L.A., 2007, Extending Airborne LIDAR Bathymetry (ALB) capabilities using Inelastic Scattering, FUDOTERAM Workshop: York University, York, ON Canada.

Rzhanov, Y., Mayer, L.A., Beaulieu, S., Soule, A., and Shank, T., 2007, The Generation of Georeferenced Video Mosaics in Support of Submersible and ROV Operations,

CenSeam Standardization Working Group and Data Analysis Working Group Meeting: Dartington Hall, Plymouth, U.K.

Rzhanov, Y., and Pe'eri, S., 2007, Mosaic Tools for LIDAR Surveying, JALBTCX 8th Annual Workshop: Seattle, WA.

Schmidt, V., 2007, An Exploration of Sound Speed Variability in the Artic and its Effect on Single-Beam Sonar, Arctic Science Summit Week: Dartmouth College, Hanover, NH.

Schwehr, K., Hatch, L., and Thompson, M., 2007, Google Earth Visualizations of the Marine Automatic Identification System (AIS): Monitoring Ship Traffic in National Marine Sanctuaries, American Geophysical Union Fall Meeting: San Francisco, CA.

Schwehr, K., Sullivan, B., and Gardner, J.V., 2007, Google Earth Visualizations: Preview and Delivery of Hydrographic and Other Marine Datasets, US Hydrographic Society Conference: Norfolk, VA.

Sweeney, E.M., Gardner, J.V., Mayer, L.A., and Johnson, J.E., 2007, Interpretations of a low-backscatter anomaly found in 12-kHz data on the U.S. Mid-Atlantic lower continental slope, The Geological Society of America: NE section: Durham, NH.

Vorosmarty, C.J., Ericson, J.P., Dingman, S.L. and Ward, L.G., 2007. Environmental monitoring of an experimental open ocean aquaculture facility in the western Gulf of Maine, Impacts of Coastal Ocean Aquaculture, American Fisheries Society Annual Meeting: San Francisco, CA.

Weirathmueller, M., Weber, T.C., Schmidt, V., McGillicuddy, G., Mayer, L.A., and Huff, L., 2007, Acoustic Positioning and Tracking in Portsmouth Harbor, New Hampshire, MTS/IEEE Oceans 2007: Vancouver, Canada.

THESES

Glynn Jr., J.M., 2007, Acoustic Calibration and Bathymetric Processing with an L-3 Klein 5410 Sidescan Sonar. [MS thesis]: Durham, University of New Hampshire.

Soares Rosa, L., A., 2007, Seafloor Characterization of the Historic Area Remediation Site using Angular Range Analysis. [MS thesis]: Durham, University of New Hampshire.

DIRECT RESEARCH PROJECTS

Forfinski, N., 2007, An Algorithm for Assessing the Horizontal Displacement Resulting from Raster-Based Bathymetric Generalization. [Direct Research Project]: Durham, University of New Hampshire.

Morgan, L.V., 2007, Development and Assessment of Airborne LIDAR Bathymetry Products for Shoreline Mapping. [Direct Research Project]: Durham, University of New Hampshire.

REPORTS

Alexander, L., 2007, Proposed Testbed/Demonstration Project on Production of Large-Scale ENCs in the MACH Region: Durham, New Hampshire, University of New Hampshire.

Alexander, L., 2007, Recommendation for Involving the Private Sector in Producing Small Scale ENCs from INT charts: Durham, New Hampshire, University of New Hampshire.

Alexander, L., and Carsey, M.J., 2007, Use of Portable Pilot Units by Maritime Pilots: Final Report: Montreal, QE, Canada, Laurentian Pilotage Authority, p. 39.

Alexander, L., and Casey, M.J., 2007, Use of Portable Pilot Units by Maritime Pilots: Draft Final Report: Montreal, QE, Laurentian Pilotage Authority, p. 26.

Gardner, J.V., 2007, U.S. Law of the Sea cruise to map the foot of the slope and 2500-m isobath of the Florida Escarpment and Sigsbee Escarpment, Northern Gulf of Mexico Continental Margin: Durham, University of New Hampshire, p. 40.

Gardner, J.V., 2007, U.S. Law of the Sea cruise to map the western insular margin and 2500-m isobath of Guam and the Northern Mariana Islands: Durham, University of New Hampshire, p. 44.

