Performance and Progress Report

NOAA Grant No: NA10NOS4000073

Project Title: Joint Hydrographic Center
Report Period: 01/01/2016 – 12/31/2016

Principal Investigator: Larry A. Mayer

CONTENTS

PERFORMANCE AND PROGRESS REPORT

UNH/NOAA Joint Hydrographic Center
NOAA Grant No: NA10NOS4000073
Report Period: 01/01/2016 – 12/31/2016
Principal Investigator: Larry A. Mayer

INTRODUCTION

On 4 June 1999, the Administrator of NOAA and the President of the University of New Hampshire signed a memorandum of understanding that established a Joint Hydrographic Center (JHC) at the University of New Hampshire. On 1 July 1999, a cooperative agreement was awarded to the University of New Hampshire that provided the initial funding for the establishment of the Joint Hydrographic Center. This Center, the first of its kind to be established in the United States, was formed as a national resource for the advancement of research and education in the hydrographic and ocean-mapping sciences. In the broadest sense, the activities of the Center are focused on two major themes: a research theme aimed at the development and evaluation of a wide range of state-of-the-art hydrographic and ocean-mapping technologies and applications, and an educational theme aimed at the establishment of a learning center that promotes and fosters the education of a new generation of hydrographers and ocean-mapping scientists to meet the growing needs of both government agencies and the private sector. In concert with the Joint Hydrographic Center, the Center for Coastal and Ocean Mapping was also formed in order to provide a mechanism whereby a broader base of support (from the private sector and other government agencies) could be established for ocean-mapping activities.

The Joint Hydrographic Center was funded by annual cooperative agreements from July 1999 until 31 December 2005. In 2005, a five-year cooperative agreement was awarded with an ending date of 31 December 2010. In January 2010, a Federal Funding Opportunity was announced for the continuation of a Joint Hydrographic Center beyond 2010. After a national competition, the University of New Hampshire was selected as the recipient of a five-year award funding the Center for the period of 1 July 2010 until December 2015. In March 2015, a Federal Funding Opportunity announced for the continuation of a Joint Hydrographic Center beyond 2015. Again, after a national competition, the University of New Hampshire was selected as the recipient of another five-year award, funding the Center for the period of 1 January 2016 until December 2020. Progress on the new award will be reported in a separate report; this report presents only the final activities of the 2010-2015 grant, carried out in calendar year 2016 under a no-cost extension to that grant and thus this report does not represent the full breadth of activities carried out by the Center for NOAA in 2016.

This report is the twenty-first in a series of what were, until December 2002, semi-annual progress reports. Since December 2002, the written reports have been produced annually; this report provides an overview of the activities of the Joint Hydrographic Center funded by Grant Number NA10NOS4000073 during the period between 1 January and 31 December 2016. As such, it represents the seventh written progress report for Grant NA10NOS4000073, but unlike previous reports, represents only a portion of the activities carried out at the Center with NOAA support. The remaining activities

can be found in the progress report for NOAA grant NA15NOS4000200 which is available from the Center's website, http://www.ccom.unh.edu. Copies of previous reports and more detailed information about the Center can also be found on the Center's website. More detailed descriptions of many of the research efforts described herein can be found in the individual progress reports of Center researchers that are available on request.

INFRASTRUCTURE

PERSONNEL

The Center has grown, over the past 15 years, from an original complement of 18 people to more than 90 faculty, staff and students. Our faculty and staff have been remarkably stable but as with any large organization, inevitably, there are changes. In 2016, **Jennifer Miksis-Olds**, joined our research faculty, expanding our growing depth in marine acoustics and bringing critically needed expertise in bio-acoustics. **Firat Eren** moved from his position as the Tyco Post-Doctoral Scholar to a member of our research staff and **Christian Stranne** joined us from the University of Stockholm as a Visiting Scholar. **Vicki Ferrini,** and **Neil Weston** have joined our affiliate faculty and **Wendy Monroe has joined** our administrative staff. **Shachak Pe'eri** rejoined his family in Maryland and took a full-time position with NOAA, though he remains an affiliate faculty member. **Victoria Price** and **Samantha Bruce** of our Super Storm Sandy team (a project which came to an end in 2016), left for positions with one of our industrial partners. Most sadly **Ben Smith**, the Captain of our research vessel, passed away this year after a brief but valiant fight with cancer. Ben was a mentor and a friend to us all – he will be missed terribly.

FACULTY

Thomas Butkiewicz received a Bachelor of Science degree in Computer Science in 2005 from Ithaca College where he focused on computer graphics and virtual reality research. During his graduate studies at The University of North Carolina at Charlotte, he designed and developed new interactive geospatial visualization techniques, receiving a Masters in Computer Science in 2007 and a Ph.D. in Computer Science in 2010. After a year as a research scientist at The Charlotte Visualization Center, he joined CCOM as a post-doctoral research fellow in 2011. In 2012, he joined the faculty as a research assistant professor.

Tom specializes in creating highly interactive visualizations that allow users to perform complex visual analysis on geospatial datasets through unique, intuitive exploratory techniques. His research interests also include multi-touch and natural interfaces, virtual reality, stereoscopic displays, and image processing/computer vision. His current research projects include visual analysis of 4D dynamic ocean simulations, using Microsoft's Kinect device to enhance multi-touch screens and provide new interaction methods, multi-touch gesture research, and developing new interface approaches for sonar data cleaning.

Brian Calder graduated with an M.Eng (Merit) and a Ph.D in Electrical and Electronic Engineering in 1994 and 1997 respectively, from Heriot-Watt University, Scotland. His doctoral research was in

Bayesian statistical methods applied to processing of sidescan sonar and other data sources, and his post-doctoral research included investigation of high-resolution seismic reconstruction, infrared data simulation, high-resolution acoustic propagation modeling and real-time assessment of pebble size distributions for mining potential assessment. Brian joined CCOM as a founding member in 2000, where his research has focused mainly on understanding, utilizing and portraying the uncertainty inherent in bathymetric data, and in efficient semi-automatic processing of high-density multibeam echosounder data. He is a Research Associate Professor, and Associate Director of CCOM, the Chair of the Open Navigation Surface Working Group, and a past Associate Editor of IEEE Journal of Oceanic Engineering.

Jenn Dijkstra received her Ph.D. in Zoology in 2007 at the University of New Hampshire, has a B.A. from the University of New Brunswick (Canada), and a M.S. in Marine Biology from the University of Bremen (Germany). She has conducted research in a variety of geographical areas and habitats, from polar to tropical and from intertidal to deep-water. Her research incorporates observation and experimental approaches to address questions centered around the ecological causes and consequences of human-mediated effects on benthic and coastal communities. Her research at CCOM focuses on the use of remote sensing (video and multibeam) to detect and characterize benthic communities**.**

Semme Dijkstra is a hydrographer from the Netherlands who has several years of hydrographic experience with both the Dutch Navy and industry. Semme in Canada. His thesis work involved artifact removal from multibeam-sonar data and development of an echosounder processing and sediment classification system. From 1996 to 1999, Semme worked at the Alfred Wegner Institute in Germany where he was in charge of their multibeam-sonar data acquisition and processing. Semme's current research focuses on applications of single-beam sonars for seafloor characterization, small object detection and fisheries habitat mapping. In 2008, Semme was appointed a full-time instructor and he has taken a much larger role in evaluating the overall CCOM curriculum, the development of courses and teaching. In 2016, Semme's position the University re-classified Semme's position to Research Scientist, however, he maintains his active role in teaching and curriculum development.

Jim Gardner is a marine geologist focused on seafloor mapping, marine sedimentology, and paleoceanography. He received his Ph.D. in Marine Geology from the Lamont Doherty Earth Observatory of Columbia University in 1973. He worked for 30 years with the Branch of Pacific Marine Geology at the U.S. Geological Survey in Menlo Park, CA where he studied a wide variety of marine sedimentological and paleoceanographic problems in the Bering Sea, North and South Pacific Ocean, northeast Atlantic Ocean, Gulf of Mexico, Caribbean and Mediterranean Seas, and the Coral Sea. He conceived, organized, and directed the 8-year EEZ-SCAN mapping of the U.S. Exclusive Economic Zone using GLORIA long-range sidescan sonar in the 1980s; participated in four Deep Sea Drilling Project cruises, one as co-chief scientist; participated in more than 50 research cruises, and was Chief of Pacific Seafloor Mapping from 1995 to 2003, a project that used high-resolution multibeam echosounders to map portions of the U.S. continental shelves and margins. He also mapped Lake Tahoe in California and Crater Lake in Oregon. Jim was the first USGS Mendenhall Lecturer, received the Department of Interior Meritorious Service Award and received two USGS Shoemaker Awards. He has published more than 200 scientific papers and given an untold number of talks and presentations all over the world. Jim retired from the U.S. Geological Survey in 2003 to join CCOM/UNH.

Jim was an Adjunct Professor at CCOM/UNH from its inception until he moved to UNH in 2003 when he became a Research Professor affiliated with the Earth Science Dept. At JHC/CCOM, Jim is in charge of all non-Arctic U.S. Law of the Sea bathymetry mapping cruises and is involved in research methods to extract meaningful geological information from multibeam acoustic backscatter through ground truth and advanced image analysis methods. Jim was awarded the 2012 Francis P. Shepard Medal for Sustained Excellence in Marine Geology by the SEPM Society of Sedimentary Geology. Jim has taught Geological Oceanography—ESCI 759/859 and the Geological Oceanography module of Fundamentals of Ocean Mapping-ESCI 874/OE 874.01. In 2013, Jim reduced his effort to half-time.

John Hughes Clarke is a Professor jointly appointed in the departments of Earth Sciences and Mechanical Engineering. For the past 15 years, John was the Chair in Ocean Mapping at the University of New Brunswick in Canada where he was a Professor in the department of Geodesy and Geomatics Engineering. During that period, he also ran the scientific seabed mapping program on board the CCGS *Amundsen* undertaking seabed surveys of the Canadian Arctic Archipelago. As a compliment to his research and teaching he has acted as a consultant, formally assessing the capability of the hydrographic survey vessels of the New Zealand, Australian, British and Dutch Navies as well as the U.S. Naval Oceanographic Office TAGS fleet. For the past 21 years John, together with Larry Mayer, Tom Weber and Dave Wells, has delivered the Multibeam Training Course that is presented globally three times per year. This is the world's leading training course in seabed survey and is widely attended by international government and commercial offshore survey personnel as well as academics. John was formally trained in geology and oceanography in the UK and Canada (Oxford, Southampton and Dalhousie). He's spent the last 27 years, however, focusing on ocean mapping methods. His underlying interest lies in resolving seabed sediment transport mechanisms.

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

Tom Lippmann is an Associate Professor with affiliation in the Department of Earth Sciences, Marine Program, and Ocean Engineering Graduate Program, and is currently the Director of the Oceanography Graduate Program. He received a B.A. in Mathematics and Biology from Linfield College (1985), and an M.S. (1989) and Ph.D. (1992) in Oceanography at Oregon State University. His dissertation research conducted within the Geological Oceanography Department was on shallow water physical oceanography and large-scale coastal behavior. He went on to do a Post Doc at the Naval Postgraduate School (1992-1995) in Physical Oceanography. He worked as a Research Oceanographer at Scripps Institution of Oceanography (1995-2003) in the Center for Coastal Studies. He was then a Research Scientist at Ohio State University (1999-2008) jointly in the Byrd Polar Research Center and the Department of Civil and Environmental Engineering & Geodetic Science. Tom's research is focused on shallow water oceanography, hydrography, and bathymetric evolution in coastal waters spanning inner

continental shelf, surf zone, and inlet environments. Research questions are collaboratively addressed with a combination of experimental, theoretical, and numerical approaches. He has participated in 20 nearshore field experiments and spent more than two years in the field.

Anthony P. Lyons received the B.S. degree (summa cum laude) in physics from the Henderson State University, Arkadelphia, AR, in 1988 and the M.S. and Ph.D. degrees in oceanography from Texas A&M University, College Station, TX, in 1991 and 1995, respectively. He was a Scientist at the SACLANT Undersea Research Centre, La Spezia, Italy, from 1995 to 2000, where he was involved in a variety of projects in the area of environmental acoustics. Tony was awarded, with the recommendation of the Acoustical Society of America, the Institute of Acoustics' (U.K.) A.B. Wood Medal in 2003. He is a Fellow of the Acoustical Society of America and a member of the IEEE Oceanic Engineering Society. He is also currently an Associate Editor for the *Journal of the Acoustical Society of America* and is on the Editorial Board for the international journal *Methods in Oceanography*. Tony conducts research in the field of underwater acoustics and acoustical oceanography. His current areas of interest include high-frequency acoustic propagation and scattering in the ocean environment, acoustic characterization of the seafloor, and quantitative studies using synthetic aperture sonar.

Giuseppe Masetti received an M.Eng. degree in Ocean Engineering (ocean mapping option) from the University of New Hampshire in 2012, and a Master's in marine geomatics (with honors) and a Ph.D. degree in system monitoring and environmental risk management from the University of Genoa, Italy, in 2008 and 2013, respectively. In addition, he graduated (with honors) in Political Sciences from the University of Pisa, Italy, in 2003 and in Diplomatic and International Sciences from the University of Trieste, Italy, in 2004. Giuseppe achieved the FIG/IHO Category A certification in 2010, and he is member of IEEE and THSOA.

He has served with the Italian Navy since 1999, and he has been Operations Officer aboard the hydrographic vessels ITN *Aretusa* and ITN *Magnaghi*. From August 2013, he was a Tyco Post-Doctoral Fellow with the Center, where he focused on signal processing for marine target detection. He joined the faculty as a Research Assistant Professor in January 2016.

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

Jennifer Miksis-Olds is the Associate Director of Research and Research Professor in the School of Marine Science & Ocean Engineering at the University of New Hampshire, also holding a research position in the Center for Coastal and Ocean Mapping. Jenn is the university Member Representative and on the Board of Trustees of the Consortium for Ocean Leadership. She is a member of the Scientific Committee of the International Quiet Ocean Experiment Program and serves as a Scientific Advisor to

the Sound and Marine Life Joint Industry Programme (International Oil & Gas Producers) which is devoted to the study of effects of sound on marine organisms. Jenn was the recipient of an Office of Naval Research Young Investigator Program award in 2011 and the Presidential Early Career Award in Science and Engineering in 2013. She is also a newly elected Fellow in the Acoustical Society of America. Jenn received her A.B. cum laude in Biology from Harvard University, her M.S. in Biology from the University of Massachusetts Dartmouth; she was a guest student at Woods Hole Oceanographic Institution, and then received her Ph.D. in Biological Oceanography from the University of Rhode Island.

David Mosher is a Professor in the Dept. of Earth Sciences and the Center for Coastal and Ocean Mapping at the University of New Hampshire. He graduated with a Ph.D. in geophysics from the Oceanography Department at Dalhousie University in 1993, following a M.Sc. in Earth Sciences from Memorial University of Newfoundland in 1987 and a B.Sc. at Acadia in 1983. In 1993, he commenced work on Canada's West Coast at the Institute of Ocean Sciences, in Sidney on Vancouver Island, studying marine geology and neotectonics in the inland waters of British Columbia. In 2000, he took a posting at Bedford Institute of Oceanography. His research focus was studying the geology of Canada's deep water margins, focusing on marine geohazards using geophysical and geotechnical techniques. From 2008 to 2015, he was involved in preparing Canada's submission for an extended continental shelf under the Law of the Sea (UNCLOS) and, in this capacity, he led four expeditions to the high Arctic. In 2011, he became manager of this program and was acting Director from 2014. In 2015, he joined UNH to conduct research in all aspects of ocean mapping, focusing on marine geohazards and marine geoscience applications in Law of the Sea. He has participated in over 45 sea-going expeditions and was chief scientists on 27 of these.

Yuri Rzhanov, a Research Professor, has a Ph.D. in Physics and Mathematics from the Russian Academy of Sciences. He completed his thesis on nonlinear phenomena in solid state semiconductors in 1983. Since joining the Center in 2000, he has worked on a number of signal processing problems, including construction of large-scale mosaics from underwater imagery, automatic segmentation of acoustic backscatter mosaics, and accurate measurements of underwater objects from stereo imagery. His research interests include development of algorithms and their implementation in software for 3D reconstruction of underwater scenes, and automatic detection and abundance estimation of various marine species from imagery acquired from ROVs, AUVs, and aerial platforms.

Larry Ward has an M.S. (1974) and a Ph. D. (1978) from the University of South Carolina in Geology. He has over 30 years' experience conducting research in shallow water marine systems. Primary interests include estuarine, coastal, and inner shelf morphology and sedimentology. His most recent research focuses on seafloor characterization and the sedimentology, stratigraphy and Holocene evolution of nearshore marine systems. Present teaching includes a course in Nearshore Processes and a Geological Oceanography module.

Colin Ware is a leading scientific authority on the creative invention, and the scientifically sound, correct use of visual expressions for information visualization. Ware's research is focused on applying an understanding of human perception to interaction and information display. He is author of Visual Thinking for Design (2008) which discusses the science of visualization and has published more than

120 research articles on this subject. His other book, Information Visualization: Perception for Design (2004) has become the standard reference in the field. He also designs, builds and experiments with visualization applications. One of his main current interests is interpreting the space-time trajectories of tagged foraging humpback whales and to support this he has developed TrackPlot, an interactive 3D software tool for interpreting both acoustic and kinematic data from tagged marine mammals. Trackplot shows interactive 3D tracks of whales with whale behavioral properties visually encoded on the tracks. This has resulted in a number of scientific discoveries, including a new classification of bubble-net feeding by humpbacks. Fledermaus, a visualization package initially developed by him and his students, is now the leading 3D visualization package used in ocean mapping applications. GeoZui4D is an experimental package developed by his team in an initiative to explore techniques for interacting with time-varying geospatial data. It is the basis for the CCOM Chart of the Future project and work on real-time visualization of undersea sonar data. In recent work with BBN he invented a patented technique for using motion cues in the exploration of large social networks. He has worked on the problem of visualizing uncertainty for sonar target detection. He is Professor of Computer Science and Director of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping, University of New Hampshire. He has advanced degrees in both computer science (M.Math, University of Waterloo) and psychology (Ph.D., University of Toronto).

Tom Weber received his Ph.D. in Acoustics at The Pennsylvania State University in 2006 and has B.S. (1997) and M.S. (2000) degrees in Ocean Engineering from the University of Rhode Island. He joined the Center in 2006 and the Mechanical Engineering department, as an assistant professor, in 2012. Tom conducts research in the field of underwater acoustics and acoustical oceanography. His specific areas of interest include acoustic propagation and scattering in fluids containing gas bubbles, the application of acoustic technologies to fisheries science, high-frequency acoustic characterization of the seafloor, and sonar engineering.

RESEARCH SCIENTISTS AND STAFF

Roland Arsenault received his Bachelor's degree in Computer Science and worked as a research assistant with the Human Computer Interaction Lab at the Department of Computer Science, University of New Brunswick. As a member of the Data Visualization Research Lab, he combines his expertise with interactive 3D graphics and his experience working with various mapping related technologies to help provide a unique perspective on some of the challenges undertaken at the Center.

Jordan Chadwick is the Systems Manager at JHC/CCOM. As the Systems Manager, Jordan is responsible for the day-to-day operation of the information systems and network as well as the planning and implementation of new systems and services. Jordan has a B.A. in History from the University of New Hampshire. He previously worked as a Student Engineer at UNH’s InterOperability Lab and, most recently, as a Network Administrator in the credit card industry.

Jennifer Crosby is the Web Developer at JHC/CCOM. As the Web Developer, Jennifer is responsible for the maintenance and development of the CCOM external and internal websites. Jennifer has more

than seven years of experience in technology and computing in various areas of concentration (DBA with system/network admin duties, QA/Testing, Configuration Management, Web Development). Jennifer holds the CompTIA Security+ certification, and is working towards Oracle PL/SQL Developer Certified Associate Certification. She has a B.A. in Biology from the University of Colorado with an emphasis in Marine Biology/Ecology. She has a single engine private pilot's license and a NAUI SCUBA license.

Firat Eren received his Ph.D. degree in Mechanical Engineering from the University of New Hampshire in 2015. During his Ph.D., he worked on development of optical detector arrays for navigation of unmanned underwater vehicles (UUVs). He got his M.S degree in Mechanical Engineering from the University of New Hampshire in 2011 and his B.S degree in Mechatronics Engineering from Sabanci University, Istanbul, Turkey in 2008. He is currently working as a Research Scientist at the Center for Coastal and Ocean Mapping (CCOM). At CCOM, he is working on Airborne LIDAR Bathymetry (ALB) systems with a focus on characterization of the measurement uncertainties due to environmental effects such as variations in water column and seafloor characteristics.

Will Fessenden is a Systems Administrator for JHC/CCOM, and has provided workstation, server, and backup support to the Center since 2005. Will has a B.A. in Political Science from the University of New Hampshire, and has over 15 years of experience in information technology.

Tara Hicks Johnson has as B.S. is in Geophysics from the University of Western Ontario, and as M.S. in Geology and Geophysics from the University of Hawaii at Manoa where she studied meteorites. In June of 2011, Tara moved to New Hampshire from Honolulu, Hawaii, where she was the Outreach Specialist for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. While there she organized educational and community events for the school, including the biennial Open House event, and ran the Hawaii Ocean Sciences Bowl, the Aloha Bowl. She also handled media relations for the School, and coordinated television production projects. Tara also worked with the Bishop Museum in Honolulu developing science exhibits, and at the Canadian Broadcasting Corporation in Toronto (where she was born and raised).

Tianhang Hou was a Research Associate with the University of New Brunswick 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. He is currently working with Briana Sullivan on the Chart of the Future project.

Jon Hunt is a UNH alumnus who studied economics and oceanography while a student at the university. Jon is now a Research Technician at the Center. Working under the supervision of Tom Lippmann, Jon has built a survey vessel which is capable of undertaking both multibeam sonar surveys and measurements of currents. Jon is a certified research scuba diver and has been a part of many field work projects for JHC/CCOM.

Paul Johnson has an M.S. in Geology and Geophysics from the University of Hawaii at Manoa where he studied the tectonics and kinematics of the fastest spreading section of the East Pacific Rise. Since finishing his masters, he has spent time in the remote sensing industry processing, managing, and

visualizing hyperspectral data associated with coral reefs, forestry, and research applications. More recently, he was the interim director of the Hawaii Mapping Research Group at the University of Hawaii where he specialized in the acquisition, processing, and visualization of data from both multibeam mapping systems and towed near bottom mapping systems. Paul started at the Center in June of 2011 as the data manager. When not working on data related issues for the Joint Hydrographic Center, he is aiding in the support of multibeam acquisition for the US academic fleet through the National Science Foundation's Multibeam Advisory Committee.

Carlo Lanzoni received a Master's degree in Ocean Engineering from the University of New Hampshire. His master's research was the design of a methodology for field calibration of multibeam echo sounders using a split-beam sonar system and a standard target. He also has a M.S. and a B.S. in Electrical Engineering from the University of New Hampshire. Carlo has worked with different calibration methodologies applied to different sonar systems. He is responsible for the operation, maintenance, and development of test equipment used in acoustic calibrations of echo sounders at the acoustic tank of Chase Ocean Engineering Lab. His research focuses on the field calibration methodology for multibeam echo sounders.

Zachary McAvoy received a B.S. in Geology from the University of New Hampshire in 2011. His background is in geochemistry, geology, and GIS. Since graduating, he has worked on various environmental and geoscience related projects for the Earths Systems Research Center and Ocean Process Analysis Laboratory at UNH; as well as the New Hampshire DOT and Geological Survey. Zach is currently a research technician working for Dr. Larry Ward. As part of a BOEM beach nourishment study, he is using geologic and geospatial datasets for synthesis in GIS and mapping the geomorphology of the New Hampshire inner continental shelf. He also assists Dr. Ward with maintaining the Coastal Geology Lab at Jackson Estuarine Laboratory.

Andy McLeod received his B.S. in Ocean Studies from Maine Maritime Academy in 1998. His duties at the Center include supporting autonomous vehicle projects from conception, pre-production through to completion, providing technical support, managing project budgets overseeing the maintenance and operations, responsibility for the completion of documentation, producing test plans and reports, prepare contract documentation for procurement services and materials, carrying out effective client liaison.

Colleen Mitchell has a B.A. in English from Nyack College in Nyack, NY and a Master's in Education from the State University of New York at Plattsburgh. She began working for the Environmental Research Group (ERG) at UNH in 1999. In July 2009, Colleen joined JHC/CCOM as the Center's graphic designer. She is responsible for the graphic identity of the Center and, in this capacity, creates ways to visually communicate the Center's message in print and electronic media.

Erin Nagel worked as a Physical Scientist for the U.S. Army Corps of Engineers and with NOAA's Atlantic Hydrographic Branch for the Office of Coast Survey before joining the Center in 2014. She has supported USACE and FEMA in emergency operations during Super Storm Sandy and Irene with emergency response mapping and pre- and post-storm analysis of Bathymetry and Lidar. Erin focused her undergraduate studies at the University of Colorado at Boulder on Geographic Information Systems and Atmospheric and Oceanic Sciences.

Abby Pagan-Allis is the administrative manager at JHC/CCOM. She has worked at the Center since 2002, overseeing the day-to-day operations at the Center and supervising the administrative staff. She earned her B.S. in Management and Leadership from Granite State College. In 2006, she completed the Managing at UNH program and, in 2009, she received her Human Resources Management certificate at the University of New Hampshire.

Victoria Price began working on the IOCM Super Storm Sandy project in 2014. She is focused on investigating effective uses of hydroacoustics for rapid post-storm response surveys, as well as developing efficient methods for acoustic data analysis. She is also focusing on pre- and post- Sandy LiDAR data to investigate the use of topobathy data for modeling habitat and shoreline changes in the wake of major weather events. Victoria received her B.S. and M.S. in Oceanography from the University of Connecticut, where she focused on the development of ecological survey methods using high-resolution imaging sonars. Her previous work includes investigating methods for quantifying predation over broad time scales using DIDSON sonar, as well as developing effective algorithms for large-batch acoustic data processing and analysis.

Val Schmidt received his bachelor's degree in Physics from the University of the South, Sewanee, TN in 1994. During his junior undergraduate year he joined the Navy and served as an officer in the submarine fleet aboard the *USS Hawkbill* from 1994 to 1999. In 1998 and 1999 the *USS Hawkbill* participated in two National Science Foundation sponsored "SCICEX" missions to conduct seafloor mapping from the submarine under the Arctic ice sheet. Val served as Sonar and Science Liaison Officer during these missions. Val left the Navy in 1999 and worked for Qwest Communications as a telecommunications and Voice over IP engineer from 2000 to 2002. Val began work in 2002 as a research engineer for the Lamont Doherty Earth Observatory of Columbia University where he provided science-engineering support both on campus and to several research vessels in the U.S. academic research fleet. Val acted as a technical lead aboard the U.S. Coast Guard Icebreaker *Healy* for several summer cruises in this role. Val completed his master's degree in ocean engineering in 2008 from the Center for Coastal and Ocean Mapping. His thesis involved development of an underwater acoustic positioning system for whales that had been tagged with an acoustic recording sensor package. Val continues to work as an engineer for the Center where his research focuses on hydrographic applications of ASVs, AUVs, and Phase Measuring Bathymetric sonars.

Ben Smith is the Captain of the JHC/CCOM 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. He designed, built, and captained his own 45-foot blue water steel ketch, S/V *Mother of Perl*. He has been master of *Coastal Surveyor* for over ten years. He holds a USCG 100 ton near coastal license with endorsements for sail and rescue towing.

Briana Sullivan received a B.S. in Computer Science at UMASS, Lowell and a M.S. in Computer Science at UNH, under the supervision of Dr. Colin Ware. Her master's thesis involved linking audio and visual information in a virtual underwater kiosk display that resulted in an interactive museum exhibit at the Seacoast Science Center. Briana was hired in July 2005 as a research scientist for the Center. She works on the Chart of the Future project which involves things such as the Local Notice to

Mariners, ship sensors, the Coast Pilot, other marine related topics. Her focus is on web technologies and mobile environments.

Emily Terry joined the Center as Relief Captain in 2009, and was promoted to Research Vessel Captain in 2014. She came to the Center from the NOAA Ship *Fairweather* where she worked for three years as a member of the deck department, separating from the ship as a Seaman Surveyor. Prior to working for NOAA, she spent five years working aboard traditional sailing vessels. Emily holds a USCG 100 ton near coastal license.

Rochelle Wigley has a mixed hard rock/soft rock background with an M.Sc. in Igneous Geochemistry (focusing on dolerite dyke swarms) and a Ph.D. in sedimentology/sediment chemistry, where she integrated geochemistry and geochronology into marine sequence stratigraphic studies of a condensed sediment record in order to improve the understanding of continental shelf evolution along the western margin of southern Africa. Phosphorites and glauconite have remained as a research interest where these marine authigenic minerals are increasingly the focus of offshore mineral exploration programs. She was awarded a Graduate Certificate in Ocean Mapping from UNH in 2008. Rochelle concentrated largely on understanding the needs and requirements of all end-users within the South African marine sectors on her return home, as she developed a plan for a national offshore mapping program from 2009 through 2012. As Project Director of the GEBCO Nippon Foundation Indian Ocean Project, she is involved in the development of an updated bathymetric grid for the Indian Ocean and management of a project working to train other Nippon Foundation GEBCO scholars. In 2014, Rochelle took on the responsibility of the Director of the Nippon Foundation GEBCO training program at the Center.

In addition to the academic, research and technical staff, our administrative support staff, **Linda Prescott** and **Renee Blinn**, and **Wendy Monroe** ensure the smooth running of the organization.

NOAA has demonstrated its commitment to the Center by assigning many NOAA employees (or contractors) to the Center:

NOAA EMPLOYEES

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

Michael Bogonko is currently working on Super Storm Sandy post-disaster research work, mostly providing support to NOAA's IOCM/JHC group in operational planning, processing practices for massive amounts of LIDAR and acoustic data to establish the best possible operational methods. Before joining IOCM/JHC, Michael worked as a consultant in engineering and environmental firms applying expertise in GIS/geospatial applications, hydrological modeling and data processing. He has been an RA and TA in the department of Civil and Environmental Engineering at UNH. Michael has an MS in Civil Engineering from San Diego State University, CA. He holds a BS focusing on GIS and geography with a minor in Mathematics from University of Nairobi. He also holds an MS in Physical Land resources in Engineering Geology from VUB, Brussels, Belgium.

John G.W. Kelley is a research meteorologist and coastal modeler with NOAA/National Ocean Service's Marine Modeling and Analysis Programs within the Coast Survey Development Lab. John has a Ph.D. in Atmospheric Sciences from Ohio State University. He is involved in the development and implementation of NOS's operational numerical ocean forecast models for estuaries, the coastal ocean and the Great Lakes. He is also PI for a NOAA web mapping portal to real-time coastal observations and forecasts. John is working with JHC/CCOM personnel on developing the capability to incorporate NOAA's real-time gridded digital atmospheric and oceanographic forecast into the next generation of NOS nautical charts.

Juliet Kinney is working on the Super Storm Sandy Project with the IOCM group. She graduated with a B.S. in Earth Systems Science from the UMass-Amherst Geosciences Department and received her Ph.D. in Marine and Atmospheric Sciences from Stony Brook University where her dissertation focused on "The Evolution of the Peconic Estuary 'Oyster Terrain,' Long Island, NY." Her study included high-resolution mapping using a combination of geophysical techniques: multibeam sonar, chirp seismic profiles, and sidescan sonar. She is interested in paleoclimate/paleoceanography and her expertise is as a geological oceanographer is in high resolution sea floor mapping.

Before joining the Center, Juliet was a temporary full time faculty member in the Department of Geological Sciences at Bridgewater State University, Bridgewater, MA for one year. Prior to graduate school, she worked at the USGS as an ECO intern for two years in Menlo Park, CA with the Coastal and Marine Geology Program, working primarily with physical oceanographic and sediment transport data.

Cassie Bongiovanni received her B.S. in Geology at the University of Washington in Seattle with a focus in Oceanography. There she spent time aboard both U.W. research vessels working with multibeam data. She is now working with NOAA's IOCM group on processing LIDAR and acoustic data for the Super Storm Sandy research effort.

Jason Greenlaw is a software developer for ERT, Inc. working as a contractor for NOAA/National Ocean Service's Coast Survey Development Laboratory in the Marine Modeling and Analysis Programs (MMAP) branch. Jason works primarily on the development of NOAA's nowCOAST project (http://nowcoast.noaa.gov), but also works closely with MMAP modelers to assist in the development of oceanographic forecast systems and the visualization of model output. Jason is a native of Madbury, NH and graduated in May 2006 from the University of New Hampshire with a B.S. in Computer Science.

Carl Kammerer is an oceanographer with the National Ocean Service's Center for Operational Oceanographic Products and Services (CO-OPS), now seconded to the Center. He is a specialist in estuarine and near-shore currents and has been project manager for current surveys throughout the United States and its territories. His present project is a two-year survey of currents in the San Francisco Bay region. Working out of the Joint Hydrographic Center, he acts as a liaison between CO-OPS and the JHC, and provides expertise and assistance in the analysis and collection of tides. He has a B.Sc. in Oceanography from the University of Washington and an MBA from the University of Maryland University College.

Elizabeth "Meme" Lobecker is a Physical Scientist for the *Okeanos Explorer* program within the NOAA Office of Ocean Exploration and Research (OER). She organizes and leads mapping exploration cruises aboard the NOAA Ship *Okeanos Explorer*. She has spent the last ten years mapping the global ocean floor for an array of purposes, ranging from shallow water hydrography for NOAA charting and habitat management purposes in U.S. waters from Alaska to the Gulf of Maine, cable and pipeline inspection and pre-lay surveys in the Eastern Atlantic Ocean, the North Sea and Mediterranean Sea, and most recently as a Physical Scientist for OER sailing on *Okeanos Explorer* as it explores U.S. and international waters around the world. So far this has included Indonesia, Guam, Hawaii, California, the Galapagos Spreading Center, the Mid-Cayman Rise, the Gulf of Mexico, and the U.S. Atlantic continental margin. Meme obtained a Master of Marine Affairs degree from the University of Rhode Island in 2008, and a Bachelor of Arts in Environmental Studies from The George Washington University in 2000. Her interests in her current position include maximizing offshore operational efficiency in order to provide large amounts of high quality data to the public to enable further exploration, focused research, and wise management of U.S. and global ocean resources.

Mashkoor Malik who received his M.S. degree from the University of New Hampshire in 2005, now a Physical Scientist in NOAA's Office of Exploration and Research where he is responsible for OER operations on the Okeanos Explorer and the OER team at the Center. In this capacity, Mashkoor is responsible for developing the data collection, processing and handling procedures and protocols for the *Okeanos Explorer*. Mashkoor works at NOAA HQ in Silver Spring But continues to be a Ph.D. student at the Center, his research focusing on understanding the uncertainty associated with backscatter measurements.

Lindsay McKenna is a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER), where she supports mapping operations aboard the NOAA Ship *Okeanos Explorer.* On shore, Lindsay works out of the Integrated Ocean and Coastal Mapping (IOCM) center, contributing to expeditions through data processing and archiving, operational planning, and mapping product development. Lindsay earned her Sc.B. in Geological Sciences from Brown University in 2007, and her M.S. in Earth Science—Ocean Mapping from the University of New Hampshire in 2013. Prior to her position with OER, Lindsay worked at CCOM as a Project Director for a Super Storm Sandy research project. Before graduate school, Lindsay was employed as a geologist at Malcolm Pirnie, Inc. in New Jersey, where she worked on a variety of water resource projects.

Glen Rice started with the Center as a Lieutenant (Junior Grade) in the NOAA Corps stationed with at the Joint Hydrographic Center as Team Lead of the Integrated Ocean and Coastal Mapping Center. He

had previously served aboard the NOAA Hydrographic Ships *Rude* and *Fairweather* along the coasts of Virginia and Alaska after receiving a M.Sc. in Ocean Engineering at the University of New Hampshire. In 2013, Glen left the NOAA Corps and became a civilian contractor to NOAA. In 2014 Glen became a permanent physical scientist with NOAA. He maintains his position as Team Lead of the IOCM Center at UNH.

Derek Sowers works as a Physical Scientist with the NOAA Office of Ocean Exploration and Research (OER) supporting ocean mapping efforts of the NOAA Ship *Okeanos Explorer*. This work involves overseeing other sonar scientists shore-side at JHC/CCOM. Derek is also a part-time Oceanography Ph.D. student at JHC/CCOM with interests in seafloor characterization data collection at sea during ocean exploration expeditions, and managing data and collaborating with, ocean habitat mapping, and marine conservation. He has a B.S. in Environmental Science from the University of New Hampshire (1995), and holds an M.S. in Marine Resource Management from Oregon State University (2000) where he completed a NOAA-funded assessment of the "Benefits of Geographic Information Systems for State and Regional Ocean Management." Derek has thirteen years of previous coastal research and management experience working for NOAA's National Estuarine Research Reserve network and EPA's National Estuary Program in both Oregon and New Hampshire. Derek has participated in ocean research expeditions in the Arctic Ocean, Gulf of Maine, and Pacific Northwest continental shelf.

Sarah Wolfskehl is a Hydrographic Data Analyst with NOAA's Sandy IOCM Center. She is located at the Joint Hydrographic Center to utilize the Centers research to improve and diversify the use of hydrographic data across NOAA in support of Integrated Ocean and Coastal Mapping projects. Previously, Sarah worked as a Physical Scientist for NOAA's Office of Coast Survey in Seattle, WA. Sarah has a B.A. in Biology from The Colorado College.

OTHER AFFILIATED FACULTY

Brad Barr received a B.S. from the University of Maine, an M.S. from the University of Massachusetts, and a Ph.D. from the University of Alaska. He is currently a Senior Policy Advisor in the NOAA Office of National Marine Sanctuaries, Affiliate Professor at the School of Marine Sciences and Ocean Engineering at the University of New Hampshire, and a Visiting Professor at the University Center of the Westfjords in Iceland. He is a member of the IUCN World Commission on Protected Areas, the International Committee on Marine Mammal Protected Areas/IUCN Marine Mammal Protected Areas Task Force. He has served on the Boards of Directors of the George Wright Society in the U.S., the Science and Management of Protected Areas Association (SAMPAA) in Canada, and, currently, on the Board of Directors of the Coastal Zone Canada Association (CZCA). He also serves on the Editorial Board of the World Maritime University Journal of Maritime Affairs. He has published extensively on marine protected areas science and management, whaling and maritime heritage preservation, with a primary research focus on the identification and management of ocean wilderness.

Jonathan Beaudoin earned his undergraduate degrees in Geomatics Engineering and Computer Science from the University of New Brunswick (UNB) in Fredericton, NB, Canada. He continued his studies at

UNB under the supervision of Dr. John Hughes Clarke of the Ocean Mapping Group and after completing his Ph.D. studies in the field of refraction related echo sounding uncertainty, Jonathan took a research position at JHC/CCOM in 2010. While there, he carried on in the field of his Ph.D. research and joined the ongoing seabed imaging and characterization efforts. He also played a leading role in establishing the Multibeam Advisory Committee, an NSF-funded effort to provide technical support to seabed mapping vessels in the US academic fleet. Jonathan returned to Canada in late 2013 where he joined the Fredericton, NB office of QPS.

Margaret Boettcher received a Ph.D. in Geophysics from the MIT/WHOI Joint Program in Oceanography in 2005. She joined JHC/CCOM in 2008 as a post-doctoral scholar after completing a Mendenhall Postdoctoral Fellowship at the U.S. Geological Survey. Although she will continue to collaborate with scientists at JHC/CCOM indefinitely, Margaret also is, since 2009, a member of the faculty in the Earth Science Department at UNH. Margaret's research focuses on the physics of earthquakes and faulting and she approaches these topics from the perspectives of seismology, rock mechanics, and numerical modeling. Margaret seeks to better understand slip accommodation on oceanic transform faults. Recently she has been delving deeper into the details of earthquake source processes by looking at very small earthquakes in deep gold mines in South Africa.

Dale Chayes has been an active instrument developer, troubleshooter, and operator in the oceanographic community since 1973 and has participated in well over a hundred and fifty field events. He has worked on many projects including hull mounted multibeams, submarine (SCAMP) and deep-towed mapping sonars (SeaMARC I), real-time wireless data systems, database infrastructure for digital libraries (DLESE) and marine geoscience data (MDS), satellite IP connectivity solutions (SeaNet), GPS geodesy, trace gas water samplers, precision positioning systems and backpack mounted particle samplers. In his spare time he is a licensed amateur radio operator, Wilderness EMT/NREMT and is in training (with his dog Frodo) for K9 wilderness search and rescue.

Vicki Ferrini has a Ph.D. in Coastal Oceanography (2004) and a Masters Degree in Marine Environmental Science (1998), both from Stony Brook University. Over the past 20+ years she has worked in environments from shallow water coastal areas to the deep sea using ships, boats, submersibles and towed platforms to map the seafloor at a variety of resolutions. Vicki is also heavily involved in the fields of geoinformatics and data management. She is a Research Scientist at Columbia University's Lamont-Doherty Earth Observatory where she spends much of her time working on projects focused on making high-quality marine geoscience research data publicly accessible.

John Hall spent his sabbatical from the Geological Survey of Israel with the Center. John has been a major player in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black, and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

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. Martin returned to a prestigious professorship in his native Sweden in April 2004 but remains associated with the Center.

Xavier Lurton graduated in Physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in Applied Acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as a R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989 he joined IFREMER (the French government agency for Oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (data transmission, fisheries sonar, ocean tomography…). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (both in physical modeling and in sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson); in this context he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer) widely based on his own experience as a teacher. He manages the IFREMER team specialized in underwater acoustics, and has been the Ph.D. advisor of about 15 students. He spent six months as a visiting scholar at UNH in 2012, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

Christopher Parrish holds a Ph.D. in Civil and Environmental Engineering with an emphasis in geospatial information engineering from the University of Wisconsin-Madison and an M.S. in Civil and Coastal Engineering with an emphasis in geomatics from the University of Florida. His research focuses on full-waveform LiDAR, topographic-bathymetric LiDAR, hyperspectral imagery, uncertainty modeling, and UAVs for coastal applications. Parrish is the Director of the American Society for Photogrammetry and Remote Sensing (ASPRS) LiDAR Division and associate editor of the journal *Marine Geodesy*. Prior to joining Oregon State University, he served as lead physical scientist in the Remote Sensing Division of NOAA's National Geodetic Survey and affiliate professor at JHC/CCOM.

Shachak Pe'eri received his Ph.D. degree in Geophysics from the Tel Aviv University, Israel. In 2005, he started his post-doctoral work at the Center with a Tyco post-doctoral fellowship award. His research interests are in optical remote sensing in the littoral zone with a focus on experimental and theoretical studies of LIDAR remote sensing (airborne LIDAR bathymetry, topographic LIDAR, and terrestrial laser scanning), hyperspectral remote sensing, and sensor fusion. Shachak Pe'eri is a member of the (American Geophysical Union) AGU and the Ocean Engineering (OE) and Geoscience and Remote Sensing (GRS) societies of IEEE and of The Hydrographic Society of America (THSOA). Shachak moved to a position with NOAA's Marine Chart Division in 2016.

Kurt Schwehr received his Ph.D. from Scripps Institution of Oceanography studying marine geology and geophysics. Before joining the Center, he worked at JPL, NASA Ames, the Field Robotics Center at Carnegie Mellon, and the USGS Menlo Park. His research has included components of computer

science, geology, and geophysics. He looks to apply robotics, computer graphics, and real-time systems to solve problems in marine and space exploration environments. He has been on the mission control teams for the Mars Pathfinder, Mars Polar Lander, Mars Exploration Rovers, and Mars Science Laboratory. He has designed computer vision, 3D visualization, and on-board driving software for NASA's Mars exploration program. Fieldwork has taken him from Yellowstone National Park to Antarctica. At the Center, he was working on a range of projects including the Chart of the Future, visualization techniques for underwater and space applications, and sedimentary geology. He has been particularly active in developing hydrographic applications of AIS data. Kurt is currently Head of Ocean Engineering at Google and an affiliate faculty in the Center.

Arthur Trembanis is the director of the Coastal Sediments, Hydrodynamics and Engineering Laboratory (CSHEL) in the College of Earth, Ocean, and Environment at the University of Delaware. The work of CSHEL involves the development and utilization of advanced oceanographic instrumentation, particularly autonomous underwater vehicles for seafloor mapping and benthic habitat characterization. He received a bachelor's degree in geology from Duke University in 1998, a Fulbright Fellowship at the University of Sydney in 1999 and a Ph.D. in marine sciences from the Virginia Institute of Marine Sciences in 2004. He is presently a visiting professor at the University of Ferrara.

Lysandros Tsoulos 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.

Dave Wells is world-renowned in hydrographic circles. Dave is an expert in GPS and other aspects of positioning, providing geodetic science support to the Center. Along with his time at UNH, Dave also spends time at the University of New Brunswick and at the University of Southern Mississippi where he is participating in their hydrographic program. Dave also helps UNH in its continuing development of the curriculum in hydrographic training.

Neil Weston's research appointment serves as a way to strengthen the academic and research ties between JHC/CCOM and the Office of Coast Survey, NOAA. His focus will be to collaborate on research activities related to GNSS/GPS positioning, geophysical phenomena affecting land/ocean interfaces, data visualization, digital signal processing, and modeling. Neil is also interested in advising/mentoring graduate students, giving invited talks/seminars, promoting OCS, NOS and NOAA scientific and technological endeavors, and strengthening high-level collaborations between the academic community and NOAA. Neil received his doctorate from Catholic University of America in 2007 in biomedical engineering and physics, and has master's degrees from Johns Hopkins University in physics (sensor systems) and the University of South Florida in physics (laser optics and quantum electronics). He also holds positions as a Science/Technical Advisor with the U.S. State Department and as a Technical Advisor for the United Nations.

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 Doerner (March–September 2002) worked on techniques for creating self-organizing data sets using methods from behavioral animation. The method, called "Analytic Stimulus Response Animation," has objects operating according to simple behavioral rules that cause similar data objects to seek one another and dissimilar objects to avoid one another.

Ron Boyd (July–December 2003) spent his sabbatical at the Center. At the time, Ron was a professor of marine geology at the University of Newcastle in Australia and an internationally recognized expert on coastal geology and processes. He is now an employee of Conoco-Phillips Petroleum in Houston. Ron's efforts at the Center focused on helping us interpret the complex, high-resolution repeat survey data collected off Martha's Vineyard as part of the ONR Mine Burial Experiment.

John Hall (August 2003–October 2004) spent his sabbatical from the Geological Survey of Israel with the Center. John has been a major player in the IBCM and GEBCO compilations of bathymetric data in the Mediterranean, Red, Black and Caspian Seas and is working with the Center on numerous data sets including multibeam-sonar data collected in the high Arctic in support of our Law of the Sea work. He is also archiving the 1962 through 1974 data collected from Fletcher's Ice Island (T-3).

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

Walter Smith (November 2005–July 2006) received his Ph.D. in Geophysics from Columbia University's Lamont-Doherty Earth Observatory in 1990. While at Lamont, he began development of the GMT data analysis and graphics software. From 1990-92 he held a post-doctoral scholarship at the

University of California, San Diego's Scripps Institution of Oceanography in the Institute for Geophysics and Planetary Physics He joined NOAA in 1992 and has also been a lecturer at the Johns Hopkins University, teaching Data Analysis and Inverse Theory. Walter's research interests include the use of satellites to map the Earth's gravity field, and the use of gravity data to determine the structure of the sea floor and changes in the Earth's oceans and climate.

Lysandros Tsoulos (January–August 2007) is an Associate Professor of Cartography at the National Technical University of Athens. Lysandros is internationally known for his work in digital mapping, geoinformatics, expert systems in cartography, and the theory of error in cartographic databases. At the Center, Lysandros worked with NOAA student Nick Forfinski exploring new approaches to the generalization of dense bathymetric data sets.

Jean-Marie Augustin (2010) is a senior engineer at the Acoustics and Seismics Department of IFREMER focusing on data processing and software development for oceanographic applications and specializing in sonar image and bathymetry processing. His main interests include software development for signal, data and image processing applied to seafloor-mapping sonars, featuring bathymetry computation algorithms and backscatter reflectivity analysis. He is the architect, designer and main developer of the software suite *SonarScope*.

Xabier Guinda (2010) is a Postdoctoral Research Fellow at the Environmental Hydraulics Institute of the University of Cantabria in Spain. He received a Ph.D. from the University of Cantabria. His main research topics are related to marine benthic ecology (especially macroalgae), water quality monitoring and environmental assessment of anthropogenically disturbed sites as well as the use of remote sensing hydroacoustic and visual techniques for mapping of the seafloor and associated communities. His stay at the Center was sponsored by the Spanish government.

Sanghyun Suh (2010) is a Senior Research Scientist at the Maritime and Ocean Engineering Research Institute (MOERI) at the Korea Ocean Research and Development Institute (KORDI) in Daejeon, Republic of Korea (South Korea). Dr. Suh received his Ph.D. from the University of Michigan in GIS and Remote Sensing. He worked with Dr. Lee Alexander on e-Navigation research and development (R&D) related to real-time and forecast tidal information that can be broadcast via AIS binary application-specific messages to shipborne and shore-based users for situational awareness and decision-support.

Xavier Lurton (August 2011–March 2012) graduated in Physics in 1976 (Universite de Bretagne Occidentale, Brest) and received a Ph.D. in Applied Acoustics in 1979 (Universite du Maine, Le Mans), specializing first in the physics of brass musical instruments. After spending two years of national service as a high-school teacher in the Ivory Coast, he was hired by Thomson-Sintra (the leading French manufacturer in the field of military sonar systems—today Thales Underwater Systems) as a R&D engineer, and specialized in underwater propagation modeling and system performance analysis. In 1989 he joined IFREMER (the French government agency for Oceanography) in Brest, where he first participated in various projects in underwater acoustics applied to scientific activities (data transmission, fisheries sonar, ocean tomography…). Over the years, he specialized more specifically in seafloor-mapping sonars, both through his own technical research activity (both in physical modeling and in

sonar engineering) and through several development projects with sonar manufacturers (Kongsberg, Reson); in this context he has participated in tens of technological trial cruises on research vessels. He has been teaching underwater acoustics for 20 years in several French universities, and consequently wrote *An Introduction to Underwater Acoustics* (Springer) widely based on his own experience as a teacher. He manages the IFREMER team specialized in underwater acoustics, and has been the Ph.D. advisor of about 15 students. He spent six months as a visiting scholar at UNH in 2012, working on issues related to sonar reflectivity processing, and bathymetry measurement methods.

Seojeong Lee (April 2012–April 2013) received her Ph.D. in Computer Science with an emphasis on Software Engineering from Sookmyung Women's University in South Korea. She completed an expert course related to Software Quality at Carnegie Mellon University. With this software engineering background, she has worked at the Korea Maritime University as an associate professor since 2005 where her research has been focused on software engineering and software quality issues in the maritime area. As a Korean delegate of the IMO NAV sub-committee and IALA e-NAV committee, she is contributing to the development of e-navigation. Her current research topic is software quality assessment of e-navigation, and development of e-navigation portrayal guidelines. Also, she is interested in AIS ASM and improvement of NAVTEX message.

Gideon Tibor (April 2012–November 2012) Gideon Tibor was a visiting scholar from Israel Oceanographic & Limnological Research Institute and the Leon H. Charney School of Marine Sciences in the University of Haifa. Gideon received his Ph.D. in Geophysics & Planetary Sciences from Tel-Aviv University. His main research interest is the development and application of high-resolution marine geophysics and remote sensing using innovative methods in the study of phenomena that influence the marine environment and natural resources. By means of international and local competitive research grants, he uses a multi-disciplinary approach for studying the Holocene evolution of the Levant margin, the Sea of Galilee, and the northern Gulf of Eilat/Aqaba.

Christian Stranne received his Ph.D. (2013) in Physical Oceanography from the University of Gothenburg, where he studied large-scale Arctic sea ice dynamics and coupled ocean-sea ice-atmosphere interactions. He has held a two-year postdoc position at Stockholm University, focusing on methane hydrate dynamics and numerical modelling of multiphase flow in hydrate-bearing marine sediments. Christian is funded by the Swedish Research Council for a three-year research project of which two years are based at CCOM. The project involves modelling of methane gas migration within marine sediments, and studies of the interaction between gas bubbles and sea water in the ocean column with an over-arching aim to set up a coupled model for methane transport within the sediment - ocean column system. He is also involved in a project evaluating water column multibeam and single-beam sonar data for its potential of revealing detailed oceanographic structure.

FACILITIES, IT AND EQUIPMENT

OFFICE AND TEACHING SPACE

The Joint Hydrographic Center has been fortunate to have equipment and facilities that are unsurpassed in the academic hydrographic community. Upon the initial establishment of the Center at UNH, the University constructed an 8,000 square foot building dedicated to JHC/CCOM and attached to the unique Ocean Engineering high-bay and tank facilities already at UNH. Since that time, a 10,000-square-foot addition has been constructed (through NOAA funding), resulting in 18,000 sq. ft. of space dedicated to Center research, instruction, education, and outreach activities. In 2016 construction began on 12,000sq. ft. expansion to the building. This expansion will include six large labs and office space for the new undergraduate ocean engineering program, nine new offices (1600 sq feet) dedicated for the Center personnel and a new shared 80 seat amphitheater-style class/seminar room (Figure 1-1).

Figure 1-1. Perspective views of Chase Ocean Engineering Lab and the NOAA/UNH Joint Hydrographic Center including new lab and office construction (left side of upper frames) and large classroom/seminar room (right side of lower frame).

Of the currently occupied 18,000 sq. ft., approximately 4,000 sq. ft. are dedicated to teaching purposes and 11,000 sq. ft. to research and outreach, including office space. Our teaching classroom can seat 45 students and has a high-resolution LCD projector capable of widescreen display. There are currently 34

faculty or staff offices (expanding to 43 with the new construction). With the influx of NOAA OER, IOCM and Super Storm Sandy personnel, the Center is now providing office space for 16 NOAA personnel. In 2016 graduate student space was upgraded to now accommodate 31 student cubicles plus an additional seven seats for the GEBCO students; included in our graduate students are one to three NOAA students. Two additional NOAA cubicles are available for NOAA Marine Operations Center employees at the pier support facility in New Castle (see below).

LABORATORY FACILITIES

Laboratory facilities within the Center include a map room with light tables, map-storage units and a number of specialized labs for training, equipment testing and development, visualization, and "telepresence interactions." The Center has a full suite of printers and plotters including a pair of large format color plotters. Users have the ability to scan documents and charts up to 36 inches using our wide format, continuous feed, high-resolution scanner. The Center continues to phase out single-function laser printers in favor of fewer, more efficient multi-function printers capable of printing, scanning, copying, and faxing documents. A UNH contracted vendor provides all maintenance and supplies for these multifunction printers, reducing overall costs.

Figure 1-2. CENTER Telepresence Console in action.

The JHC/CCOM Presentation Room houses the Telepresence Console (Figure 1-2) as well as the Geowall high-resolution multi-display system. The Geowall is a multipurpose system utilized for the display of additional video streams from Telepresence-equipped UNOLS vessels, as well as educational and outreach purposes. The hardware for the Telepresence Console consists of three high-end Dell Precision workstations used for data processing, one Dell multi-display workstation for streaming and decoding real-time video, three 42" LG HDTV displays through which the streams are presented, and a voice over IP (VoIP) communication device used to maintain audio contact with all endpoints (Figure 1-2). The multi-display Dell workstation provides MPEG-4 content streaming over Internet2 from multiple sources concurrently. All systems within the Presentation Room are connected to an Eaton Powerware UPS to protect against power surges and outages. Over the last several field seasons, JHC/CCOM has joined forces with the NOAA vessel *Okeanos Explorer* and URI's exploration vessel

Nautilus on their respective research cruises. Both vessels have had successful field seasons each year since 2010 utilizing the telepresence technology to process data and collaborate with scientists and educators ashore. The success has led to increased interest in deploying the technology to other vessels in the UNOLS fleet in 2016 - 2017. The JHC/CCOM IT Group expects to utilize both the Telepresence Console and the Geowall to support all current and future initiatives.

The Center's Computer Classroom consists of 15 Dell workstations (Figure 1-3). A ceiling-mounted NEC high resolution projector is used to provide classroom instruction. All training that requires the use of a computer system is conducted in this room. Students also frequently use the classroom for individual study and collaborative projects. In addition to these purposes, a high-resolution camera allows for web conferencing and remote teaching.

Figure 1-3. CCOM Computer Teaching Lab equipped with new computers and displays in 2014.

The JHC/CCOM Video Classroom also provides for web conferencing, remote teaching, and the hosting of weekly webinars. The IT Group collaborates with the JHC/CCOM seminar organizers to provide both live webinar versions of the JHC/CCOM Seminar Series, as well as video and audio archives available through the web after most events. Building on the success of the 2011 through 2016 seminar series, the IT Group continues to make improvements to both the quality and accessibility of these seminars through better video and audio hardware, as well as distribution of the finished product through the JHC/CCOM website, Vimeo, and YouTube. In early fall, UNH IT announced a new campus-wide web conferencing solution, Zoom, which the IT Group plans to evaluate for both web-based meetings and seminar broadcasts throughout 2017.

The Center's Visualization Lab includes an ASL eye-tracking system and multiple Polhemus electromagnetic trackers for collecting data in human factors studies, an immersive large-format tiled display, custom 3D multi-touch monitors, and a virtual reality system. The immersive tiled display consists of five vertically mounted 70-inch monitors, in a 120-degree arc (Figure 1-4), allowing it to completely fill the field-of-view of users. It is used for collaborative analysis, ship simulations, and presentations to large groups. The custom built multi-touch stereoscopic 3D displays are used for interactive exploratory analysis of ocean flow models and other complex datasets. The HTC VIVE

virtual reality system has a high resolution (2160x1200) stereoscopic 3D head-mounted display, two hand-held six degree-of-freedom controllers, and a laser-based system for precisely tracking these components over a wide (25m²) portion of the lab, allowing users to naturally walk around virtual environments, e.g. a ship's bridge.
We have also built a LIDAR Simulator Lab, providing a secure and safe environment in which to perform experiments with our LIDAR Simulator. The Center also maintains a full suite of survey, testing, electronic, and positioning equipment.

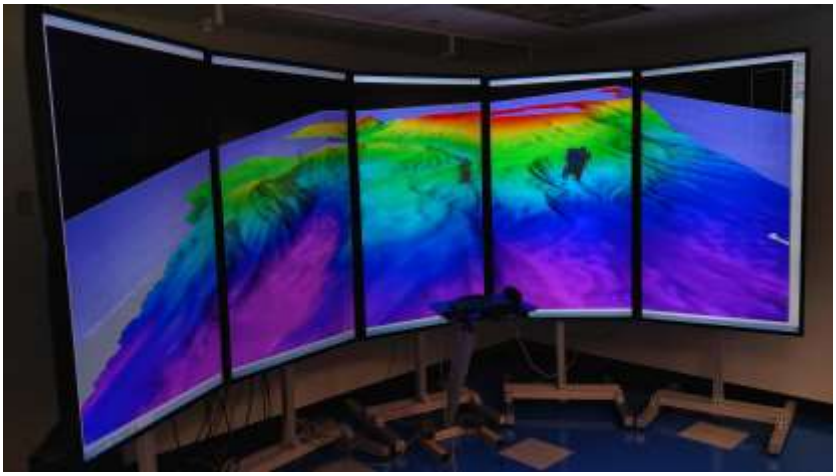


Figure 1-4. Semi-Immersive Large-Format Tiled Display.

The Center is co-located with the Chase Ocean Engineering Lab. The Lab contains a high-bay facility that includes extensive storage and workspace in a warehouse-like environment. The high bay consists of two interior work bays and one exterior work bay with power, lights, and data feeds available throughout. A 5000-lb. capacity forklift is available.

Two very special research tanks are also available in the high bay. The wave/tow tank is approximately 120 ft. long, 12 ft. wide and 8 ft. deep. It provides a 90-foot length in which test bodies can be towed, subjected to wave action, or both. Wave creation is possible using a hydraulic flapper-style wave-maker that can produce two-to-five second waves of maximum amplitude approximately 1.5 feet. Wave absorption is provided by a saw-tooth style geo-textile construction that has an average 92% efficiency in the specified frequency range. The wave-maker software allows tank users to develop regular or random seas using a variety of spectra. A user interface, written in LabView, resides on the main control station PC and a wireless LAN network allows for communication between instrumentation and data acquisition systems. Data acquisition has been vastly improved with 32 channels of analog input, four channels of strain measurement, and Ethernet and serial connectivity all routed through shielded cabling to the main control computer. Power is available on the carriage in 120 or 240 VAC. In 2015, the wave-maker was repaired and the wave-tank saw 114 days of use of which 20% was Center-specific work.

The engineering tank is a freshwater test tank 60 ft. long by 40 ft. wide with a nominal depth of 20 ft. The 380,000 gallons that fill the tank are filtered through a 10-micron sand filter twice per day providing

an exceptionally clean body of water in which to work. This is a multi-use facility hosting the UNH SCUBA course, many of the OE classes in acoustics and buoy dynamics, as well as providing a controlled environment for research projects ranging from AUVs to zebra mussels. Mounted at the corner of the Engineering Tank is a 20-foot span, wall-cantilevered jib crane. This crane can lift up to two tons with a traveling electric motor controlled from a hand unit at the base of the crane. In 2003, with funding from NSF and NOAA, an acoustic calibration facility was added to the engineering tank. The acoustic test-tank facility is equipped to do standard measurements for hydrophones, projectors, and sonar systems. Common measurements include transducer impedance, free-field voltage sensitivity (receive sensitivity), transmitting voltage response (transmit sensitivity), source-level measurements and beam patterns. The standard mounting platform is capable of a computer-controlled full 360-degree sweep with 0.1 degree resolution. We believe that this tank is the largest acoustic calibration facility in the Northeast and is well suited for measurements of high-frequency, large-aperture sonars when far-field measurements are desired. In 2015, the engineering tank saw 136 days of use of which 58% were dedicated to Center activities.

Several other specialized facilities are available in the Chase Ocean Engineering Lab to meet the needs of our researchers and students. A 750 sq. ft., fully equipped, electronics lab provides a controlled environment for the design, building, testing, and repair of electronic hardware. A separate student electronics laboratory is available to support student research. A 720 sq. ft. machine shop equipped with a milling machine, a tool-room lathe, a heavy-duty drill press, large vertical and horizontal band saws, sheet metal shear and standard and arc welding capability are available for students and researchers. A secure facility for the development and construction of a state-of-the-art ROV system has been constructed for our collaboration with NOAA's Ocean Exploration Program. A 12 ft. x 12 ft. overhead door facilitates entry/exit of large fabricated items; a master machinist/engineer is on staff to support fabrication activities. In 2015 we repurposed the "ROV Lab" to support our autonomous vehicle activities.

PIER FACILITIES

In support of the Center and other UNH and NOAA vessels, the University constructed a new pier facility in New Castle, N.H., in 2008. The new pier is a 328 ft. long and 25 ft. wide concrete structure with approximately 15 ft. of water alongside. The pier can accommodate UNH vessels and in 2013 became the homeport for the new NOAA Ship *Ferdinand R. Hassler*, a 124-foot LOA, 60-foot breadth, Small Waterplane Area Twin Hull (SWATH) Coastal Mapping Vessel (CMV), the first of its kind to be constructed for NOAA. Services provided on the new pier include 480V-400A and 208V- 50A power with TV and telecommunications panel, potable water and sewerage connections. In addition to the new pier, the University has constructed a new pier support facility**,** approximately 4,500 sq. ft. of air-conditioned interior space including offices, a dive locker, a workshop, and storage. Two additional buildings (1,100 sq. ft. and 1,300 sq. ft.) are available for storage of the variety of equipment and supplies typically associated with marine operations.

INFORMATION TECHNOLOGY

The IT Group currently consists of four full-time staff members, one part-time web developer, and one part-time help desk staff. Jordan Chadwick fills the role of Systems Manager and deals primarily with the day-to-day administration of the JHC/CCOM network and server infrastructure. He is also

responsible for leading the development of the Information Technology strategy for the Center. The Systems Administrator, William Fessenden, is responsible for the administration of all JHC/CCOM workstations and backup systems. In addition, William serves as Jordan's backup in all network and server administration tasks and contributes to the planning and implementation of new technologies at the Center. Paul Johnson, JHC/CCOM's Data Manager, is responsible for organizing and cataloging the Center's vast data stores. Paul is currently exploring different methods and products for managing data, and verifying that all metadata meets industry and Federal standards. Daniel Tauriello serves as an IT support technician, specializing in marine systems and day-to-day operations of the Center's survey vessels. Jennifer Crosby, the JHC/CCOM web developer, is responsible for developing and maintaining the external and internal websites maintained at the Center.

All JHC/CCOM servers, storage systems, and network equipment are consolidated into nine full height cabinets with one or more Uninterruptible Power Supplies (UPS) per cabinet. At present, there are a total of 18 physical servers, 39 virtual servers, two NetApp storage systems fronting eight disk arrays, two compute clusters consisting of 15 nodes combined. A Palo Alto Networks PA-3020 next-generation firewall provides boundary protection for our 10-gigabit and gigabit Local Area Network (LAN).

At the heart of the JHC/CCOM's network lies its robust networking equipment. A Dell/Force10 C300 switch serves as the core routing and switching device on the network. It is currently configured with 192 gigabit Ethernet ports, all of which support Power over Ethernet (PoE), as well as 24 10-gigabit Ethernet ports. An additional line-card, offering eight 10-gigabit Ethernet ports was purchased at the beginning of 2016 and was used to expand the 10-gigabit Ethernet port capacity of the C300 switch this year. The 10-gigabit ports provide higher-throughput access to network storage and the Center's compute cluster. A Brocade ICX 6610 switch stack provides 192 gigabit Ethernet ports for workstation connectivity and 32 10-gigabit Ethernet ports, to be used for access to the network backbone as well as for certain workstations needing high-speed access to storage resources. These core switching and routing systems are supplemented with several edge switches, consisting of a Dell PowerConnect 2924 switch, a Dell PowerConnect 2848, four Brocade 7131N wireless access points centrally managed with a Brocade RFS4000 management device, a Ubiquiti Networks Outdoor 5G access point, and a QLogic SANBox 5800 Fiber Channel switch. The PowerConnect switches handle edge applications such as the Center's Electronics Laboratory, and out-of-band management for servers and network equipment. The SANBox 5800 provides Fiber Channel connectivity to the Storage Area Network for backups and high-speed server access to storage resources. The C300 PoE ports power the wireless access points as well as the various Axis network cameras used to monitor physical security at Chase Lab. The Brocade wireless access points provide wireless network connectivity for both employees and guests. Access to the internal wireless network is secured through the use of the 802.1x protocol utilizing the Extensible Authentication Protocol (EAP) to identify wireless devices authorized to use the internal wireless network.

Increasing efficiency and utilization of server hardware at JHC/CCOM remains a top priority. The Center has set out to virtualize as many servers as possible, and to use a "virtualize-first" method of implementing new servers and services. To this end, the IT staff utilizes a three-host VMware ESXi cluster managed as a single resource with VMware vSphere. The cluster utilizes VMware High Availability and vMotion to provide a flexible platform for hosting virtual machines. All virtual machines in the cluster are stored in the Center's high-speed SAN storage system, which utilizes

snapshots for data protection and deduplication for storage efficiency. An additional VMware ESXi host serves as a test platform. Together, these systems house nearly 40 virtual servers at present, and plans are in place to virtualize more servers as current physical servers reach the end of their hardware lifecycle. Current virtual machines include the JHC/CCOM email server, email security appliance, CommVault Simpana management server, Visualization Lab web server, the MARVeL Lab web server, Certification Authority server, several Linux/Apache web servers, an NTRIP server for RTK data streams, a Windows Server 2008 R2 domain controller, version control server, a JIRA project management server, an FTP server, Skype for Business 2015 real-time collaboration server, two Oracle database servers, and two ESRI ArcGIS development/testing servers.

Figure 1-5. Center SAN and NAS infrastructure in the primary server room.

The Center's storage area network (SAN) systems currently consist of a NetApp FAS3240 cluster, and a NetApp FAS3140 storage appliance (Figure 1-5). The FAS3240 currently hosts 128 terabytes (TB) of raw storage and is capable of expanding to nearly two petabytes (PB). The FAS3240 also supports clustered operation for failover in the event of system failure, block-level de-duplication to augment efficiency of disk usage, and support for a number of data transfer protocols, including iSCSI, Fiber Channel, NFS, CIFS, and NDMP. JHC/CCOM IT staff also built, configured, and installed a custom-built locally-redundant NAS storage system in the first quarter of 2013. This storage system is used to supplement the NetApp SAN by moving less critical datasets onto a less expensive medium. In the four years this system has been in use, it has proven a popular and reliable option for large, static data sets and as such, the disk drives in the array were upgraded to increase the available storage to 75TB. The IT Staff utilizes Microsoft's Distributed File System (DFS) to organize all SAN and NAS data shares logically by type. In addition to DFS, a custom metadata cataloging web application was developed to make discovering and searching for data easier for both IT Staff and the Center as a whole. Throughout 2016, the IT group has been researching the next generation storage system that the Center will utilize over the next five to seven years. The overarching goals of the new system are to expand capacity, improve data processing performance, and centralize all storage resources into a single platform. The new system is expected to be brought online in the first quarter of 2017.

Constantly increasing storage needs create an ever increasing demand on JHC/CCOM's backup system. To meet these demands, the IT Group utilizes a CommVault Simpana backup solution which consists of two physical backup servers, three media libraries, and the Simpana software management platform. This environment provides comprehensive protection for workstation, server, and storage systems. The system utilizes de-duplicated disk-to-disk backup in addition to magnetic tape backup, providing two layers of data security and allowing for more rapid backup and restore capabilities. For magnetic tape backup, the IT Group utilizes a Dell PowerVault TL4000 LTO6 tape library, capable of backing up 250TB of data without changing tapes. In addition, a second PowerVault TL4000 LTO7 tape library is utilized for primary workstation and server backups. Full tapes from both libraries are vaulted in an off-site storage facility run by Iron Mountain. The IT Group completed a major version change migrating from Simpana 9 to Simpana 10 in 2015, which added support for the latest desktop and server operating systems and virtual server hypervisors.

As previously mentioned, the JHC/CCOM network is protected by a Palo Alto Networks PA-3020 next-generation firewall. The firewall provides for high-performance packet filtering, intrusion prevention, malware detection, and malicious URL filtering. The former Cisco ASA 5520 firewall serves as a remote access gateway, providing a SSL VPN portal, which permits access to JHC/CCOM network services remotely.

The IT staff maintains an eight-node Dell computer cluster, running Windows HPC Server 2012 (Figure 1-6). The cluster utilizes eight enterprise-class servers with 20 CPU cores and 64 GB of RAM per system, totaling 160 CPU cores and 512 GB of RAM. The cluster is used for resource-intensive data processing, which frees up scientists' workstations while data is processed, allowing them to make more efficient use of their time and resources. The cluster runs MATLAB DCS, and is used as the test-bed for developing next-generation, parallel-processing software with Industrial Consortium partners. The former Dell cluster hardware, installed in 2008, sees continued use as a test environment for a variety of parallel processing applications.

Figure 1-6. Dell computer cluster in its rack, installed in 2014.

The Center has continued to upgrade end users' primary workstations, as both computing power requirements, and the number of employees and students have increased. There are currently 265 high-end Windows and Linux desktops/laptops, as well as 31 Apple computers that serve as faculty, staff, and student workstations. All Windows workstations at the Center are running Windows 7 Professional or Windows 10 Pro. On the Apple side, macOS versions 10.11 and 10.12 are in-use throughout the Center.

JHC/CCOM also maintains key IT infrastructure at UNH's Coastal Marine Lab facility in New Castle, NH. At the site's Pier Support Building, JHC/CCOM's core network is extended through the use of a Cisco ASA VPN device. This allows a permanent, secure connection between the New Castle site and the Chase Ocean Engineering Lab over a UNH-leased public gigabit network. The VPN connection allows the IT Group to easily manage JHC/CCOM systems at the facility using remote management and, conversely, systems at the facility have access to resources at Chase Lab. Additionally, both of the current JHC/CCOM research vessels, *R/V Cocheco*, and the newly commissioned *R/V Gulf Surveyor*, are located at the pier portion of the facility. *R/V Gulf Surveyor* replaced the aging *R/V Coastal Surveyor*, and its network and computing systems were repurposed for the new vessel in May of 2016. Both vessels' networks and computers systems are maintained by the IT Group, with Daniel Tauriello providing primary IT support at the pier. All launches have access to Internet connectivity through the wireless network provisioned from the Coastal Marine Lab and 4G LTE cellular data when away from the pier.

In September of 2013, UNH received a grant from the National Science Foundation intended to improve campus cyber infrastructure. The express intent of the grant was to improve bandwidth and access to Internet2 resources for scientific research. JHC/CCOM was identified in the grant as a potential

beneficiary of such improved access, and the project achieved operational state in late 2015, providing a 20-gigabit connection to UNH's Science DMZ, and from there a 10-gigabit connection to Internet2. Plans are in place to upgrade the UNH campus Internet2 connectivity, shared with the University of Maine, to 100 Gbps in 2017. This infrastructure has allowed for improved performance of the UNOLS telepresence video streams, as well as for the fast and secure transmission of data to NOAA NCEI. The IT Group is currently looking into leveraging this bandwidth for other collaborative projects on campus.

Information security is of paramount importance for the IT Group. For the last several year, members of the JHC/CCOM staff have been working with NOS and OCS IT personnel to develop and maintain a comprehensive security program for both NOAA and JHC/CCOM systems. The security program is centered on identifying systems and data that must be secured, implementing strong security baselines and controls, and proactively monitoring and responding to security incidents. Recent measures taken to enhance security include the installation of a virtual appliance-based email security gateway, designed to reduce the amount of malicious and spam email reaching end users. The aforementioned Palo Alto firewall was installed in 2015 to replace JHC/CCOM's former firewall/IPS hardware. JHC/CCOM also utilizes Avira AntiVir antivirus software to provide virus and malware protection on individual servers and workstations. Avira server software allows for centralized monitoring and management of all Windows and Linux systems on the JHC/CCOM network. The AntiVir solution is supplemented by Microsoft ForeFront EndPoint Protection for systems dedicated to field work that do not have the ability to check-in with the management server on a periodic basis. Microsoft Windows Server Update Services (WSUS) is used to provide a central location for JHC/CCOM workstations and servers to download Microsoft updates. WSUS allows the IT staff to track the status of updates on a per-system basis, greatly improving the consistent deployment of updates to all systems.

In an effort to tie many of these security measures together, the IT Group utilizes Nagios for general network and service monitoring. Nagios not only provides for enhanced availability of services for internal JHC/CCOM systems, but has been a boon for external systems that are critical pieces of several research projects, including AIS ship tracking for the U.S. Coast Guard. In the spring of 2015, the server formerly dedicated to Nagios service monitoring and log aggregation was replaced with a new Dell server offering larger and faster internal hard drives, a faster CPU, and increased memory. A new security event management system, utilizing Open Source Security (OSSEC) and Splunk, was implemented as part of the migration to the new server hardware. OSSEC performs threat identification, and log analysis. Splunk is used for data mining and event correlation across systems and platforms.

Where physical security is concerned, Chase Ocean Engineering Lab utilizes a biometric door access system, which provides 24/7 monitoring and alerting of external doors and sensitive IT areas within the facility. The primary data center utilizes two factor authentication to control physical access. Security cameras monitor the data center as well as the network closet in the building. Redundant environment monitoring systems, managed internally at the Center and centrally through UNH Campus Energy, monitor the temperature and humidity sensors in the data center and network closet.

The IT Group utilizes Request Tracker, a helpdesk ticket tracking software published by Best Practical. JHC/CCOM staff, students, and faculty have submitted over 12,000 Request Tracker tickets since its inception in mid-2009. Through the end of 2016, the IT Staff was able to resolve 90% of tickets within three days. The software is also used for issue tracking by the JHC/CCOM administrative staff, lab and

facilities support team, web development team, and scientists supporting the NSF Multibeam Advisory Committee project.

JHC/CCOM continues to operate within a Windows Active Directory domain environment, and in early 2012, migrated the majority of its domain services to 2008 R2 Active Directory running on Windows Server 2008 R2. A functional 2008 R2 domain allows the IT Group to take advantage many modern security and management features available in Windows 7 and later operating systems. The Windows 2008 R2 Active Directory servers also provide DHCP, DNS, and DFS services. Policies can be deployed via Active Directory objects to many computers at once, thus reducing the IT administrative costs in supporting workstations and servers. This also allows each member of the Center to have a single user account, regardless of computer platform and/or operating system, reducing the overall administrative cost in managing users. In addition, the JHC/CCOM IT Group maintains all NOAA computers in accordance with OCS standards. This provides the NOAA-based employees located at the JHC with enhanced security and data protection.

JHC/CCOM currently utilizes two separate version control mechanisms on its version control virtual server – Subversion (SVN) and Mercurial (Hg). The Mercurial system went online in 2011 and presently, the JHC/CCOM IT Group encourages developers to use Mercurial for new projects, while continuing to support Subversion for existing projects. Mercurial uses a decentralized architecture which is less reliant on a central server, and also permits updates to repositories without direct communication to that server. This allows users in the field to continue software development while still maintaining version history. The IT Group hosts a Jira software project management server to aid in tracking bugs and new features for software projects.

JHC/CCOM also utilizes Bitbucket to facilitate software collaboration between its own members as well as industrial partners and other academic colleagues. Bitbucket is a source control management solution that hosts Mercurial and Git software repositories. Atlassian, the company behind Bitbucket, states that Bitbucket is SAS70 Type II compliant and is also compliant with the Safe Harbor Privacy Policy put forth by the U.S. Department of Commerce.

The JHC/CCOM website, http://ccom.unh.edu, utilizes the Drupal content management system. Drupal allows for content providers within the Center to make changes and updates with limited assistance from a web developer. Drupal also allows for the creation of a more robust platform for multimedia and other rich content, enhancing the user experience of site visitors. Work also continues on the development of Center-wide Intranet services using the Drupal content management software. The Intranet provides a centralized framework for a variety of information management tools, including the Center's wiki, purchase tracking, library, data catalog, vessel scheduling, and progress reporting systems. The progress reporting system is entering its sixth reporting period and has greatly improved the efficiency and completeness of the Center's annual report. Additionally, development continues on the Center's ArcGIS server. As this resource evolves, more Intranet services will be brought online to assist in the search for Center-hosted data and access to this data through Intranet-based mapping services.

RESEARCH VESSELS AND PLATFORMS:

For many years the Center has operated two dedicated research vessels, the 40-foot R/V *Coastal Surveyor* (Center owned and operated) and the 34-foot R/V *Cocheco* (NOAA owned and Center maintained and operated). Over the past few years it became increasingly clear that our workhorse survey vessel, the R/V *Coastal Surveyor* was reaching the limit of its useable service and that the R/V *Cocheco* was not a suitable candidate to take over the role as a sonar-mapping platform. The *Coastal Surveyor's* fiberglass hull was delaminating and a number of drivetrain failures had been encountered, some in hazardous areas with students on-board. *Coastal Surveyor* was also very limited in her capabilities as an educational platform due to the limited space in the cabin. R/V *Coastal Surveyor's* greatest strength was the versatile transducer strut that allowed for the robust installation of many different instruments, albeit that the installation of these systems was cumbersome and not without risk. Given this situation, we embarked, in 2015, on the acquisition of a new vessel that offers the same versatility for instrument deployment (in a much easier fashion), while providing better cabin space to house students, researchers, and navigation crew. We took delivery of this new vessel – the R/V *Gulf Surveyor* – in April 2016 and have been successfully using her since. At the same time the R/V *Coastal Surveyor* was retired, though she provided five days of training in 2016 for students before the arrival of the *Gulf Surveyor*.

R/V GULF SURVEYOR

(48 ft. LOA, 17 ft. beam, 4.6 ft. draft, cruising speed 14 knots)

Figure 1-7: New JHC Research Vessel R/V Gulf Surveyor off New Castle New Hampshire

The *Gulf Surveyor* (Figure 1-7) was designed specifically for coastal hydrography and was constructed by All American Marine, Inc. (AAM) in Bellingham, WA. The overall design is based on the success of the R/V *Auk* that AAM built for NOAA in 2006, and the 45-foot R/V *David Folger* built for

Middlebury College in 2012. At an overall length of 48 feet and beam of 18 feet, the catamaran vessel follows the advanced *Teknicraft Design*, Ltd. (Auckland, New Zealand). This includes a signature hull shape with symmetrical bow, asymmetrical tunnel, and integrated wave piercer. Main propulsion is provided by twin Cummins QSB 6.7 Tier 3 engines rated 250 mhp at 2600 rpm. Auxiliary power is supplied via a Cummins Onan 21.5kW generator. The suite of deck gear includes a hydraulic A-frame, davit, scientific winch, side mount sonar strut, and moon pool with deployable sonar strut.

The construction of the vessel was completed in January 2016 and a team from UNH and our local representative went to Bellingham for initial sea trials. Upon completion of the sea trials, the vessel was brought to Victoria, British Columbia on 2 February where she was loaded aboard the HHL *Volga* for ocean transport through the Panama Canal to Port Canaveral, FL., arriving 26 March, 2016. Lee Alexander, Capt. Paul Peltier and Mate Dan Tauriello, then brought the vessel 1400 nm up the Atlantic coast arriving in New Castle, New Hampshire on 30 April 2016. Upon arrival in New Castle, Capt. Emily Terry took command and coordinated the fabrication of the IMU mount for the transducer strut with Paul Lavoie and installed it prior to the survey of the vessel. The vessel was then brought to a local shipyard where a detailed laser scan survey to establish reference coordinate frame of the vessel was completed including 43 individual set-ups,200 registration targets and a point cloud of more than 100 million points (Figure 1-8). The final survey resolution of the establishment of 13 survey monuments with uncertainty of less than 1mm.

Figure 1-8: Laser Scan point cloud of R/V Gulf Surveyor

The vessel was issued a USCG inspection certificate on 9 June 2016 and immediately started to support Center activities. Captain Terry and Dan Tauriello have been writing up standard and emergency procedure documentation as well as conducting safety training and drills with new crew members aboard the vessel. Terry and Tauriello have been learning the new systems, trouble-shooting and solving minor break-in issues and providing regular maintenance.

We are still in the process of fully equipping the *Gulf Surveyor*, however the current list of scientific, navigation and support equipment includes:

Scientific Equipment:

- Teledyne RD Instruments WH Mariner 600 kHz Coastal Vessel Mounted DR ADCP
- Odom THP 200/24-4/20 transducer
- Applanix POS/MV version 5
- Trimble Trimark 3 radio modem
- (2) Custom Dell Precision Rack 7910
- (4) 24” Dell Monitors
- (2) SmartOnline 6000 VA power modules
- Dell PowerConnect 2848 Network Switch
- Verizon Mifi wireless hotspot
- Buffalo AirStation router

Navigation Electronics:

- Custom Dell Precision Rack 7910 running Rose Point Coastal Explorer
- Custom Dell Precision Tower 3420
- AXIS Q6045 Mk II PTZ Dome Network Camera
- AXIS Q6045-S Mk II PTZ Dome Network Camera
- (2) AXIS M2014 Cameras
- Dell X1018 network switch
- Standard Horizon VLH-3000 Loud Hailer
- Airmar 200WX weather station
- (2) UTEK 4-port RS-485/422 serial to USB converters
- (2) ICOM M-4240 radios
- 8x8 Black Box HDMI matrix switch
- (4) 19” Dell Monitors

Simrad Systems:

- DX64s Radar
- Broadband 4G radar
- AP70 Autopilot
- AC80S Autopilot Processor
- RF45X Rudder Feedback Unit
- (2) QS80 Remote Steering Control
- NSO evo2 processor
- NSO OP40 controller
- (2) MO19T monitors
- GS25 GPS antennae
- RC42 Rate Compass
- RI10 Radar Junction Box

Garmin Systems:

- GNX 21 data display
- GSD 25 Sonar Module
- GT51M-TH transducer
- GPSMAP 8500 processor
- GRID remote input device
- GPSmap 840xs
- GCV 10 transducer

Various multibeam sonar systems have already been efficiently deployed through moon pool using the hydraulic strut specifically designed for the *Gulf Surveyor* (Figure 1-9).

Figure 1-9: Bottom of 3.5m long hydraulic ram for mounting sonars and deploying through moon pool (covered by yellow grating) on R/V Gulf Surveyor.

R/V *Gulf Surveyor* – Research and Education Operations for 2016

Month	Days	User
May	5, 12, 16, 24	maneuvering practice
May	12	USCG inspection
May	25	POS/MV GAMS calibration
June	1	maneuvering practice
June	2-30	Summer Hydrographic Field Course - MBES, BS, Video
July	12, 13, 14	Val Schmidt - Klein Testing
July	18	Semme Dijkstra - PosMV GAMS calibration
July	20	Semme Dijkstra - rapidCAST testing
July	25, 26, 27, 28	John Kidd - LIDAR
August	3	Matt Birkebak - LIDAR
August	23, 24	Tom Weber - seep generator testing
September	7	John Hughes-Clark - Ocean Mapping Lab

September	8	Tom Weber - seep generator testing
September	14, 15	Val Schmidt - ASV testing
September	21, 28	John Hughes-Clark - Ocean Mapping Lab
September	29, 30	Val Schmidt - ASV testing
October	6, 13	Larry Ward - grab sampling, underwater video
October	19	John Kidd - LIDAR
October	25, 26	Val Schmidt - ASV testing
October	27	Tom Weber - seep generator & sonar detection
November	1	Larry Ward - grab sampling, underwater video
November	2, 3, 16, 17	Tom Weber - seep generator & sonar detection
December	6, 7, 8, 9	Val Schmidt - ASV testing
TOTAL:	**71 DAYS**	

R/V COCHECO

(34 ft. LOA, 12 ft. beam, 5.5 ft. draft, cruising speed 16 knots)

Figure 1-10: R/V Cocheco.

R/V *Cocheco* (Figure 1-10) was designed for fast transits and over-the-stern operations from her A-Frame. Several years ago, a hydraulic system and winch equipped with a multi-conductor cable were

installed making the vessel suitable for deploying or towing a wide variety of samplers or sensors. She provides an additional platform to support sampling and over-the-side operations necessary for our research programs and adds a critical component to our Hydrographic Field Camp. In 2009, AIS was permanently installed on *Cocheco*, her flux-gate compass was replaced, and improvements made to her autopilot system. In addition, *Cocheco's* 12V DC power system, hydraulic system wiring and communications wiring were updated. In 2010, a second VHF radio and antenna were installed and several battery banks were replaced and upgraded. In 2013 the *Cocheco* had an extended yard period that, in addition to the annual maintenance, included engine maintenance to improve performance and limit oily exhaust, repairs to the hydraulic steering system, and replacing the non-skid paint on the aft deck. In 2015, routine preventative maintenance of R/V *Cocheco* was performed (e.g., replacing fluids and filters, cleaning the bilge, having the liferaft inspected, etc.) and unexpected problems addressed (e.g., replacing the battery charging system, and completing a refit of the hydraulic system which powers her A-frame and winch). R/V *Cocheco* had annual maintenance performed at the boatyard this summer, including new bottom paint and zincs. Routine maintenance and winterization were completed this fall. With the arrival of the *Gulf Surveyor* the *Cocheco* saw limited operations in 2016.

R/V *Cocheco* Research and Educational Operations for 2016

Month	Days	User
April	28	Seamanship Course, Buoy operations
June	5-8	Hydro Field Camp

Total Days: 4

Both 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. They carry life rafts and EPIRBs (Emergency Position Indicating Radio Beacons), electronic navigation systems based on GPS, and radar. Safety briefings are given to all crew, students, and scientists. Random man-overboard and emergency towing exercises are performed throughout the operating season. The Center employs two permanent captains.

CBASS – VERY SHALLOW WATER MAPPING SYSTEM

Difficulties working in shallow hazardous waters often preclude accurate measurement of water depth both within the river channel where high flows rapidly change the location of channels, ebb tide shoals, and sand bars, and around rocky shores where submerged outcrops are poorly mapped or uncharted. To address these issues, Tom Lippmann has developed the Coastal Bathymetry Survey System (CBASS; Figure 1-11). In 2012, numerous upgrades were made to the CBASS including the development of full-waveform capabilities for the 192 kHz single beam echosounder on board, the integration and field use of a hull-mounted 1200 kHz RDI Workhorse Acoustic Doppler Current Profiler (ADCP) for observation of the vertical structure of mean currents in shallow water, particularly around inlets and river mouths where the flows are substantial, and most importantly, the addition of a 240 kHz Imagenex Delta-T multibeam echosounder (MBES) with a state-of-the-art inertial measurement unit (IMU). The system

was tested over a four week period in May 2012 at New River Inlet, NC, as part of the Office of Naval Research (ONR) sponsored Inlet and River Mouth Dynamics Experiment (RIVET). During RIVET, bathymetric maps were produced at 10-20 cm resolution from multiple overlapping transects in water depths ranging from 1 to 12 m within the inlet. Ultimately, the noise floor of bathymetric maps obtained with the CBASS (after incorporating CUBE uncertainty analysis) was found to be between 2.5 and 5 cm, with the ability to resolve bedforms with wavelengths greater than 30 cm, typical of large ripples and megaripples. A leak and subsequent battery fire in the CBASS late in 2012 kept it out of the field for most of 2013, but it has been brought back to operational status in 2014. Search for a replacement craft began in 2015 and was completed in 2016 with the acquisition of a new small craft made by industrial partner Higgs Marine.

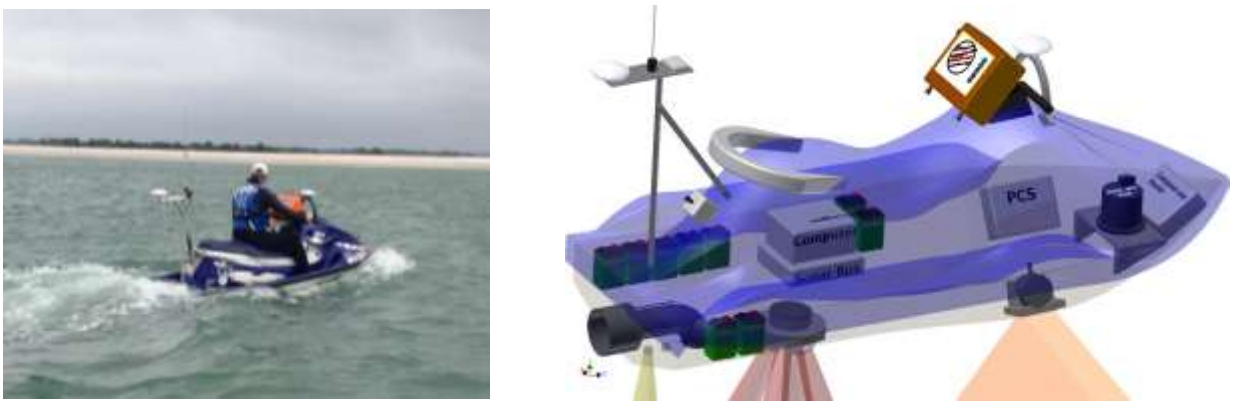


Figure 1-11. CBASS in action surveying in New River Inlet NC (left) and CAD drawing (right) showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery packs, GPS and RTK antennae, and navigational display monitor

ZEGO BOAT – VERY SHALLOW WATER MAPPING SYSTEM

After careful research, the decision was made to replace the CBASS with a new shallow water vessel, called a Zego Boat (Figure 1-12). The new vessel is being outfitted with a full suite of hydrographic survey equipment similar to the Coastal Bathymetry Survey System (CBASS). The Zego boat, obtained from Higgs Hydrographic, Inc., is a twin-hulled catamaran made from durable plastic material and has a 30 hp outboard motor. The vessel has a very shallow draft allowing it to operate in depths as little as 40-50 cm (depending on motor skeg depth) and is very stable in the presence of both waves (breaking and nonbreaking) and strong current conditions. The vessel has a front ram assembly that will make testing and integrating of equipment much easier than possible for other vessels of this size (such as the

CBASS). Critical vessel equipment includes an Applanix POS-MV 320 for highly accurate orientation measurements that can be integrated with a variety of multibeam echo sounders. We are presently in the process of installing custom mounts and integrating the equipment onboard the vessel. The CBASS will continue to be operated as long as it can, but we expect that its life-expectancy is quite limited.

Figure 1-12: The JHC Zego Boat, a highly maneuverable and stable twin-hulled catamaran that will be outfitted into a state-of-the-art shallow water survey vessel with MBES, SBES, and ADCP capabilities.

EDUCATIONAL PROGRAM

CURRICULUM DEVELOPMENT

At its inception, the Center, under the guidance of Capt. Armstrong, developed an ocean mapping-specific curriculum that was approved by the University and certified (in May 2001) as a Category A program by the FIG/IHO/ICA International Advisory Board for Standards of Competence for Hydrographic Surveyors. We also established a post-graduate certificate program in Ocean Mapping. The certificate program has a minimum set of course requirements that can be completed in one year and allows post-graduate students who cannot spend the two years (at least) necessary to complete a Master's degree a means to upgrade their education and receive a certification of completion of course work.