Mayer, L.A., Fonseca, L., Kraft, B.J., and Trembanis, A., 2007, Remote Identification of Seafloor Properties in Denied Areas, Office of Naval Research: Durham, University of New Hampshire.

Moser, M.S., 2007, H11636 Descriptive Report, Hydrographic Survey: Silver Spring, National Oceanic and Atmospheric Administration, p. 11.

Pe'eri, S., 2007, LADS sensor fusion, Durham, University of New Hampshire, p. 1.

Pe'eri, S., 2007, LIDAR theory study meeting and Navy LIDAR products (obstruction features) on NOAA charts, Durham, University of New Hampshire, p. 7.

Pe'eri, S., 2007, Shoreline mapping in RSD/NGS/NOAA, Durham, University of New Hampshire, p. 3.

Ward, L. G., Irish, J. D., and Grizzle, R., 2007, Environmental Monitoring Program: Progress Report to UNH/NOAA Atlantic Marine Aquaculture Center, Durham, NH, University of New Hampshire.

TALKS

Alexander, L., "Electronic Charting: Present Challenges, Future Opportunities." Seminar at 2007 Mariners Workshop, Port of Montreal, Montreal, Canada. 6-7 February 2007.

Alexander, L., "Future IHO Geospatial Standard for Hydrographic Data: S-100", "Europe – North America – Russian Federation - Inland ENC Harmonization Group", "Marine Information Overlays." Seminar/workshop series on Electronic Charting at PAIGH, 12th Commission on Hydrography Conference, Veracruz, Mexico. 7-9 March 2007.

Dean, G., L. Alexander, and R. Ponce., "Pilot Project on Production of ENCs in Cooperation with Private Sector." Seminar presentation at PAIGH, 12th Commission on Hydrography Conference, Veracruz, Mexico. 7-9 March 2007.

Niles, A. and L. Alexander, "Inland ENCs: International Development and Standardization." Seminar/Workshop at 2007 US Hydrographic Conference, Norfolk, VA. 17 May 2007.

Alexander, L., "Electronic Charting and e-Navigation: Challenges and Opportunities." Presentation at IALA e-Navigation Seminar, London. 4 July 2007.

Alexander, L., "Electronic Charting and e-Navigation: Challenges and Opportunities." Presentation at IALA e-Navigation Seminar, Tokyo, Japan. 29 October 2007.

Alexander, L., "Electronic Charting and e-Navigation: Challenges and Opportunities." Presentation at 3rd ECDIS Stakeholders Forum, Rotterdam, the Netherlands. 7 November 2007.

Armstrong, A., "2007 Activity Report for the NOAA/UNH Joint Hydrographic Center" 36th Joint Meeting, UJNR Sea Bottom Surveys Panel, Honolulu, HI. 4-6 December 2007.

Armstrong, A., and J. V. Gardner, "United States UNCLOS Surveys in 2007" 36th Joint Meeting, UJNR Sea Bottom Surveys Panel, Honolulu, HI. 4-6 December 2007.

Arsenault, R., "The Life Autonomous with Doerri, the AUV." CCOM Seminar Series, University of New Hampshire, Center for Coastal and Ocean Mapping/ NOAA-Joint Hydrographic Center, Durham, NH. 5 October 2007.

Calder, B.R., "Processing Multibeam Data." Seminar/Workshop at the 2007 US Hydrographic Conference, Norfolk, VA. 17 May 2007 [Invited].

Calder, B.R., "Aligning CUBE to Phase Measuring Bathymetric Systems." GeoAcoustics Seminar, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 24 May 2007 [Invited].

Calder, B.R., "An Introduction to CUBE: Processing for High-Resolution, High-Rate MBES Data." GEBCO Students Bathymetry Class, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 02 May 2007 [Invited].

Calder, B.R., "Seafloor Characterization Class." University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. [Spring Semester 2007].

Calder, B.R., "Statistical Theory of Communications Class." University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. [Spring Semester 2007].

Calder, B.R., "What Else Can You Do With Ocean Mapping?" Orkney College, Kirkwall, Orkney, Scotland. 9 July 2007 [Public, Invited].

Calder, B.R., "Marine Heritage Monitoring with High Resolution Survey Tools." USCGC HEALY. 07 September 2007.

Calder, B.R., "Bathymetric Uncertainty, Part 1." CCOM/JHC Graduate Student Seminar, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 31 October 2007 [Invited].

Case, J., "CCOM Data Management Update." Seminar Presentation, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. May 2007.