Although our students have a range of general science and engineering courses to take as part of the Ocean Mapping Program, the Center teaches several specifically designed courses. 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 and Statistics, a specialized math course, taught at the Center. This course is designed to provide Center students with a background in the math skills needed to complete the curriculum in Ocean Mapping. The content of this course has been designed by Semme Dijkstra and Brian Calder specifically to address the needs of our students and is being taught by professors from the UNH Math Dept. In 2008, in recognition of the importance of our educational program, we created an internal position of full-time instructor in hydrographic science. Semme Dijkstra, who led the effort to revamp our curriculum and renew our FIG/IHO/ICA Cat. A certification (see below), has filled this position.

The original FIG/IHO/ICA Certification received by the Center at its inception required renewal in 2011 and in light of the need for a new submission to the FIG/IHO/ICA, the extraordinary growth of the Center (and expansion of faculty expertise), and the recognition that certain aspects of our curriculum were leading to unrealistic demands on our students, the Center, under the leadership of Semme Dijkstra, re-designed the entire ocean mapping curriculum.

The goals of the new curriculum were to:

1) Reduce the number of required credit hours for our certificate students,
2) Create a keystone, two-semester "Fundamentals of Ocean Mapping" course that would cover all the fundamentals defined by the members of our faculty and the FIG/IHO/ICA,
3) Take broad advantage of the expertise available at the Center,
4) Meet the standards required for FIG/IHO/ICA Cat. A certification, and
5) Be modular so that components may be taught on their own at the Center or other locations.

This curriculum was presented to the FIG/IHO/ICA education board by Dijkstra and Capt. Armstrong and accepted (the board lauded the UNH submission as "outstanding"). Thus the Center maintains an IHO Category A Certification and continues to be one of only two Category A programs available in North America. The new curriculum (Appendix A) has subsequently been accepted by the College of Engineering and Physical Sciences curriculum committee, approved by the graduate school, and was

presented for the first time in 2012. A complete list of courses established by the Center can be found in Table 53-1.

Table 53-1: JHC – Originated Courses

Course	Instructors
Applied Tools for Ocean Mapping	Dijkstra, Wigley
Fundamentals of Ocean Mapping I	Hughes Clarke, Calder, Dijkstra.
Fundamentals of Ocean Mapping II	Armstrong, Dijkstra, Mayer
Geodesy and Positioning for OM	Dijkstra
Hydrographic Field Course	Dijkstra, Armstrong
Interactive Data Visualization	Ware
Mathematics for Geodesy	Wineberg (Math Dept.)
Nearshore Processes	Ward, Gardner
Seafloor Characterization	Mayer, Calder
Seamanship and Marine Weather	Armstrong, Kelley
Seminars in Ocean Mapping	All
Special Topics: Bathy-Spatial Analysis	Wigley
Special Topics: Ocean. Data Analysis	Weber
Time Series Analysis	Lippmann
Underwater Acoustics	Weber

FUNDAMENTALS OF OCEAN MAPPING COURSES

Based on discussions within the Center, a decision was made in 2016 to reorganize the two term Fundamentals of Ocean Mapping (FOM) Course. The too-brief geologic and oceanographic sections have been removed and will be incorporated into new half-term courses. With the freeing up of about one-quarter of the FOM-I schedule, there is now the opportunity to rationalize the existing two term option allowing expansion elsewhere to better cover the technical aspects of multibeam mapping.

As part of the reorganization of the core FOM classes, the survey system integration section in the old FOM-II class was taught by Hughes Clarke this February in preparation for consolidation into a newly-reorganized FOM-I class. That new class now takes the students, step-by-step, through the components of an integrated acoustic seabed mapping system. This includes the relevant acoustic principles, their implementation in modern multi-sector multibeam sonars, and the integration of position, orientation, and sound speed.

This new model for FOM-I was implemented for the first time in Fall 2016. The majority of the course was taught by a single lecturer (Hughes Clarke), with significant contributions by Dijkstra (field and lab exercises and motion sensors), and Calder (digital filtering).

A specific example of the change in the curriculum and teaching objectives is the new series of assignments which directly address survey system integration in multibeam systems. This new assignment suite was developed by Hughes Clarke, taking advantage of sample data from Naval

Oceanographic Office testing in open ocean conditions (large lever arms combined with significant rotations; Figures 53-1 and 53-2).

An additional benefit of the proposed reorganization of the FOM-I/II material is that all the technical aspects of seabed imaging can be now be contained within a single term (Fall). As a result, they may also be offered in parallel as a senior year undergraduate elective in the new Bachelor of Science in Ocean Engineering Program. This new course will be called: OE774 – Integrated Seabed Mapping Systems.

The curriculum in Ocean Mapping offered through JHC/CCOM is one of the key components of the NOAA grant. NOAA staff are routinely assigned to UNH for graduate and diploma-based training. Thus continual updating and reassessment of the focus and relevance of this curriculum is essential. Multibeam system integration (and imperfections therein) is probably the single largest concern for operational hydrographic surveys by OCS. This new course is a direct response to that pressing need.

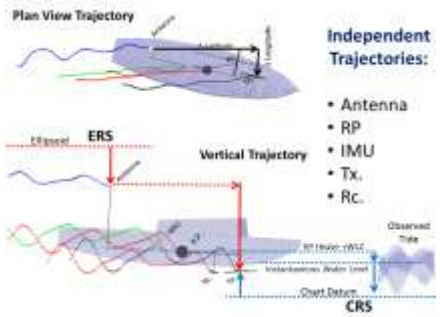


Figure 53-1: Illustration of the dynamic nature of the trajectories of the component sensors in an integrated multibeam system.

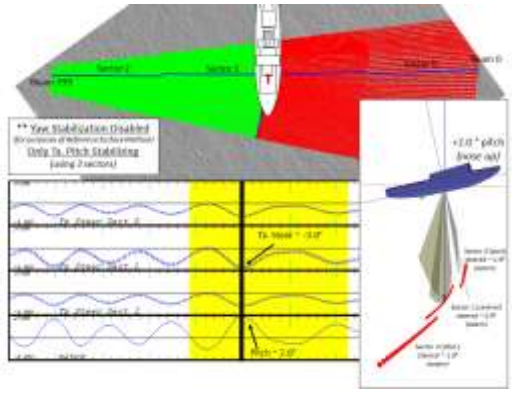


Figure 53-2: Illustration of the additional complications involved in the integration of multi-sector systems.

As part of this change, in 2016, we developed a new physical oceanography course that will be taught during the 'J-term' in January 2017. We plan to combine this course with a geological oceanography course, allowing students to take either of the topics as a section, or the course as a whole as needed.

TOOLS FOR OCEAN MAPPING COURSE:

Our "Tools for Ocean Mapping" course is now a 21-step practical assignment. As part of this assignment the students combine data for various data sources including bathymetry, DTMs, video, etc., into a single GIS database and learn to process and manipulate the data (e.g., changing datums) using a variety of software tools. As part of this process the students need to evaluate various coordinate reference frames used for the data acquisition and QA/QC the data. This exercise involves extensive use of ArcGIS, data manipulation in Excel, programming in Matlab, creating Windows terminal scripts and Ubuntu Linux scripts. Finally, the students have to use these data to plan future data collection using Hypack and present the data using the Generic Mapping Tools.

GEODESY COURSE

Dijkstra continued development of the Geodesy and Positioning for Ocean Mapping course to bring the curriculum more in line with the needs for our ocean mapping students, keep abreast in development of technologies, particularly with respect to Kinematic GNSS networks, while ensuring that the course still meets the requirements outlined by the FIG/ICA/FIG educational board.

GEBCO CERTIFICATE PROGRAM

The Center was selected to host the Nippon Foundation / GEBCO Bathymetric Training Program in 2004 through an international competition that included leading hydrographic education centers around the world. UNH was awarded $0.6 M from the General Bathymetric Chart of the Oceans (GEBCO) to create and host a one-year graduate level training program for seven international students. Fifty-seven students from thirty-two nations applied and, in just four months (through the tremendous cooperation of the UNH Graduate School and the Office of International Students and Scholars), seven students were selected, admitted, received visas and began their studies. This first class of seven students graduated (receiving a "Graduate Certificate in Ocean Mapping") in 2005. Twelve classes, with seventy-two scholars from thirty-three Coastal States, have since completed the Graduate Certificate in Ocean Mapping from the University of New Hampshire.

Funding for the 13th and 14th year of this GEBCO training program was received from the Nippon Foundation and the selection process followed the new guidelines of including input from the home organizations of prospective students. This year the recruiting process for Year 13 was further refined by adding former alumni to the selection committee to continue scholar interactions. The 2016 class of six were selected from eighty-one applications from thirty-seven countries, attesting to the on-going demand for this course. The current 13th class of 2015/2016 includes six students selected from Madagascar, Mauritius, Egypt, Thailand, Russia and Japan – adding two new coastal states to the alumni network (Figure 1-15).

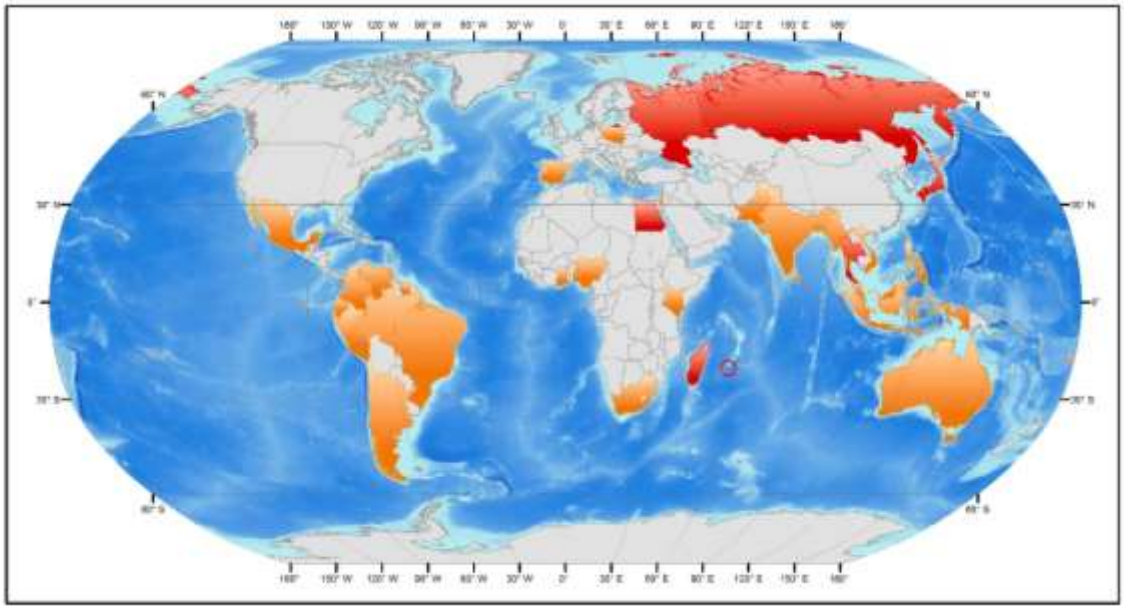


Figure 1-15: The 35 home nations of Nippon Foundation / GEBCO Scholars (Includes Year 1 to 13) with Year 13 in red.

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 Rochelle Wigley to our faculty in the position of Program Director for the Nippon Foundation / GEBCO training program.

In 2016, the 12th Nippon Foundation / GEBCO class (2014/2015) attended an intense two day training session at NOAA's National Centers for Environmental Information (NCEI) and co-located International Hydrographic Organization Data Center for Digital Bathymetry (IHO-DCDB) in Boulder, CO in January 2016. The students were introduced to the Marine Geology and Geophysics Division research team and the projects being undertaken in terms of data management and stewardship during this visit.

The six year-12 Nippon Foundation / GEBCO Training Program students together with six other international cartographers and hydrographers from 12 countries participated in the 2nd NOAA Chart Adequacy Workshop from 11-13 July 2016 at the NOAA's Office of Coast Survey. Attendees learned techniques to evaluate the suitability of nautical chart products using chart quality information and publicly available information. Involving guest cartographers and hydrographers in hands-on GIS layer development and use, instructors demonstrated that the procedure is a low-cost tool that can help any hydrographic office assess the adequacy of its charts. Participants came from Barbados, Brazil, Canada, Japan, Malaysia, Pakistan, Peru, Russia, Vietnam, the Netherlands, Mexico, and Thailand. Instructor presentations and GIS laboratory exercises were provided by Dr. Shachak Pe'eri and Lt. Anthony Klemm (Figure 1-16).

Figure 1-16: Attendees of 2nd NOAA Chart Adequacy Workshop in Silver Spring, MD.

The Indian Ocean Bathymetric Compilation (IOBC) project is ongoing, with the establishment of a database comprised of more than 700 available single beam surveys and compilation grids and 85 cleaned MBES surveys. The IOBC is also used as a training tool in the Spring Semester at UNH, where Nippon Foundation / GEBCO students work on assimilating a dataset into the IOBC database – which gives them practical experience in getting data from a World Data Center to a final map product. This project has proved to be an excellent working case study for the students to understand the complexities of downloading and working with publicly-available bathymetric datasets. The first IOBC grid was presented at the Nippon Foundation / GEBCO Forum for Future Ocean Floor Mapping in Monaco from 15-17 June 2016.

The first phase of the Nippon Foundation / GEBCO Short Video Series: "GEBCO: Standing on the Shoulders of Giants" has been completed, with interviews of selected members of the GEBCO community in attendance at the GEBCO Guiding Committee (GGC), Technical Sub-Committee on Ocean Mapping (TSCOM), and Sub-Committee on Regional Undersea Mapping (SCRUM) meetings in Kuala Lumpur, Malaysia in October 2015. The first two short videos by Zlatka Creative, LLC are available and focus on the training program at the Center and its impact on alumni and the GEBCO community.

These videos are available at:

- https://www.youtube.com/watch?v=blfuyzzS_Gg
- https://www.youtube.com/watch?v=Wuq7syaZ--wza

The Nippon Foundation awarded additional funds for the Future of the Ocean Floor Forum to be held in the Principality of Monaco from 14-17 June 2016, where Rochelle Wigley was part of the logistics team involved in the planning of this international event. The Forum was opened by His Serene Highness Prince Albert II of Monaco and Mr Sasakawa, Chairman of the Nippon Foundation, on 15 June 2016, followed by keynote speakers Robert Ballard, Larry Mayer, David Heydon, Simon Winchester, Kristina Gjerde, Bjørn Jalving and Jyotika Virmani at the Oceanographic Museum in Monaco. The second and third days comprised of panel discussions where delegates, led by a panel of moderators, shared their views on what is needed to get the ocean mapped and why this is important, with the aims to

bring together the deliberations into a sort of 'roadmap' for the future of ocean floor mapping. Invited collaborators and panelists from major ocean-related organizations and academic institutions also discussed critical ocean issues and their view of the future.

This event was attended by 47 alumni of the Nippon Foundation / GEBCO Training Program (Figure 1-17) as well as more than 150 leaders in the field of ocean mapping from academia, government and industry from a wide range of sectors (Figure 1-18). The outcome of the Forum will be the development of the GEBCO Roadmap for Future Ocean Floor Mapping, which will enable us to realize our vision of mapping 100% of the ocean floor. The Chairman of the Nippon Foundation, Mr Sasakawa, also highlighted the achievements of the Nippon Foundation / GEBCO Scholar program to date. He also spoke about initiating of a Scholars alumni organization, to foster the network of these alumni of the Training Program at the Center. The Forum elicited positive feedback from all attendees, has had a ripple effect in improving communication between ocean mappers, and raised the awareness of ocean mapping in the media.

Figure 1-17: 47 scholars from the 13 Years of the Training program met in Monaco to re-build existing networks and develop new networks amongst alumni

Figure 1-18: Nippon Foundation / GEBCO Scholars meeting Prince Albert II at Opening Ceremony of Forum for Future Ocean Floor Mapping.

One other outcome of the Forum for Future Ocean Floor Mapping, was the establishment of the GEBCO-NF Team for the Shell Ocean Discovery XPRIZE. The core GEBCO-NF Team is made up of eight alumni of the Nippon Foundation/GEBCO Training Program and is being advised and mentored by selected GEBCO and industry experts (Figure 1-19). The GEBCO-NF Team is distinguished by its diversity. The Team has a global distribution with representatives from academic institutions, offshore survey and technology industries, as well as national hydrographic offices. Their backgrounds range from ocean mapping, hydrography, geology, engineering, software development, physics, naval architecture, and offshore project management.

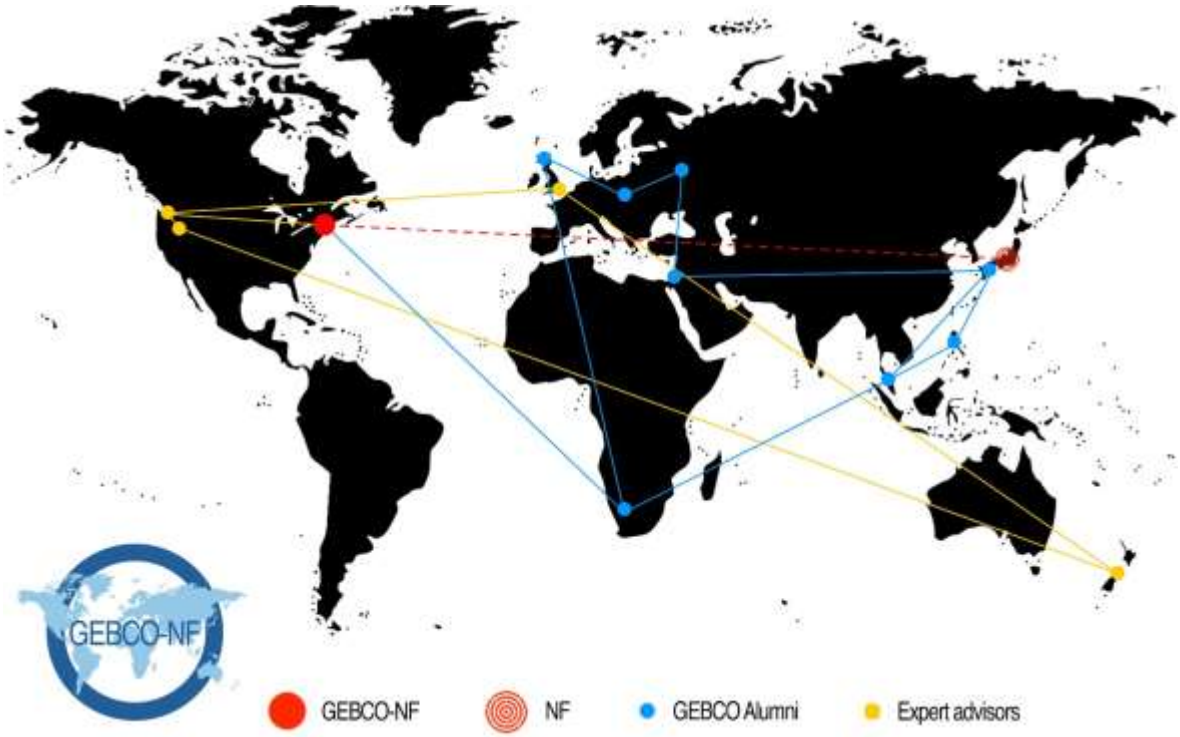


Figure 1-19: GEBCO-Nippon Foundation X-Prize Team

The GEBCO-NF Team is developing a solution to allow the world's oceans to be affordably mapped and monitored. The Team will leverage state-of-the-art surveying technology with new innovations in

offshore logistics, backed by industry leading companies, to collect higher resolution bathymetric data through autonomous means. The strategic approach is to augment the hardware, integration and software needs of the Team by developing strong partnerships with technology and service providers

Visits were made to alumni of the Nippon Foundation / GEBCO Training Program in Sri Lanka, Bangladesh and Vietnam by the Project Director. The overall objective was to build better relationships with Nippon Foundation / GEBCO alumni home organizations by educating high-level individuals within the host organizations and national government on GEBCO and its goals in ocean mapping, and informing the above nations / organizations of the role Nippon Foundation / GEBCO alumni can and must play within GEBCO, and ocean mapping in general, into the future. Building networks between ocean mapping organizations and informing alumni of GEBCO projects is an important added aspect of these visits.

Presentations were made and meetings held at:

- National Aquatic Resources Research and Development Agency (NARA) in Sri Lanka with alumni Dr Priyantha Jinadasa (Yr 4) Roshan Ranaweera (Yr 7) and Nilupa Samarakoon (Yr 11)
- Institute of Marine Sciences and Fisheries of the University of Chittagong with Mohammad Chowdhury (Yr 8) and Munna Uddin (Yr 7)
- Vietnam Maritime Institute (VIMARU) with Xinh Le Sy (Yr 9). He also organized meetings with National Hydrographic Office (VNHO) of the Vietnam People's Navy and Vietnam Maritime Safety – North
- Research Institute For Marine Fisheries (RIMF) with Thanh Duh Nguyen (Yr 3)
- Institute of Marine Geology and Geophysics (IMGG) of Vietnam Academy of Science and Technology (VAST) with Than Trung Than (Yr 8).
- A courtesy visit was also made to Department of Geodesy of Hanoi University of Mining and Geology.

Academic Year 2016 Graduate Students		
Student	**Program**	**Advisor/Mentor**
BIRKEBAK, Matthew	MS OE	S. Pe'eri
BONGIOVANNI, Cassie	MS E. Sci O. Mapping	L. Mayer
CHAUVEAU, Bryan (NOAA)	Cert OE Mapping	A. Armstrong
Di STEFANO, Massimo	PhD ES Oceanography	L. Mayer
FREIRE, Ramos Ricardo	PhD OE	S. Pe'eri
HEFFRON, Erin	MS ES Mapping	L. Mayer
HIRSCHFELD, Coral Moreno	PhD OE	L. Mayer
HOY, Shannon	MS ES Mapping	L. Mayer
IRISH, Irish	MS ES Mapping (rec'd 2016)	L. Mayer
KIDD, John (NOAA)	MS ES Mapping	A. Armstrong
KOZLOV, Igor	MS CS	Y. Rzhanov
LORANGER, Scott	PhD ES Oceanography	T. Weber
MAINGOT, Brandon	MS OE Mapping	L. Mayer
MALIK, Mashkoor (NOAA)*	PhD NRESS	L. Mayer
MUNENE, Tiziana	MS OE	A. Armstrong
NIFONG, Kelly	MS ES Mapping (rec'd 2016)	L. Ward
NORTON, Ashley	PhD NRESS	S. Dijkstra
PADILLA, Alexandra	PhD OE	T. Weber
PECANHA, Anderson Barbarosa	MS ES Mapping (rec'd 2016)	A. Armstrong
REED, Samuel	MS EE	V. Schmidt
RICE, Glen (NOAA)*	PhD OE Mapping	T. Weber
RYCHERT, Kevin	MS OE	T. Weber
SANCHEZ-ESPINOZA, Nilton	MS OE Mapping (rec'd 2016)	A. Armstrong
SMITH, Michael	MS OE Mapping	L. Mayer
SOWERS, (NOAA)*	PhD NRESS	L. Mayer
STEELE, Shannon-Morgan	MS ES Mapping	L. Mayer
STEVENS, Andrew	PhD CS	T. Butkiewicz
VON KRUSENSTIERN, Katherine	MS E. Sci O. Mapping	T. Lippmann
WEIDNER, Elizabeth	MS ES Mapping	T. Weber

* Part-time

GEBCO students (2016-2017)		
Student	**Institution**	**Country**
ELSAIED, Mohamed Moawed	Ministry of Higher Education and Scientific Research, NIOF	Egypt
MARTIN, Tina	Institut Halieutique et des Sciences Marines	Madagascar
PUAHENGSUP, Pichet	Commander in Royal Thai Navy	Thailand
RYZHOV, Ivan	Federal State Budgetary Institution , AARI	Russia
SEEBORUTH, Sattiabaruth	Hydrographic Unit of the Ministry of Housing and Lands (MHL)	Mauritius
SUMIYOSHI, Masanao	Hydrographic and Oceanographic Department, Coast Guard	Japan

HYDROGRAPHIC FIELD COURSE

The 2016 Summer Hydrographic Field Course brought the R/V *Gulf Surveyor* (RVGS), R/V *Cocheco*, 11 JHC/CCOM students, and several technical staff under the supervision of Semme Dijkstra to the nearshore waters between North Hampton, NH and Salisbury, NH. The primary objective was to map an area of Salisbury Beach at the request of the Massachusetts Coastal Zone Management (CZM) agency. CZM requires these data to better manage Salisbury Beach as a critical habitat for the piping plover, to address beach erosion, and to identify offshore deposits of beach-compatible sand. CZM states that identifying offshore deposits of beach-compatible sand is an essential step when considering beach nourishment. Nourished shorelines provide a number of benefits including increased area for recreation, increased revenue from tourism, habitat improvement for shore dependent species, greater protection of the coastline from coastal storms, reduced need for armor, and increased public access.

Data were collected using a Kongsberg EM2040 multibeam sonar system provided by Kongsberg through their industrial sponsorship. Initially, a test area was identified so all could familiarize themselves with the new vessel. In this area, 190.4 nm of main scheme lines were collected, with an additional 21.13 miles of cross lines in water depths ranging from 10 to 25m below MLLW for a total areal coverage of 6.23 nm^2. Initial data collection indicated the great functionality of the new vessel as well as the excellent survey work and system integration (Figure 1-20). After the test work, the RVGS moved to the priority area near Salisbury Beach. For the Salisbury Beach survey 70.43 nm of main scheme lines were collected, with an additional 9.13 miles of cross lines in water depths ranging from 1 to 22m below MLLW for a total areal coverage of 1.76 nm^2 Additionally, 11 video stations were occupied, at four of which grab samples were recovered.

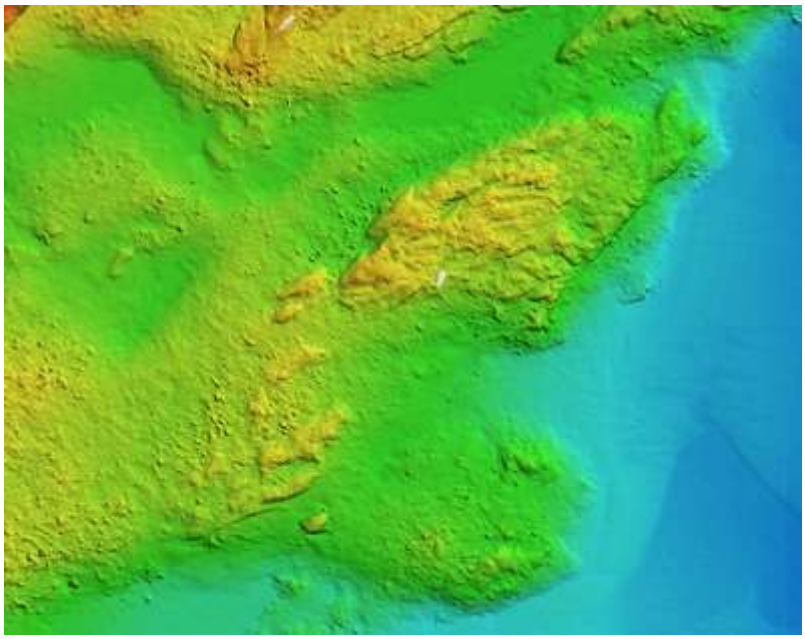


Figure 1-20: Some of the first multibeam data collected with the new research vessel R/V Gulf Surveyor. Note that the data align very well as a result of the IMU placement near the transducer arrays and the accurate survey of vessel offsets (rms < 1mm).

The data were processed using SIS, HYPACK, Qimera, FMGT and CARIS. A comparison with Charts 13274, 13278 and 13282 was performed and the observed depths generally matched the charted depths, but close to the various rocky outcrops shoaler depths were observed resulting in 1 DTON (affecting eight charts). The charted contours generally align well with the automatically generated contours from the dense MBES data (Figure 1-21).

The course benefitted tremendously from the capabilities of the new research vessel *Gulf Surveyor*. The work spaces were significantly more pleasant and spacious, but more significantly, the movable strut with the IMU mounted near the transducer allowed us to cruise to the work area with the strut up and the moon pool closed and then deploy the sonar once on site. This led to an estimated increase in survey time of nearly two hours on a daily basis, leading to a 60% increase in available survey time to the students. Surveying near Salisbury, MA would previously have required us to dock the vessel in Hampton Harbor, NH or Newburyport, MA, significantly adding to the already complex logistics of the course.

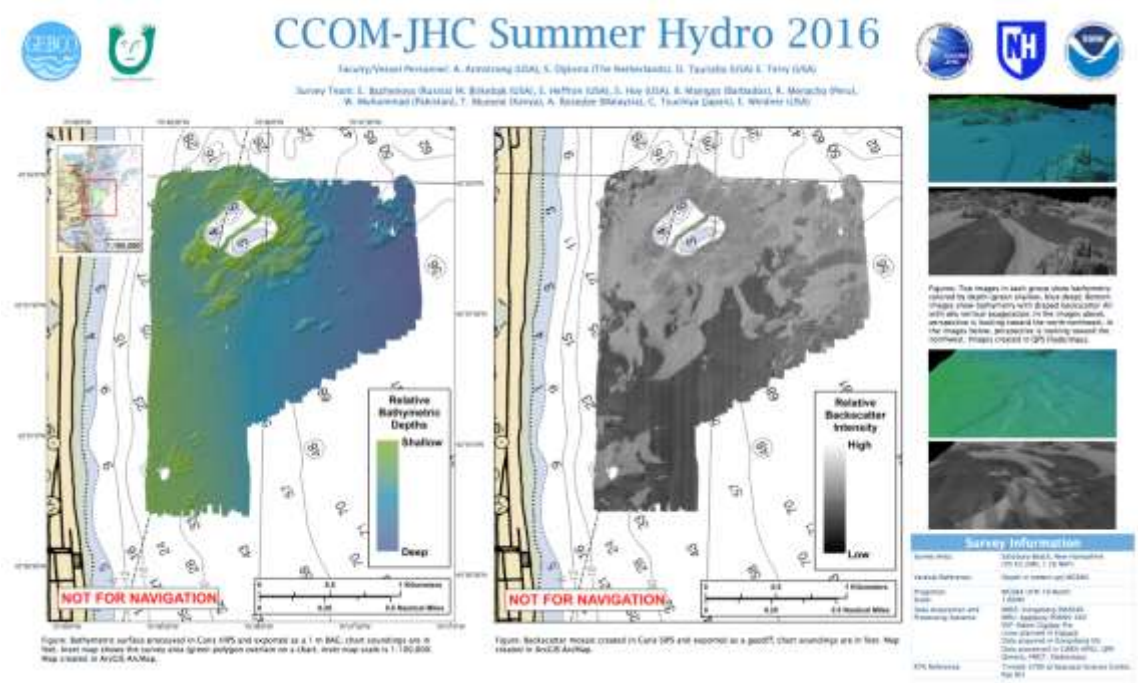


Figure 1-21: Result of Hydro Field Camp survey of Salisbury Beach area.

EXTENDED TRAINING

With our fundamental educations programs in place, we are expanding our efforts to design programs that can serve undergraduates, as well as government and industry employees. We have a formal summer undergraduate intern program we call SURF (Summer Undergraduate Research Fellowship), host NOAA Hollings Scholars and continue to offer the Center as a venue for industry and government training courses and meetings (e.g., CARIS, Triton-Elics, SAIC, Geoacoustics, Reson, R2Sonics,

IVS/QPS, ESRI, GEBCO, HYPACK, Chesapeake Technologies, ATLIS, IBCAO, SAIC, the Seabottom Surveys Panel of the U.S./Japan Cooperative Program in Natural Resources (UJNR), FIG/IHO, NAVO, NOAA, NPS, ECS Workshops, USGS, Deepwater Horizon Subsurface Monitoring Unit, and others). In 2016, we hosted short courses from CARIS, ESRI, QPS, HYPACK, and MATLAB as well as several NOAA and other inter-agency meetings on a range of topics. These meeting and courses have proven very useful because our students can attend them and are thus exposed to a range of state-of-the-art systems and important issues. Particularly important have been visits to the Center by a number of members of NOAA's Coast Survey Development Lab and National Geodetic Service in order to explore research paths of mutual interest.

Center staff are also involved in training programs at venues outside of the Center. John Hughes Clarke, Larry Mayer and Tom Weber continue to teach (along with David Wells) the internationally renowned Multibeam Training Course; in 2016, courses were taught in New Orleans and Den Helder Netherlands. Larry Mayer regularly teaches at both the Rhodes (Greece) and Yeosu (Korea) Academies of Law of the Sea.

Undergraduate Mentoring:

While most of the Center efforts are focused on graduate students, many of the Center faculty are also involved with mentoring undergraduates through the employment of students on an hourly or work-study basis. Over the past two and a half years, we have had an exceptional example of the value that the Center can play to undergraduate training as well as an excellent example of selflessness and commitment on the part of one of our graduate students. NOAA Corps. Officer, LTJG Damian Manda volunteered to be the graduate advisor to a group of UNH senior engineering and computer science students developing an autonomous boat for their capstone project (UNH Autonomous Surface Vehicle (ASV) Team). In addition to leading weekly progress meetings, Manda offered advice and guidance to members of the team on selection of electronics, programming, and concepts of positioning systems including GPS and acoustics. The project used the deep tank at the Center for testing and had a workspace in the high bay, with funding for materials provided through a grant from the Naval Engineering Education Center (NEEC). Damian graduated in the spring of 2016 but has left a valuable legacy at the University.

STATUS OF RESEARCH: JANUARY–DECEMBER 2016

When the Center was established in 1999, four primary research directions were identified:

(1) *Innovative sensor design – understanding capabilities and limitations*;

(2) *New approaches to multibeam and sidescan sonar data processing*;

(3) *New approaches to data visualization, fusion, and presentation,* and;

(4) *Tools and approaches for seafloor characterization.*

Within each of these themes, projects were chosen with long-range research goals designed to make fundamental contributions to the fields of hydrography and ocean and coastal mapping, and short-term objectives designed to address immediate concerns of the hydrographic community in the United States. Over the years, in response to the needs of NOAA and others, several new research themes were added:

(5) *Electronic Chart of the Future*;

(6) *Water-column mapping*;

(7) *Capabilities and limitations of LIDAR for bathymetry, seafloor characterization and shoreline mapping*;

(8) *Coastal process studies – very shallow water mapping*;

(9) *Understanding the capabilities and limitations of AUVs as hydrographic tools, and*;

(10) *Developing innovative approaches for mapping in support of Law of the Sea*.

As our research progressed and evolved, the boundaries between these themes became more blurred. For example, from an initial focus on sonar sensors we expanded our efforts to include LIDAR, and more recently, satellite-derived bathymetry. Our data-processing efforts merged into our data-fusion and Chart of the Future efforts. The data-fusion and visualization projects have blended with our seafloor characterization and Chart of the Future efforts as we began to define new sets of "non-traditional" products. This is a natural (and desirable) evolution that slowly changes the nature of the programs and the thrust of our efforts.

With the transition to the Cooperative Agreement of 2011-2015, the research themes were re-defined. The request for proposals for the new Cooperative Agreement prescribed seven thematic headings:

1) Improving the sensors used for hydrographic, ocean and coastal mapping (sonar, LIDAR, AUVs, etc.) with emphasis on increasing accuracy, resolution, and efficiency especially in shallow water; (*SENSORS*)

2) Improving and developing new approaches to hydrographic, ocean and coastal mapping data processing with emphasis on increasing efficiency while understanding, quantifying, and reducing uncertainty; (*PROCESSING*)

3) Developing tools and approaches for the adaptation of hydrographic, coastal and ocean mapping technologies for the mapping of benthic habitat and exploring the broad potential of mapping features in the water-column; (*HABITAT AND WATER COLUMN MAPPING*)

4) Developing tools, protocols, non-standard products, and approaches that support the concept of "map once – use many times," i.e., integrated coastal and ocean mapping; (*IOCM*)

5) Developing new and innovative approaches for 3D and 4D visualization of hydrographic and ocean mapping data sets, including better representation of uncertainty, and complex time- and space-varying oceanographic, biological and geological phenomena; (*VISUALIZATION*)

6) Developing innovative approaches and concepts for the electronic chart of the future and e-navigation, and; (*CHART OF THE FUTURE*)

7) Being national leaders in the planning, acquisition, processing, analysis and interpretation of bathymetric data collected in support of a potential submission by the U.S. for an extended continental shelf under Article 76 of the United Nations Convention on the Law of the Sea. (*LAW OF THE SEA*)

These thematic headings do not represent a significant departure from our previous research endeavors. However, inasmuch as our efforts since 2011 have been conducted under these thematic headings, our 2016 research efforts under Grant NA10NOS4000073 will be described in the context of these seven themes. As with the earlier themes, many of the projects areas overlap several themes. This is particularly true for HABITAT, IOCM, and PROCESSING efforts. In this context, distribution of projects among the themes is sometimes quite "fuzzy." The activities of the Center conducted under the 2016-2020 grant (NA15NOS4000200) are presented in a separate progress report (available on the CCOM website – http://www.ccom.unh.edu) and are done so in the context of a new set of programmatic priorities.

THEME 1: IMPROVING THE SENSORS USED FOR HYDROGRAPHIC, OCEAN AND COASTAL MAPPING (SONAR, LIDAR, AUVS, ETC.) WITH EMPHASIS ON INCREASING ACCURACY, RESOLUTION, AND EFFICIENCY ESPECIALLY IN SHALLOW WATER

Short name: ***SENSORS***

The Center's work in understanding and improving ocean mapping sensors has steadily grown and encompassed new dimensions. A key component of many of these efforts is our access to, and continued development of, state-of-the-art sonar (and LIDAR) calibration facilities that allow us to better understand the performance of systems and to develop new approaches to their calibration. Included in our discussion of sensors are our efforts to better understand the behavior of several new sonar systems (both traditional multibeam and phase measuring bathymetric sonars) being offered by our industrial partners, to better understand the performance of LIDAR and satellite sensing systems for shoreline mapping, bathymetry, and seafloor characterization studies, to explore the potential of AUVs and ASVs as platforms for bathymetric and other measurements, and to make better measurements of the temporal and spatial variability of sound speed in the areas where we are working.

SONARS

SONAR CALIBRATION FACILITY

DEVELOPING APPROACHES TO CALIBRATE MBES IN THE FIELD

We continue to make progress in the upgrades to the Center's sonar calibration facility (originally funded in part by NSF), which is now one of the best of its kind in New England. The facility is equipped with a rigid (x, y)-positioning system, computer controlled transducer rotor (with resolution of 0.025 degree) and a custom-built data-acquisition system. Measurements that can now be made include transducer impedance (magnitude and phase) as a function of frequency, beam patterns (transmit and receive), open circuit voltage response (receive sensitivity), and transmit voltage response (transmit sensitivity). In addition, the A/D channel inputs have been optimized as a function of beam angle and the cross-correlation and r.m.s. levels of the transmitted and received channels can be computed in real-time. In 2014 the acoustic tank instrumentation was upgraded to include an automated mechanism to perform complete three-dimensional combined transmit/receive beam pattern measurements of electro-acoustic transducers in just one run. This mechanism controls the vertical position of a standard target in the acoustic tank and has been incorporated into the high-resolution Yuasa rotor of the tank, providing angular resolution of less than 0.1^{o} for the two directions during beam-pattern measurements and optimized operation time.

In 2016 several new upgrades were performed on the calibration facility. The first was the development of a new trigger signal generator, designed and built to allow the generation of two simultaneous TTL trigger signals that can be used with the acoustic tank instrumentation for sonar system calibrations. The first output signal has a period (ping interval) ranging from 50 ms to 2.5 s, adjustable in 50 ms increments and the second output signal is a copy of the first signal with a time delay ranging from 0 ms to the

period of the first signal minus 50 ms. This device employs an inexpensive Arduino Nano microcontroller which can be reprogrammed to accommodate necessary changes to the output trigger signals according to the task for which it is to be used.

The second upgrade in 2016 was the development of a sound speed and temperature data logger designed to enable us to continuously measure and monitor the sound speed of the tank water. The system is composed of a pair of radio transceiver modules: a transmitter station which measures the water temperature using a DS18B20 digital temperature sensor, calculates the sound speed using the Bilaniuk and Wong 112-point equation for sound speed in fresh water, and wirelessly sends the measured/calculated values to a receiver station. The receiver station displays the water temperature and sound speed values on an LCD display and logs these values along with a time stamp in a text file to a micro SD card. The display updates every three seconds and logs data every 30 minutes under continuous operation. The performance of the system was evaluated by comparing its computed sound speed to the sound speed values from a Digibar Pro at different water temperatures. The results show that both systems agree with differences below 0.09%.

Finally, the vertical target positioning system needed for automated three-dimensional beam pattern measurements was upgraded to allow increased robustness, longer acoustic range of operation, and to incorporate a safety limit switch to avoid driving the target out of the vertical limit of operation. This system controls the vertical position of a standard target in the acoustic tank and has been incorporated into the high-resolution Yuasa rotor of the tank, providing angular resolution smaller than 0.1^{o} in two directions during beam pattern measurements with optimized operation time. This new system is connected to the computer which runs the main code for the measurements via two USB ports, instead of using the data acquisition board from the computer (Figure 3-1).

Figure 3.1. Upgraded vertical target positioning system on bench

CALIBRATION OF SONAR SYSTEMS

Along with supporting our own research projects, the Center's acoustic calibration facility is also available to NOAA, our industrial partners, and others for use in quantifying the behavior of new or existing sonar systems. In 2016, a number of systems and sonars were tested or calibrated in our facility

or in the field so as to better understand their performance and capabilities (Figure 3-2). These calibrations include measurements of radiation beam pattern, impedance, transmit voltage response (TVR) and receive sensitivity (RS):

1. An MSI constant beamwidth transducer was tested by Tom Weber as part of his efforts to more precisely locate and characterize small midwater targets (in particular oil droplets and gas bubbles). This work is discussed further in the section on the WATER COLUMN MAPPING theme.

2. A Simrad ES120 sonar tested in linear FM mode to evaluate detection and quantification capabilities for oil droplets (Scott Loranger)

3. A Simrad ES200 sonar tested in linear FM mode to evaluate detection and quantification capabilities for oil droplets (Loranger)

4. An Edgetech PVDF transducer was used to determine capabilities with respect to small target detection (Weber and Carlo Lanzoni)

Figure 3-2. Some of the transducers tested in the acoustic tank in 2016. Left: Simrad ES120 and 200 and MSI Constant Beamwidth Transducer; Right: Edgetech PVDF transducer.

EK80 WIDEBAND TRANSCEIVER:

We have also begun a collaborative effort with industrial partner Kongsberg Maritime, NOAA fisheries scientists, and scientists at the Woods Hole Oceanographic Institution to look at the capabilities of Kongsberg's new wideband transceiver (WBT), the EK80. Wideband acoustic echo sounders offer great promise for characterizing several phenomena (e.g., the seafloor, marine organisms, gas bubbles), as well as very high precision range measurements using pulse compression techniques. A handful of wideband acoustic systems have been previously built, but have not been readily available on the commercial market. This has changed with the introduction of the new EK80 wideband transceiver, which is intended to interface to Kongsberg's fisheries echo sounder transducers (one of which the Center is using on the NEWBEX project).

Following up on initial calibrations, in the summer of 2014, Larry Mayer and Kevin Jerram deployed an EK80 on board the Icebreaker *Oden* as part of the Swedish and NSF-funded SWERUS-C3 field program in the Eastern Siberian Arctic Ocean and Tom Weber deployed an EK80 on board the R/V *Endeavor* as part a DOE-sponsored program to map gas seeps in the vicinity of Hudson Canyon. In preparation for these field programs a Simrad ES-18 (18kHz) transducer similar to that used aboard the *Oden* was calibrated in the Center's acoustic test tank using the EK-80 WBT. The prototype WBT was interfaced to an ES18-11 transducer and used to transmit linear frequency-modulated acoustic pulses between 10-30 kHz as the ES18-11 was rotated from -90° to +90° along its equator. The tests demonstrated that the main beam behaves as expected, with a one-way -3 dB beamwidth that varies smoothly from 6° near 30 kHz to 19° at 10 kHz, with maximum sidelobe levels of -18 dB near the design frequency (close to a theoretically predicted value of -17 dB). Above 22 kHz, increased sidelobes (or suppressed grating lobes) appear that are likely due to the echosounder construction (consisting of 44 individual Tonpilz transducer elements), but these sidelobe levels are still lower than -15 dB (1-way). The tests also revealed that the frequency-dependent figure of merit (combined transmit and receiving response) for the ES18-11 is relatively flat between 16-22 kHz (Figure 3-3). Field trials conducted by the Weber, Mayer and Jerram on the R/V *Cocheco* just before the departure for the Arctic revealed that the WBT was capable of producing an optimal response from a target sphere between approximately 15 and 30 kHz.

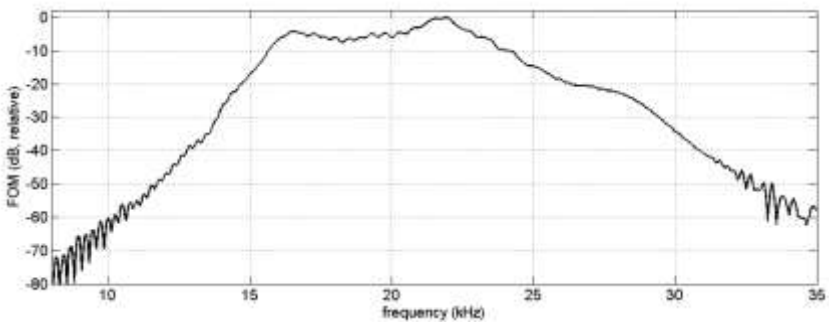


Figure 3-3. Figure of merit (combined transmit/receive response) of ES18 using WBT in decibels, relative to its peak value.

The EK80 on board the *Oden* was calibrated in the Arctic using calibration spheres and a complex setup of outriggers to maneuver the spheres beneath the acoustic center of the EK80 transducer. In 2015, the EK80 was once again deployed on the *Oden*, this time in the Eastern Siberian Arctic Ocean. The data collected in 2015 have proven critical in developing quantitative approaches to determining gas bubble size from the acoustic signal (and thus gas flux) and will be discussed more under the WATER COLUMN theme.

In 2016, the EK-80 was once again deployed on the *Oden* by Jerram, as part of a geophysical training cruise and Swedish support for Canadian ECS activities in the high Arctic. While funded by other sources (Swedish), Jerram's participation provided another important data set to better understand the capabilities of this unique sonar. Mayer and visiting scholar Christian Stranne provided support from shore for an ongoing project to compare acoustic observations of suspected stratified water masses and internal waves with *in situ* salinity and temperature measurements from CTD profiles. Early analysis of the 2016 data indicates an impressive ability to detect stratified water column structure with the EK80, building on the 2014 and 2015 datasets demonstrating this system's advantages in resolution and

frequency response for characterizing marine gas bubbles and biological scatterers. This work is discussed more in the progress report for Grant NA15NOS4000200.

NEW BROADBAND SONAR

For Information -- funded by non-NOAA sources

This NSF-funded project is focused on the development of a broadband system to help assess the fate of methane gas bubbles exiting the seabed. During the last few months of 2016, a prototype low-frequency (1-10 kHz) acoustic echo sounder has been assembled and tested on the R/V Gulf Challenger. This system has undergone testing in the Eastern Bering Sea (in collaboration with NOAA fisheries, who is interested in this system for measuring fish swim bladders) and at the Coal Oil Point gas seeps.

In addition, graduate student Kevin Rychert is working on a synthetic seep that will be used to generate controlled/quantified gas bubbles in the field (up to 100 m depth) for performing controlled experiments on the acoustic systems being developed and to help further assess the current models we use for modeling gas dissolution in water. A prototype seep generator has been constructed and used in the acoustic tank to help generate 'wobbly' bubbles (bubbles that are non-spherical and oscillate on ascent) for Alex Padilla's work.

Graduate student Alex Padilla is working on several aspects of this project (funded by the NSF Graduate Research Fellowship Program), including examining the acoustic target strength of large wobbly bubbles (as found in many natural gas bubbles) in order to, ultimately, refine our acoustic estimates of bubble size and flux. Padilla is also working on developing and analyzing new low-frequency acoustic transducers in order to extend the performance of our low-frequency acoustic transducers.

SEA ACCEPTANCE TRIALS – MULTIBEAM ADVISORY COMMITTEE

For Information -- funded by non-NOAA sources (NSF, OET, SOI)

The expertise of the researchers at the Center has been sought over the years to help ensure that that new multibeam sonar systems being installed by the U.S. academic fleet are working properly. In 2010, Jonathan Beaudoin, Val Schmidt, and Jim Gardner started this process by participating in the sea acceptance trials of three new multibeam systems, and this role of the Center in evaluating the performance of the academic community's MBES systems was formalized in 2011 with funding from the National Science Foundation, to PaulJohnson and Jonathan Beaudoin (along with Vicki Ferrini at LDEO), for the establishment of a Multibeam Advisory Committee (MAC). The goal of the MAC is to ensure that consistently high-quality multibeam data are collected across the U.S. academic research fleet (UNOLS vessels). The strategy is to create a community of stakeholders that includes representatives from operating institutions, funding agencies, and key outside experts from the user and technical/engineering communities that can assist in providing guidance on a broad array of multibeam issues. A part of the MAC effort is the development and dissemination of best-practice documentation and quality assurance software as well as collaboration on maintenance agreements and a spare parts pool. The best-practice documents, software guides and reports on the status of the multibeam systems in the UNOLS fleet can be found at the MAC website: http://mac.unols.org.

With the departure of Beaudoin to work for QPS, his involvement with the MAC has greatly diminished. This has meant that Johnson has taken on more of the responsibility of the management and operations of the MAC, acting as the point person for questions submitted to the MAC's help desk from multibeam operators across the U.S. academic fleet. These questions tend to deal with best practices for multibeam acquisition, technical questions on multibeam performance, questions about patch tests, and requests for data review of problematic datasets. Kevin Jerram is now assisting Johnson with this project, particularly with sea-going efforts.

2016 MAC Activities: R/V *Neil Armstrong*

In February of 2016, Jerram, Erin Nagel, and Johnson, from the Center, along with Glen Rice and Chen Zhang from NOAA, conducted shipboard acceptance tests (SATs) on the R/V *Neil Armstrong*'s newly installed EM122 and EM710 multibeam echosounders. The *Armstrong*'s SAT was conducted off the Atlantic coast, southeast from Charleston, SC, with the EM122 test being conducted at the Blake Nose site (see Figure 3-4), where previous Law of the Sea datasets had been collected making planning very easy, and at a site closer to shore in the shallow waters for the EM710 SAT.

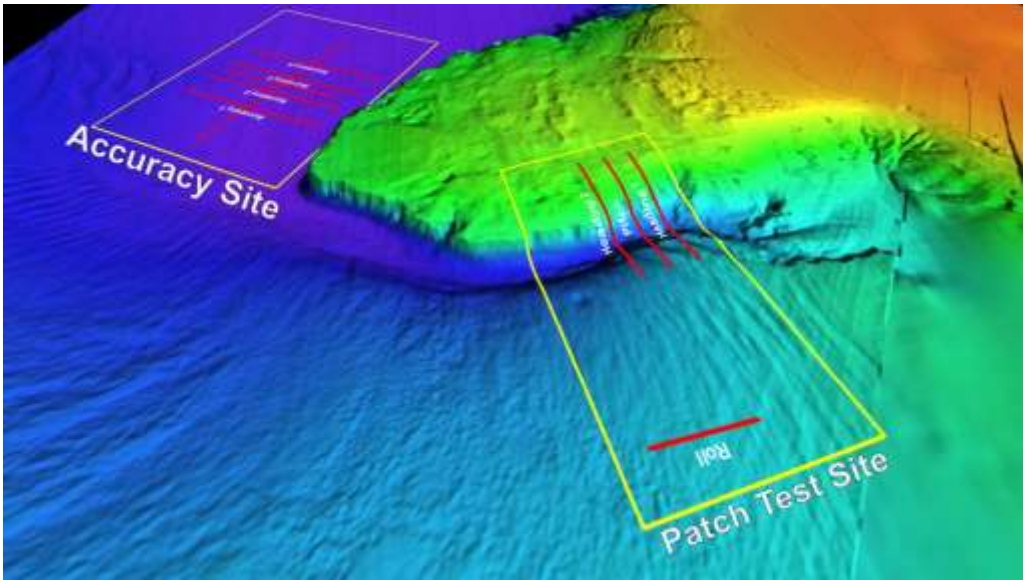


Figure 3-4. Overview map of the EM122 shipboard acceptance test site at Blake Nose for the R/V Neil Armstrong.

This SAT was challenging in many ways, including working within and around the Gulf Stream current, very large seas inhibiting the ability to collect quality data (see Figure 3-5), and a lack of quality testing sites within a short distance from Charleston. That said, both the EM122 and EM710 sonars had a full review of their system and sensor geometries, were successfully calibrated, and were evaluated for swath performance (extinction), system depth accuracy, and ship self-noise. A final report documenting the results of the SAT was submitted to ship's technical group at Woods Hole Oceanographic Institute during the Fall of 2016 and will be published on the MAC website once comments have been returned.

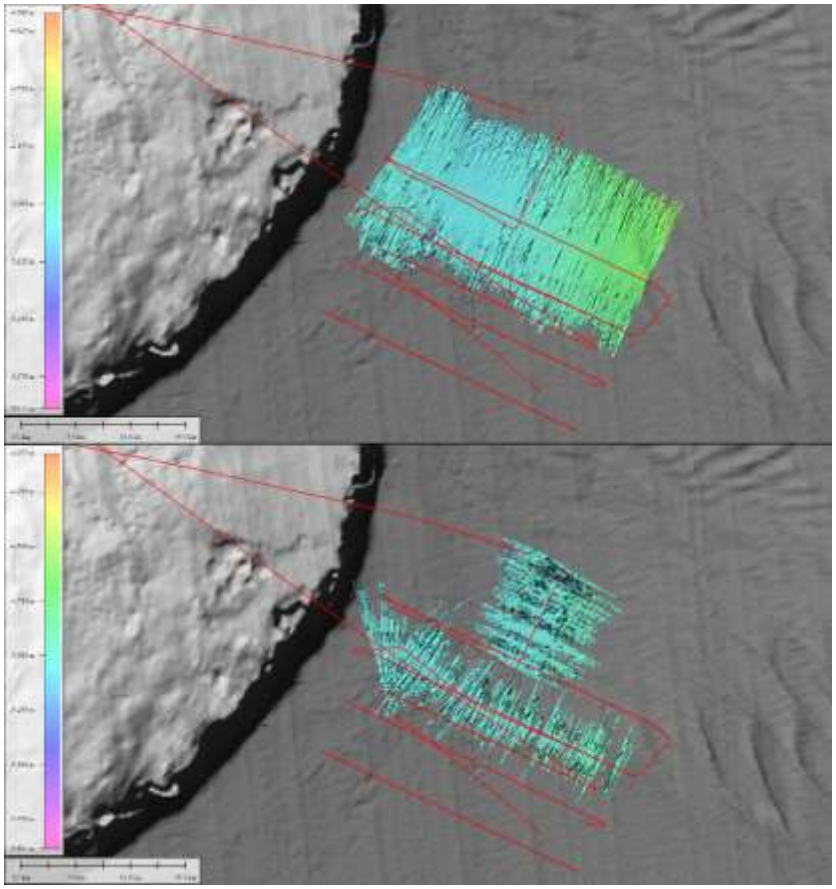


Figure 3-5. Examples of heading-dependence on the quality of data for the R/V Armstrong's new EM122. The top figure shows good quality bathymetry collected over a proposed reference surface site. The bottom figure shows poor quality bathymetry collected with headings opposite and orthogonal to the top figure.

R/V *Sally Ride*

In July of 2016, Johnson planned and executed the SAT on the R/V *Sally Ride*, the sister ship to the *Armstrong*, near Anacortes, WA. The *Sally Ride*, like the *Armstrong* is equipped with an EM122 deep water multibeam, however the *Sally Ride* is also outfitted with the newest EM712 multibeam system, an update from the *Armstrong*'s EM710 Mk.II. During the SAT, a review was conducted of the installation and geometries foreach multibeam system and their sensors, the systems were calibrated, evaluated for swath performance (Figure 3-6), and assessed on depth accuracy. A final report of the SATs will be released in early 2017.

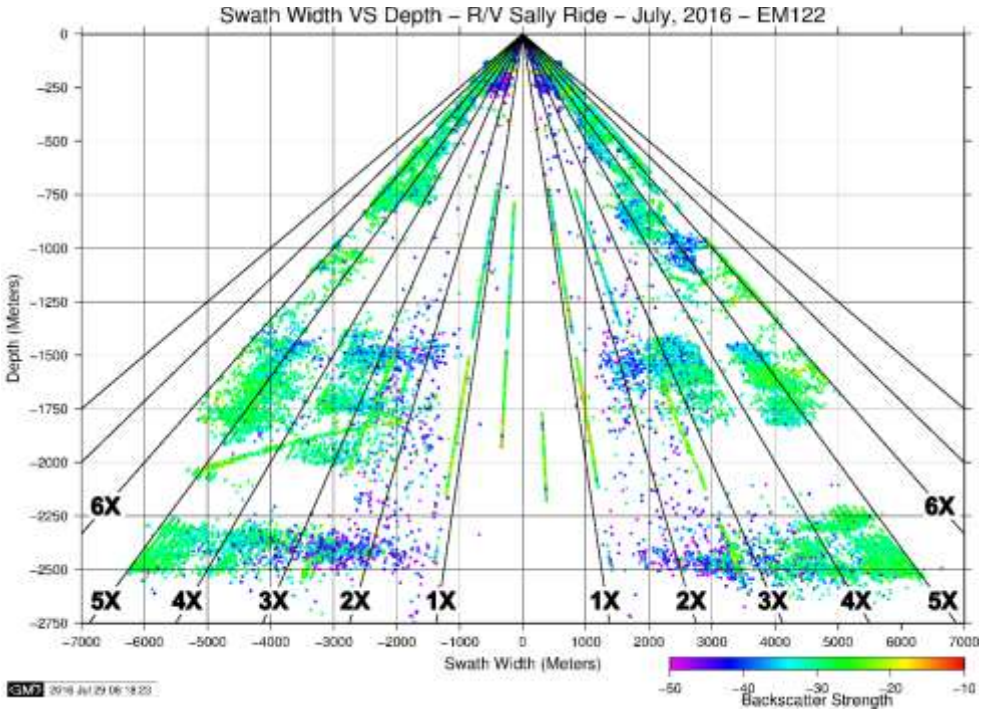


Figure 3-6. Swath extinction test for the R/V Sally Ride's EM122 system.

Institutions outside of the UNOLS fleet have also come to us for assistance with their MBES systems. The Center, in collaboration with colleagues from IFREMER in France, assisted the Schmidt Ocean Institute (SOI) with the harbor and sea acceptance trials of all acoustic systems on their newly refitted vessel R/V *Falkor* and has entered an agreement with SOI for long-term assistance in maintaining technician skill sets, monitoring of acoustic system health, etc. The Center has a similar arrangement with Dr. Robert Ballard's Ocean Exploration Trust and their vessel E/V *Nautilus*, and more recently with the Israel Oceanographic and Limnological Research Institute for their new research vessel *Bat Galim*.

E/V *Nautilus*

In 2016, Johnson and Jerram conducted a multibeam Quality Assurance visit on board the E/V *Nautilus*, off Victoria, British Columbia. During the cruise, Johnson and Jerram were able to fully validate the installation and quality of data from the ship's multibeam. This included verifying the *Nautilus*'s MBES installation geometries, testing the impedance values of the arrays, conducting a patch test in order to determine static offset values, running system accuracy tests in shallow and deep areas, determining self-noise and noise spectra as a function of speed and sea direction, and conducting swath performance tests (Figure 3-7). As was the case observed during last year's QAT visits, the *Nautilus*'s EM302 multibeam as still performing very well and did not show any signs of degradation.

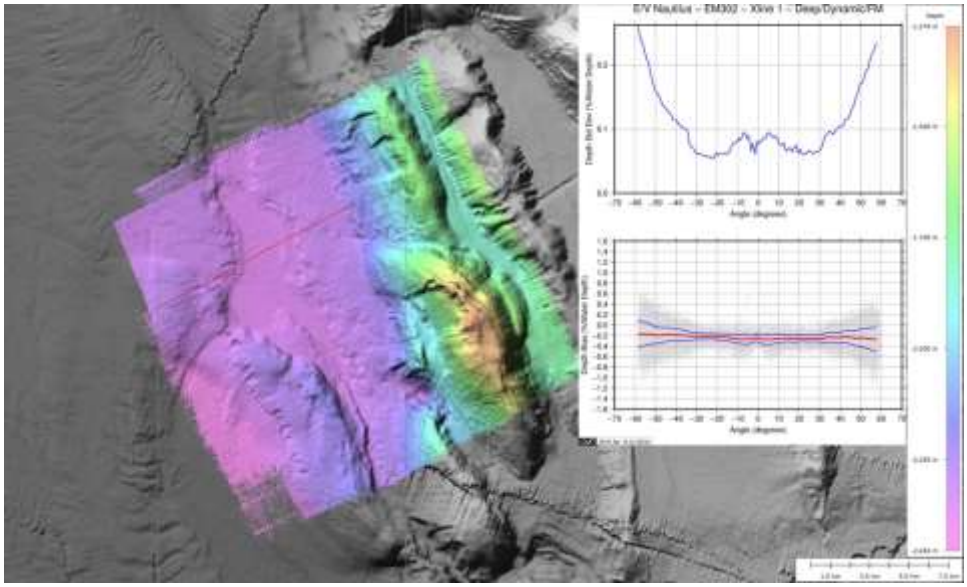


Figure 3-7. EM302 accuracy testing from the 2015 E/V Nautilus Quality Assurance Visit. Background map shows the data contributing to the extinction calculation (colored bathymetry). Inset figure on the upper right shows the results of the accuracy test, plotting depth standard deviation as a percentage of water depth vs. swath angle, and depth bias as a percentage of water depth vs. swath angle.

By scheduling these types of Quality Assurance checkups on a yearly basis, the QA team is able to look for changes in the performance and provide the vessel owners a warning if their systems are not collecting the highest quality multibeam data possible.

R/V BAT GALIM

In February of 2016, Johnson planned and directed the shipboard acceptance trials for the new EM2040 and EM302 systems installed aboard the R/V *Bat Galim*, the research vessel of the Israel Oceanographic and Limnological Research Institute. These tests, which were conducted off Haifa, Israel, involved a review of the installation for the EM2040 and EM302 systems, patch tests for both systems (see Figure 3-8), swath accuracy testing, water column imaging evaluation, and swath performance testing. After completion of the field work, Johnson completed the analysis of the data and submitted a report to IOLR and to the MAC, documenting the performance of both multibeam systems on the *Bat Galim*.

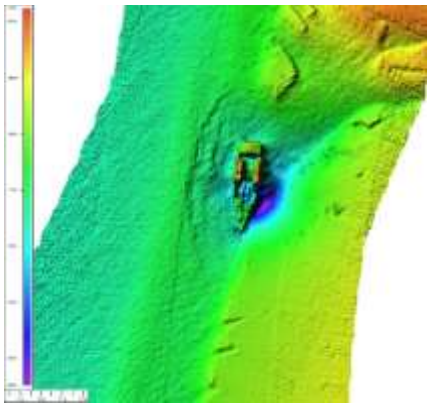


Figure 3-8. The wreck used as part of the EM2040 patch test for the R/V Bat Galim shipboard acceptance test.

SEA ACCEPTANCE TRIALS AND WORK WITH NOAA

The experience gained by the MAC team has now led to direct involvement in NOAA multibeam sonar system evaluations. In 2016, Center personnel participated in two sea-going evaluations of multibeam systems on NOAA vessels.

NOAA Ship *Thomas Jefferson*

In October of 2016, Johnson assisted Rice with the Shipboard Acceptance Tests (SATs) of the NOAA Ship *Thomas Jefferson*'s new EM2040 and EM710 Mk.II multibeam systems. Both systems were subjected to a rigorous test protocol including patch test calibrations, swath performance testing (extinction), object detection, self-noise measurements, and detection mode verification. These tests were conducted off of Chesapeake Bay and on the Atlantic continental margin. Rice is currently producing a final evaluation of the collected data and generating a report documenting the test results.

NOAA Ship *Ron Brown*

The MAC team also participated, in January of 2016, in a multibeam quality assurance test (QAT) cruise on the NOAA Ship *Ron Brown* in the waters around the island of Oahu (Figure 3-9). This test was run prior to the *Brown's* departure for the Law of the Sea mapping program around Palmyra and Kingman Reef. This QAT visit included conducting a thorough review of the ship's EM122 and associated sensor geometries, troubleshooting the *Brown's* POS/MV installation, conducting a patch test, evaluating the ship's self-noise (Figure 3-10 - left), examining the system's swath performance, and testing the accuracy of the system (Figure 3-10 - right). Following the cruise, analysis was conducted on the data by Rice and Johnson, and a full report was produced documenting the performance and health of the EM122 system. To date, four cooperative shipboard acceptance test or quality acceptance test have been conducted by individuals from both the MAC and NOAA. These joint cruises are excellent opportunities that allow for the sharing of tools, techniques, and knowledge between the MAC and NOAA.

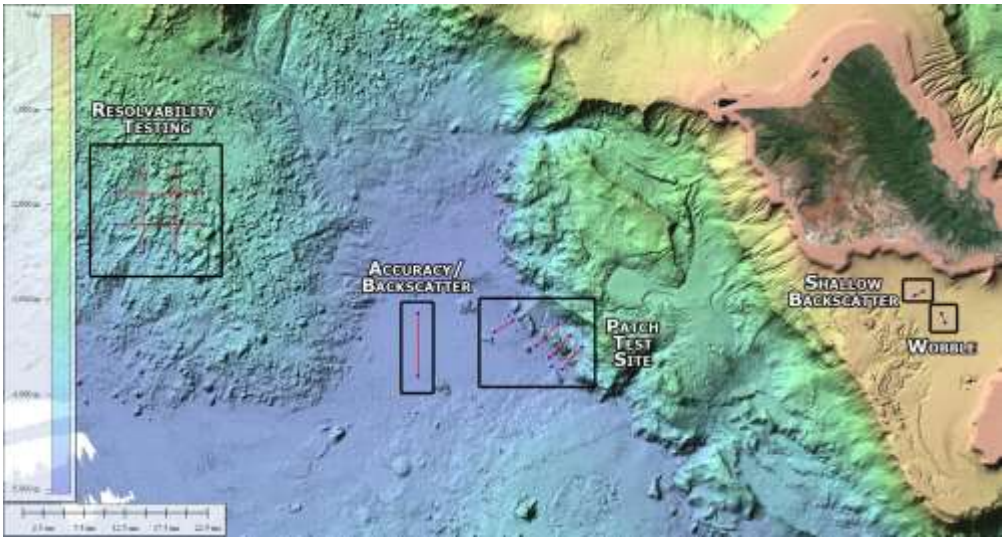


Figure 3-9. Quality assurance testing areas for the NOAA Ship Ron Brown's EM122.

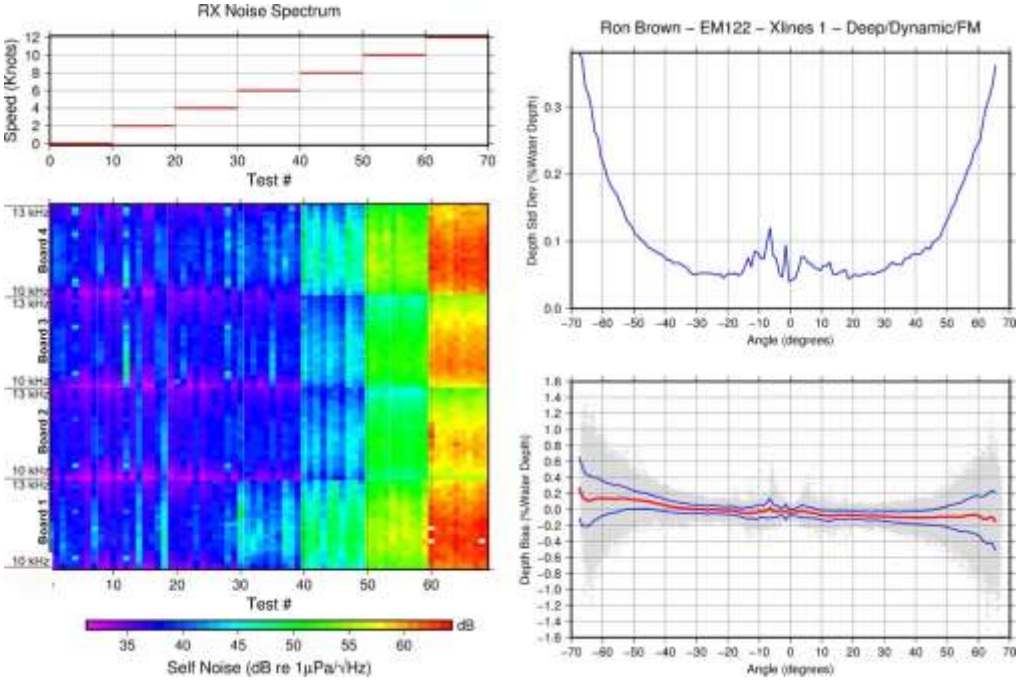


Figure 3-10. Examples of quality assurance testing data for the NOAA Ship Ron Brown's EM122. Figure on the left is the results of RX Noise Spectrum BIST data and the figure on the right is results from the accuracy testing.

NOAA Ship *Okeanos Explorer*

In direct support of NOAA operations, Jerram acted as the mapping lead for the NOAA Ship *Okeanos Explorer* during Leg 1 of the *Deepwater Exploration of the Marianas* expedition (EX1605L1) between Guam and Saipan. EX1605L1 was heavily focused on ROV operations, providing an excellent opportunity for Jerram to gain experience leading the day-to-day mapping operation in a poorly charted region, where communication with the ROV teams and rapid turnaround of data products were critical for selection of scientifically intriguing sites and safe navigation of the ship and vehicles. In addition to

the bathymetric data, water column data were collected using the 30 kHz multibeam echosounder and split-beam echosounders operating at several frequencies (18, 70, 120, and 200 kHz) throughout the cruise to help identify active venting of particulate-laden waters from calderas and hydrothermal vent sites for ROV operations.

Review of NOAA Fleet Recapitalization

At the request of the NOAA Office of Marine and Aviation Operations (OMAO), John Hughes Clarke joined an independent review team (IRT) in January 2016 looking at the NOAA fleet recapitalization plan. This involved monthly meetings where the IRT was briefed on NOAA line office activities and their respective future needs for access to the sea. A particular focus of Hughes Clarke was on the future fleet requirements to meet seabed mapping needs of both the Office of Coast Survey (OCS) and other groups within NOS and NMFS. The report was completed in October 2016 with NOAA briefing the House and Senate in November. The report can be found at:
http://www.omao.noaa.gov/sites/default/files/documents/IRT%20Final%20Report_2016-10-17.pdf.

PHASE MEASURING BATHYMETRIC SONAR SYSTEMS (PMBS)

Under the leadership of Val Schmidt and Tom Weber, the Center has invested a significant effort in trying to understand the potential of phase-measuring bathymetric sonars (PMBS—multiple-row sidescan sonars that use phase differences from the multiple rows to determine depth as well as backscatter) for hydrographic use. With the arrival of Tony Lyons, our ability to explore the efficacy of PMBS sonars for hydrographic and other applications has greatly expanded. While this is clearly a "SENSOR" issue, our efforts have been focused on the processing aspects of the problem rather than hardware aspects. Thus our efforts involving PMBS will be discussed under the DATA PROCESSING theme rather than the SENSOR theme.

LIDAR

We have long recognized that one of the greatest challenges presented to the hydrographic community is the need to map very shallow coastal regions where multibeam echo sounding systems become less efficient. Airborne bathymetric LIDAR systems offer the possibility to rapidly collect bathymetric (and other) data in these very shallow regions but there still remains great uncertainty about the accuracy and resolution of these systems. Additionally LIDAR (both bathymetric and terrestrial) offer the opportunity to extract other critical information about the coastal zone including seafloor characterization and shoreline mapping data. We have thus invested heavily in LIDAR-based research and will report on most of this effort under the HABITAT theme later in the report. Here, however, we report on those aspects of the research that are focused on understanding the capabilities of the LIDAR sensor.

MOBILE LASER SCANNER INTEGRATION

Within the context of the SENSOR theme we report on a new laser-based effort begun in 2014 by Shachak Peʻeri in collaboration with graduate student/NOAA Corps officer John Kidd, NOAA Coast Survey Development Lab (CSDL) and Navigation Services Division, and Vitad Pradith of Hypack. Survey launches of the OMAO hydrographic fleet and Navigation Response Vessels often encounter natural and man-made non-contiguous shoreline features during shoreline feature surveys that need to be validated, such as piers, jetties and exposed shoal features. To assist with this task, the Center and Hypack introduced the capability to utilize an industrial laser scanner for mapping of surface features

within the past two years. Research efforts have been focused on the integration of the system on a survey vessel and analysis of system performance. System performance parameters assessed include range uncertainties, extension range, data density potential, and internal reference frame validation. Additionally, a new method for boresight calibration is being attempted. Center efforts have been in concert with OCS/CSDL efforts to introduce the system and make it a standard shoreline survey tool aboard NOAA field units (currently only on NOAA Ship *Fairweather* with plans to integrate on NOAA Ship *Rainer,* NOAA Ship *Thomas Jefferson, and* NOAA Ship *Ferdinand R. Hassler* during winter 2016/2017).

The Velodyne VLP-16 laser scanner unit was chosen as the best candidate for a survey system because it can be easily integrated aboard survey launches given its detection capabilities, size, weight, power requirements, fully sealed design, and low cost. This industrial laser scanner, which currently costs $8,000, uses 16 laser beams that cover a vertical field of view of ± 15°. These laser/detector pairs also rotate at an adjustable rate from 5 Hz to 20 Hz to cover a horizontal field of view of 360°. The infrared lasers (at 903nm wavelength), provide the ability to map targets above the water surface up to 100 m while also mapping the water surface.

The reported 2.00^{o} angular offsets between each laser beam were independently verified in a controlled experiment. Using an ultra-high precision rotating compass, accurate up to 0.04^{o}, the laser scanner was rotated until the laser beam intersected a narrow strip of aluminum, similar to the static alignment procedure described in previous progress reports (Figure 3-11). By positioning the target at a range at which the beam footprint matched the target's width, the angular offset between each beam could be measured by rotating the scanner by small intervals of 0.04^{o} around a particular laser beam to resolve the peak intensity (Figure 3-12, left). Because the rotating compass could only be adjusted with high-precision by ±5°, four relative reference frames were established on the -11°, -3°, +3°, and +11° laser beams to cover the full range of the scanner (±15°). From each of these relative reference frames, the surrounding four laser beams were verified, resulting in one redundant measurement between the +1° and -1° beam (Figure 3-12, right). Results show an average net offset of all beams with respect to the reference frames of -0.014^{o} with a standard deviation of 0.053^{o}. Data distribution seems to suggest that the drift in the offset is random. The precession of all laser beams were also assessed using methods described in previous progress reports and were found to be well within the manufactures' specifications.

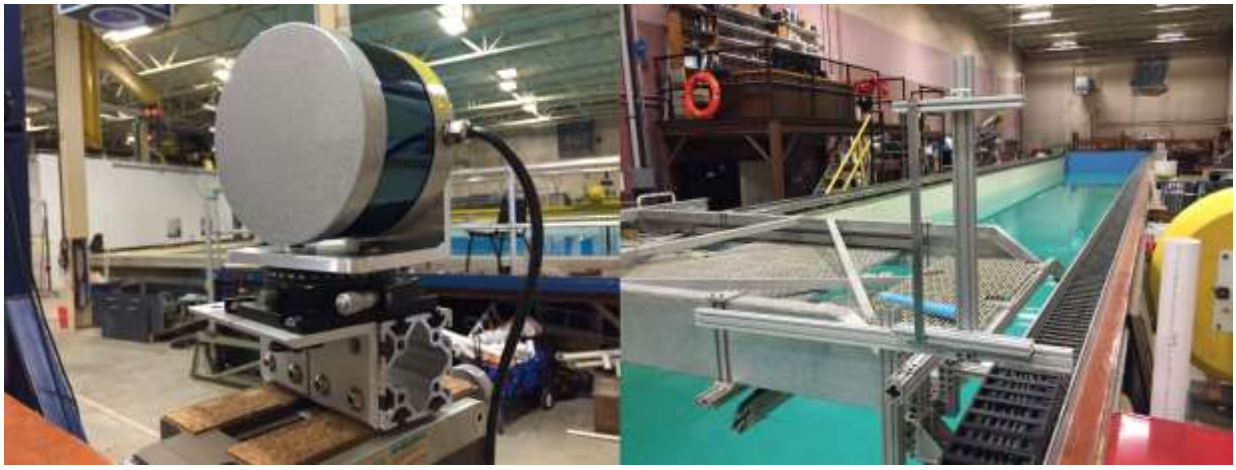


Figure 3-11: Left: Laser scanner mounted vertically centered over the ultra-high precision rotating compass. Right: Narrow vertical aluminum target.

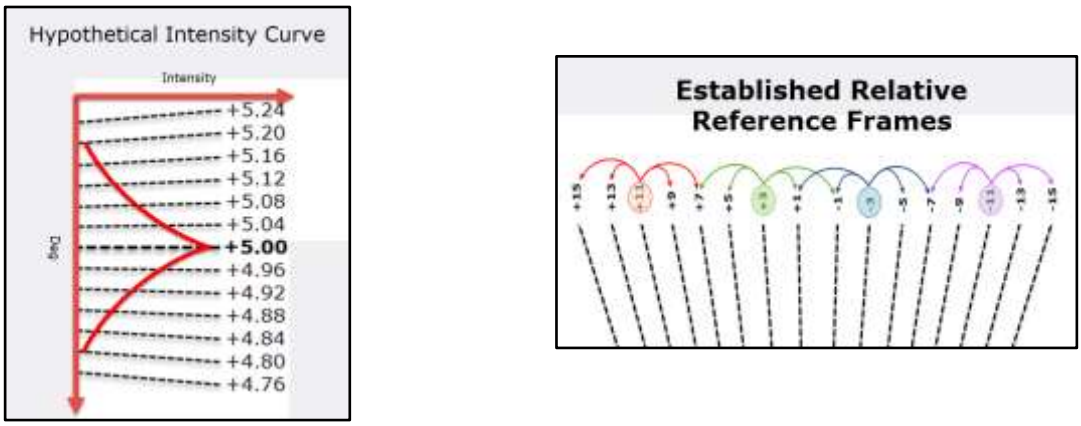


Figure 3-12: Left- Hypothetical intensity returns centered around the +5º beam, caused by rotating the scanner by increments of 0.04º through a window of ±0.24º centered around the assumed location of the laser beam. Right: Relative reference frames were established on the -11º, -3º, +3º, and +11º beams to cover the ±15º window of the scanner. From each of these reference frames, the four surrounding laser beams were verified with a redundant measurement occurring between the +1º and -1º beam.

In July 2016, a three-day cruise aboard the R/V *Gulf Surveyor* was conducted within Portsmouth Harbor in New Hampshire to collect data to empirically assess the scanner's extinction range, quantify data density relative to various mounting orientations and scanner rotation rates, and the ability to detect overhead cables crossing the channel. (Figure 3-13)

The effective extinction range of the laser scanner, defined as the range at which the vessel can survey from and collect enough data to adequately decipher a target with only one pass, appears to be approximately 70-80m. Further data analysis, yet to be completed, will refine this estimate. Data density was assessed by collecting lines of data along the UNH pier-face, a vertically flat and relatively smooth surface, at ranges 10-100m at 10m increments, at scanner rotation rates of 300RPM and 1200RPM, and in two mounting configurations: vertically, and with a 45º pitch angle forward. These various configurations resulted in 40 lines of data. The results showed a clear decrease in data density with

range with an inverse square relationship, but at a given range various scanner configurations (rotation rates and mounting angles) have only minor effect on data density. The largest contributor of these random variations is most likely due to vessel motion (particularly changes in speed and yaw angles). A controlled laboratory experiment replicating these experimental configurations, except on a well-controlled platform, will hopefully clarify the influence various rotation rates and mounting angles have on data density.

The ability of the system to depict bridges (Figure 3-13) and overhead cables crossing the channel (Figure 3-14) was also assessed during the initial field tests by surveying several bridges and two cable crossings in Portsmouth Harbor. Both cables, with authorized clearances of 65ft (19.8m) and 165ft (50.2m) were mapped with more than sufficient data density. The ability to map such a discrete targets could be valuable for verifying published vertical clearance values in the field during surveys of opportunity.

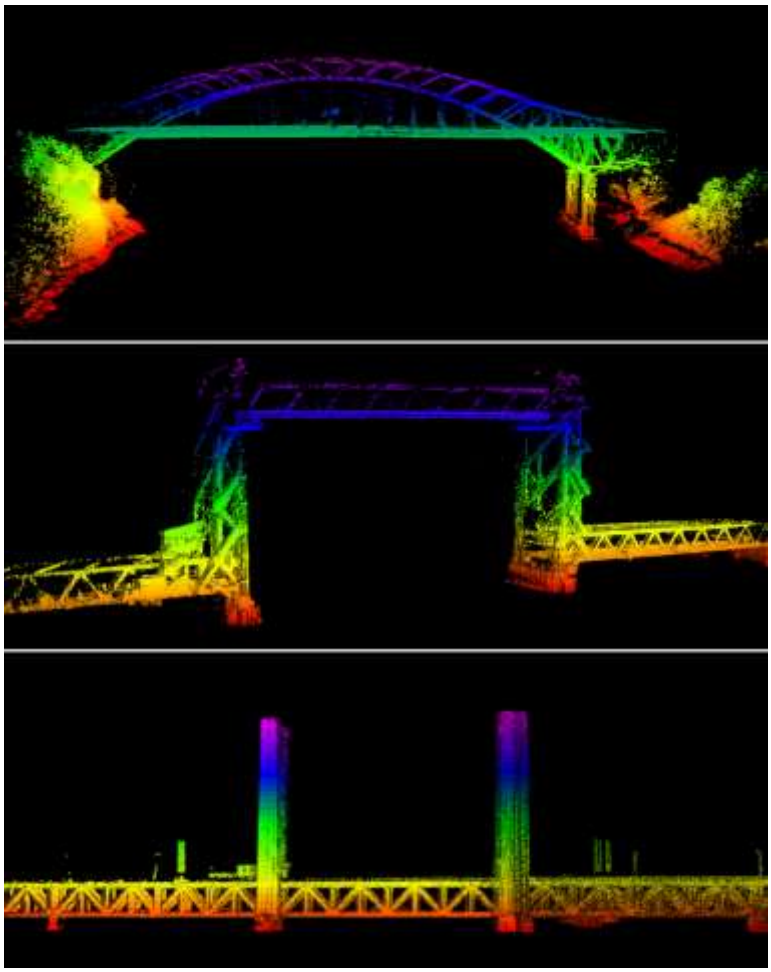


Figure 3-13: Laser scanner data of three bridges within Portsmouth Harbor. Top: I-95 Bridge. Middle: Memorial Bridge. Bottom: Sarah Mildred Long Bridge.

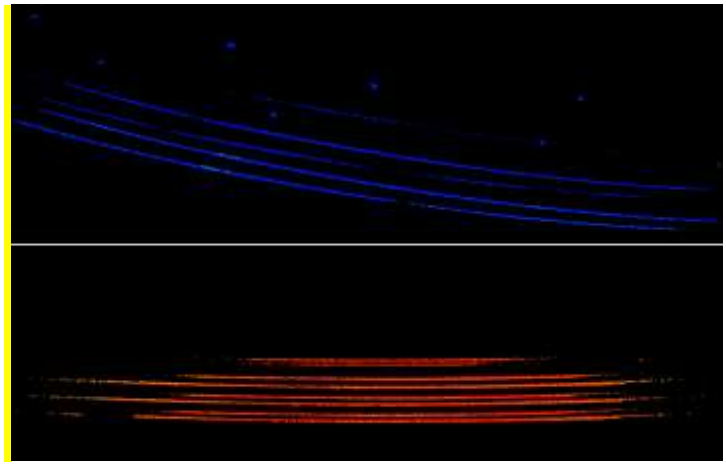


Figure 3-14: Laser scanner data on two sets of overhead power cables within Portsmouth Harbor. Top: 165ft high cables crossing the main channel north of the I-95 Bridge. Bottom: 65ft high cables crossing Back Channel near Portsmouth Naval Yard.

MOBILE LASER SCANNER FOR SEA SURFACE CHARACTERIZATION:

Firat Eren and graduate student Matthew Birkebak are looking at the feasibility of using the mobile laser scanner to spatially map the water surface at a sub-meter horizontal resolution and a centimeter vertical accuracy in order to measure the dynamic draft in underway survey vessels. An elevation map of the water surface is also important for laboratory work as a reference for experiments that require the height and slope of the water surface (for example, refraction of LIDAR beams through the water column). The instantaneous water level provides dynamic measurements that can be used to support uncertainty calculations of optical remote sensing technologies or in coastal processes.

In addition to an industrial laser scanner's ability to measure ranges to surface features, the laser scanner can map the water surface due to the fact that the water is opaque to the infrared laser. Laser returns are received at up to 8˚ angle of incidence to the water surface. When capillary and gravity waves are present on the water surface, returns to the laser scanner can observed up to 40˚ off-nadir angles. Algorithms have been implemented to characterize the water surface spatially and temporally based on this data.

Over the past year, water surface experiments were conducted in both the wave and tow tanks and also in field experiments with R/V *Gulf Surveyor*. The lab experiments included both capillary waves, fan-generated winds, and gravity waves generated by the wave paddle in the tank. The efforts were focused on a general characterization of the water surface and following the motion of the laser measurements over the water surface. The wavelength and the frequency of the water surface wave were identified from the data (Figure 3-15). The wave period results were within 0.05 seconds of the wave paddle period in the Tow and Wave Tank.

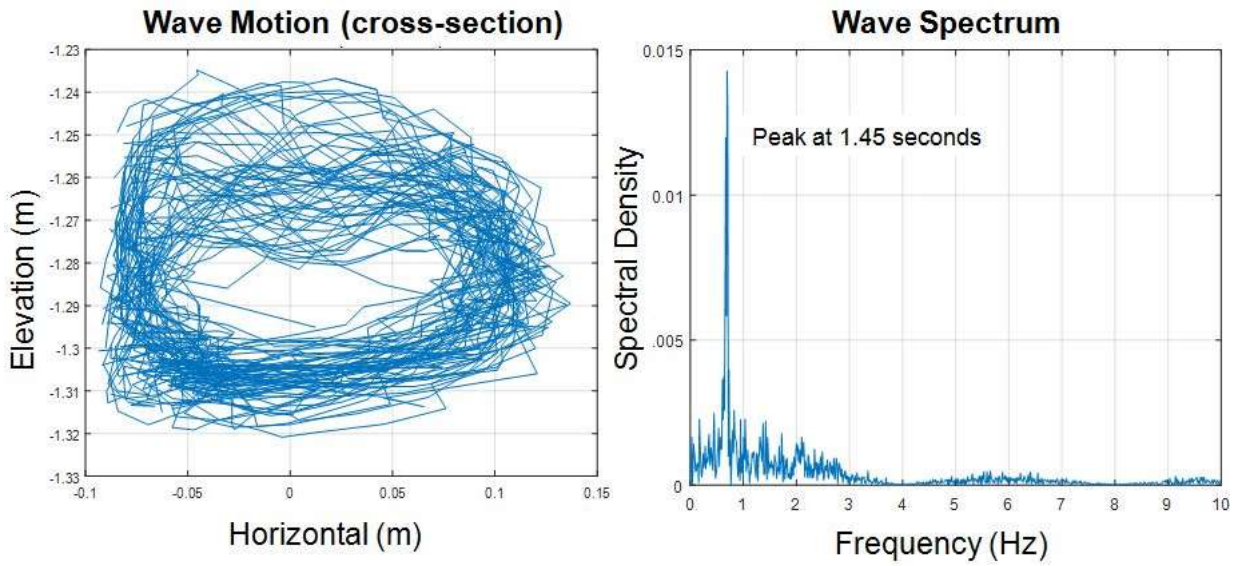


Figure 3-15: The water surface measured by the Velodyne laser scanner: (Left) position and amplitude of the waves. (Right) wave spectrum of the waves.

In field experiments conducted by Birkebak, the VLP-16 laser scanner was mounted on the bow of the R/V *Gulf Surveyor*. The experiments included running the vessel in various directions relative to the ocean waves. The water surface data were collected as the vessel passed over both large gravity and small capillary waves (Figure 3-16). The angular steering uncertainty of the beam due to capillary waves on the water surface was found to be between 1.5° to 2.2° in both along wind and cross wind axis for normal ALB survey conditions (3-10kts wind speeds). Beam steering due to surface waves causes horizontal and vertical uncertainty in the measurement. The surface data combined with motion and attitude data can be used to estimate the dynamic draft of the vessel at any epoch.

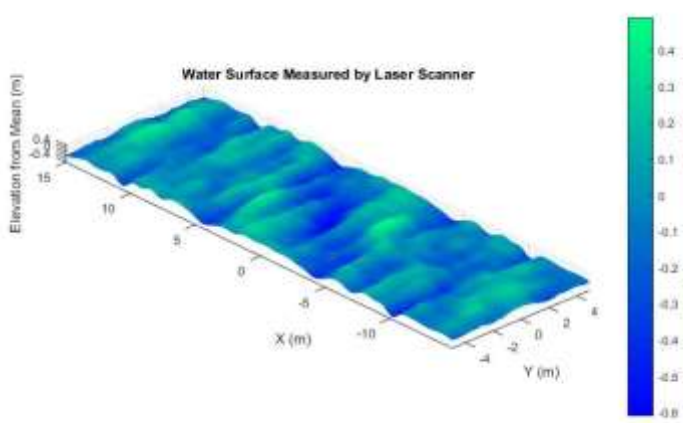


Figure 3-16. The water surface as mapped by the laser scanner and with position and attitude corrections applied in HYPACK.

LIDAR SIMULATOR: ALB UNCERTAINTY DERIVATION USING A DETECTOR ARRAY

Large uncertainty still remains as to the influence of the water column, surface wave conditions, and bottom type on an incident Airborne Laser Bathymetry (ALB) pulse. Unless these uncertainties can be reduced, the usefulness of ALB for hydrographic purposes will remain in question. To address these questions, Firat Eren and graduate student Mathew Birkebak have continued the development of the LIDAR simulator—a device designed to emulate an ALB system in the laboratory. As part of the Lidar Simulator project, we are investigating the effect of variation in the water surface, the water column, and the bottom return on the laser pulse measurements in an ALB system. Each of these environmental conditions introduce an uncertainty factor which potentially biases depth measurements and the seafloor characterization process. To do this, laser pulse intensity is measured by a planar optical detector array that was designed by Eren during his Ph.D. work.

The simulator system includes a transmitter unit and a modular planar optical detector array as the receiver unit. The detector array is used to characterize the laser beam footprint and analyze waveforms in time-series (Figure 3-17**)** in both horizontal (water surface measurements) and vertical (water column measurements) configurations. Image processing algorithms were developed to quantify the laser beam uncertainty in the water column under controlled environmental conditions (see PROCESSING THEME).

When an ALB green laser beam is emitted from the transmitter unit, the beam diverges. Once it hits the water surface, its ray-path geometry is affected by interactions with the water surface, water column and the bottom. The LIDAR simulator allows us to characterize the laser beam on a sub-footprint level. Thus, it is possible to identify geometric and radiometric distortions or variations that can affect the ALB measurement uncertainty.

Calibration procedures and algorithms were developed and implemented for characterization of the laser beam measurements in the Center's laser lab, as well as the wave and tow tank facilities. All experiments were conducted according to OSHA and UNH safety regulations. The current focus has been on the spatial distribution of the ALB beam; waveform analysis will be conducted in the future.

Water surface experiments:

When a 532nm laser beam is emitted from an ALB system, the first interaction is with the water surface. Surface waves with varying slopes and amplitudes alter the beam's incidence angle and direction of propagation through the water column. The variation of the surface waves thus induce uncertainty on the ALB measurements.

Over the past six months, several water surface conditions were created using fan-generated winds that produced capillary and gravity waves on the water surface. As wind conditions were varied, the variation in the laser beam geometry was sampled using the optical detector array (Figure 3-17). The distribution of the ALB beam was calculated utilizing image processing algorithms. The horizontal shift of the beam due to surface waves can be seen in Figure 3-18. It has been seen that the capillary waves cause a beam shift of up to 0.05m at a depth of 0.25m.