Fonseca, L., "Fundamentals of Seafloor Backscatter Mapping with Multibeam and Sidescan Sonars." Short Course- NOAA, Norfolk, VA. 28-30 January 2007.

Fonseca, L., "Remote Acoustic Seafloor Characterization." aSeminar, Centre interdisciplinaire de développement en cartographie des océans (CIDCO), Rimouski, Quebec, Canada. 26-28 February 2007 [Invited].

Gardner, J.V., "Law of the Sea Mapping Program Overview." Presented to visiting group from India, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 20 August 2007.

Gardner, J.V., "Overview of Center for Coastal and Ocean Mapping/ NOAA-Joint Hydrographic Center." Presented to Rob Mollar, Legislative Director for Congresswoman Shea-Porter, University of New Hampshire, Durham, NH. 23 August 2007.

Gardner, J.V., "Overview of the Law of the Sea Mapping." Presented to U.S. National Committee on Census of Marine Life, University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham**,** NH. 9 October 2007.

Gardner, J.V., "UNCLOS (Law of the Sea) Bathymetry Mapping." Presented to U.S. MG&G Data Systems Advisory Committee, Lamont-Doherty, Earth Observatory, Palisades, NY. 23-24 October 2007.

Glynn, Jr., J.M., "Acoustic Calibration and Bathymetric Processing with an L-3 Klein 5410 Sidescan Sonar." Master's Thesis Defense: Center for Coastal and Ocean Mapping/NOAA- Joint Hydrographic Center, University of New Hampshire, Durham, NH. 12 April 2007.

Mayer, L. A., "Delimiting the Outer Boundary of the U.S. Extended Continental Shelf." NOAA Office of General Counsel 2007 International Law Training Seminar, Silver Spring, MD. 31 January 2007 [Invited].

Mayer, L. A., "New Directions in Seafloor Mapping and Data Visualization." Portsmouth Propeller Club, Portsmouth, NH. 15 February 2007 [Invited lecture].

Mayer, L. A., "New Directions in Seafloor Mapping and Data Visualization." University of New England, Bidderford, ME. 16 February 2007[Invited Seminar].

Mayer, L. A., "Multibeam Echosounding as a Tool for Fisheries Habitat Studies." Mayer, L.A. and Fonseca, L., Marine Habitat Mapping Technology Workshop, Anchorage AK. 2 April 2007 [Invited Lecture].

Mayer, L. A., "New Views of Seafloors and Tsunamis: Interactive Visualization of Geospatial Data." Institute for Pure and Applied Math, Univ. of Calif. Los Angeles, CA. 21 May 2007 [Invited Seminar].

Mayer, L. A., "Progress on U.S. Mapping in Support of an Extended Continental Shelf." Task Force on U.S. Extended Continental Shelf, Washington D.C. 29 May 2007 [Invited Presentation].

Mayer, L. A., "Testimony to House Subcommittee on Fisheries Wildlife and Oceans." Washington, D.C. 5 June 2007.

Mayer, L. A., "Hydrography: It's not just for charting anymore." Capital Hill Oceans Week, Washington, D.C. 6 June 2007 [Invited Presentation].

Mayer, L. A., "Changing Perspectives of the Seafloor – Geologischce Vereiningung e.V." Bremen, Germany. 4 October 2007 [Invited Plenary Lecture].

Mayer, L. A., "New Directions in Seafloor Mapping and Visualization." InWaterTec: International Conference on Marine Technologies, Kiel, Germany. 10 October 2007 [Invited Plenary Lecture].

Monahan, D., "Satellite Altimetry, Bathymetry and the Boundaries of

Nations." Royal Military College, Kingston, Ontario, Canada. 17 March 2007.

Monahan, D., "Boundaries created by the United Nations Convention on the Law of the Sea (UNCLOS)." Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, NB, Canada. 13 November 2007.

Pe'eri, S., "Extending Airborne LIDAR Bathymetry (ALB) Capabilities Using Inelastic Scattering." University New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 6 April 2007.

Schwehr, K., "Exploration Visualization" Seminar Presentation: Univ. of New Hampshire Computer Science Graduate Seminar Series, Durham, NH. 19 February 2007.