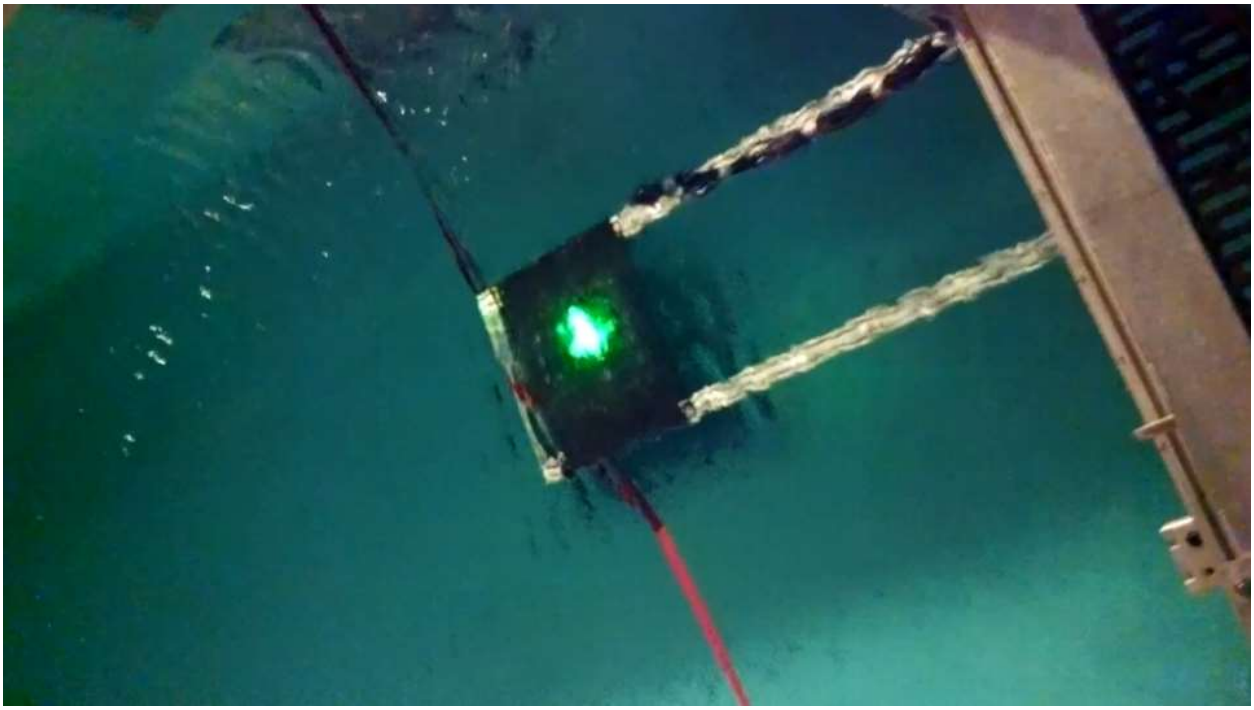


Figure 3-17: Optical detector array submerged in the water. The waves alter the shape and positon of the beam.

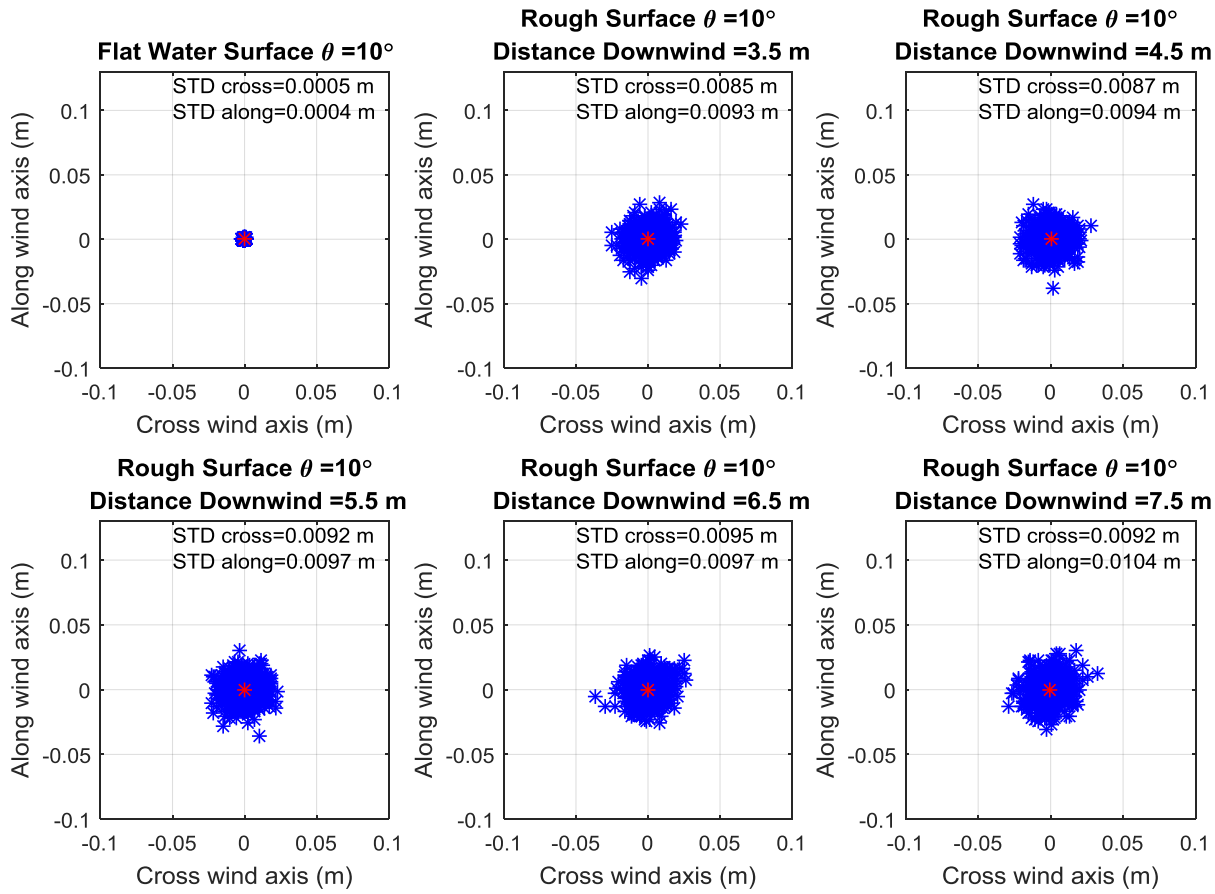


Figure 3-18: The varying location of beam center over time. The still water beam center remains very constant. Once waves are introduced the beam center is constantly shifting by ~0.05m.

Water column experiments:

The laser beam ray path in the water column was measured in the tow tank (Figure 3-19). The beam footprint intersecting the detector array was measured at ranges varying from 4.73-8.73 m in 0.5 m increments on the x-axis and by varying from -1 m to 1 m at 0.5 m increments on both the y- and z-axes. The goal is to understand the scattering of the laser beam and the expansion of the laser pulse with respect to changing range.

Figure 3-19. Left- Optical detector array mounted vertically for water column experiments. Right-Laser beam ray-path geometry in the water column. The detector array intersects the laser beam at a specified distance.

The data were recorded in both intensity and time. The time averaged laser beam footprint results for 200 samples are given in Figure 3-20. The results indicate that the laser is spreading in the water column with an extended beam footprint size. The key now will be to quantify these changes so that we can better understand the uncertainty associated with ALB bathymetric measurements.

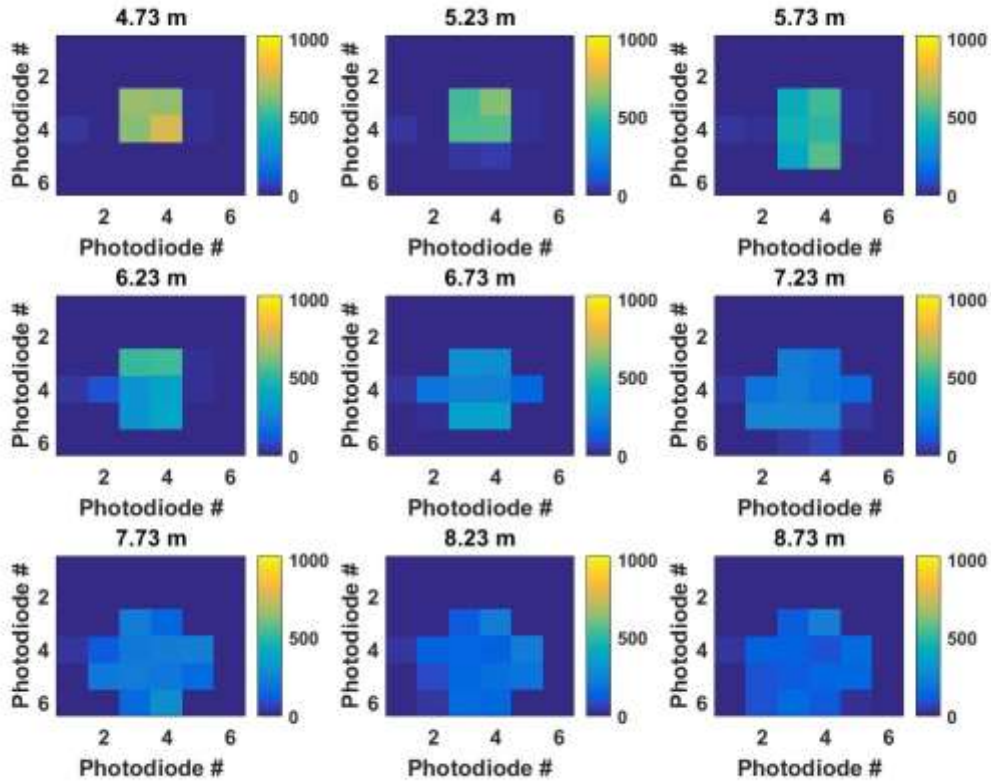
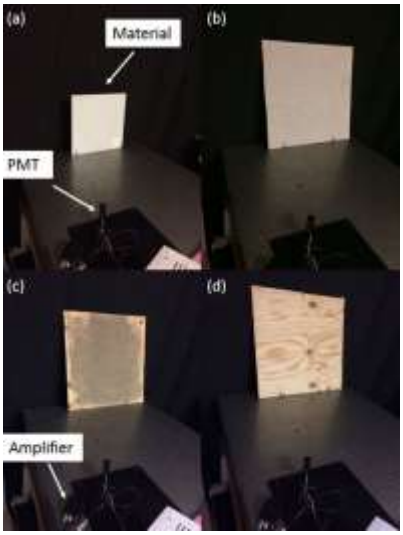


Figure 3-20. The laser beam footprint at distances from 4.73m to 8.73m at varying distances.

Bottom characteristics measurements:

The final part of the environmental interaction of the laser beam is with the bottom. In order to understand the bottom return characteristics from a laser beam, a variety of experiments were conducted. For these experiments, the Minilite pulsed Nd:YAG green laser was used in the Center's laser lab (Figure 3-21 – left). A photo-multiplier tube (PMT) was used as the receiver, simulated the typical setup for ALB systems. For the bottom characteristics experiments, the bottom return waveforms from four different materials (white board, sand, concrete and wood) were measured by the PMT unit (Figure 3-21 - right). The waveforms recorded from these materials can be seen in Figure 3-22.



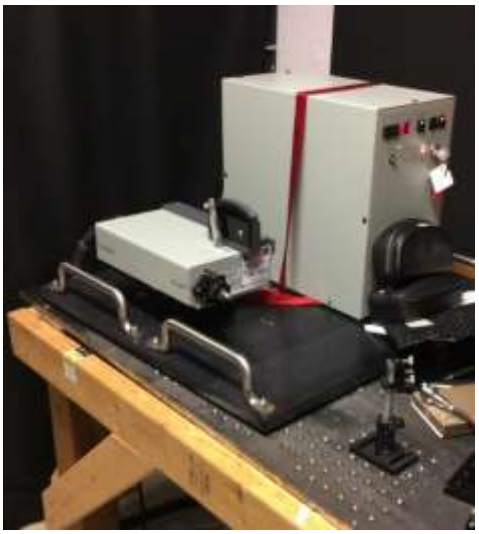


Figure 3-21 (Left) The green pulsed Nd:YAG laser unit (Continuum Minilite) used in the bottom return experiments with mirror guides used for alignment. Right - Materials that were used in the bottom return calculations. (a) white board (b) concrete (c) sand (d) wood

The bottom return measurements from these four materials show different reflectivity values for the same laser power. White board was demonstrated to be the most reflective material with the highest amplitude, with sand providing the least reflectivity. Concrete and wood reflectivity values were close to each other, in between white board and sand.

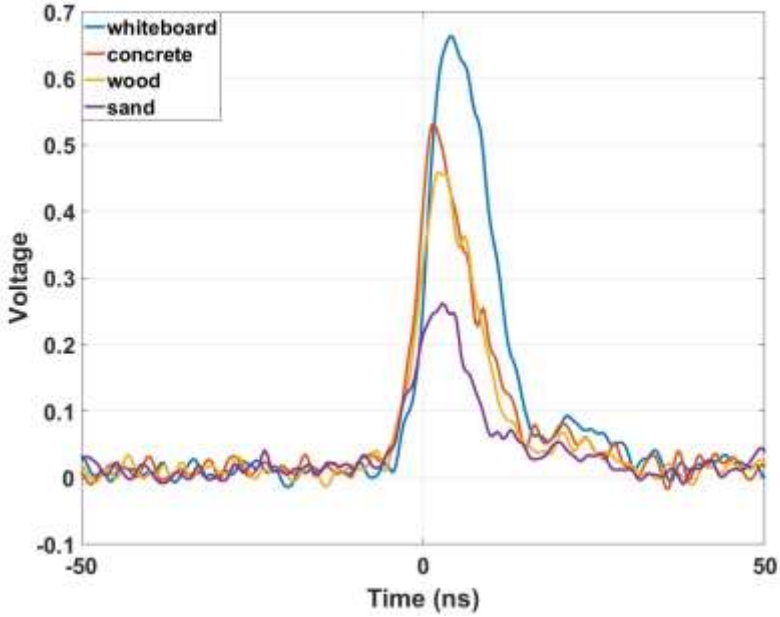


Figure 3-22: Return signal amplitudes from four different materials as measured by PMT unit.

AUV/ASV ACTIVITIES

AUVS

In 2006, the Center began an effort to explore the applicability of using a small Autonomous Underwater Vehicle (AUV) to collect critical bathymetric and other data. We teamed with Art Trembanis of the University of Delaware to obtain use of his *Fetch 3* vehicle. We purchased, calibrated and integrated a small multibeam sonar (Imagenex Delta-T) into this AUV and over the course of 2007 began to explore its applicability for collecting both hydrographic quality bathymetric data and seafloor characterization data. Unfortunately, the *Fetch 3* vehicle suffered a catastrophic failure during a mission in the Black Sea; fortunately, the system was fully insured and we were able to replace the *Fetch* and Delta-T with a *Gavia* AUV and a 500 kHz GeoAcoustics GeoSwath phase-measuring bathymetric sidescan and a Kearfott inertial navigation system. Additional capabilities include sensors for temperature, sound speed, salinity (derived), dissolved oxygen, chlorophyll and turbidity, a downward-looking camera and a Marine Sonics 900 kHz/1800 kHz sidescan sonar. The new system is a much more mature AUV than was the *Fetch*, with imagery, bathymetry, and particularly positioning capabilities far beyond the original vehicle. We have also purchased a WHOI acoustic modem for the new vehicle that allows enhanced positioning and two-way communication.

Val Schmidt has been providing support to both the Center and the University of Delaware AUV operations. He has established a series of standard procedures and checklists for AUV operations and has written a considerable amount of software to monitor and support the *Gavia*, including code to explore an alternative, and hopefully improved and more deterministic, pipeline for processing phase-measuring bathymetric sonar data. Additionally, Schmidt and Trembanis have hosted a series of very popular "AUV Bootcamps." AUV Hydrographic Bootcamp is an engineering and development workshop focused on forwarding the art of the use of AUVs for hydrographic survey. The bootcamps have provided the opportunity to operate NOAA's REMUS 600 AUV with experienced operators and hydrographers from the public, private, and military sectors, and to scrutinize every detail of operations, data collection, and processing in a hydrographic context.

In 2016, this collaboration with the University of Delaware continued, with Schmidt assisting in the field testing of a Teledyne Gavia autonomous underwater vehicle (AUV) outfitted with a Geometrics magnetometer. Magnetometers provide remote sensing capability for ferrous objects and are particularly useful for identifying shipwrecks and unexploded ordinance. Schmidt acted as engineering lead and provided operational field support in collaboration with Geometrics engineers to develop methods and modes of operation for magnetic measurement compensation on the AUV. Establishment of compensation coefficients allows for removal of attitude dependent self- and induced-magnetic field influences that can mask desired signals from small objects.

ASVS

In late 2014 we began a new effort designed to explore the feasibility of using Autonomous Surface Vehicles (ASVs) as a platform for the collection of hydrographic data. The initial focus of our efforts have revolved around the work of former graduate student and NOAA Corps Officer LTJG Damian Manda whose thesis work focused on development of hardware and software for small autonomous

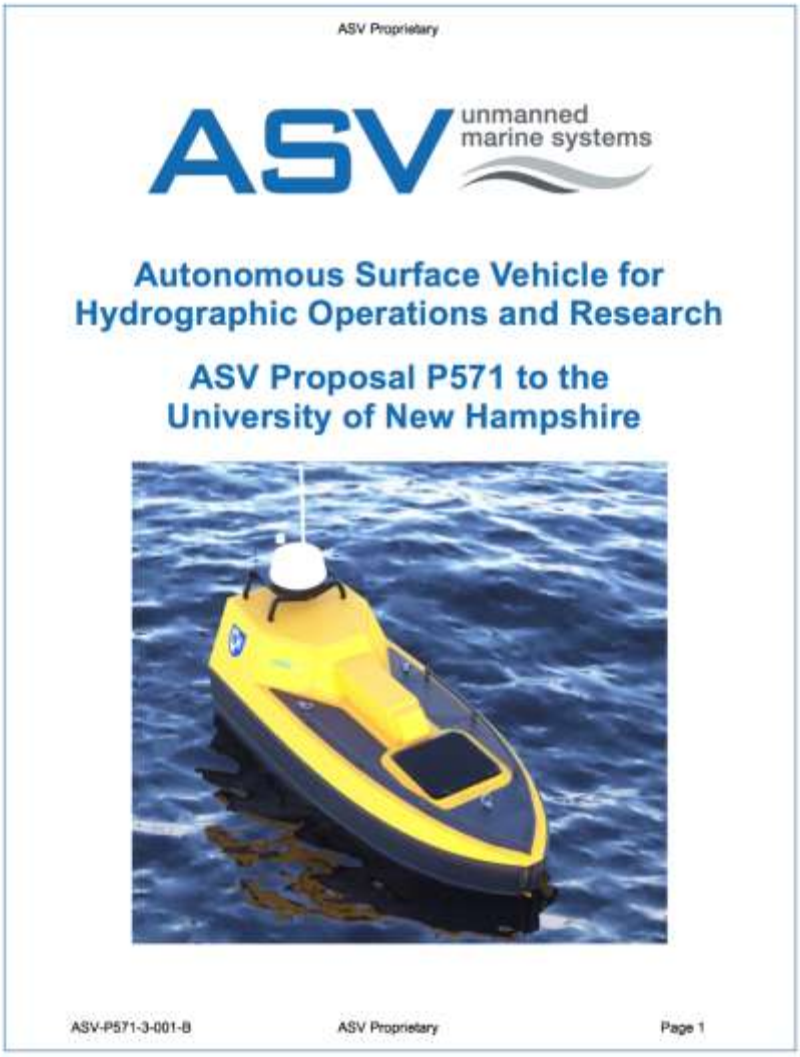
surface vehicles with hydrographic surveying targeted behaviors. These behaviors allow a craft to start from a given line and complete a survey area without previous knowledge of the bathymetry. Paths adapt based on detected hazards and are spaced dynamically depending on the depth for applicability to varying width multibeam swaths (Figure 3-17). These algorithms and an associated operational routine were implemented into the MOOS-IvP autonomy system and field tested both with single beam sonar using a simulated swath and the Teledyne Odom MB-1 multibeam system.

Manda also tested his software on Teledyne Z-Boats that are now in operation on the NOAA Ship *Thomas Jefferson* and loaned to the Center by industrial partner Teledyne Ocean Science (Figure 3-23). Manda adapted his low cost system for operation with the Z-Boat, including writing necessary drivers for the positioning, sonar and motor interface systems and designing a simpler hardware module. These systems were tested and deployed on the *Thomas Jefferson* culminating with an autonomous vessel in Virginia successfully completing survey acquisition while being managed by Manda in New Hampshire. Details of these efforts can be found in the 2015 Progress Report.

Figure 3-23. Teledyne Oceanscience Z-Boat provided to Center as part of our Industrial Partnership.

ASVs might provide real gains in efficiency to production hydrographic surveys without suffering the navigational challenges of underwater vehicles, both in endurance and positioning uncertainty. Toward this end, in January 2015, the Center began a survey of the state of the art of commercially available ASVs, evaluating them in the context of the mission objectives of NOAA and the ability of our own researchers to quickly integrate new sensors and behaviors into existing systems.

After careful evaluation of a number of commercial ASVs, (see discussion in 2015 Progress Report), the Center decided to partner with ASV Global Ltd., and have entered a co-development agreement for a 4m long, “CWorker 4,” diesel-powered autonomous platform (Figure 3-24) having payload and endurance capabilities suitable for production hydrographic survey similar to that of a standard NOAA launch.


ASV Proprietary

ASV unmanned marine systems

Autonomous Surface Vehicle for Hydrographic Operations and Research

ASV Proposal P571 to the University of New Hampshire

ASV-P571-3-001-B ASV Proprietary Page 1

Figure 3-24: CWorker 4 Proposal to the Center from ASV Global Ltd.

The 4 m vessel will be equipped with a 30 HP Yanmar diesel engine, Almarin jet drive, 1 kW electrical payload and over 16 hours of endurance at six knots. While the costs associated with the initial research into the acquisition of these systems and some post-acquisition testing (Figure 3-25) were covered by this grant, the actual acquisition and development costs were covered by NOAA grant NA15NOS4000200 and will be reported on more fully in the progress report associated with it.

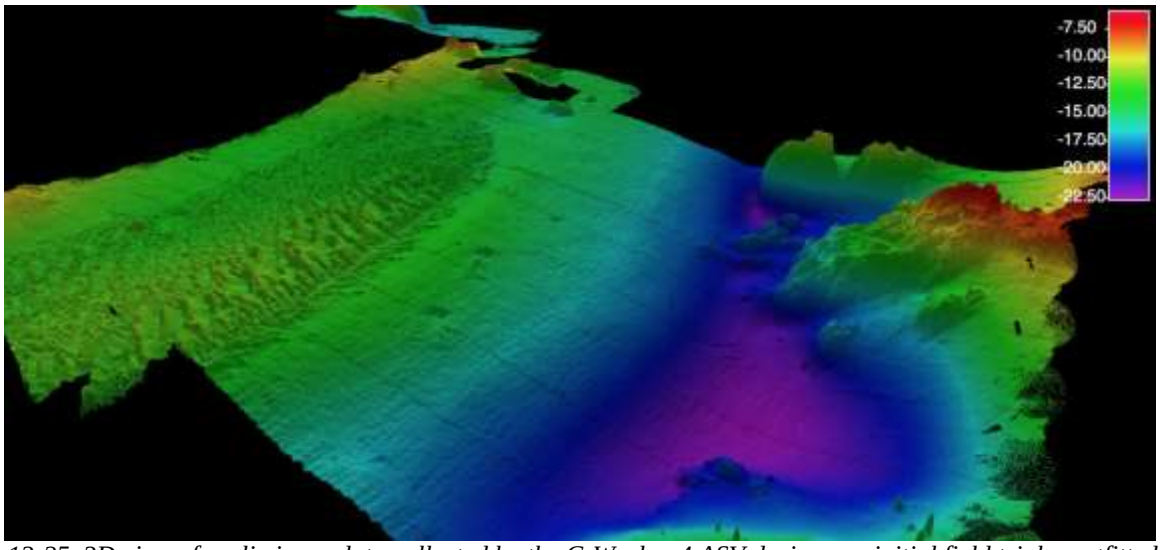


Figure 13-25. 3D view of preliminary data collected by the C-Worker 4 ASV during our initial field trials; outfitted with a Kongsberg EM2040p and Applanix POS/MV positioning system. Vertical exaggeration: x6.

THEME 2: IMPROVING AND DEVELOPING NEW APPROACHES TO HYDROGRAPHIC, OCEAN AND COASTAL MAPPING DATA PROCESSING WITH EMPHASIS ON INCREASING EFFICIENCY WHILE UNDERSTANDING, QUANTIFYING, AND REDUCING UNCERTAINTY

Short name: **PROCESSING**

The development of better and more efficient means to process hydrographic data has been a long-term goal of Center activities. As the number and type of sensors with which we are involved, and the scope of ocean mapping expands, so does the range of processing challenges we face. In this section we begin with our "bread and butter;" a discussion of bathymetric processing tools that we have developed and are developing for both traditional multibeam echo sounders and phase measuring bathymetric sonars. We then look at the concept of "trusted community" or "crowd-sourced" data collection and explore the usefulness of existing datasets and suggest new directions that might be taken. We also look at processing tools being developed to extract bathymetric, shoreline and other data from satellite and other imagery. In parallel with our work on bathymetric data processing we are also investigating approaches to understanding the uncertainty associated with the backscatter that is provided by swath mapping systems and applying this understanding to efforts to characterize the seafloor. We also introduce a new processing effort that began with our efforts associated with Super Storm Sandy—a project aimed to develop tools for the automated detection of marine debris. Finally, we recognize our critical responsibility to manage and deliver the data that we collect in an appropriate fashion and thus discuss our efforts to develop state-of-the-art data management and delivery systems.

IMPROVED BATHYMETRIC PROCESSING

CUBE, CHRT 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. Data-processing is one of the most serious bottlenecks in the hydrographic "data-processing pipeline" at NOAA, NAVO, and hydrographic agencies and survey companies worldwide. After evaluating a number of approaches, our efforts have focused on a technique developed by Brian Calder that is both very fast (10's to 100's of times faster than then contemporary processing approaches) and statistically robust. The technique, known as CUBE (Combined Uncertainty and Bathymetric Estimator), is an uncertainty model-based system that estimates the depth plus a confidence interval on each node point of a (generalized) bathymetric grid. In doing this, the approach provides a mechanism for automatically processing most of the data and, most importantly, the technique produces an estimate of uncertainty associated with each grid node. When the algorithm fails to make a statistically conclusive decision, it will generate multiple hypotheses, then attempt to quantify the relative merit of each hypothesis and present them to the operator for a subjective

decision. The key is that the operator needs to interact only with that small subset of data for which there is some ambiguity rather than going through the conventional, very time-consuming process of subjectively examining all data points.

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

Based on these verification trials and careful evaluation, Capt. Roger Parsons, then director of NOAA's Office of Coast Survey, notified NOAA employees as well as other major hydrographic organizations in the U.S. (NAVO and NGA) of NOAA's intent to implement CUBE as part of standard NOAA data processing protocols. As described by Capt. Parsons in his letter to NAVO and NGA, CUBE and its sister development, The Navigation Surface:

> *"…promise considerable efficiencies in processing and managing large data sets that result from the use of modern surveying technologies such as multibeam sonar and bathymetric LIDAR. The expected efficiency gains will reduce cost, improve quality by providing processing consistency and quantification of error, and allow us to put products in the hands of our customers faster."*

In light of NOAA's acceptance of CUBE, most providers of hydrographic software have now implemented CUBE into their software packages (CARIS, IVS/QPS, SAIC (now Leidos), Kongsberg Maritime, Triton-Imaging, Reson, Fugro, GeoAcoustics, HyPack, and IFREMER). Dr. Calder continues to work with these vendors to ensure a proper implementation of the algorithms as well as working on new implementations and improvements. The progress made in 2016 is described below.

MULTIRESOLUTION GRIDS – CHRT

The CHRT project implements a multi-resolution, data-adaptive estimation layer on top of the core CUBE hydrographic data processing algorithm. This allows for better control over many of the parameters in CUBE that otherwise have to be specified by the user, and eases many of the issues with variant implementations of the CUBE algorithm in the industrial sector.

In the current reporting period, Brian Calder has continued to work with the Center's Industrial Partner organizations, and government labs, to improve the performance of the algorithm, and to adapt the parameters of the algorithm. This has included work with CARIS on extending the range of the expected distance computation used for uncertainty propagation, and an adjustment of the node placement algorithm to ensure stable behavior with extremes of resolution estimates while still avoiding placing overlapping nodes; and work with NRL Stennis on a more mathematically rigorous statement of the underlying argument for the uncertainty propagation equation itself. The work has also provided for a

simplified, one-dimensional version of the algorithm, which allows for more detailed analysis and explication of the way in which the algorithm behaves (Figure 4-1).

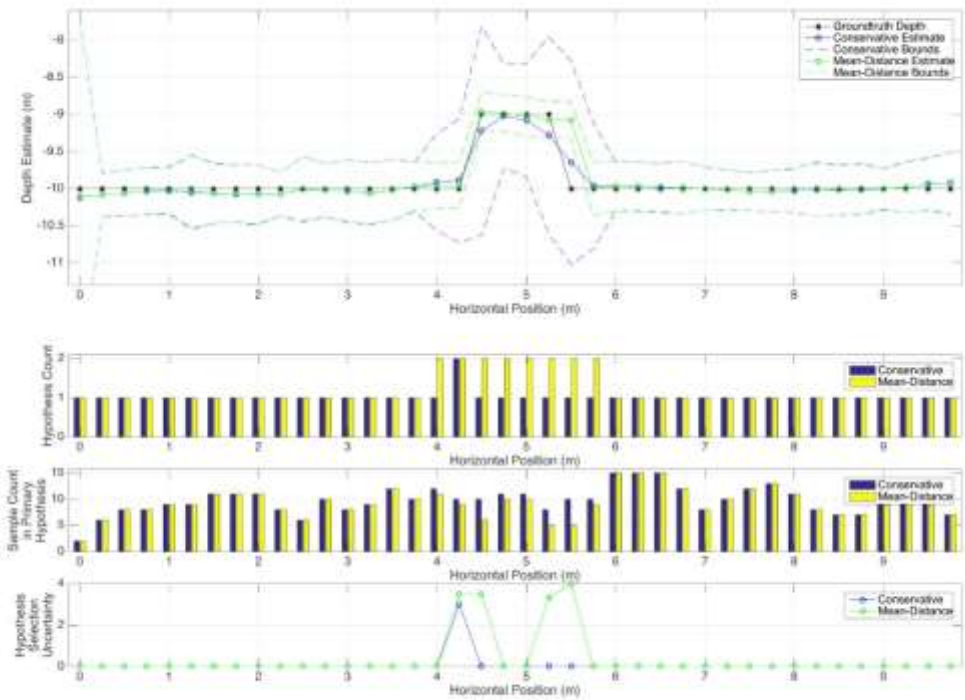


Figure 4-1: An example of the one-dimensional version of CHRT applied to a synthetic dataset. Here, the behavior of the original, and modified, propagation algorithms are compared over a small object. This demonstrates that the modified algorithm (as implemented in CHRT) provides for significantly better fidelity to the actual shape of the object, but also provides for much better insight into how the algorithm does this, making it ideal for demonstration and training.

CHRT is being co-developed between the Center and its Industrial Partner network. In the current reporting period, the code base has benefited significantly through multiple software pull requests from CARIS, contributing back to the project a set of bug-fixes, algorithm enhancements, and additional code to support better interface flexibility. This close working relationship with professional software developers also enhances testing, which brought to light a corner-case for estimation node layout that was sub-optimal. The investigation by CARIS allowed Calder to reassess this algorithm component and redesign it to avoid the (unexpectedly deep mathematical) issue; Calder and Stuart MacGillivray (CARIS) then worked together to approve the fix for adoption into the code base, making it available for all co-developers.

Working with the Open Navigation Surface Working Group, Calder proposed, implemented, and had adopted, a set of extensions to the BAG library that provide a *de facto* standard method for storing variable resolution surfaces such as those generated by CHRT (q.v.). Calder and Giuseppe Masetti have included these into CHRT, and ensured that the code is cross-compilable on a variety of Windows, Mac OS, and Unix-like platforms. As part of this work, a set of source data and variable resolution surfaces

were provided to QPS, allowing them to focus on support issues for variable resolution surfaces in visualization applications.

An important goal for the CHRT co-development agreement is to establish a conformance test suite that is capable of demonstrating that a vendor's implementation matches the behaviors of the reference implementation of the algorithm maintained by the Center. Working with Glen Rice, Calder has therefore documented the network API used by the algorithm, which defines the facilities that vendors must support at the lowest level, and Calder and Matt Plumlee have developed a formal conformance test suite (Figure 4-2) that can be used to define a precise set of tests, capture the expected results, and then do automated comparisons between results from the implementation under test and those from the reference system. A first implementation of the system has been developed and made available to the Industrial Partner co-developers. Future work to extend the range of tests available, and to improve the coverage of the tests with different datasets, is expected to be done in conjunction with the co-developers and NOAA HSTB.

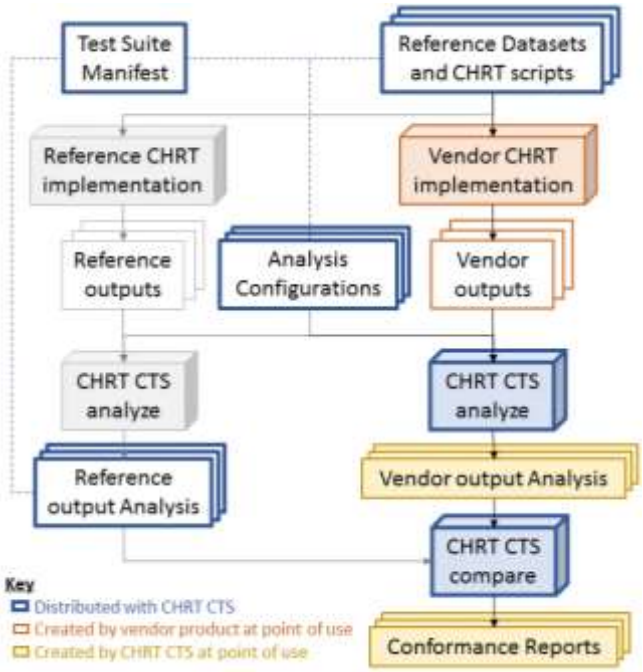


Figure 4-2: Flowchart for the CHRT conformance test suite comparison sequence.

As part of the development work for the conformance test suite, multiple improvements to the CHRT base code have been completed, which have significantly improved the computational performance of the algorithm. The algorithm has also been extended to allow for the output projection system to be specified by the user, and Calder and Plumlee have begun development of a software-only rendering system (i.e., avoiding use of a GPU) to ensure traceability of the code, and consistency of results between hardware systems. A particular request from many CHRT co-developers has been for the Center to provide as much guidance as possible on the calibration of the algorithm, and recommended usage. As part of the development of an academic paper on the algorithm, Calder has developed a method to appropriately calibrate the expected number of observations at each estimation node, demonstrating that

the algorithm responds to the mean number of observations, rather than the minimum. Given that the minimum number of observations is typically the parameter specified by hydrographic agencies, this means that the calibration constant given to the algorithm has to be adjusted to compensate. By testing the algorithm on example datasets (Figure 4-3), a calibration curve can be developed. In addition to this work, Calder has been collaborating with NOAA HSTB to better define future survey specifications and standards to include variable-resolution efforts, and how to specify and require uncertainty computations in a variable-resolution work-flow.

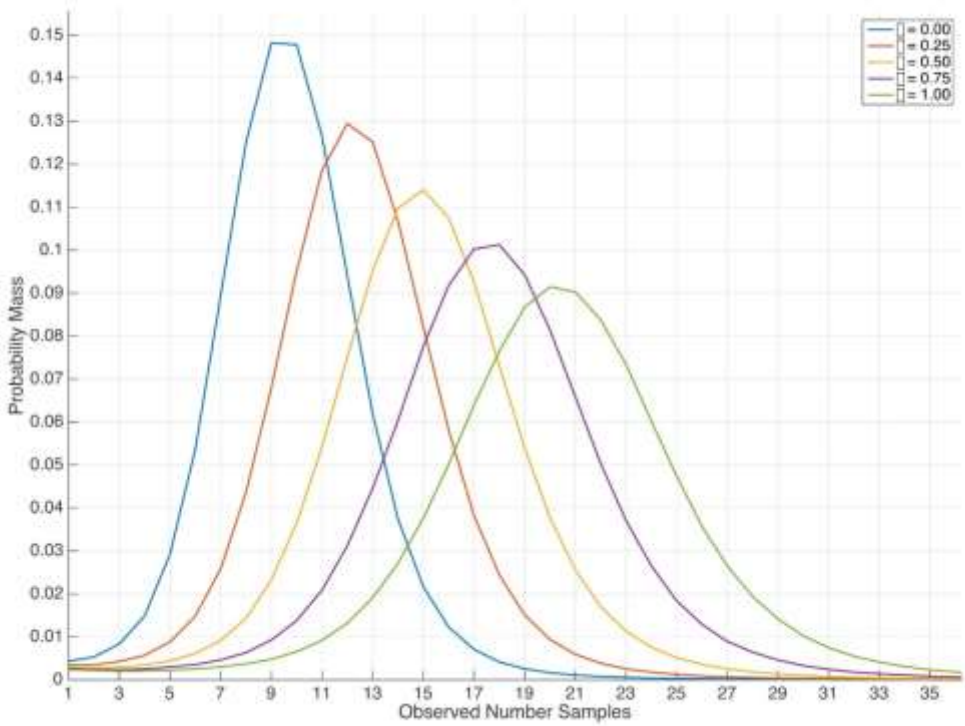


Figure 4-3: Probability mass of observations in primary CHRT hypothesis for a typical shallow-water MBES dataset as a function of selected excess parameter. The algorithm limits are usually specified in terms of a left-tail probability, but the control parameters set the mean observation rate. A compensation factor, derived from results like this, allows for conversion between the two.

Further development as part of the same effort resolved a number of outstanding issues with parallel (multi-threaded) implementation of the algorithm, and significantly improved the performance of the code. Being able to efficiently process data en masse is critical for many survey organizations in their ping-to-chart optimization efforts; hardware limitations with single-processor desktop systems have encouraged many organizations to consider more distributed computational models. Consequently, Calder and Plumlee have started work on a development effort to convert the multi-threaded single-processor parallel implementation to a fully-distributed, fine-grained parallel process.

EVALUATION OF THIRD-PARTY PROCESSING SOFTWARE

The many visits of the Multibeam Advisory Committee (MAC) team to multibeam equipped vessels during 2016 provided an opportunity to test successive versions of the recently released QPS Qimera seafloor and water column mapping software package. In addition to providing a streamlined bathymetry processing path, Qimera includes several useful calibration and diagnostic features which have been tested alongside traditional Kongsberg, Reson, and Caris tools during SAT and QAT missions. Kevin Jerram's expedition aboard the NOAA Ship *Okeanos Explorer* provided an important opportunity to test Qimera alongside existing NOAA bathymetric workflows and draft a shipboard standard operating procedure (SOP) for the new software.

Jerram also developed a processing pipeline that proved particularly useful for operations on the *Okeanos Explorer* where an ROV dive must follow immediately after survey data is collected. Given the remote and relatively unexplored nature of the expedition area, ROV dives were frequently pre-planned using coarse bathymetric grids derived from satellite data. The processing path from arriving on site and securing the multibeam sounders through cleaning, gridding, and exporting high-resolution bathymetric surfaces for the ROV pilots was routinely completed in under 15 minutes. Beyond rapid turnaround of bathymetry for ROV navigation, the streamlined processing path may improve the efficiency of more routine mapping efforts across NOAA's operations.

TRUSTED COMMUNITY AND CROWD SOURCE BATHYMETRY

Crowd-source bathymetry, or Volunteered Geospatial Information, has been a topic of some debate within the hydrographic community, with the primary questions being whether there is indeed a "bathymetric" crowd, to what extent the data can be trusted, and how the data should best be managed and curated.

In an attempt to address the first of these questions, Calder and graduate student Shannon Hoy are collaborating with Adam Reed and Anthony Klemm at NOAA, and through them with Rose Point Navigation Systems, who recently released an option to their widely-used Coastal Explorer ECS that will allow users to opt to send their VGI directly to the IHO Data Center for Digital Bathymetry, hosted at NCEI in Boulder, CO. As part of this trial project, we expect to be able to assess whether there are a sufficient number of participants to satisfy the spatio-temporal requirements for a bathymetric crowd, if there are things which might be done to support this process, and what can be achieved with the data after it is collected. Obvious topics include determination of limits on areas where data density is sufficient for bathymetry determination, to what extent therefore bathymetry may be determined by such methods, and other tasks to which this data might be put (e.g., providing a "recreational" traffic analysis to complement AIS data from larger ships).

Addressing the second question, Calder and Hoy are working on a method by which data can be graded on a spectrum between VGI and fully authoritative. In particular, the goal is to estimate the information content of the observations so that a formal method of combining them can be devised; to support this, an estimate of "reputation" for each observer is being designed so that demonstrated super-observers from the less reliable end of the spectrum can have their data used for more challenging applications. At an early stage of development, it is expected that this work will form the basis of Hoy's thesis.

Finally, addressing the question of data management, Calder has continued to serve on the IHO Crowd Source Bathymetry Working Group, assisting in drawing up the chapter of the guidance document on uncertainty estimation and management. The first working draft of the guidance document was accepted and commended by the IHO during 2016, and the working group subsequently met in Warnemünde, Germany in November 2016 in order to substantially complete the draft of the document. The document will be sent to stakeholders for comment early in 2017.

IMPROVED PROCESSING FOR PHASE-MEASURING BATHYMETRIC SONARS

Phase-measuring bathymetric sonars (PMBS) (multi-row sidescan sonars that look at the phase differences of the acoustic signals between the rows to derive a bathymetric solution) have the potential of offering much wider coverage in shallow water than conventional beam-forming multibeam sonars. NOAA and other mapping agencies have recognized this potential benefit and have explored the feasibility of using PMBS as a hydrographic tool but until recently they have not been approved by NOAA for hydrographic survey. However, for the first time, with input from Val Schmidt, NOAA is now accepting PMBS data when surveyors demonstrate that the capabilities of their chosen system along with their survey methodologies meet the uncertainty and object detection requirements of the Office of Coast Survey's *Specifications and Deliverables*. Efforts by the Center to encourage manufacturers to bin their data to reduce noise and as well as to produce real-time uncertainty estimates and robust outlier rejection tools have helped to provide systems more readily suitable to production hydrographic work.

Schmidt has been working closely with NOAA contractors, Cassandra Bongiovanni, Juliet Kinney, and Sarah Wolfskehl, in the IOCM division co-located at the Center, to assess the chartability of PMBS data collected by the USGS in Buzzard's Bay off the Massachusetts coast in 2009-10. Schmidt and Bongiovanni presented the results of their analysis at the Office of Coast Survey's Field Procedures Workshop and again at the Canadian Hydrographic Conference in Halifax, NS. The data set was found to be well navigated and well documented, but validation cross-lines run by a NOAA launch at the request of Schmidt and Bongiovanni showed a residual uncorrected roll bias; and swath widths approaching 10 x water depth were found not to meet IHO uncertainty requirements for vertical uncertainty at their outer edges. None-the-less, while not wholly up to NOAA's internal standards, the surveys were found to be immediately useful for chart update, identifying 10 previously uncharted shipwrecks and at least 17 potential dangers to navigation (Figure 4-4).

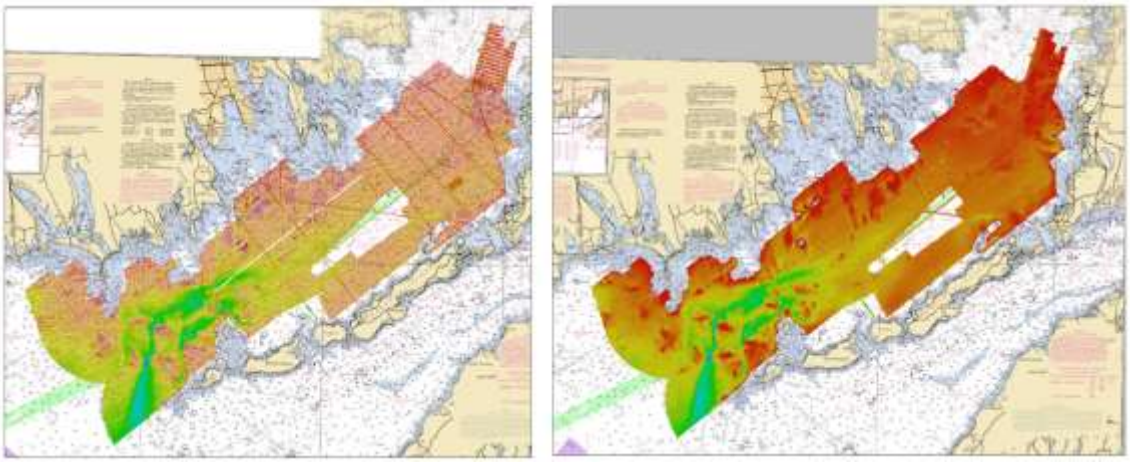


Figure 4-4: SEASwath Plus PMBS data provided to NOAA by the USGS. The full data set is shown on the right while data truncated to 3.4 x water depth is show on the left after omitting data not meeting IHO requirements for vertical uncertainty. It was noted in the course of this work that while not wholly meeting IHO requirements the full data set was generally preferable for identifying hazards to navigation, providing more geologic context that the limited swath-width data.

In addition to the USGS analysis, Schmidt has been working with Klein Inc. to assess the quality of their Hydrochart 3500 phase measuring bathymetric sonar system. The system was deployed from the R/V *Gulf Surveyor* in July of 2016, collecting data for reference surface evaluation at various depths. Analysis of the data and the system is ongoing.

EVALUATION OF UNCERTAINTY IN BATHYMETRY, NAVIGATION AND SHORELINE DATA FROM LIDAR, PHOTOGRAMMETRY OR SATELLITE IMAGERY

Also covered within the PROCESSING theme are various efforts aimed at developing better ways to extract information about bathymetry, navigation and shorelines from LIDAR, photogrammetry or satellite imagery. Many of the tools developed for these tasks have come out of our focused effort on understanding the impact of Super Storm Sandy, funded by another NOAA grant (Brian Calder–PI) though they also draw on personnel and efforts supported under this grant. We refer the reader to http://sandy.ccom.unh.edu/ and references therein for more detailed descriptions of the work done under the Super Storm Sandy grant. Some of the applications this work are under the HABITAT and IOCM themes.

UNCERTAINTY ESTIMATION OF LIDAR DATA

As discussed in the SENSORS section, we are striving to better understand the uncertainty associated with airborne lidar bathymetric (ALB) measurements, through the quantifying environmental factors (water surface and water column effects) that may affect the range measurements of the system. In concert with the LIDAR simulator work, we also are developing computer simulations using ray tracing to compare

models to the measured results. A realistic water surface covered in capillary waves was simulated using MATLAB. The refraction of each ray is then calculated in order to follow their path through the water column and to find the shape of the laser beam footprint (Figure 4-5) in order to understand the shape of the laser beam footprint and its deviation from a still water condition.