Schwehr, K. "Introduction to Python" Seminar Presentation: University of New Hampshire, Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, Durham, NH. 30-31 January 2007, 13 March 2007, 05 March 2007, 3 April 2007.

deJong, Andres, and Schwehr, K., "Mars Program Science Office Overview Discussion and Status Report of the Mars Visualization Pipeline." Present to Dr. Richard Zurek and Charles Budney, Mars Science Office Manager, Presented results from the Mars Reconnaissance Orbiter Image Viewer and adapting the UNH/NOAA Digital Coast Pilot for navigation on the Mars surface, Pasadena, CA. 16 October 2007. (Mars Program is managed by JPL/CalTech for NASA).

Ware, C., "Cognitive Tools and First Order Cognitive Modeling for Data Visualization" Rensselaer Polytechnic Institute, Distinguished Speaker Series: Troy, NY. 7 November 2007.

Ware, C., "Effective Flow Visualization." NOAA Hazmat Group: Seattle, WA.
7 May 2007.

Ware, C. "Networks and Stereo." The National Center for Microscopy and Imaging Research (NCMIR): University of California San Diego, CA. 11 April 2007

Ware, C., "Patterns and Words: Logic and Narrative: What can we expect of a visual language?" Visual Languages Conference: Coeur d'Alene, Idaho. 24 September 2007.

Ware, C., "Space, Time, Whales and Simple Cognitive Models of Data Visualization." Institute for Software Visualization Distinguished Speaker Series: University of California-Irvine, CA. 13 April 2007.

Ware, C. "Update on UNH Flow Visualization Projects." NOAA Silver Spring, MD.
9 February 2007.

Weber, T., "Water column imaging with Multibeam sonars." Gulf of Maine Research Institute, Portland, ME. 13 December 2007 [Invited].

APPENDIX E: MEETINGS AND CONFERENCES ATTENDED

Alexander, L., U.S. Army Corps of Engineers FY2007 IENC Program Review, Tampa, FL. 8-10 Jan 2007.

Alexander, L., 2007 Mariner's Workshop, Port of Montreal, Montreal, Canada. 6-7 February 2007.

Alexander, L., Development of MIOs for Sea Ice Coverage in Canadian Waters: Project Review, Ottawa, Ontario. 8 February 2007.

Alexander, L., 2007 Annual Meeting of RTCM SC-109 (Electronic Charting), St. Petersburg, FL. 8 May 2007.

Alexander, L., (Chair) 4th Meeting of Harmonization Group on MIOs (HGMIO), CCOM-JHC, University of New Hampshire, Durham, NH. 22-23 May 2007.

Alexander, L., 14th Meeting of IHO Transfer Standard Maintenance Activity Development (TSMAD) Working Group. UK Hydrographic Office, Taunton, UK.
4-8 June 2007.

Alexander, L., US Coast Guard VTS/AIS Program Review, Syracuse, NY.
11-13 June 2007.

Alexander, L., (Co-Chair) RTCM SC 121, Use of AIS for Expanded VTS Working Group, Arlington, VA. 1 October 2007.

Alexander, L., 8th IHO Mesoamerican – Caribbean Sea Hydro Commission (MACHC), Niteroi, Brazil. 8-9 October 2007.

Alexander, L., Europe – 4th North America – Russian Federation Inland ENC Harmonization Group (IEHG), Niteroi, Brazil. 10-12 October 2007.

Alexander, L., 19th Meeting of IHO Committee on Hydrographic Resource Information Systems (CHRIS), Rotterdam, The Netherlands. 4-9 November 2007.

Alexander, L., Technical Workshop on Hydro Surveying for Fluvial Navigation, Iquitos, Peru. 14-16 November 2007.

Calder, B.R., ONR Quantifying, Predicting and Exploiting Uncertainty DRI Planning meeting, Arlington, VA. 18-19 June 2007.

Calder, B.R., Open Navigation Surface Working Group. Discussion of current development plans, and new data models being proposed by NAVO, Norfolk, VA. 16 May 2007.

Calder, B.R., UNH Marine Program Information Day. Presentation of information on CCOM to Undergraduate students, University of New Hampshire, Durham, NH. 22 October 2007.

Calder, B.R., GIS Day. Presentation of work of Center for Coastal and Ocean Mapping/NOAA-Joint Hydrographic Center, to general public, University of New Hampshire, Durham, NH. 14 November 2007.

Case, J., Oceans 2007 Vancouver, BC, Canada. 29 September – 4 October 2007.

Case, J., Moser, M., IWG-OCM Meeting, CSC/NOAA, Charleston, SC. 11-14 September 2007.

de Moustier, C., IEEE Oceanic Engineering Society, Executive Committee meetings, Falls Church, VA. 3 February 2007.

de Moustier, C., IEEE Oceanic Engineering Society, Administrative Committee meeting Monday June 18, 2007, Aberdeen, Scotland , Sep. 29, 2007, Vancouver, BC, Canada.

de Moustier, C., IEEE Publications Services and Products Board, Universal City, CA. 15-16 February 2007, Philadelphia, PA.14-15 June 2007, Boston, MA.15-16 November 2007.

de Moustier, C., IEEE Panel of Editors Annual meeting, Chicago, IL. 27-28 April 2007.

de Moustier, C., U.S. Hydro 2007 conference, Norfolk, VA.14-16 May 2007.

de Moustier, C., Acoustical Society of America, spring meeting, Salt Lake City, UT. 4-7 June 2007.

de Moustier, C., IEEE/MTS OCEANS '07 conference, Vancouver, BC, Canada. 2 9 Sep 29 - 4 October 2007.

de Moustier, C., L3-Klein review of swath bathymetry prospects for Klein 5410 sonar Salem, NH. 30 May 2007.

Felzenberg, J., Northeastern Section GSA 42 Annual meeting, University of New Hampshire Durham, NH. 12-14, March 2007.

Monahan, D., GEBCO Nippon Foundation Training Management Committee, Paris, France. 6 November, 2007.

Monahan, D., GEBCO Guiding Committee, Paris, France, 7-8 November, 2007.

Moser, M., Interagency Workgroup for Ocean and Coastal Mapping, Charleston, SC. 11-14 September 2007.

McGillicuddy, G., UNH Alternative Energy Meeting, University of New Hampshire, Durham, NH. 8 November 2007.

Pineo, D., 2007 IEEE Visualization Conference, Sacramento, California.
28th October – 1st November 2007.

Schmidt, V., Arctic Science Summit Week, Dartmouth College, Hanover, NH. 14-20 March 2007.

Schmidt, V., 154th Annual meeting of the Acoustical Society of America, New Orleans, LA. 27-30 November 2007.

Schwehr, K, Geologic Society of America, New East Section Meeting, Durham, NH. 12-13 March 2007.

Schwehr, K., Environmental Response Data Collection Standard, Durham, NH.
25-27 September 2007. Was a group lead for the discussion.

Schwehr, K., eNavigation 2007, Seattle, WA. 13-14 November 2007.

Sullivan, B., 3rd Shallow Water Survey Conference, Board meeting, Durham, NH.
9 January 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 24 January 2007.

Sullivan, B., Marine Communications meeting, Durham, NH. 1 March 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 20 March 2007.

Sullivan, B., Shallow Water Survey Conference, Board meeting, Durham, NH.
9 April 2007.

Sullivan, B., Marine Communications meeting, Durham, NH. 10 May 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 14 June 2007.

Sullivan, B., Shallow Water Survey Conference, Board meeting, Durham, NH. 15 June 2007.

Sullivan, B., SkyScan meeting, Manchester, NH. 31 July 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 23 August 2007.

Sullivan, B., Anchor Publication meeting, Durham, NH. 30 August 2007.

Sullivan, B., Shallow Survey Committee meeting, Durham, NH. 27 September 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 27 September 2007.

Sullivan, B., Anchor Publication meeting, Durham, NH. 3 October 2007.

Sullivan, B., Marine Program Student Information Fair, Durham, NH. 22 October 2007.

Sullivan, B., CEPS PR Committee meeting, Durham, NH. 25 October, 2007.

Sullivan, B., Shallow Survey Committee meeting, Durham, NH. 29 October 2007.

Sullivan, B., Healy0703 data status meeting, Durham, NH. 31 October 2007.

Sullivan, B., GIS Day 2007, Durham, NH. 14 November, 2007.

Sullivan, B., Anchor Publication Meeting, Durham, NH. 20 November 2007.

Sullivan, B., CEPS PR Committee Meeting, Durham, NH. 29 November 2007.

Sullivan, B., Anchor Publication Meeting, Durham, NH. 12 December 2007.

Sullivan, B., CEPS PR Committee Meeting, Durham, NH. 20 December 2007.

Weber, T., ONR Fish Acoustics Science Review, Plymouth, MA. 1-2 November 200