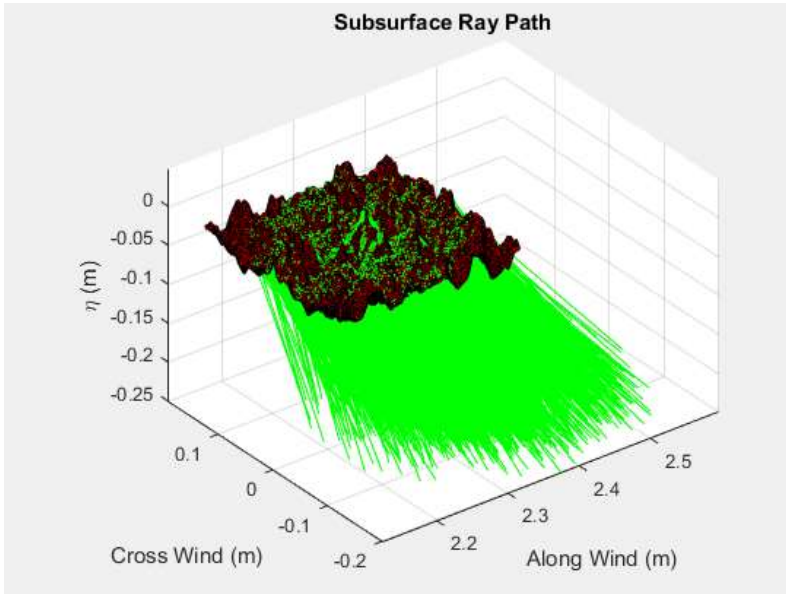


Figure 4-5. Simulated LIDAR ray paths after refracting through a capillary wave surface.

UNDERSTANDING IMPACT OF SEAFLOOR TYPE ON LIDAR UNCERTAINTY

ALB waveforms contain information on the environment as a result of the laser beam interaction with the water surface, water column and seafloor. One important aspect of the waveform is the bottom return, which potentially has descriptive features related to seafloor morphology and bathymetric uncertainties. A waveform processing procedure has been developed to extract the bottom return features to be used in seafloor characterization and total propagated uncertainty (TPU) models.

The amplitude and shape of bottom returns in the ALB waveform are related to laser beam interactions with the seafloor. For example, the bottom return from a flat and uniform seafloor demonstrates a more uniform pattern whereas the bottom return from a rocky surface demonstrates a more complex pattern (Figure 4-6). This complex pattern also alters the estimation of the true interface location along the ray-path, which affects the depth estimate and thus induces additional bathymetric uncertainties.

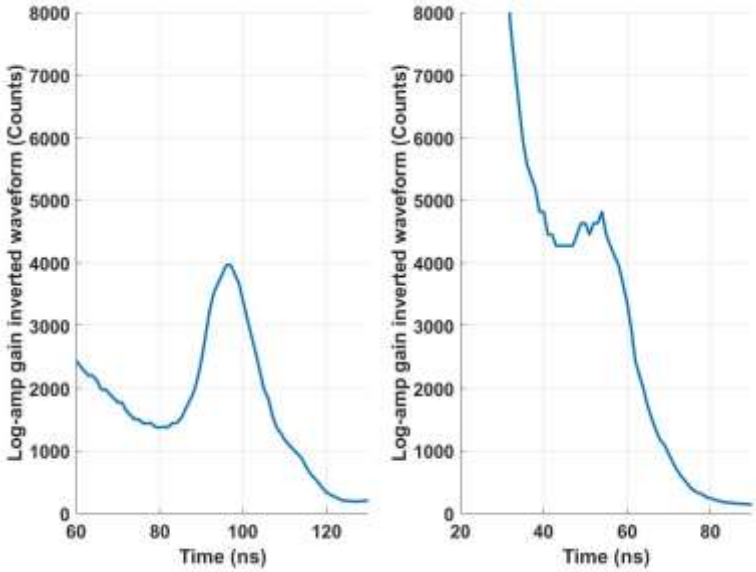


Figure 4-6: Two different bottom returns from SHOALS-1000 data after interaction with two different sediment types. Left- Bottom return corresponding to sandy bottom. Right- Bottom return corresponding to rocky bottom.

Current research efforts are focused on the construction of waveform classifiers for bottom return characterization. Theoretical models were used to generate a bottom return that represents a flat and uniform seafloor. The output of the procedure is a residual which provides a reference measurement for comparison between different waveforms. Theoretically, the higher the deviation from a modeled bottom return, the higher the distortion of the bottom return due to sediment roughness. The enclosed region, i.e. the residual, was correlated with experimental bottom returns (Figure 4-7).

The developed procedure only uses the ALB waveform without additional data sets and can be applied to ALB waveforms from different LIDAR systems (i.e., independent of the hardware). The output of this procedure can also be used for seafloor characterization studies (see Habitat and Water Column mapping theme) or uncertainty evaluation.

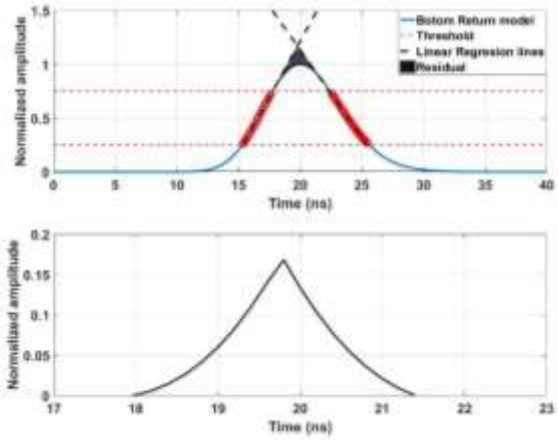


Figure 4-7: Top- The bottom return modeled as a Gamma function and the applied threshold limit for the developed procedure. Bottom-The residual of the area between the triangle and the bottom return.

Over the past six months, the waveform processing procedures were modified to remove the logarithmic compression effects on the waveforms due to the log-amp amplification. Then using the developed waveform processing techniques, a total of 13 classifiers were extracted from the waveform. These classifiers along with the corresponding ground truth can be used as training data in supervised classification. The supervised classification process using these classifiers are demonstrated in the HABITAT and WATER-COLUMN theme.

BATHYMETRY FROM IMAGERY

The ability to derive bathymetry from satellite imagery is of increasing interest to a number of government agencies and private sector firms, due, in part, to the reported capabilities of a number of new algorithms and satellite sensors. For example, Landsat 8, WorldView-2, and the planned WorldView-3 have all been reported to provide enhanced capabilities for coastal bathymetric mapping. A Center team, headed by Shachak Pe'eri, has been developing and evaluating approaches to extracting bathymetry from satellite imagery (Satellite Derived Bathymetry–SDB) as well as exploring the applicability of SDB for change analysis, benthic habitat mapping, depth retrieval in remote regions, and hydrographic survey planning (Pe'eri et al., 2013). In the first stage of this research effort, the potential use of Landsat satellite imagery to map and portray shallow-water bathymetry was investigated at three study sites: U.S., Nigeria, and Belize. Publicly available, multi-spectral satellite imagery and published algorithms were used to derive estimates of the bathymetry in shallow water. The study determined the most appropriate algorithms based on their performance using different combinations of frequency bands and spatial filters. The accuracy of the results was modeled using a Monte Carlo simulation and validated empirically using a reference dataset. Based on the success of this first stage, the procedure was published in a GEBCO "cookbook" for the use of hydrographic offices worldwide.

The great potential for Satellite Derived Bathymetry has led to its testing and application in a number of regions. In the 2013 Progress Report we described approaches for deriving bathymetry from very clear waters around Haiti (an easier case). We also demonstrated an approach for deriving bathymetry from regions where water clarity is very variable (using the North Slope of Alaska as the example). In these regions we use multiple satellite images and define areas that are "clear" by comparison (i.e., minimum water clarity change between two satellite images). In 2014 we described the application of SBD for the location of navigation channels in Bechevin Bay, AK and changes in the Intercoastal Waterway in South Carolina.

Following the US-Canada Hydrographic Commission (USCHC) meeting in March 2015, NOAA's Office of Coast Survey decided to outline an internal NOAA policy regarding the use of SDB as supplementary information that can support the hydrographer/cartographer with decision making on the need to update a chart. Shachak Pe'eri has been consulting with NOAA's Marine Charts Division (MCD) on the policy (written and managed by John Barber and Anthony Klemm.

Multi-area non-linear SDB estimation and bottom identification

With the departure of Pe'eri to MCD, the SDB work has continued through the efforts of graduate student Ricardo Friere under the supervision of Pe'eri and with the collaboration of Affiliate Associate Professor Christopher Parrish and NOAA's Anthony Klemm. This project is focused on the development of new processing tools to better estimate water depth and its associated bottom type from

satellite imagery. It takes advantage of Landsat 8 imagery and previous work by Dierssen and Zimmerman (2003) who developed an optical channel ratio analysis. It is particularly focused on deriving approaches for SDB estimation in challenging environmental conditions, where traditional approaches would fail.

The approach is to subdivide the study area into smaller subsets that can be processed using traditional linearization of equations. First, the water-column contribution, per optical channel, is determined using weighted correlation analysis. Second, the bottom and upwelling/downwelling attenuation coefficients, for each channel, are indirectly evaluated by a linear regression of the model against sounding control points. Each subset will have its own SDB values and reference parameters. Both root mean square error and determination coefficient approaches are used to verify which subsets are beyond extinction depth and remove them from further calculations. Additionally, those channel pairs which give the best response are determined.

Thus, a more reliable depth estimation is available to the operator compared with traditional SDB optimization methods. The last step in this approach consists of solving the linear equations that relate the bottom contributions per channel within each subset, and comparing the results to adjacent areas. Results are subject to physical constraints on the constituent parameters of observed radiance in the shallow water equation. If the bottom solutions for two adjacent areas are consistent, both subsets are clustered. This process is performed across all subsets, creating clusters of areas with similar bottom returns.

Multi-image SDB Approach for Updating Nautical Charts:
This effort was inspired by previous work the team had done as part of the Super Storm Sandy recovery efforts, and collaboration with MCD. The dynamic environments of inlets and river mouths require constant update. In many cases, it is not possible to have reliable sounding control points to vertically reference to chart datum. This research investigates a multi-image SDB approach to updating nautical charts.

For remote areas with no reference soundings, the challenge is to derive bathymetry strictly from the imagery. This is done through calculating the band ratio in the images (relative attenuation of blue and green bands) and then defining boundaries of features that pose a danger to navigation. Several methods of edge detection were tested in order identify and track features over time. A Canny edge-detection algorithms was identified as the most suitable for our application. In order to keep track and observe the changes in position and shape of the feature over time, we used a geometric primitive (i.e., an ellipse) to mark and track the features over time. The fitting of an ellipse to each feature was conducted using a least squares method. It is important to note that the initial fitting always left some residuals and required a few iterations in order to account for potential outliers that relate to the feature (Figure 4-8). Given the estimated ellipsoidal boundaries, it was possible to identify dynamic and stable areas as well as shifting trends of shoal features.

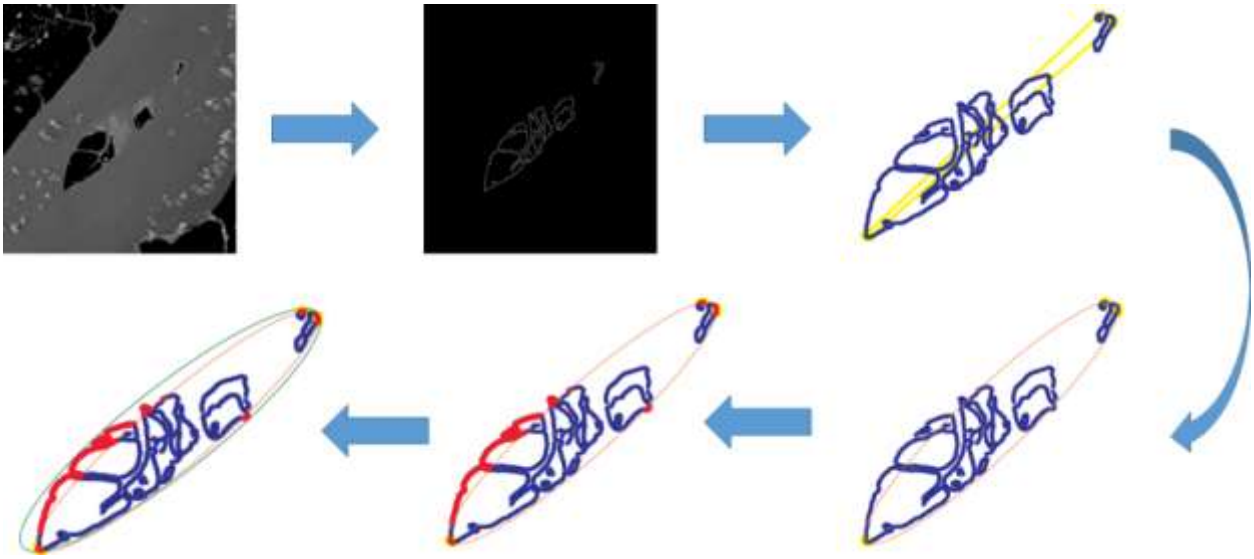


Figure 4-8: Processing workflow, applied to the Amazon River, showing the process from band ratio until a final envelope ellipse.

Two study sites were used in this project: the entrances of the Yukon (Alaska) and Amazon (Brazil) rivers. In the case of the Yukon River, the last survey for NOAA chart 16240 was 1899, and last survey for the DHN (Brazil) chart 203 over the Amazon River was conducted in 1977. By using Landsat imagery, it was possible to see erosion and accretion of sediments due to the rivers' hydrodynamic characteristics, but since we had few available images over the years (mainly due to cloud coverage), the ellipses gave an indication of the shift of the features over the years. It was possible to check the results on the Yukon River against ship-traffic as indicated by AIS data, tracking matches with the ellipse boundary generated from the study (Figure 4-9). Based on these ellipses, it is possible to predict near future feature dynamics. Figure 4-10 presents the Amazon River prediction (two yellow ellipses) and actual feature identification (green ellipse), using 1982-2008 data to estimate 2013, 2014 and 2015. The limitation of the approach is that water level can vary, depending on river run-off, introducing potential errors in calculating the motion of the feature and predicting its position.

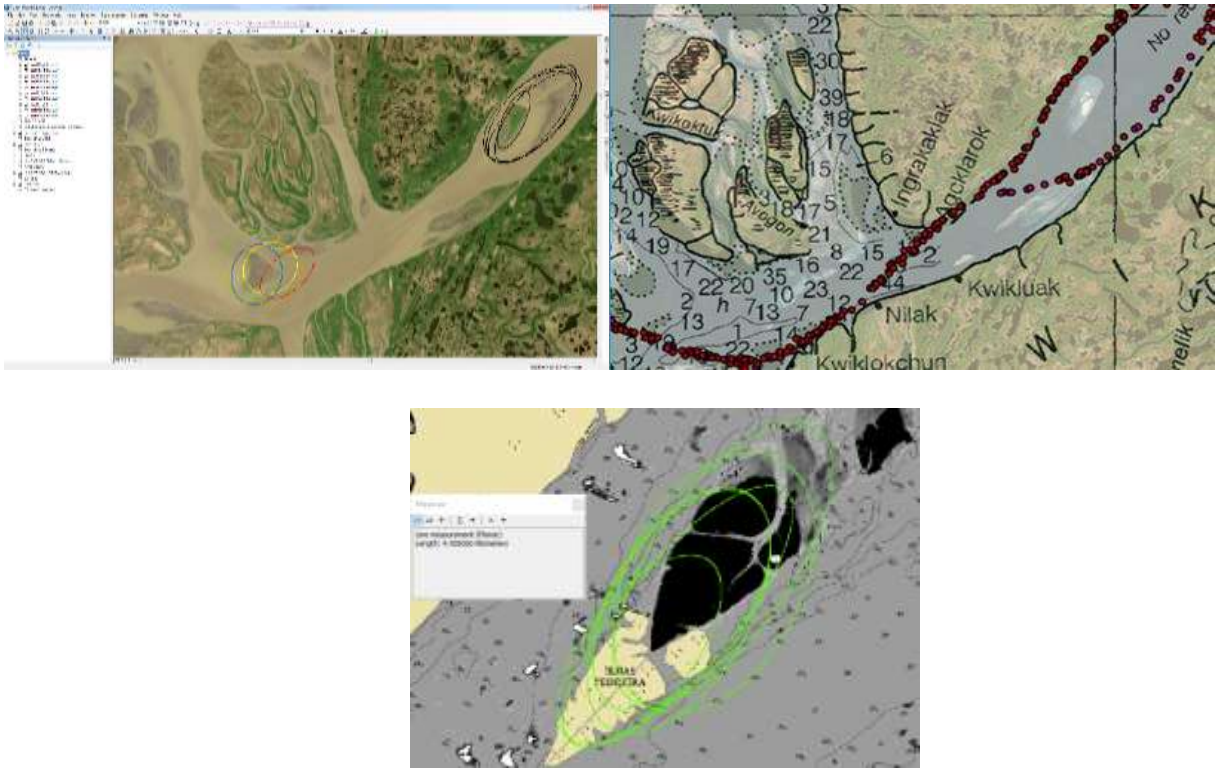


Figure 4-9: (Upper left image) Shoal features identified from satellite imagery between 2005 and 2015 in the Yukon River. (Upper right image) AIS tracks of vessel traffic (2013) on the NOAA chart confirming the location of the shoals by navigating around them. (Lower image) Movement of shoal features from 1986 to 2008 in the Amazon River.

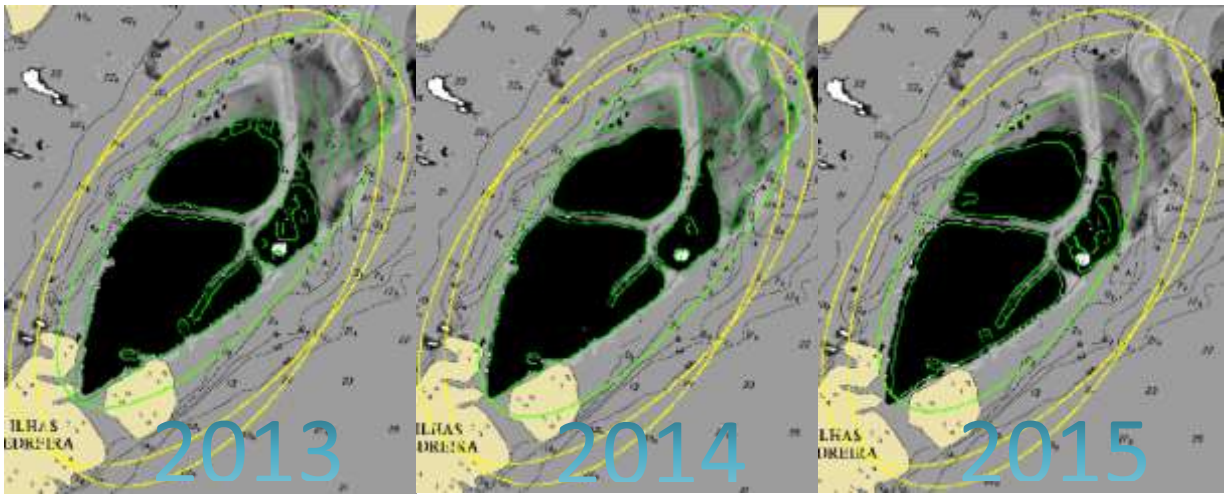


Figure 4-10: Shoal feature predicted boundaries (yellow ellipses) using satellite imagery from 1982 to 2008, in the Amazon River, compared against observed data (green ellipses), for the years 2013, 2014 and 2015.

ENHANCED DATA PROCESSING FLOW: HYDROFFICE

Ocean mapping procedures, like survey review and nautical chart compilation, are often characterized by the repeated execution of many operations that can be automated. When correctly implemented,

automated tools can safely reduce the time from data acquisition to chart publication/updates (or database update) providing data analysts the time to focus their energy on specific problem issues (e.g., bathymetric blunders, anomalies in sound speed profiles, etc.) rather than repeated tasks. The automation of some processing steps may also enhance the consistency, accuracy and traceability of the final products. For these reasons, Giuseppe Masetti and Brian Calder, in close collaboration with Matt Wilson, (NOAA OCS Atlantic Hydrographic Branch physical scientist and Center alumnus), have begun an effort to define the requirements (through a whitepaper written in April 2015) and to start the implementation of a new software environment (called *HydrOffice*) designed to create a mechanism whereby processing algorithms can be quickly developed and tested within the current data processing pipeline and, if proven effective, quickly go into operation through implementation by industrial partners.

The goal of HydrOffice is to lower the barrier to creating ocean mapping apps, by easing configuration management difficulties and leveraging existing infrastructure to easily facilitate additional hydro-solutions. As free and open source software, the apps are available for use, and for additional contributions, to students, NOAA, and industry partners. The overall goal is to speed up both algorithm testing and Research-to-Operation (R2O). So, rather than a monolithic code structure required to solve each problem, HydrOffice has several small specific applications (hydro-solutions) that share a common base code.

Several hydrographic-specific libraries have been developing during the reporting period. Built on top of the popular Python scientific stack, they all have a modular design to make them readily available for other applications. This structure makes it easy to add more solutions and encourages contributions. The current HydrOffice research sub-themes are:

- The HOME app simplifies the download and update of HydrOffice packages, and also grants access to a collection of tools to ease the creation of new HydrOffice libraries and applications.
- HUDDL is designed to simplify and standardize the description of hydrographic data files (Calder and Masetti, 2015).
- SOUND SPEED MANAGER is an application and sound speed library built to bridge the gap between sound speed profilers and multibeam echo-sounders. Originally created by Dr. Jonathan Beaudoin, many new functionalities have recently been added.
- The BAG library provides access to BAG-specific features, as well as a collection of tools to verify and manipulate BAG data files.
- OCEANO is a library to process acoustic backscatter, with three main components: ARES to create acoustic reflectivity surfaces, ARCH for seafloor characterization, and Matador for target detection.
- QC Tools facilitates hydrographic survey review and nautical chart compilation, with features specific to the NOAA review process. It currently includes a Survey-oriented tab and a Chart-specific tab, and ENC X (a tool to explore the content of ISO 8211-based formats, as used for S-57/S-100 ENCs, at multiple levels of abstraction from the physical content to the Product Specification level).

To encourage their adoption, individual HydrOffice apps are also provided to the public as "frozen", standalone click-and-use solutions that do not require the installation of a Python environment on the user machine. Some are currently available for download (while others are coming to the end of the incubation phase) on the recently-created, Django-based HydrOffice website (https://www.hydroffice.org/) (
Figure), along with additional information and links that further describe the HydrOffice project.

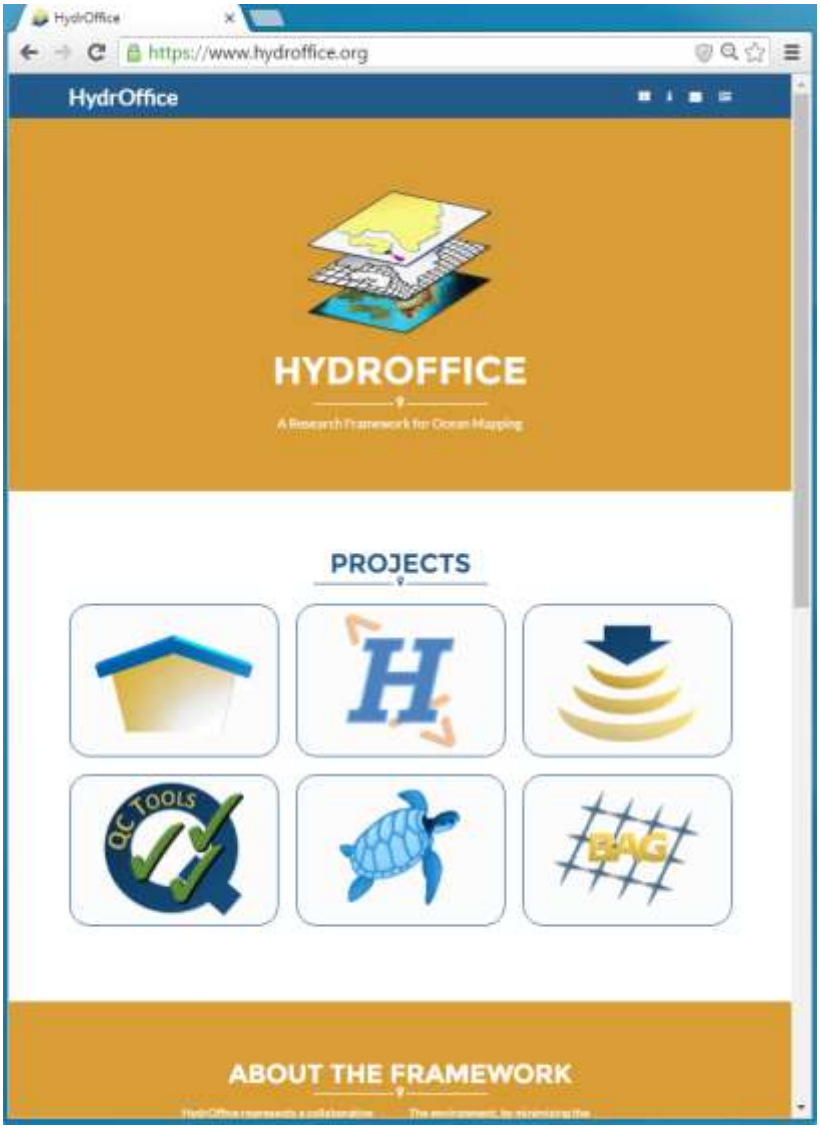


Figure 4-11: The main page of the HydrOffice project website with the current research sub-themes: clockwise from the top left, the HydrOffice Managed Environment application (HOME); the Hydrographic Universal Data Description Language (HUDDL); Sound Speed Manager; the Bathymetric Attributed Grid (BAG) library and explorer; Oceano, and QC Tools.

SSP MANAGER AND SOUND SPEED MANAGER

The use of inaccurate sound speed data heavily affects all survey products, from bathymetry to the backscatter mosaic, through to water column imagery. Thus, sound speed profiling (SSP) represents a key element for any workflow that aims to collect high-quality echosounder data. Historically, the SSP has been handled by surveyors using a mixture of manufacturer-specific tools, spreadsheets, scripts and some manual hacking. Far from optimal, this approach carries a number of disadvantages and can be error prone and inconsistent among different sound profile systems.

SSP Manager, based on the HydrOffice Sound Speed library, bridges the gap between sound speed profilers and multibeam echo-sounders (MBES). The application supports several data formats as file and network inputs (Castaway, Digibar, Idronaut, Seabird, Sippican, Turo, UNB, MVP). Once successfully imported, the application provides tools and functionalities to edit, improve (e.g., by using oceanographic atlases) and extend the collected raw samples. The resulting SSP can be then exported to files or sent directly to hydrographic data acquisition software (e.g., Hypack, Kongsberg SIS, QPS Qinsy, Reson). SSP Manager provides a mechanism to store the (raw, processed, and transmitted) data samples into a database so that additional analysis can be applied to the SSPs collected during the whole survey. The stored profiles can also be exported in other well-known geographic data formats for further analysis and visualization. The application's initial code was based on SVP Editor, an application developed at the Center through the Multibeam Advisory Committee, and many new functionalities and bug fixes have been recently added based on copious feedback coming from professionals and researchers that are using SSP Manager in their standard operational workflow.

In previous years, NOAA's Office of Coast Survey has addressed similar SSP issues by developing a tool called Velocipy, which largely overlaps in scope with SSP Manager. Leveraging the common experience, a jointly-developed open-source NOAA-JHC initiative has been created to provide a long-term, reliable solution for SSP handling. After a meeting in February at NOAA OCS Hydrographic Systems Technology Branch, a detailed plan on how to merge SSP Manager and the NOAA-developed Velocipy was developed.

The new application, named Sound Speed Manager (Figure 4-12), has been designed to ease the integration in existing data acquisition workflows, and its open source license provides a way to easily adopt the processing solution as well as to adapt the application to specific organizational needs. Adaptation is simplified by the modular design of the application, with the NOAA-specific functionalities organized so that they can be easily deactivated. The main functionalities include: wide support of commonly-used sound speed formats for input and output, full integration with existing data acquisition/integration applications (e.g., Kongsberg SIS), profile enhancement based on real-time and climatologic models, and database management of the collected data with built-in functionalities for analysis and visualization (Figure 4-13).

Sound Speed Manager is in the advanced phase of prototyping and a first release has been provided to NOAA users and the public for feedback. A paper with title "Sound Speed Manager: An Open-Source

Initiative to Streamline the Hydrographic Data Acquisition Workflow" will be presented at the upcoming US Hydro 2017 conference.

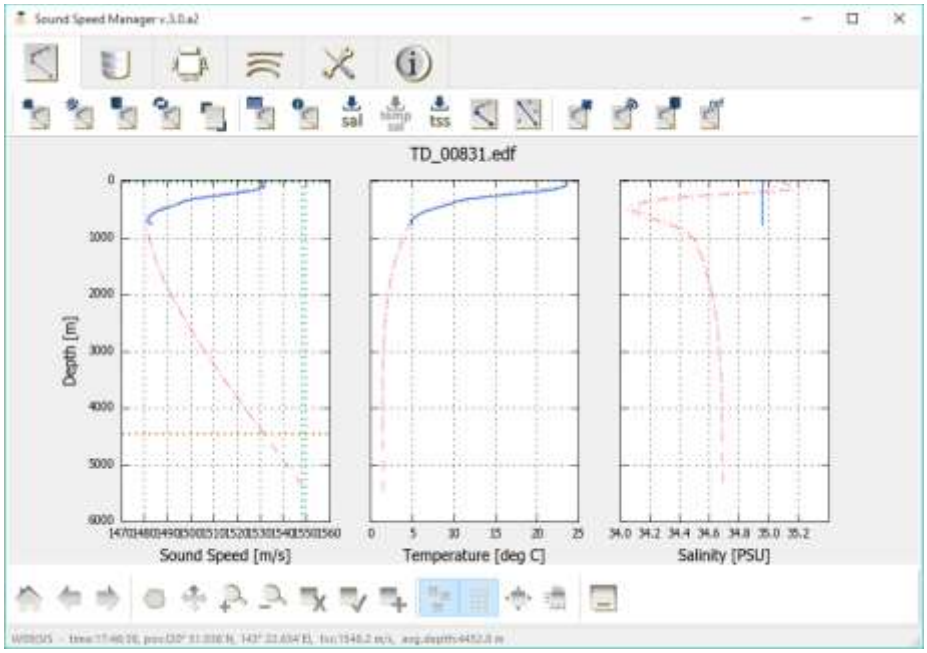


Figure 4-12: The redesigned GUI of Sound Speed Manager has the goal of simplifying the user experience, adopting several task-oriented tabs

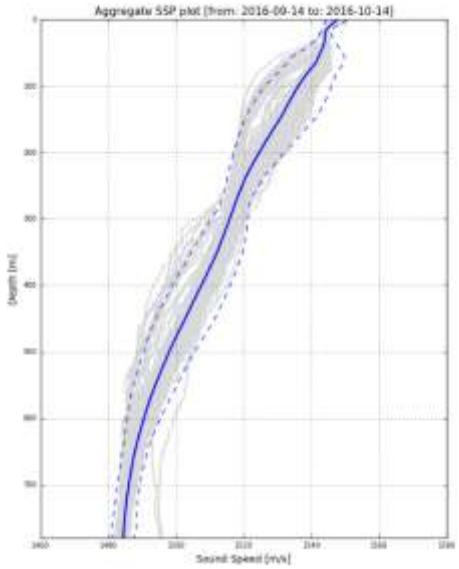


Figure 4-13: Based on its database capabilities, Sound Speed Manager provides functionalities for data analysis and visualization such as aggregated plots of data captured.

BAG EXPLORER

BAG Explorer is a light application, based on HDF Compass and the HydrOffice BAG library, to explore BAG data files. The application provides a mechanism to explore the tree-like structure of a BAG file, to visualize and validate the XML metadata content (Figure 4-14), to inspect the tracking list, and to plot the elevation and uncertainty layers.

The project has recently become available as an official plugin of HDF Compass (with version 0.6 released June 12, 2016), an open-source tool to access generic HDF files that has Masetti as the current first contributor. BAG Explorer is also available as a stand-alone application on the project website (https://www.hydroffice.org/bag/main) and as part of the NOAA's Pydro environment, enhanced with a number of features that cannot be inluded in the open-source version. The application also supports the recently published IHO S-102 standard, and there are ongoing efforts to improve support for variable resolution surfaces.

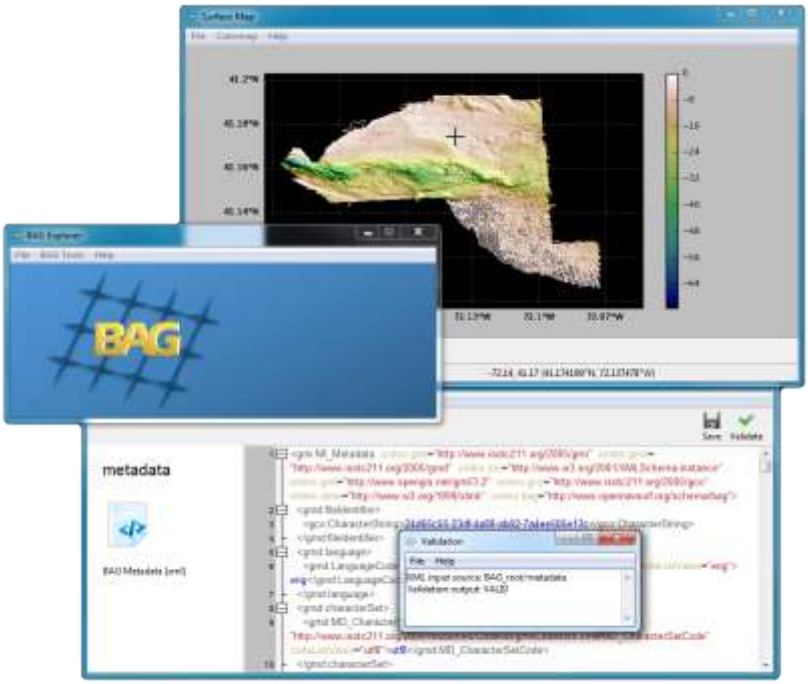


Figure 4-14: BAG Explorer in use, hill shading the bathymetric layer and validating the metadata content of a BAG file.

IMPROVED BACKSCATTER PROCESSING

In parallel with our efforts to improve bathymetry processing techniques several processing efforts are aimed at improving our ability to extract high quality, and hopefully quantitative, backscatter data from our sonar systems that can be used for seafloor characterization, habitat assessment and many other applications. Although these efforts are discussed under the PROCESSING theme, they are clearly closely related to our HABITAT and IOCM themes.

UNCERTAINTY OF BACKSCATTER MEASUREMENTS: NEWBEX

As the use of backscatter data becomes more common (and particularly as we begin to use backscatter for seafloor characterization), we must face the same questions we have asked about bathymetric data and now need to understand the uncertainty associated with backscatter measurements. Most simply put, when we see a difference occur in the backscatter displayed in a sonar mosaic, does this difference truly represent a change in seafloor characteristics or can it be the result of changes in instrument behavior or the ocean environment? Mashkoor Malik is completing a Ph.D. aimed at addressing the very difficult question of identifying and quantifying the uncertainty sources of multibeam echosounder (MBES) backscatter surveys. An evaluation of MBES backscatter uncertainty is essential for quantitative analysis of backscatter data and should improve the collection of backscatter data and processing methodologies. Malik has examined sources of error both theoretically and empirically. The empirical component requires that the effect of each uncertainty source be isolated and observed independently. These efforts began in 2008 as part of Malik's thesis (see the 2008 Annual report for full description of these experiments and update below) but have seen renewed focus prompted by the visits of Xavier Lurton in 2012 and 2013 and a lab-wide decision to refocus on backscatter issues in the light of the needs of NOAA's Integrated Ocean and Coastal Mapping (IOCM) program.

This effort has manifested itself in the "Newcastle Backscatter Experiment" (NEWBEX) a new (or renewed, from the laboratory perspective) effort aimed at testing our ability to properly collect and interpret seafloor backscatter data collected with hydrographic multibeam echosounders. The project is a collaboration of many Center and NOAA participants including Tom Weber, Jonathan Beaudoin, Glen Rice (NOAA), Briana Welton (NOAA), Val Schmidt, Brian Calder, Yuri Rzhanov, Larry Mayer, Larry Ward, and Carlo Lanzoni. With respect to seafloor backscatter, it is important to note that the term "calibrated" takes on multiple meanings in the context of this work, ranging from the calibration of settings to ensure we understand the real effect of a system setting change to a full absolute calibration where the output of the multibeam echo sounder can be used as an estimate of the true seafloor scattering strength. This project brings together several different existing lab efforts: Malik's thesis work, Carlo Lanzoni's work toward an absolute backscatter calibration for MBES, former student and NOAA Corps officer Sam Greenaway and Glen Rice's efforts toward field procedures for proper backscatter data collection, backscatter mosaicing (Fonseca's GeoCoder), backscatter inversion (Fonseca's ARA algorithms), and backscatter ground truth (e.g., optical imagery, bottom sampling, high accuracy positioning). In bringing together scientists with disparate backgrounds to address a common problem, the NEWBEX project epitomizes the strength of the Center. As problems arise we can call upon local expertise (be it signal processing, image processing, geology, acoustics, etc.) to quickly and collaboratively seek solutions.

Many of the details of the NEWBEX experiment were presented in earlier progress reports. In late December, 2013 we finished an eight-month field campaign that established a "standard backscatter line" conveniently located near the UNH pier in New Castle, NH. In developing this line, we collected weekly 200 kHz calibrated EK60 data, weekly sediment samples at two locations, and conducted several seasonal sampling trips where more sediment samples and bottom images were collected at several locations along the line. These data have served as a basis for many studies, including those continued in the 2016 reporting period.

Over the last six months there have been two activities related to the NEWBEX project. The first is the production of a publication based on the M.Sc. work of John Heaton, who developed an efficient calibration method for MBES using a controlled extended target. This has involved reprocessing Heaton's data, generating publication quality images, and developing a manuscript-quality description of the work. This manuscript was submitted in December, titled "An extended surface target for high-frequency multibeam echo sounder calibration" by Heaton, Rice, and Weber. The main results of this work are the calibration results (Figure 4-15) and the calibrated angle-dependent seafloor backscatter collected from the NEWBEX standard line (Figure 4-16), both collected with a Reson T20-P MBES operating at 200 kHz.

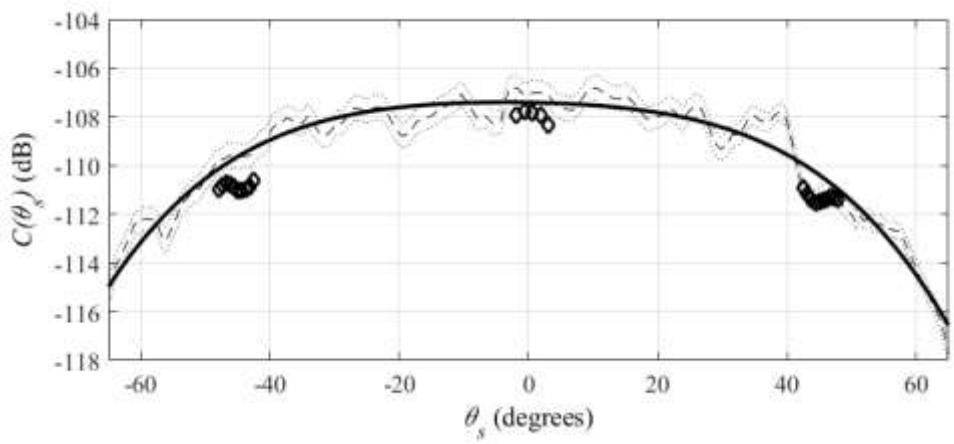


Figure 4-15: The calibration factor (C) for the MBES presented as a function of beam steering angle, θs. The dashed line bounded by the dotted lines represents the average C and the upper and lower 2 standard deviation bounds; the thick solid line represents a polynomial fit to the data, and the diamonds represent the results of calibration checks using a standard target sphere.

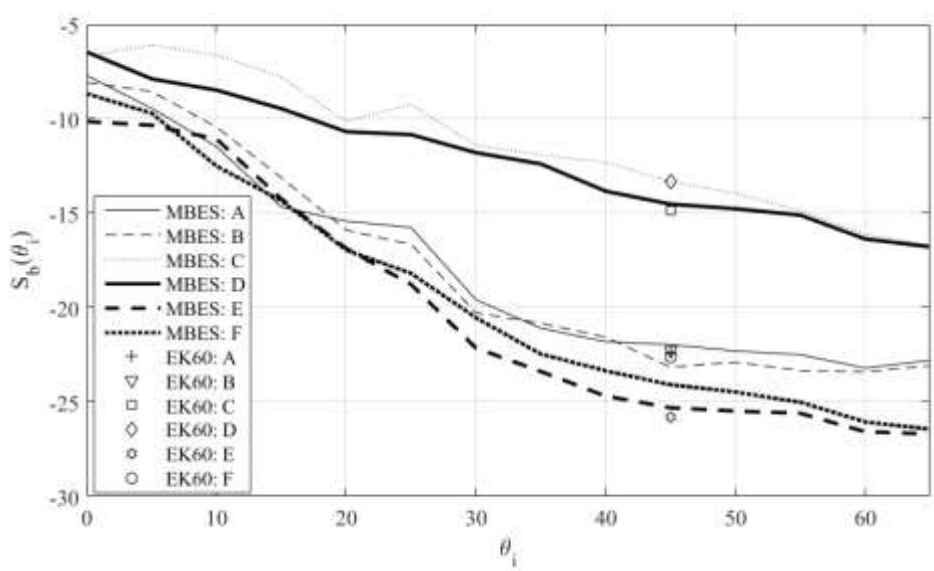


Figure 4-16: Field observations of Backscatter Strength (Sb) collected with the 200 kHz calibrated MBES at incidence angles between 0-64 ^{0}, and comparison to a calibrated 200 kHz SBES at an incidence angle of 45 ^{0}. The data are collected at six different locations which are characterized by Weber and Ward, 2015 as follows. A,B: medium sands with high shell

hash content and bedforms ranging from ripples to sand waves; C,D: very poorly to poorly sorted sandy pebble gravels or pebble gravels; E, F: very fine sands to pebbly fine sands with 88%-99% sand content and sometimes abundant sand dollars.

The second activity is the recent work by Michael Smith (now an M.Sc. graduate student) to compile MBES data from the "standard-line" in New Castle. The currently available data were collected with a Reson 7125, a Reson T20-P, a Kongsberg EM2040, and an R2Sonic 2022 from both the R/V Coastal Surveyor and from the NOAA Ship *Ferdinand Hassler* over the last few years. Smith is currently working on cataloguing these data, and will then turn toward unpacking the raw data, working towards estimates for seafloor backscattering strength using the manufacturer's specifications and/or previous calibration work, and then comparing the results between different systems.

DATA MANAGEMENT

We were delighted to report in 2011 that we filled the position for a Data Manager for the Center with the very capable Paul Johnson who came to us from the University of Hawai'i's Mapping Research Group. Johnson has made tremendous progress in ensuring that our data holding are protected, documented, organized, and easily accessible to our researchers and to any others who need them.

ARCGIS DATA SERVER:

Over the course of 2016, Johnson and Erin Nagel have continued the process of expanding the data and services available through the Center's GIS Server and GIS Portal. The GIS portal is meant to work hand-in-hand with the Center's GIS server to ease the process of data discovery and user interaction with the data, much as ESRI's arcgis.com service does. Over the spring and summer of 2016, the Center's GIS server was upgraded to the newest version of the ESRI software, meaning all existing services had to be rebuilt. During this process, the Center's GIS portal transitioned from being only accessible by users within the Center, to being available to the world at large. By allowing access to the portal, the Center was than able to leverage the tools and services available from the portal to develop new feature rich dynamic maps, which are now available through the Center's website (Figure 4-17).

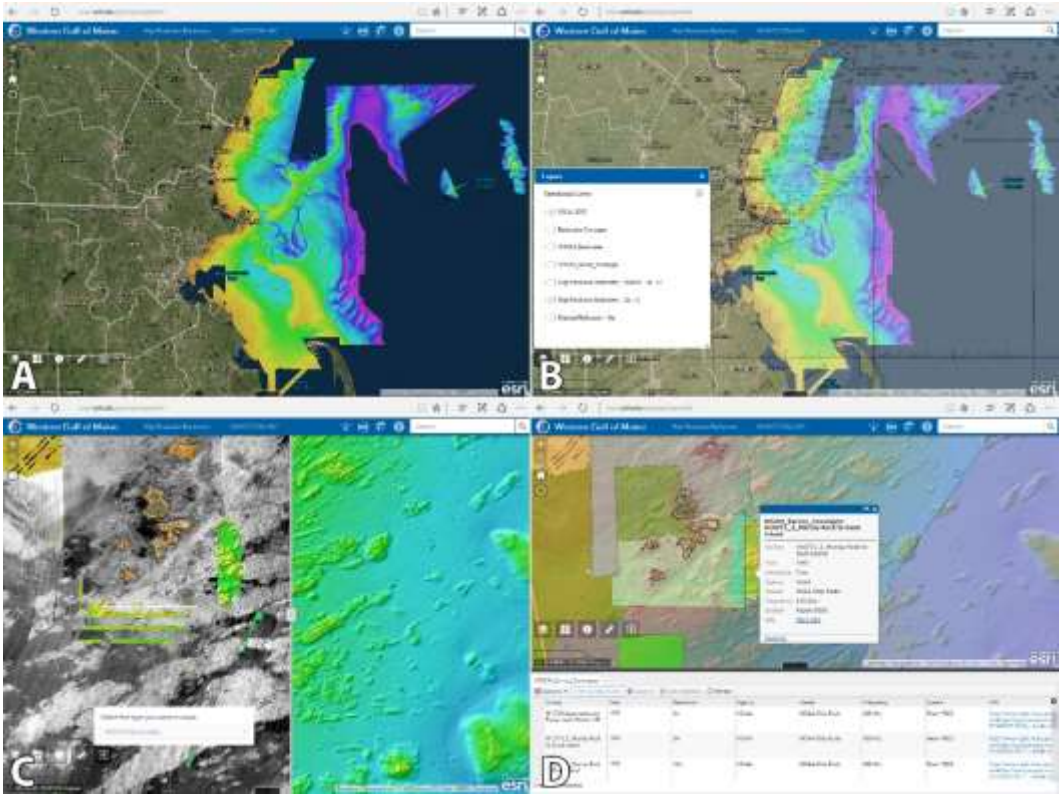


Figure 4-17: Dynamic web maps (http://ccom.unh.edu/gis/maps/wgom2m) served through the Center's website with content provided from the Center's GIS Server and Portal.

Previously, the Center's dynamic maps were developed using a mixture of Adobe Flash and JavaScript, with each respective code base interacting either with ESRI's ArcGIS.com servers or directly with the Center's GIS server to access the data. With the integration of the GIS Portal/Server combination, the dynamic maps are now being developed strictly using JavaScript, meaning the code is optimized for both desktop and mobile web environments and from a security standpoint is much safer. Stand-out examples of what the GIS Portal allows the Center to do are the newly developed dynamic maps for the Law of the Sea datasets (see LAW OF THE SEA section) and dynamic maps for the Gulf of Maine Bathymetry and Backscatter synthesis (see discussion below).

The JavaScript based dynamic maps allow users to easily and intuitively interact with the Center's data. These interactions include toggling layers on and off (Figure 4-17A), overlaying NOAA raster navigation charts (Figure 4-17B), being able to swipe and overlay datasets (Figure 4-17C), measuring distances and areas, changing underlying basemaps, rendering maps to JPEGs, PDFs, or PNGs, and easily querying information from the served datasets (Figure 4-17D).

ORGANIZATION, VISUALIZATION, AND DISTRIBUTION OF BATHYMETRY AND BACKSCATTER DATA FROM PORTSMOUTH HARBOR, GREAT BAY ESTUARY AND THE GULF OF MAINE

Many of the field activities of the Center are focused on the local waters of Portsmouth Harbor, Great Bay, and the Gulf of Maine resulting in the collection of many years of data from the region and

numerous requests for these data. The 15 years of collection of these data have resulted in multiple data sets, in various forms, that are scattered throughout our data storage systems. This has made it a challenge at times when faculty, students, staff, or people from outside the Center have sought to determine what data is available for different areas and the quality of that particular dataset. In order to streamline this process and make it easier for both the users and for the Data Manager, Johnson began organizing these datasets into geodatabases, which were in turn linked to a GIS project and mapping services.

During 2016, Johnson and Nagel continued to work on the Western Gulf of Maine (WGOM) Bathymetric and Backscatter Synthesis. This work included the release of a new 2-m resolution version of the bathymetric synthesis which integrated the coastal bathymetric LIDAR with the existing multibeam data, generation of new web services which were optimized for viewing the shallow areas of the bathymetric synthesis, and improving the ways that users can interact with each datasets through the Center's webpages. The new improved interface, which can be seen at http://ccom.unh.edu/gis/scenes/wgom and in Figure 4-18, works much like a "Google Earth" style viewer.

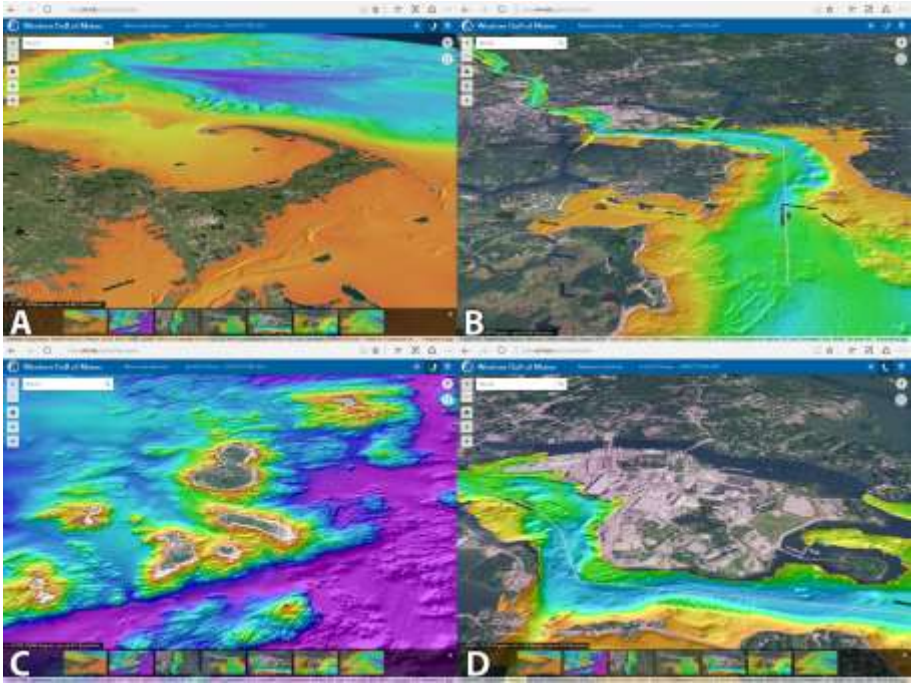


Figure 4-18: Examples of the GIS Portal driven three dimensional geospatial browser. This service can be accessed through **http://ccom.unh.edu/gis/scenes/wgom**.

This type of viewer allows users to easily shift perspective, allowing datasets to be viewed from any angle or altitude. The viewer also allows users to quickly zoom to stored viewpoints which are accessible through a panel at the bottom of the browser window (Figure 4-18A). These predefined views allow for the designation of which datasets to display, the angle and elevation to show the data from, and the definition of which basemap to display beneath the primary datasets. An example of this is the Figure 4-18A which shows a view of Cape Cod using the lower resolution regional bathymetric dataset with a color palette optimized for the whole bathymetric range of the regional dataset. Contrast this

view to Figure 4-18B, which shows only the high resolution bathymetric data with a color palette optimized for shallow water.

Hampton Harbor Database

In support of the research efforts of Tom Lippmann, Nagel has produced Topographic Bathymetric LIDAR digital elevation models for Hampton Harbor research. Data processing and dissemination included the compilation of LIDAR datasets of various ages, quality, and density. Nagel collected seven sets of coastal topographic and bathymetric data sets to create the most comprehensive seamless coverage of Hampton Harbor, NH. Starting from the raw LAS files, and removed features such as bridges as well as noisy lidar classes, the ground and bathymetric classes were extracted. Nagel then analyzed the accuracy and vertical profiles of the datasets and compared the data to nautical charts and other reference surfaces. The data was then translated horizontally and vertically to MLLW and NAVD88 and then gridding to 10 meters, per the request of Lippmann and M.Sc. student Kate von Krusenstiern. The deliverables included seven 10m grids and a seamless topographic and bathymetric grid utilizing multiple datasets, providing full coverage of the focused research area. This data will serve as input for hydrodynamic numerical models and understanding nearshore seabed flux. Nagel then created webmap services and a dynamic web page to promote data discovery (Figure 4-19).

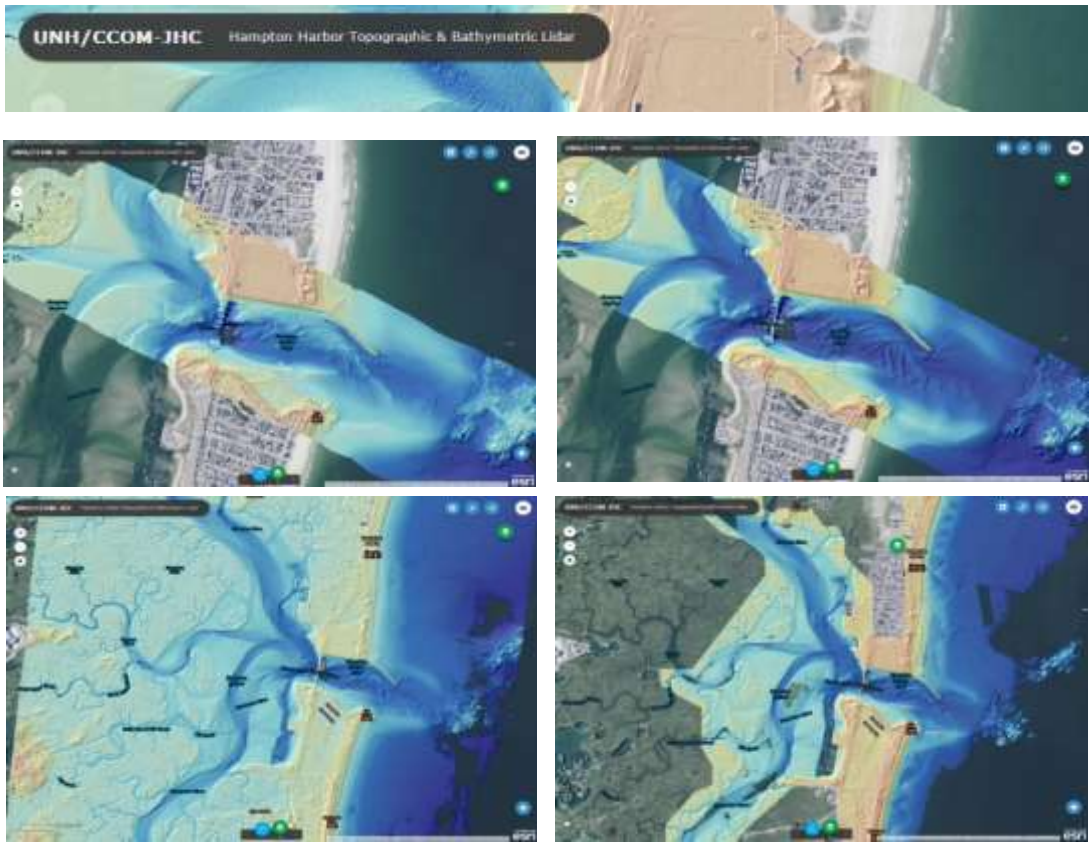


Figure 4-19: Hampton Harbor Topographic and Bathymetric Lidar Digital Elevation Models

THEME 3: DEVELOPING TOOLS AND APPROACHES FOR THE ADAPTATION OF HYDROGRAPHIC, COASTAL AND OCEAN MAPPING TECHNOLOGIES FOR THE MAPPING OF BENTHIC HABITAT AND EXPLORING THE BROAD POTENTIAL OF MAPPING FEATURES IN THE WATER COLUMN

Short name: **HABITAT and WATER COLUMN MAPPING**

The initial focus of early multibeam echo sounder development was the collection of dense, high-resolution bathymetry in support of chart-making and other aspects of safe navigation. With the evolution of sonar development came the simultaneous collection of backscatter (amplitude) information, initially from the seafloor and, most recently, from both the seafloor and the water column. This backscatter information offers a wealth of additional information beyond the depth data initially provided by the time-of-flight measurements of the multibeam echo sounder. The Center has long pursued research focused on trying to better understand and calibrate the backscatter measurements provided by the various sonar systems available (see Backscatter section of PROCESSING theme). Understanding the nature of the backscatter produced by the sonar systems is an essential component of any seafloor characterization research. In parallel with these efforts, we are also developing approaches to apply backscatter measurements to problems of benthic habitat determination and the mapping of water column targets. All of these applications also have direct relevance to our IOCM Theme.

HABITAT MAPPING

While "habitat mapping" is a desired end product of many seafloor mapping efforts, just what "habitat mapping" means is not well defined. Our response to this question is to focus on the development of approaches for characterizing the seafloor through the analysis of data we can derive from the sensors with which we work (sonars, LIDAR, satellite imagery and hyperspectral scanners). As we perfect these techniques (which are currently far from perfect) we work closely with biologists and fisheries scientists to see how the data we provide can be used to answer the critical questions they face. From a seafloor perspective, the key parameter that offers the best chance for quantitative characterization of the seafloor is acoustic backscatter. However, if sonar backscatter data are to be used to correctly characterize seafloor properties, then the measured backscatter must embody changes in the seafloor rather than instrumental or environmental effects. Although many system and geometric corrections are applied by instrument manufacturers in their data collection process, some corrections are not applied or can only be approximated in real time (e.g., local slope), and for others, many questions remain about how and where the corrections are applied. As described under the SENSORS theme and in the Backscatter Processing section of the DATA PROCESSING theme, we have been working closely with NOAA and the manufacturers to fully and quantitatively understand the nature of the collected backscatter data and to develop tools (e.g., GeoCoder) that can properly make the needed adjustments to the data. At the core of this effort are the NEWBEX experiment and Mashkor Malik's research into backscatter uncertainty (described under the DATA PROCESSING theme). Once proper corrections are made, the resulting

backscatter values should be much more representative of true seafloor variability and can then provide an important component of efforts to remotely characterize the seafloor.

SEAFLOOR CHARACTERIZATION AND HABITAT STUDIES AND RESOURCE STUDIES OFFSHORE NEW HAMPSHIRE

SEAFLOOR CHARACTERIZATION AND MARINE MINERAL RESOURCES

The continental shelves of New Hampshire and vicinity provide an excellent setting to further our ability to characterize the seafloor utilizing high resolution MBES surveys and archived geophysical databases. During 2016 our grant-funded work focused on developing approaches for identifying resources (sand and gravel) while externally funded work by the Bureau of Ocean Energy Management (BOEM) Marine Minerals Service (MMS) supported the mapping and evaluation of the sand and gravel resources on the New Hampshire shelf. In addition to the BOEM project, a primary goal was to explore best practices and workflow to take advantage of data collected for other purposes in support of seafloor characterization (an IOCM objective).

Utilizing high resolution bathymetry, backscatter, archived analog subbottom seismics, and archived bottom sediment samples, a detailed seafloor sediment map with major morphologic features identified was developed using the Coastal and Marine Ecological Classification Standards (CMECS). This mapping effort produced the highest resolution and most detailed seafloor geology maps of the New Hampshire and vicinity shelf to date. An important goal of this effort was to develop the protocol and workflow to describe and map the seafloor geology with the highest resolution possible with the data at hand. This goal was based on the practical assumption that recently available, as well as archived data of varying quality, needs to be used to develop seafloor maps. It is not likely that all areas of the seafloor will be resurveyed, and therefore all available databases that can contribute need to be utilized.

The upgraded or new surficial geology maps include seafloor morphologic features or geoforms (Figures 5-1 and 5-2) and surficial sediment classifications (Figures 5-3 and 5-4). CMECS was chosen as a classification scheme because it is the standard being used by a number of federal and state agencies charged with seafloor mapping responsibilities. Furthermore, CMECS has a number of advantages as the substrate classifications are grouped and allow differing levels of detail depending on the needs and the data available. When using archived databases of varying extent and quality, this becomes a major advantage.

The surficial geology maps were developed from the Western Gulf of Maine (WGOM) Bathymetry and Backscatter Synthesis (http://ccom.unh.edu/project/wgom-bathbackscatter), several bathymetric derivatives (e.g., hillshade and roughness), and archived ground truth (grain size data and some video from archives). The MBES bathymetry for the WGOM synthesis provides exceptional detail of the seafloor morphology for much of the study area which extends from the New Hampshire coast to Jeffreys Ledge; the backscatter is of varying quality, but nevertheless very helpful in mapping the seafloor. Initial efforts to develop seafloor maps using an automated classification system (in ArcGIS) were encouraging, but overall showed significant differences from ground truth observations. Further exploration of these techniques is warranted, but ultimately expert opinion was used to produce the current maps.

An important result of the characterization of the seafloor of the New Hampshire and vicinity continental shelf and the development of the surficial geology maps is the reaffirmation of the complexity of the seafloor in previously glaciated environments (paraglacial) (Figures 5-1 through 5-4). Because of this complexity, characterizing and mapping of the seafloor to understand the geology, locate marine minerals, or identify critical habitats is more challenging than in non-glaciated areas. Therefore, the quality and magnitude of information needed for characterizing the seafloor in paraglacial (and glaciated) regions is greater and requires new approaches. Part of the research here is to develop conceptual models that capture this complexity and explain relationships between physiographic features (geoforms) and seafloor sediments. (i.e., marine modified glacial features and associated sand and gravel deposits). This will aid future efforts in seafloor mapping and identifying marine mineral resources.

It is anticipated that the results of this study will be provided through the Center's website, which will display the seafloor geology maps, provide access to the bottom sediment grain size database, and provide an overview of the ongoing and completed research. This has already been done for the WGOM Bathymetry and Backscatter Synthesis and Jeffreys Ledge projects. This will be a continuation of those sites.

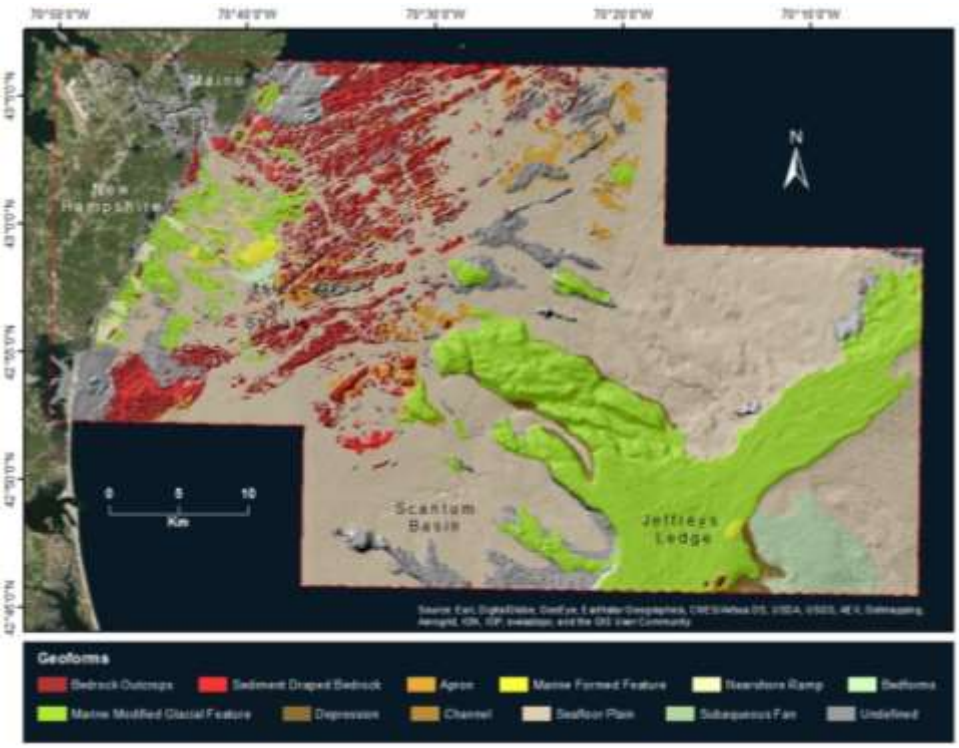


Figure 5-1: Major geoforms or physiographic features of the New Hampshire and vicinity continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS).

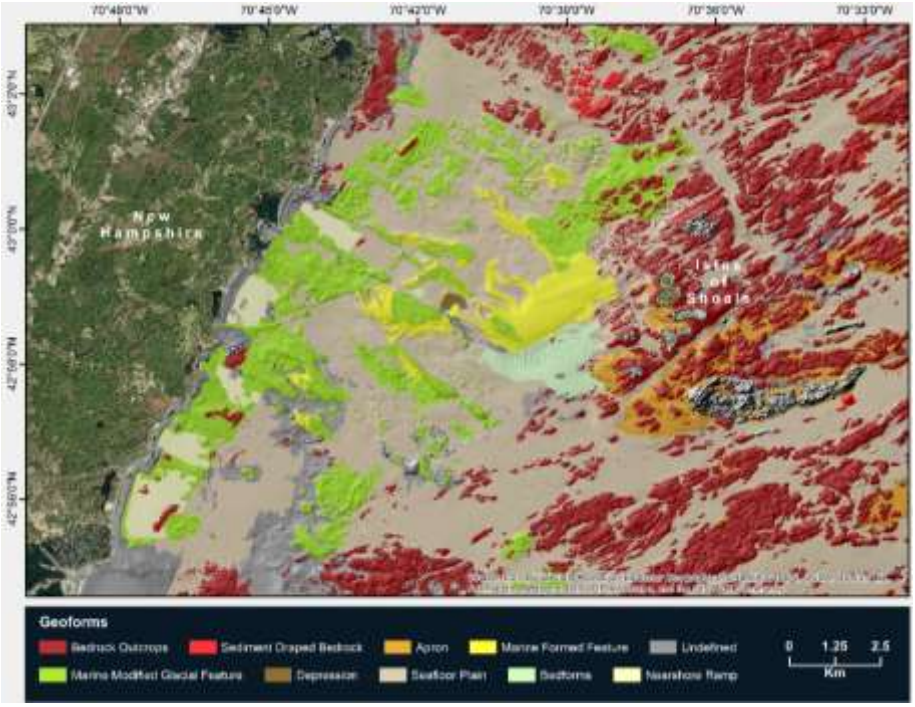


Figure 5-2: Major geoforms or physiographic features of the inner New Hampshire continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS). The map is an enlargement of Figure 5-1 nearshore region.

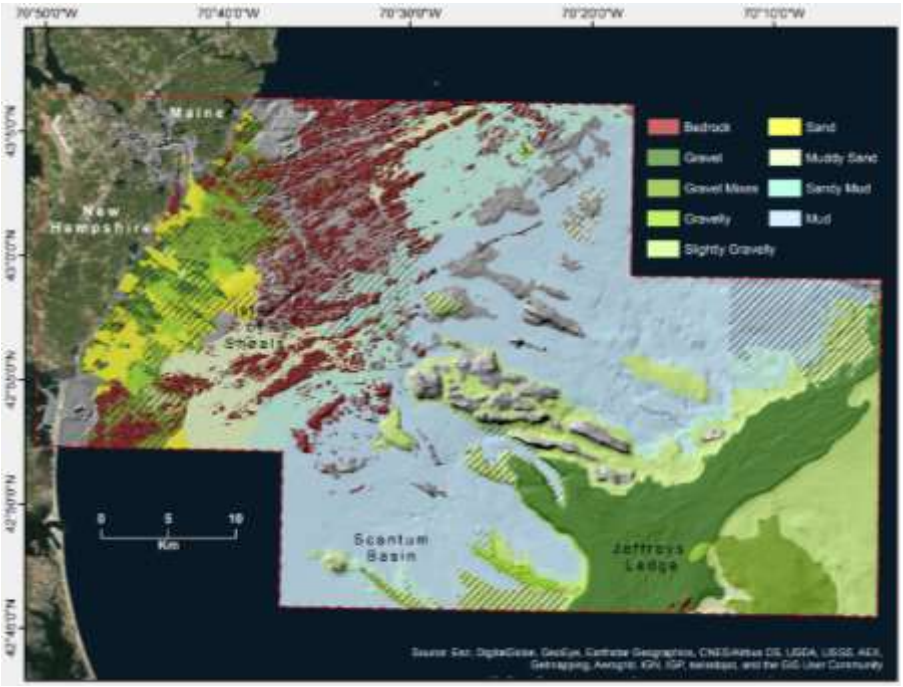


Figure 5-3: Surficial sediment map of the New Hampshire and vicinity continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS) Geologic Substrate Groups.

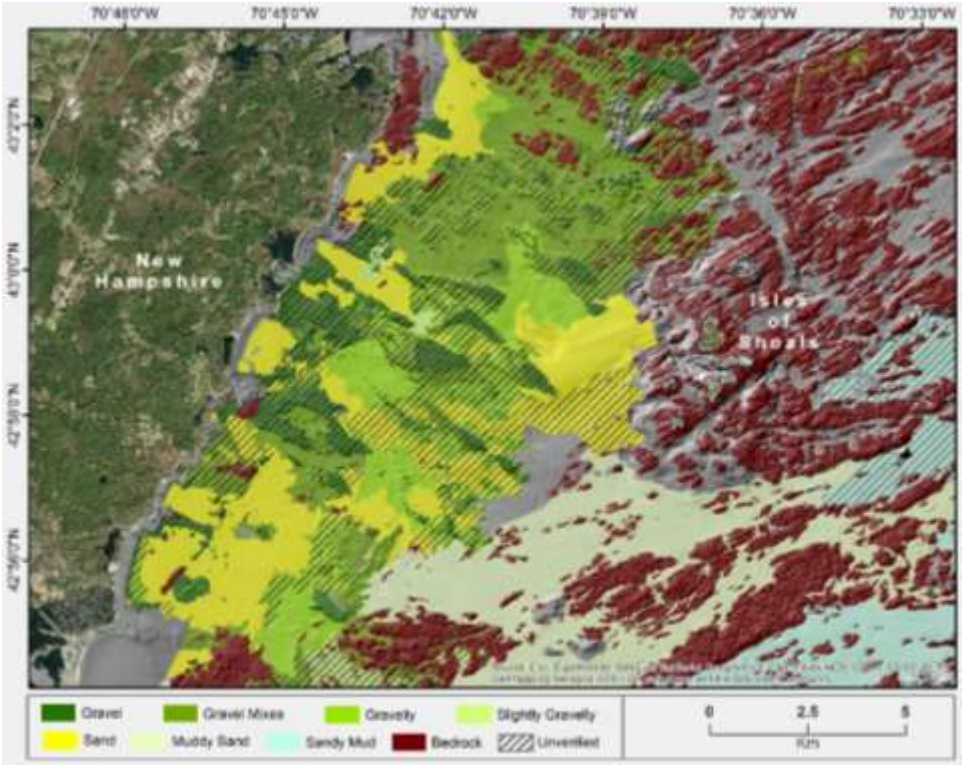


Figure 5-4: Surficial sediment map of the New Hampshire continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS) Geologic Substrate Groups. The map presented here is an enlargement of Figure Figure 5-2 nearshore regions.

Seafloor Characterization of the New Hampshire and Vicinity Inner Continental Shelf
Assessment of Offshore Sand and Gravel Resources
(For information only – funded by other sources - BOEM)

Potential sand and fine gravel deposits on the New Hampshire and vicinity continental shelf were characterized and mapped with funding largely from BOEM (Cooperative Agreement between BOEM, UNH CCOM, and the New Hampshire Geological Survey), with the overarching goal of identifying sediment resources to use for beach nourishment. The New Hampshire cooperative is part of BOEM's "Hurricane Sandy Coastal Recovery and Resiliency – Resource Identification, Delineation and Management Practices" program.

Utilizing funding from this program, the potential marine mineral resources were identified and mapped to the extent possible using existing databases, much of which had been developed by the Center during past studies. The databases included the Western Gulf of Maine Bathymetry and Backscatter Synthesis (http://ccom.unh.edu/project/wgom-bathbackscatter), the new surficial sediment and geoform maps (discussed above in this progress report), and an extensive geophysical data archive (including seismics, sediment grain size data, and vibracores). The tasks and workflow to build and synthesize this database

and to map sand bodies were described in the 2015 JHC annual progress report. Only recent updates and results are reported here.

Five potential sites where sand and fine gravel deposits are located in quantities suitable for extraction for beach nourishment were identified. Two examples are included here. The Northern Sand Body (NSB) is located ~10 km offshore just landward of the Isles of Shoals. The feature is relatively large and extends between what appears to be the roots of two eroded drumlins (Figures 5-5 and 5-6). Adjacent to the NSB are additional sand and gravel deposits that are interpreted as marine modified glacial features and marine formed shoals that likely resulted from the erosion of glacial geoforms such as drumlins or eskers and subsequent transport and deposition of sand and fine gravel by marine process.

The New Hampshire continental shelf has extensive marine modified glacial deposits and associated marine formed shoals. The marine formed features, as well as some of the offshore eroded drumlins, are hypothesized as possible targets for marine mineral resources and will be examined in greater detail in continuation of this work. Relevant to the new JHC-related research on marine mineral resources is the identification and initial description of sand and fine gravel deposits. These sites will provide initial field study areas for new research using acoustics to identify marine minerals and for developing conceptual models of deposit distribution and formation.

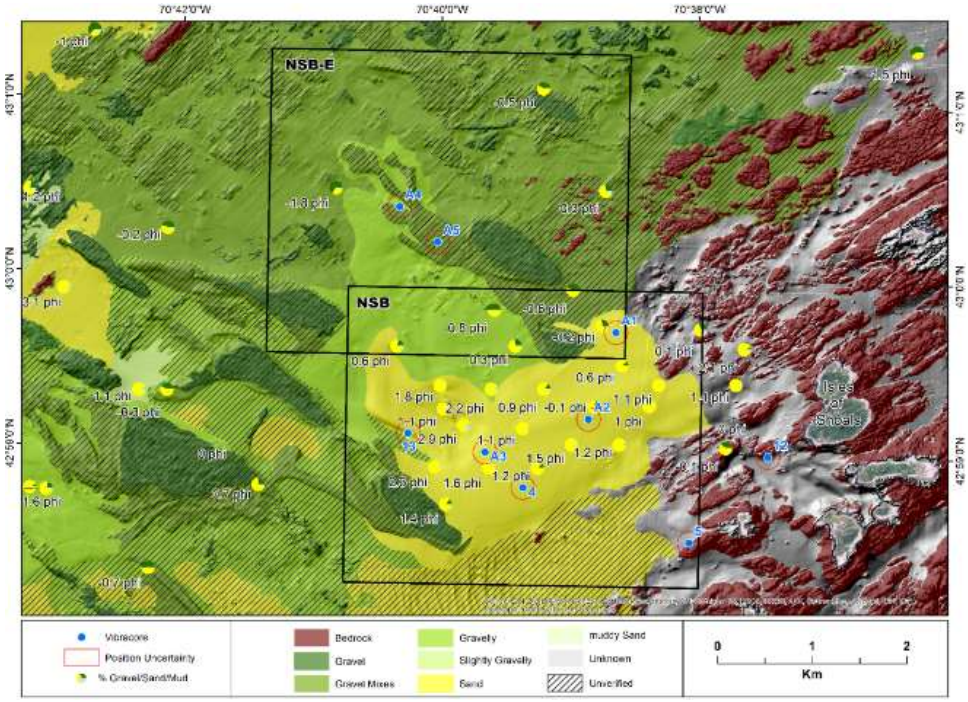


Figure 5-5: Surficial sediment map of the northern sand body (lower box) and adjacent marine modified glacial deposits and associated shoals (upper box).

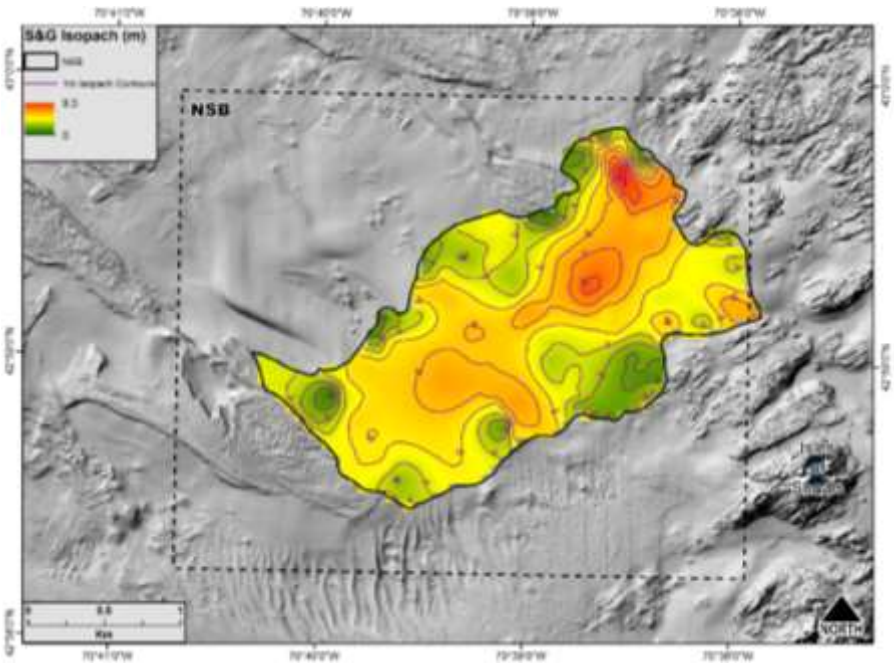


Figure 5-6: Potemtial sand and gravel thickness (isopachs) for the northen sand body.

Shoreline Characterization and Coastal Resiliency
(For information only – funded by other sources - BOEM)

During the last year, seven major beaches along the New Hampshire coast were sampled for sediment grain size under low energy, accretional conditions (summer). The beaches were sampled to build a baseline knowledge of the sediment characteristics of the beaches and to define the type of sediment (grain size and shell content) needed for future beach nourishment projects. Further work is needed to complete this effort as the sediments also need to be characterized under high energy, erosional conditions (fall and winter, following storms. This effort will continue over the next year with funding from BOEM. Each time the beaches were sampled for sediment, a beach profile was run to establish the state of the beach (erosional or accretional) and to place the sediment samples in the context of the beach morphology (i.e., backshore, berm, low tide terrace, etc.). In addition, the beach profiles were periodically re-run over the remainder of the year to establish seasonal changes and response to storm activity and to begin to assess volumetric changes. The beach profiles were run primarily using a GNSS rover system and post processing using CORS stations. A UNH Earth Sciences M.S. student (Kaitlyn McPherran) conducted the field work and developed the workflow for data analysis.

As reported previously in the 2015 JHC annual progress report, an unexpected and important finding from investigating the seafloor characteristics of the New Hampshire inner shelf, but critical to understanding beach sediment characteristics, morphology, and erosional-accretional patterns (volumetric changes) is the presence of bathymetric highs that extend seaward off headlands between several of the beaches. These features would not have been identified without the nearshore acoustical surveys conducted by the Center's hydrographic field course and the coastal lidar that was merged into

the WGOM Bathymetry and Backscatter Synthesis (http://ccom.unh.edu/project/wgom-bathbackscatter). These bathymetric highs are most prominent north of Great Boars Head and appear to be either bedrock or eroded glacial deposits as indicated by the bathymetry and the backscatter (Figure 5-7). The significance of the bathymetric highs is that longshore transport of sand may be interrupted or even prohibited between the beaches, resulting in a predominance of onshore-offshore, rather than longshore, sand transport.

The research conducted on the New Hampshire beaches will aid management of this important resource and help build coastal resiliency. However, another important outcome related to the work is that a new project has been funded by the New Hampshire Coastal Program (NHCP) that will develop a "Volunteer Beach Profiling Program". The project is being run out through the UNH Extension Program, but the Center is providing the scientific expertise to design the field program and analyze the data. Basic equipment will be used such as the Emery beach profiling method (using calibrated staffs and the horizon), but reliable long term data can be generated if set up properly. Maine has used a similar program for over a decade with excellent success. The establishment of this volunteer beach profiling program will be an important Outreach project that, although run through UNH Cooperative Extension, will benefit the Center.

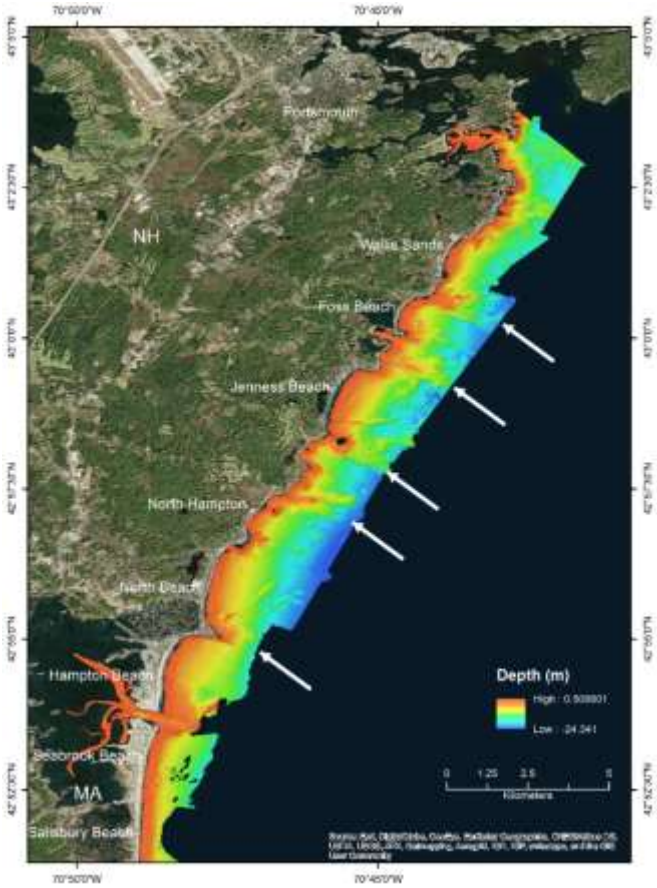


Figure 5-7: Nearshore bathymetry of the coast of New Hampshire based on a 2010 lidar survey by USACE JALBTCX. Arrows point to obstructions separating New Hampshire beaches and likely interrupting longshore sediment movement.

GREAT AND LITTLE BAY BATHYMETRIC CHANGES

The Great Bay estuary has been studied by JHC/CCOM and others at UNH in general since at least the mid 1980's yet there is little understanding of the bathymetric changes that may have occurred. As part of our recent modeling investigations, we observed qualitative changes to the morphology and bathymetry of the Bay. Unfortunately, there is no quantitative guidance as to the nature of the bathymetric evolution in the Great Bay because only one high resolution survey (from 2009) has been conducted with acceptable vertical datum control. As a consequence we have no way of knowing how much change may have occurred since that time, and may not be correctly representing water depths in areas where other measurements are being made. This is a problem not unique to the Great Bay, and in general occurs in most (if not all) estuaries where little repeated surveying takes place (e.g., due to the expertise, manpower, and resources needed to map shallow environments adequately).

To better understand how shallow estuarine environments evolve in time, the Great Bay Estuary was re-surveyed over a 5-month period between December 2015 and April 2016 with a single-beam echo-sounder, and compared with the previous survey from 2009. Approximately 400 Transect lines were equally spaced at 20 m increments (Figure 5-8). The Odom Hydrographic CV-2 echo-sounder with Airmar M108 dual frequency transducer (24 and 200 kHz) were mounted on the R/V Galen J using a vertical pipe connected to the vessel. A GPS antenna was placed at the top of the pipe. GPS differential corrections were applied during post-processing using base data from the UNH CORS site. Survey lines were the same as those used in the last bathymetric survey with acceptable vertical datum control, conducted by the Center in 2009. Figure 2 shows both the 2009 and the 2015-16 survey. Note that Little Bay, adjacent to the Great Bay, was surveyed in 2013 by CCOM, the results of which are included in Figure 5-9 from 2009. Figure 5-10 shows the vertical difference between the two surveys. Clearly the channels are where the largest changes to the bathymetry occur, sometimes exceeding +/- 1 m vertical change. The mean difference is about + 2 cm, a value indistinguishable from zero considering our estimated sounding accuracies (about +/- 5 cm) based on an inter-comparison of data from 2009). A close-up of the south-western lobe of the Great Bay is shown in Figure 5-11 with a cross-estuary transect across the bay that illustrates changes to the elevation along the profile lines.

It is clear that significant changes have occurred to the Great Bay over this seven-year period of time between surveys, and for the first time we have some idea how the Great Bay may evolve. These data will be used to evaluate how changes may occur through hydrodynamic modeling of sediment transport in the Bay.

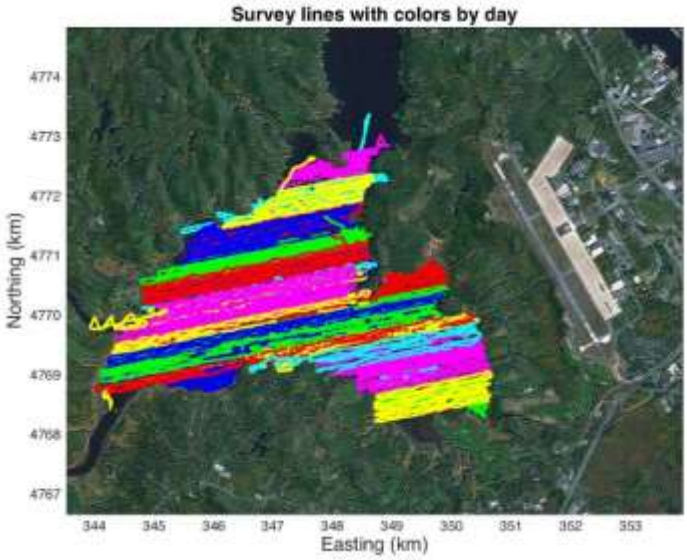


Figure 5-8: The region surveyed in the Great Bay. The transect lines for each day are color coded in sequence. The transect lines were nominally spaced at 20 m increments 18 Hz pulse repetition rate. Raw data are typically gridded to 10 m spacing.

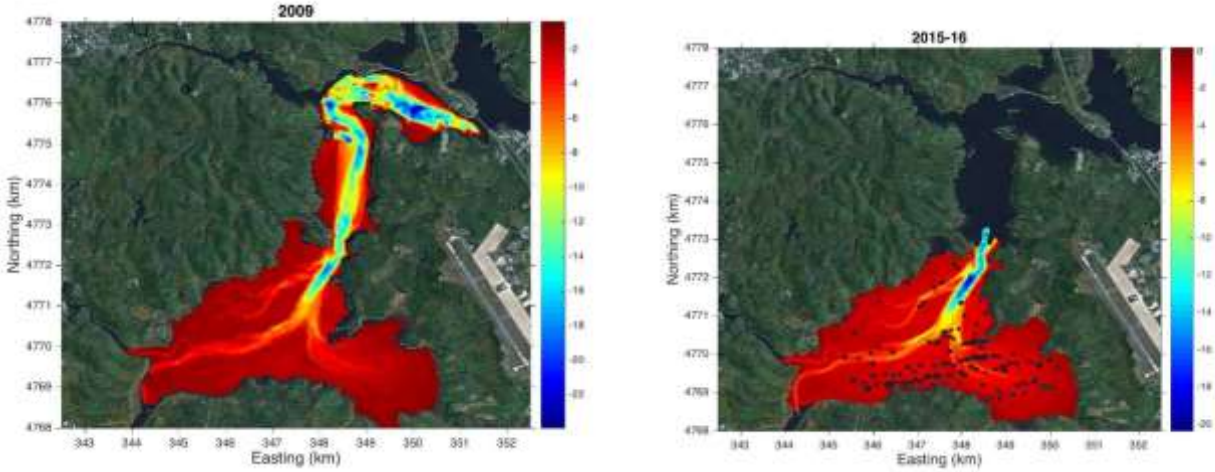


Figure 5-9: (left panel) Observed bathymetry interpolated onto a 10 m grid from the Great Bay in 2009 and the Little Bay in 2013. (right) The observed bathymetry on the same 10 m grid from the Great Bay in 2015-16. Color contours are elevations in meters relative to NAVD88 (approximately at mean sea level).

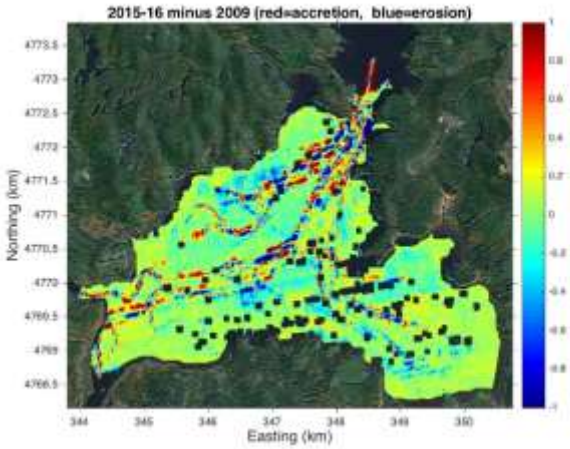


Figure 5-10: Plot of the depths in 2015-16 minus those observed in 2009. Positive differences (shown in redder colors) indicate regions that have accumulated sediment, and negative differences (shown in bluer colors) indicate regions where sediments have eroded.

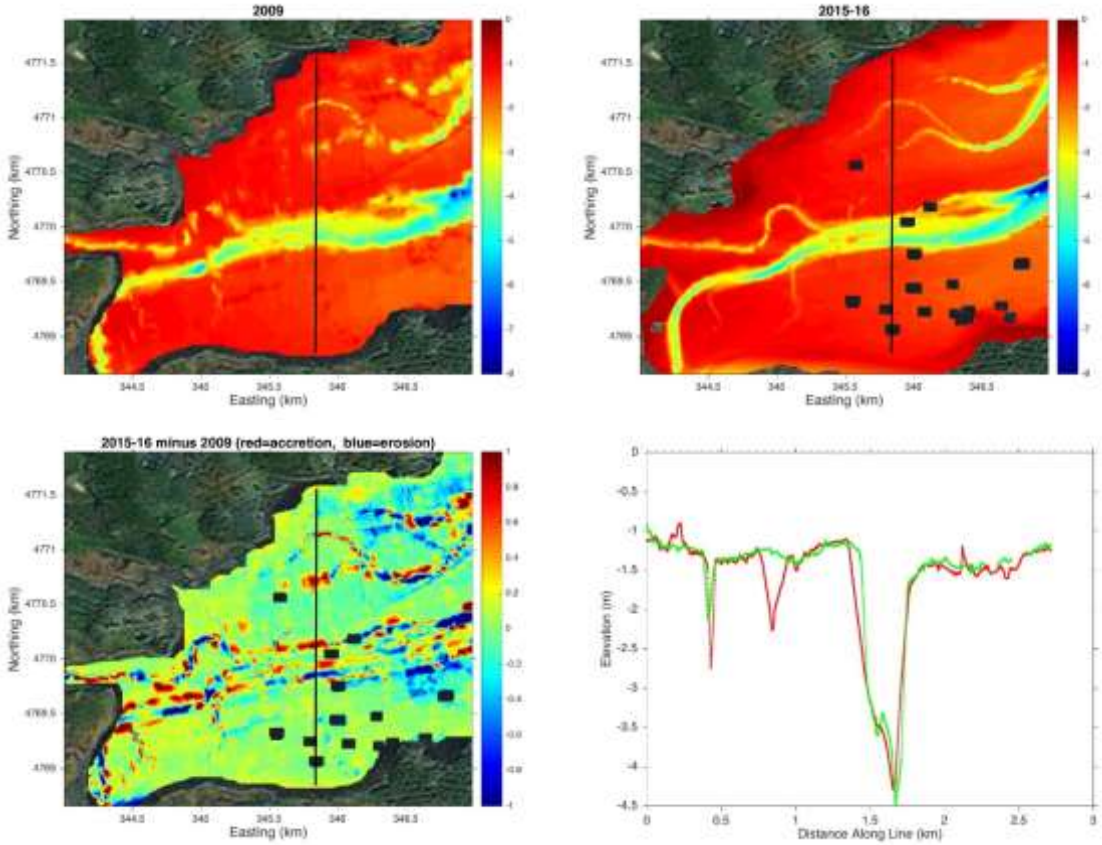


Figure 5-11: Upper panels show a close up of the south-western portion of the Great Bay from 2009 (left) and 2015-16 (right), with a transect line drawn on the map. The lower left panel shows the difference between the 2 surveys and the same transect line. The lower right panel shows the bathymetric profile along the transect lines shown in the upper two panels, with the red line from 2009 and the green line from 2015-16.

MULTI-SPECTRAL BACKSCATTER

Along with the more traditional approaches to seafloor characterization described above, we continue to seek new and innovative approaches to the use of acoustic data in providing quantitative information on the nature of the seabed. Seabed characterization using multibeam backscatter has become an increasingly routine step for NOAA mapping operations. While problems continue to plague operators concerning proper calibration and data reduction, reasonable results can be obtained in separating major seabed types. One of the frustrations, however, has been that ambiguities in classification can remain where quite different seafloors can produce similar scattering characteristics. This is in part because we are only examining scattering using a single center frequency, analogous to using a single frequency laser to image a scene.

If, in contrast, the seabed can be imaged using two or more discrete center frequencies (with significantly different wavelengths) the frequency dependence of the backscatter may be used as an additional classifier. Previously, this option had not been feasible due to the strong frequency dependence of attenuation. Recent advances, however, in FM processing have allowed markedly improved range performance and thus (for at least shelf depths) multi-frequency multibeam is now practical.

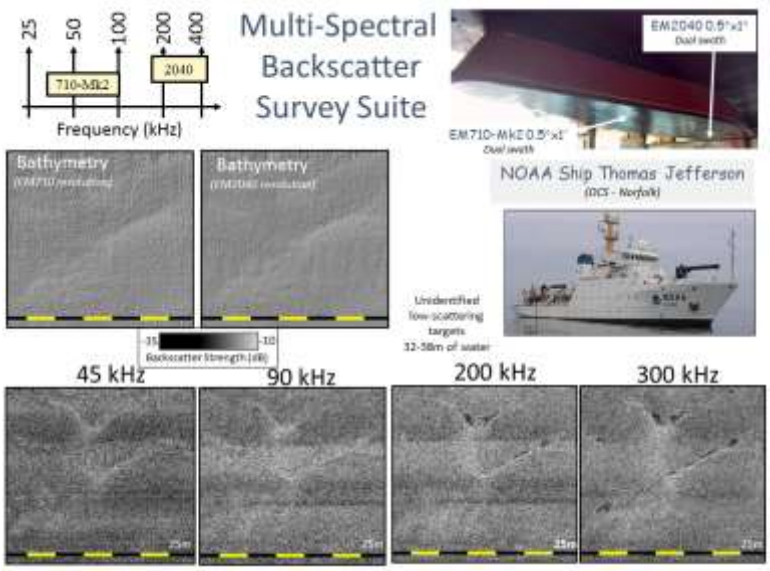


Figure 5-12: Using two passes (90 and 300 kHz, and 40 and 200 kHz) over the same seafloor, four frequency views of the same seafloor are presented. Data from NOAA Ship Thomas Jefferson, October 2016.

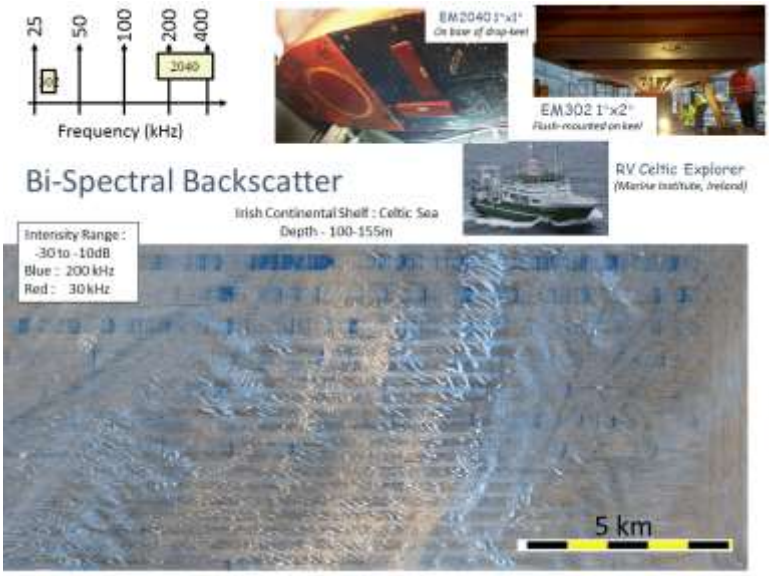


Figure 5-13: RV Celtic Explorer – operational bi-spectral survey results from the Irish Continental Shelf, September 2016

Following first field trials in 2012 and 2014 by Hughes Clarke, this methodology has now been implemented operationally for the first time this year (2016) both within NOAA (the NOAA Ship Thomas Jefferson) and as part of a collaboration with the Marine Institute in Ireland (RV Celtic Explorer).

Both organizations simultaneously operate two multibeam sonars with frequencies ranging from ~ 30-40 kHz to 300+ kHz. The MI use an EM302 and an EM2040 whereas NOAA use an EM710 Mk2 and an EM2040. All of these are multi-sector systems, which, while they result in excellent sounding density, significantly complicate the calibration of the backscatter data. Data from both vessels were collected in 2016 and processed at the Center to produce the first operational examples of regional multi-spectral seabed backscatter surveys (Figures 5-12 and 5-13).

As a first, and essential, step towards deriving calibrated backscatter strength measurements from multibeam sonars, the sonar radiation pattern must be estimated. This consists of the product of the transmit radiation pattern and the receiver sensitivity, both of which vary as a result of sonar-relative angle. Notably those angles vary both across track, and along track. The across track variations have been previously deduced using empirical methods, but the along track pattern has never before been addressed. It, however, is a significant additional complication for the new generation of multi-sector sonars.

To directly address this Anand Hiroji, a recently graduated PhD student of Hughes Clarke, has developed a new algorithm to extract these beam patterns independent of the seabed angular response (Figures 5-14 and 5-15). These backscatter algorithms have now been tested on two deployments:

- July 2016: USNS Maury (TAGS-66) - EM122 and EM710 multi-sector multibeams.
- October 2016: NOAA Ship Thomas Jefferson - EM710 and EM2040 multi-sector multibeams.

Hiroji joined the Center as a post-doctoral fellow (funded under the Kongsberg "Integrated Multibeam" research grant to Hughes Clarke) in August.

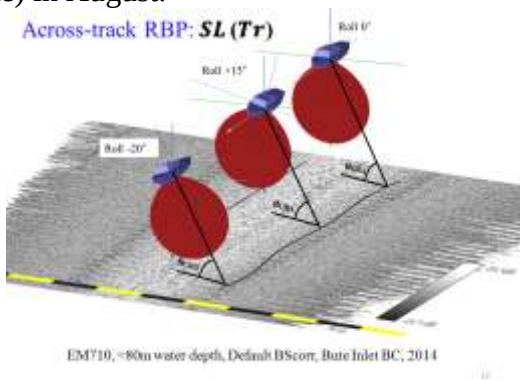


*Figure 5-14: Showing the influence of roll modulation on the overprint of the **across**-track sonar-relative beam pattern on uncorrected seafloor backscatter data.*

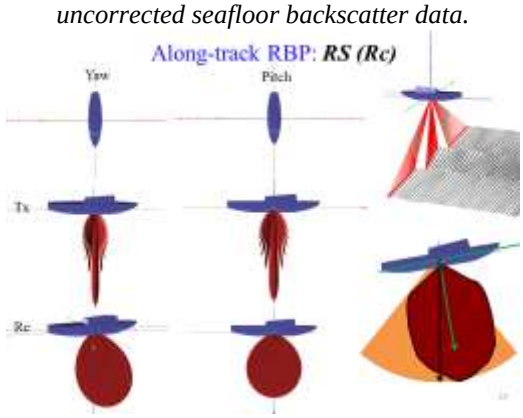


*Figure 5-15: showing the effect of pitch or yaw perturbations on the **along**-track receiver beam pattern*

With the upgrade of the NOAA Ships *Nancy Foster*, *Fairweather* and *Thomas Jefferson*, these ships will have the EM710 MkII allowing operation between 40 and 100 kHz. Uniquely, the *Thomas Jefferson* will also be getting an EM2040 as part of her upgrade, allowing a major NOAA platform to undertake 40-400 kHz multi-spectral backscatter imaging. All of these systems will require determination and removal of the 3D beam pattern. Successful habitat mapping work will require proper beam pattern removal.

ASSESSMENT OF GULF OF ALASKA UNTRAWLABLE HABITAT IN SUPPORT OF ROCKFISH STOCK ASSESSMENT

The NOAA AFSC is exploring new ways to assess rockfish in untrawlable habitats in the Gulf of Alaska. These efforts are based in part on past studies for which CCOM has played a role (Jones et al., 2012; Weber et al. 2013; Pirtle et al. 2015). During the summer of 2015 acoustic/trawl survey for walleye pollock in the Gulf of Alaska (nine total weeks of survey), 5 km^2 regions that have been historically classified as either trawlable or untrawlable are being randomly revisited. In each 5 km^2 region, an ME70 survey (not full coverage) is run followed by 15 minute drop camera transects in 2-3 surveyed parts of the grid. CCOM is playing a supporting role for the analysis of the ME70 data, using algorithms previously written for generating bathymetry and seafloor backscatter and two new metrics selected by

Pirtle et al. [2015] in her general linear model (GLM) that was used to classify the seabed as trawlable or untrawlable based on ME70 data alone. Pirtle et al. [2015] used two topographic metrics: bathymetric position index (BPI) which essentially classifies a location as a bathymetric high or low, and a vector ruggedness measure (VRM) that looks at how the orientations of the cells in gridded bathymetry are distributed. CCOM has provided MATLAB code and help with interpretation to AFSC who are leading the ME70 data analysis. Examples of the seafloor characterization metrics from a 5 km^2 grid are shown in Figure 5-16. AFSC will also be analyzing the camera drop data to help identify the substrate,enumerate species present, etc. A prime example of Research to Operations (R2O).

Jones, D., C. Wilson, A. De Robertis, C. Rooper, T. Weber, and J. Butler, "Evaluation of rockfish abundance in untrawlable habitat: combining acoustic and complementary sampling tools," *Fish. Bull*. 110: 332-343. 2012.

Weber, T., C. Rooper, J. Butler, D. Jones, C. Wilson, "Seabed classification for trawlability determined with a multibeam echosounder on Snakehead Bank in the Gulf of Alaska," *Fish. Bull.*, 111: 68-77. 2013.

Pirtle, J., T. Weber, C. Wilson, and C. Rooper, "Assessment and untrawlable seafloor using multibeam-derived metrics," Methods in Oceanography, May 2015.

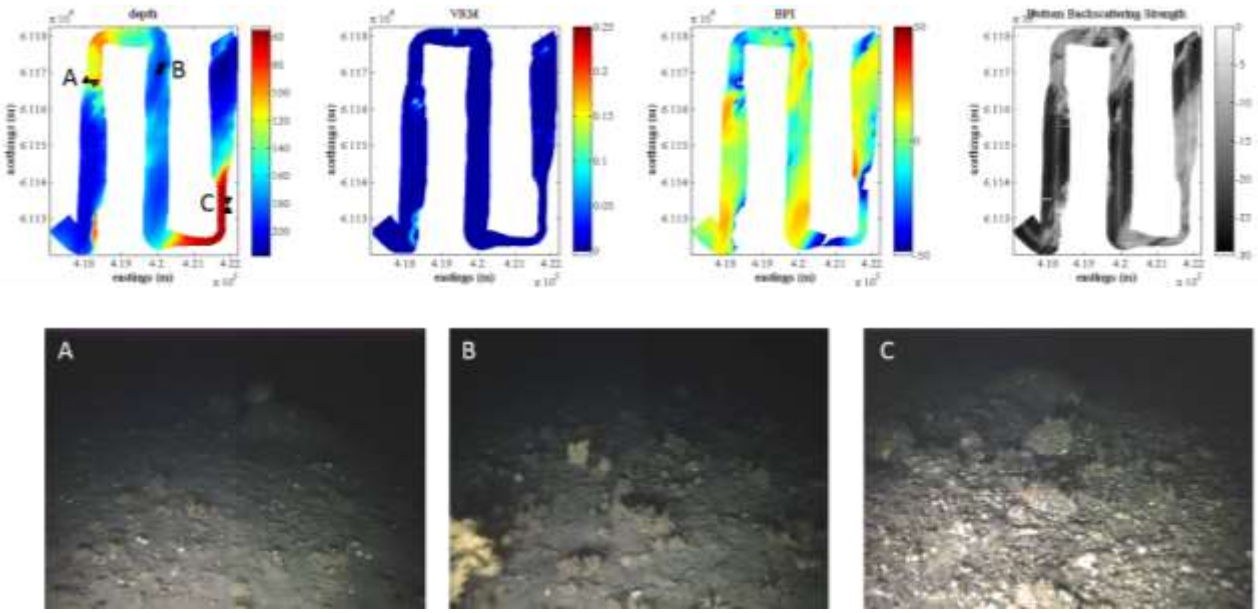


Figure 5-16. Seafloor backscattering metrics from Pirtle et al [2015] extracted from a survey grid during cruise DY1506 on the Oscar Dyson in June 2015. The metrics are derived from Simrad ME70 data and include bathymetry, a vector ruggedness measurement (VRM), bathymetric position index (BPI), and bottom backscattering strength. Camera drops (bottom) are conducted in 2-3 locations in each grid.

MAPPING AND CHARACTERIZING THE EELGRASS CANOPY

Ashley Norton, working with Semme Dijkstra, continues her dissertation research aimed at mapping and characterizing eelgrass canopy through automated processing of water column data from multibeam echo-sounders. In late May of 2016, Norton deployed a stationary acoustic experiment in an eelgrass bed adjacent to the UNH/NOAA pier in New Castle, NH. The purpose of the experiment was to determine whether the acoustic signal of the eelgrass canopy changes with current-induced variations in

canopy morphology, and to examine the acoustic signal of the eelgrass canopy across a range of beam angles in a well-characterized site. The experiment frame had an Odom MB1 multi-beam sonar, an AquaDopp high-resolution current profiler, and a high-definition video camera attached, each instrument collecting data over roughly the same patch of canopy and seafloor. Profiles of acoustic backscatter in the near-nadir beams of the MB1 and profiles of current velocity were correlated in time, and, although the acoustically-measured canopy height does decrease when current magnitude increases, the canopy height does not appear to decrease as much as predicted by a published model by Luhar and Nepf. This discrepancy may be because of a bias in our canopy detection methods (e.g., picking up on a single taller blade vs. the majority of the plants in the canopy (Figure 5-16), or because of the scale of the model (e.g., is this model only appropriate for the deflected height of a single blade instead of the height of an entire canopy?). Further analyses will hopefully resolve this issue.

Acoustic backscatter amplitude also appears to increase when current magnitude increases, maybe due to an increase in blade density in the sonar footprint when the plants layover on top of each other (Figure 5-17); backscatter amplitude also appears to respond to photosynthetic activity, increasing when bubbles are visible on plants in the video data (Figure 5-18). Future directions for this research are to further examine the relationship between backscatter amplitude and time of day and/or light level measurements across all beams of the multibeam and all days of the experiment, to quantify differences in acoustic signal due to canopy posture, and to tease out implications from this dataset for acoustic surveying of eelgrass beds.

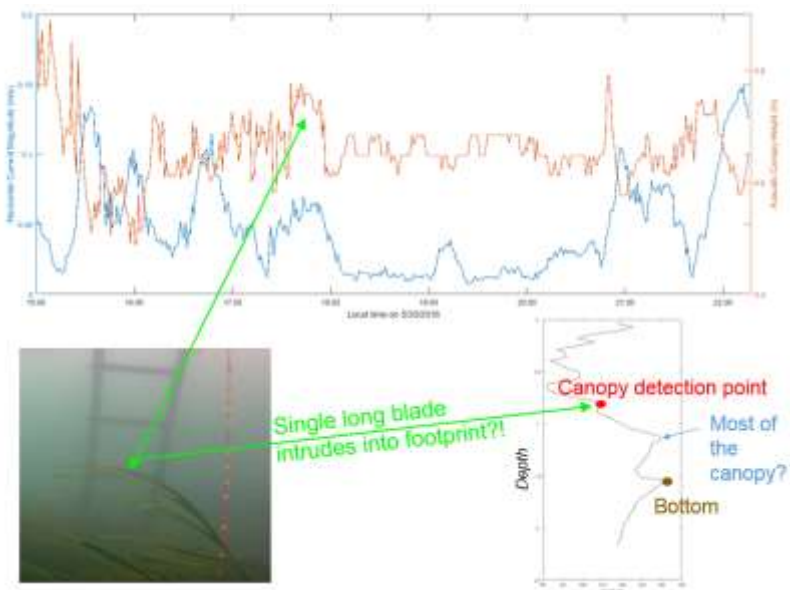


Figure 5-17: Current magnitude and acoustically-measured canopy height from a single tidal cycle. In most cases, when current magnitude increases, canopy height decreases, with the notable exception around 17:30, where video data indicates that a single taller blade above the canopy may be biasing the canopy height measurement.

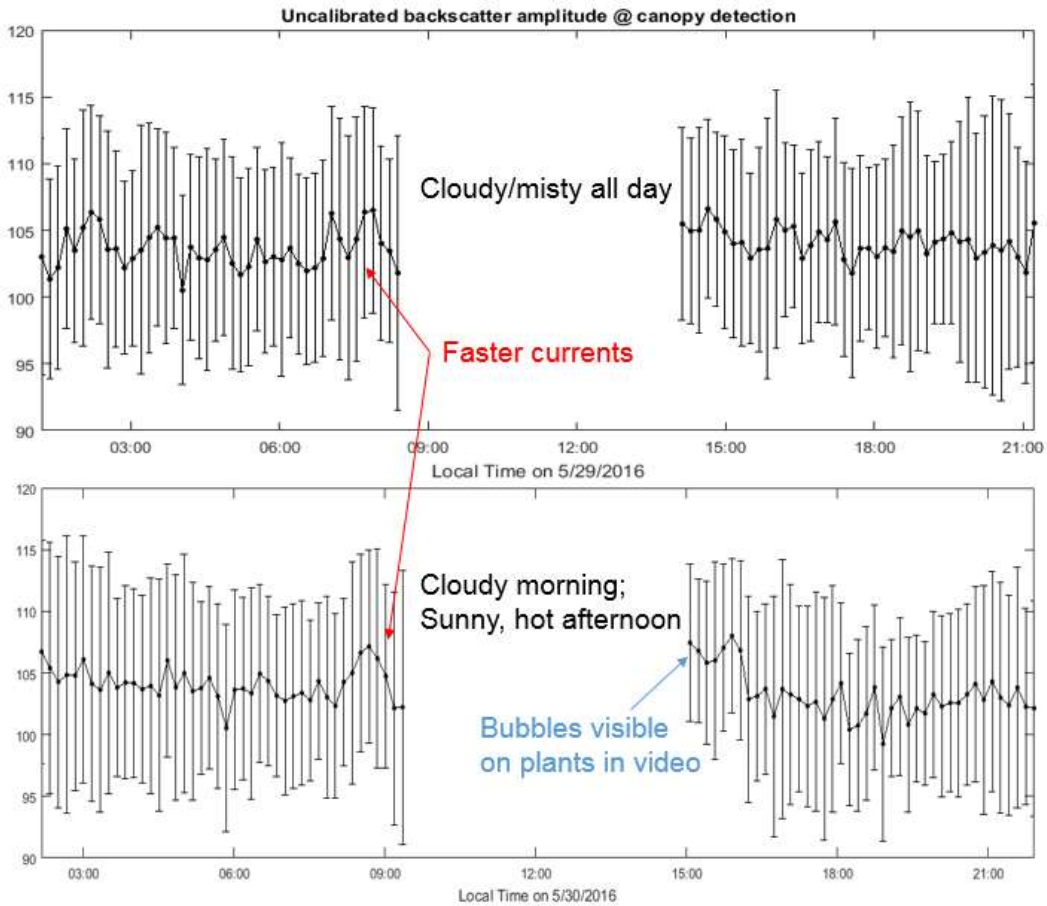


Figure 5-18: Uncalibrated acoustic backscatter amplitude at the canopy detection point, with times of higher current magnitudes and bubble presence from video data indicated.

LIDAR, Hyperspectral and Optical Approaches to Habitat and Seafloor Characterization

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

Benthic Habitat Mapping From LIDAR

Seafloor characterization using ALB waveforms

The bottom return intensity values from ALB raw time-series observations (waveforms) represent the upwelling radiance returning to the detectors and can, if properly understood, be used to characterize different bottom features such as grain size and vegetation on the bottom. Erin Nagel, with input from Shachak Pe'eri and Chris Parrish has been developing waveform processing procedures (as described in the Processing Theme) to characterize the seafloor returns by using the features extracted from the ALB observations along with the ground truth data.

Over the past year, a novel ALB waveform processing procedure has been developed for bottom characterization. To demonstrate the procedure, ALB data set collected in 2007 with a SHOALS-1000 system over Merrimack River Embayment, Gulf of Maine was used. Ground-truth from grab samples and underwater imagery taken in 2009 were used to associate certain ALB waveform features to bottom type. In November 2016, additional ground truth surveys were conducted in the study area with RV *Gulf Surveyor* to increase the bottom classification capability and better understand the ALB waveform response to different seafloor conditions. These ground truth measurements were combined to increase the number of training data sets. Using a supervised classification (through a Support Vector Machine), the bottom was segmented into: vegetated vs. non-vegetated regions; and grain size regions (i.e., fine sand vs. coarse sand) (Figure 5-19).

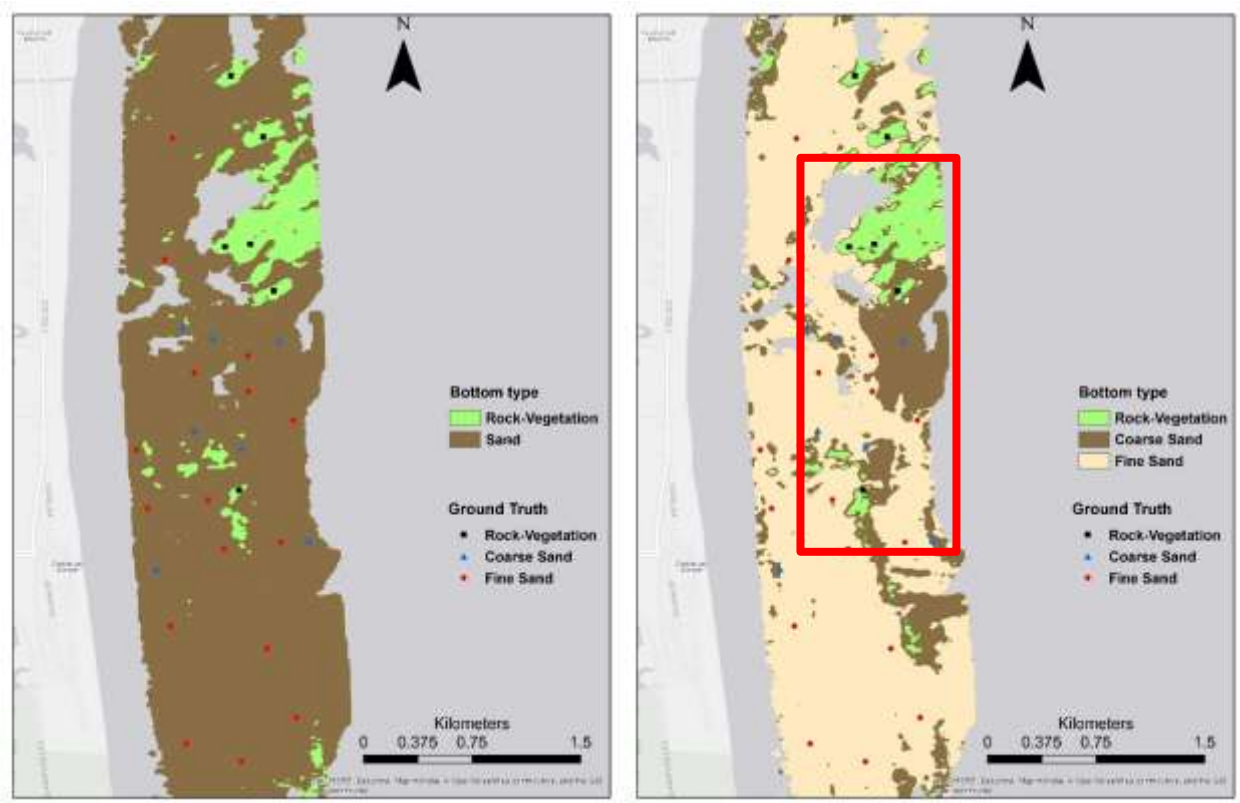


Figure 5-19: Bottom classification results. Left: Sand vs. Rock classification. Right: Fine Sand-Coarse Sand-Rock classification. The red box is the backscatter data collected in the area.

The results were also compared to the acoustic backscatter data collected in the survey area (Figure 5-20). Although there is a time difference between ALB and backscatter collection times, there is qualitative association between the two methods in some regions. High intensity (light) backscatter areas correlate with the coarse sand results whereas lower intensity (dark) backscatter areas contain mostly fine sands. The salt-pepper texture in the acoustic backscatter map are observed to correlate well with the Rock-Vegetation class. The implication is that, in a constrained area, when seafloor changes are

large enough, uncalibrated backscatter may offer an indication of changes in sediment type as long as a single sonar system has been used to make the measurements and appropriate corrections made to the backscatter data.

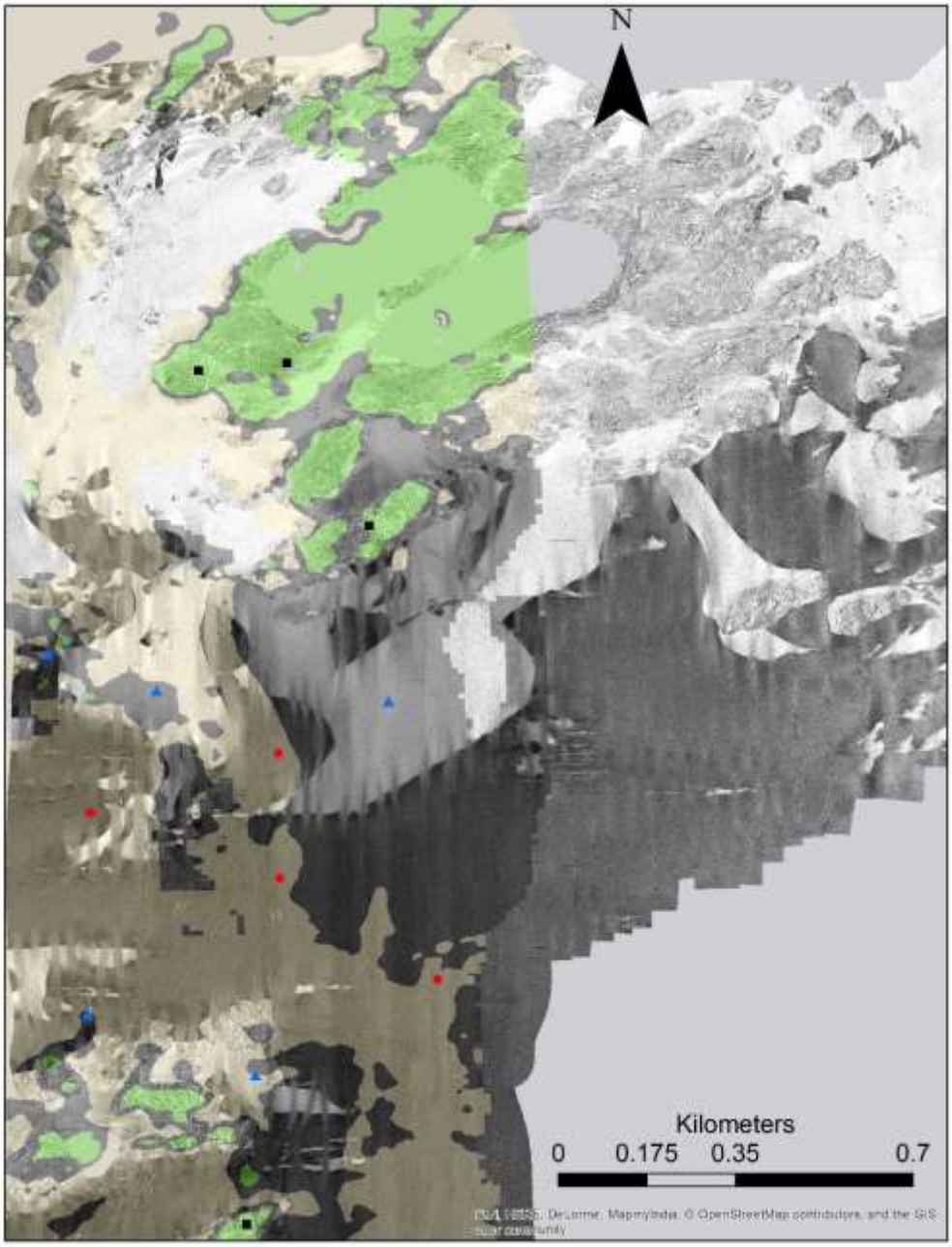


Figure 5-20: ALB derived bottom map correlation with acoustic backscatter collected in the Breaking Rocks region.

INSTRUMENTS AND APPROACHES TO GROUND TRUTH SONAR, ALB, HYPERSPECTRAL AND OTHER REMOTELY SENSED DATA

As we strive to better understand the ability of our sonar or LIDAR systems to provide quantitative information about the seafloor and water column, we inevitably must ground-truth the remote measurements we make. To ensure that we can accurately determine the properties of the seafloor upon, and water column within, which we are making our measurements, we have developed a suite of tools and approaches.

OPTIMAL SETTINGS FOR A MULTI-CAMERA

Researchers at the Center, under the direction of Yuri Rzhanov, have developed a multi-camera rig for high-resolution stereo imagery of the seafloor (Figure 5-21). The multi-camera rig allows for resolution of higher spatial frequencies than "monocular" stereo (structure-from-motion), or conventional stereo setups. However, quantitative investigations of the advantages have never been conducted and if we are to obtain quantitative results on objects of a given size (e.g., nodules, pebbles, etc.) we need to understand the required characteristics of hardware (e.g., rig sizes, image resolution, range to the target).

These issues have been examined through a set of numerical experiments. Images of synthetic DEMs have been generated using traditional (OpenGL) and cutting-edge (Embree - Intel's photorealistic renderer) techniques, and these images were then used for reconstruction of the source DEMs, which could be compared with the ground truth data (Figure 5-21 -right). Varied parameters included (but were not limited to): number of cameras, their relative pose, spatial frequencies of DEM and texture, DEM vertical contrast, texture dynamic range.

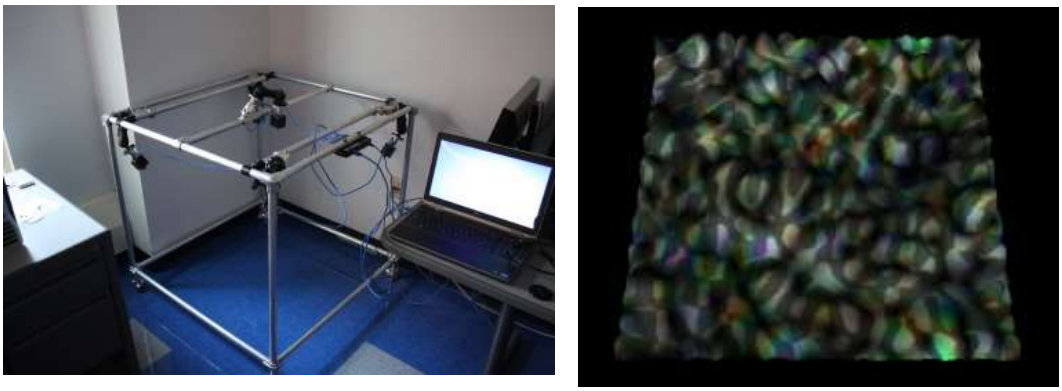


Figure 5-21: Multicamera-rig (left) and computer generated image (right). Spatial frequencies of DEM and texture have different ranges and are not correlated.

Over the past half year the emphasis has been on analysis of how images and subsequent 3D reconstructions are affected when the cameras are put underwater in water-resistant housings. A series of experiments have been carried out to investigate the quality of reconstruction depending on texture and elevation spatial frequency, and image size, camera position and number. One of the major challenges of underwater 3D reconstruction is the presence of optical refraction at the air/glass and glass/water interfaces of the underwater camera housing. To obtain quantitative results, corrections for this refraction have to be incorporated in the camera model.

Software for the visualization of camera views (used for interactive adjustment of cameras) and for acquisition of images has been developed. All cameras have been calibrated intrinsically and the procedure for extrinsic calibration of the rig which is required after each readjustment of the cameras has been verified. We have conducted experiments with two different targets. The first target was a pile of gravel, and the second target consisted of a coarse sand with an imprinted shape. An exact reconstruction of a shape was of secondary interest in this study; the prime interest was the spatial frequency content that would allow interpretation of the content of a target. Figure 5-22 shows the spectra of the targets. The blue curve shows the presence of objects of at least four different sizes with a dominant frequency around 29 mm (average gravel size ~26 mm). The red curve demonstrates dominance of smaller objects in the presence of larger ones. High-frequency noise is noticeably lower in the case of coarse sand, which is likely to be related to higher texture frequency than in the case of the relatively homogeneously-colored gravel pieces, and hence provides better reconstruction quality.

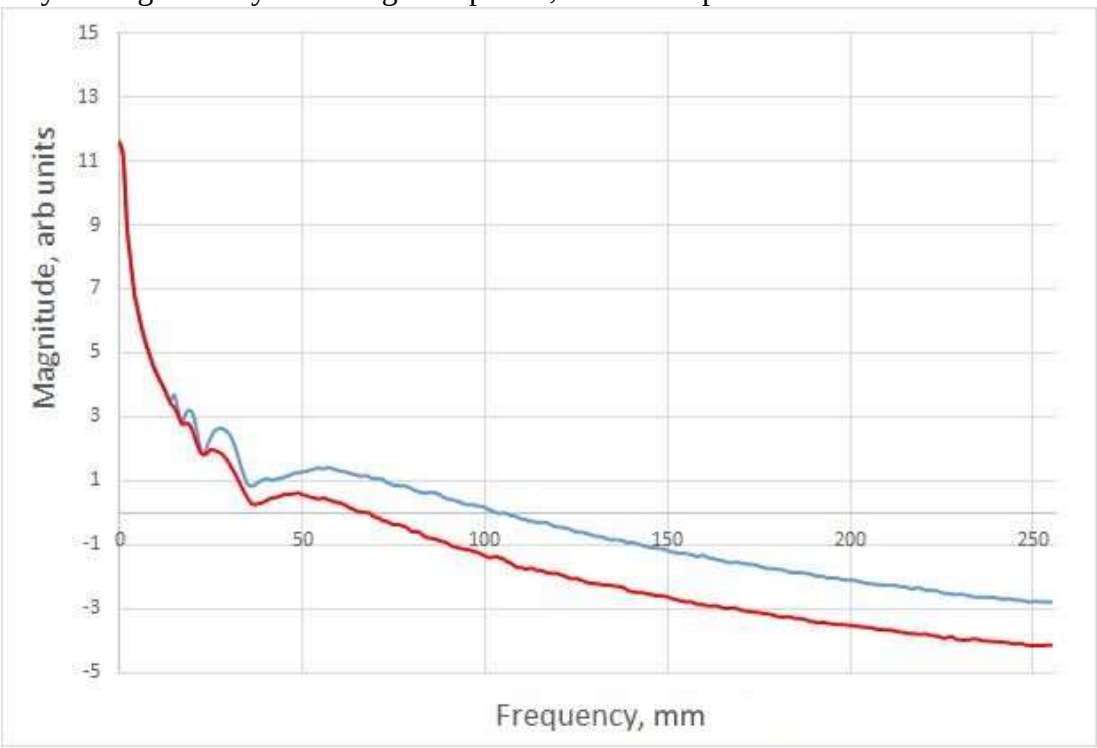


Figure 5-22: Blue - gravel, red - coarse sand with few gravel pieces.

Figure 5-23 demonstrates the usefulness of 3D reconstruction compared to a set of still images. Whereas the image on the left (a) barely shows some indentations of the surface, image (b) showing the result of reconstruction show the imprint.

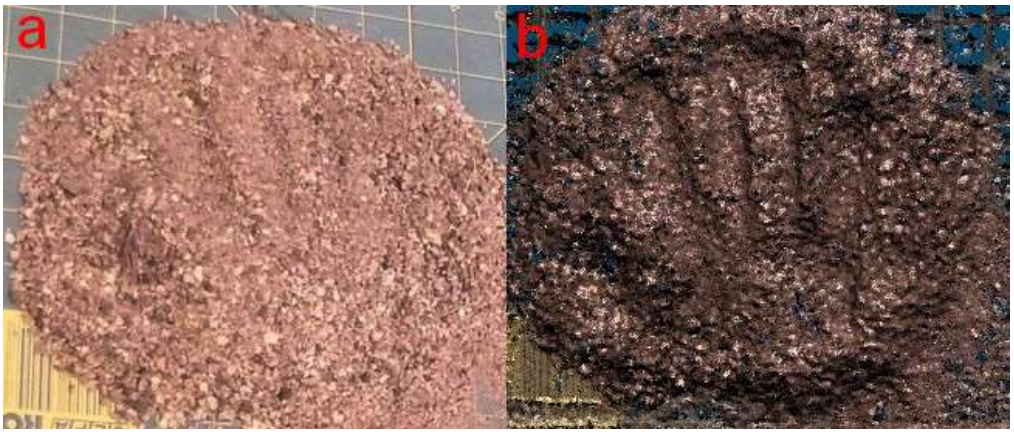


Figure 5-23: a) single image, b) 3D reconstruction with normals and oblique illumination from multiple images.

IMAGING GRAB SAMPLER:

During conventional hydrographic operations, survey units are required to take sediment samples in order to determine, among other things, suitability of an area for anchoring. Most commonly in current practice this is done with a small grab sampler of some kind, often a Petite PONAR system. One common problem with this, however, is that if the grab sampler does not return any sediment, it is unclear to the operators whether this is because the sediment is sufficiently hard to preclude sampling, or if the sampler simply did not correctly trigger on contact with the sea floor. After some experimentation with a simple GoPro camera attached to their grab sampler, personnel from the NOAA Ship HASSLER approached the Center to see whether we might use some of the expertise gained through other camera systems developed previously in order to improve on the system. Consequently, Calder, McLeod, Pe'eri, Rzhanov, and Lavoie have been working on a project to engineer a reliable and robust camera system that can be deployed readily by field personnel, and which matches the operational tempo of NOAA field units.

After discussion with NOAA personnel on the requirements for the camera, and operational constraints, the project team developed a set of core requirements, and then designed and fabricated an experimental camera system to meet those constraints. The camera system, Figure 5-24, is compact and relatively light, is powered by standard Lithium rechargeable batteries, and can be controlled from the outside of the pressure casings via WiFi (camera) and a modified reed-switch mechanism (lights) to allow them to be manipulated on deck without having to open or otherwise adjust the water-tight seals. The camera and light are designed to be field positionable with respect to the grab sampler through a specially machined clamp that rides on the support pole, and to operate for a full survey day without having to either recharge batteries, or off-load data.

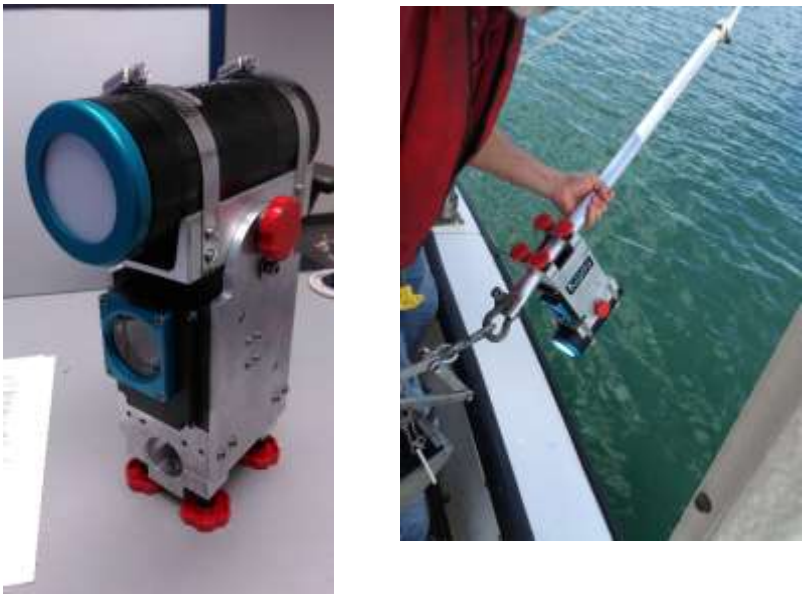


Figure 5-24: Prototype grab camera system

Intended functionality was achieved in all respects with the camera controlled by the GoPro smartphone app or PC application. The ability to change modes, begin and end capture sequences, and download example imagery, was effectively seamless. The Nautilux light provided sufficient light in the test tank to generate clear imagery with a maximum depth rating of 1,450m (where we only needed to achieve 100m).

When deployed in the field (Portsmouth Harbor) a design limitation of the GoPro became evident. The Hero series cameras were designed for use by surfers and skiers: both operate in an environment with significant light. It follows that the Hero is not particularly effective in low light situations, such as underwater off the New England coast. We believed that the 2,000 lumens available from the Nautilux would be sufficient to drive the shutter speed high enough to capture images in a low motion situation. This turned out not to be the case. We also found that the weight and drag of the cast line had a tendency to cause the sampler to lie down giving a close but limited view of the ocean floor.

The second iteration of the camera replaced the Nautilux light with 4 Goldengulf diver lights providing a total of 3,300 lumens though reducing the depth rating to 100 m (the design depth). The lie down events when impacting the bottom were resolved by adding a COTS net float to the top of the support strut providing a restorative force. The standard 8” ball is easily found at any marine supply house. A storage and calibration frame added to the sampler provided multiple modes of deployment. During casts, the frame orients the camera normal to the bottom, reducing distortion. Additionally, the 2cm check pattern provides a built-in calibration feature and the stand allow the sampler to be transported and stored more easily (Figure 5-25). The system is now being tested in the fleet and will be modified based on feedback.

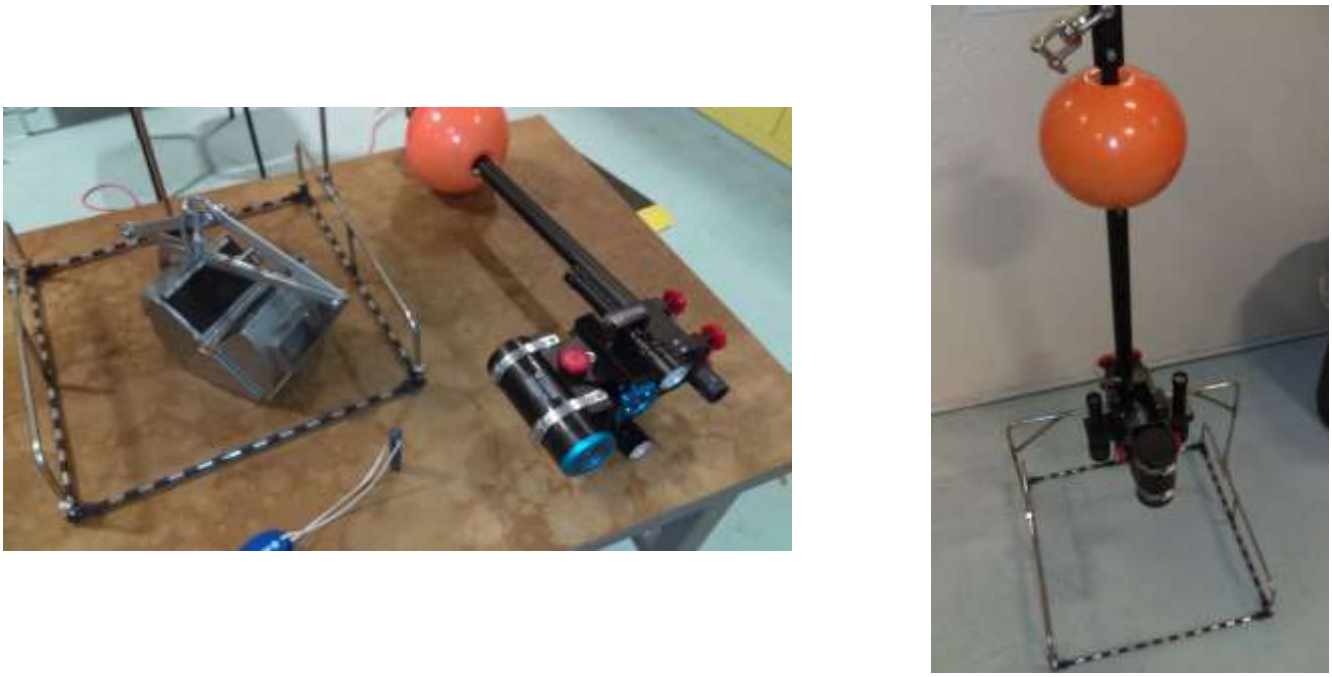


Figure 5-25: Second generation Imaging Grab Sampler. Left – with Pohner corer, Right – standing.

VIDEO MOSAIC FOR THE DUAL PURPOSE OF GROUND-TRUTHING SONAR DATA AND HABITAT CHARACTERIZATION

Yuri Rzhanov has developed a suite of automated mosaicing algorithms and software to generate mosaics of benthic communities dominated by different algal species. These mosaics have been used by Jen Dijkstra and colleagues as ground-truth for acoustic data and to spatially characterize benthic habitats. The goal of this research is the identification of small-scale (visually measured) variables that can be used to describe the distribution and abundance of fish at larger scales in which remote-sensing tools such as sonar, LIDAR or satellite imagery are used to quantify seascape pattern.

Videos were collected at nine sites dominated by different algal species using a GoPro Hero 2 and 3+ with video dimensions of 1920x1080 at 30 frames per second. While SCUBA diving, a 100 m^2 rope grid was laid out over a seaweed bed with attached parallel ropes every 4 ft. The diver remained one to two meters above the algal bed, or as high as visibility allowed and swam in a lawnmower pattern to record the video. A number of steps were completed to create the mosaic including changing the format of the video from an MP4 to AVI and segmenting into video frames. During this process the video was filtered to obtain a frame that was reduced by 2:1. To account for this reduction, the focal length and principal points of the video were also reduced by a factor of four. Individual frames were automatically co-

registered and "bad" matches were removed manually. Once this was complete, each line in the mosaic was created and then each line pieced together in to recreate the full 100m^2 mosaic (Figure 5-26).

Analysis involved manual delineation and identification of seaweeds to the lowest possible classification and performing spatial analyses on the resultant seascape. Results indicate that introduced seascapes are more complex (fractal dimension and mean shape index) and fragmented (higher number of patches, smaller patches, greater length of patch edges) than native seascapes.

In connection with this project, a GoPro Hero3+ camera was deployed at the edge of each seascape assemblage to examine fish abundance and behavior (Figure 5-27). GoPros were deployed for 1 hour and maximum fish abundance, hiding and feeding behavior were recorded. A Principal Component Analysis (PCA) was then used to determine which seascape variables were highly correlated and corresponded to maximum fish abundance. PCA grouped the variables into seven components of which the first three were retained as they had eigenvalues greater than 1. Diversity, Mean Patch Edge (MPE) and Medium Patch Size (MedPS) were most representative of the first three clusters. A multiple linear regression was then used to examine the relationship between fish abundance, MPE, MedPS, and patch diversity. A significant regression equation was found ($F(3,4)=16.91$, $p < 0.01$), with an adjusted R^2 value of 0.87.

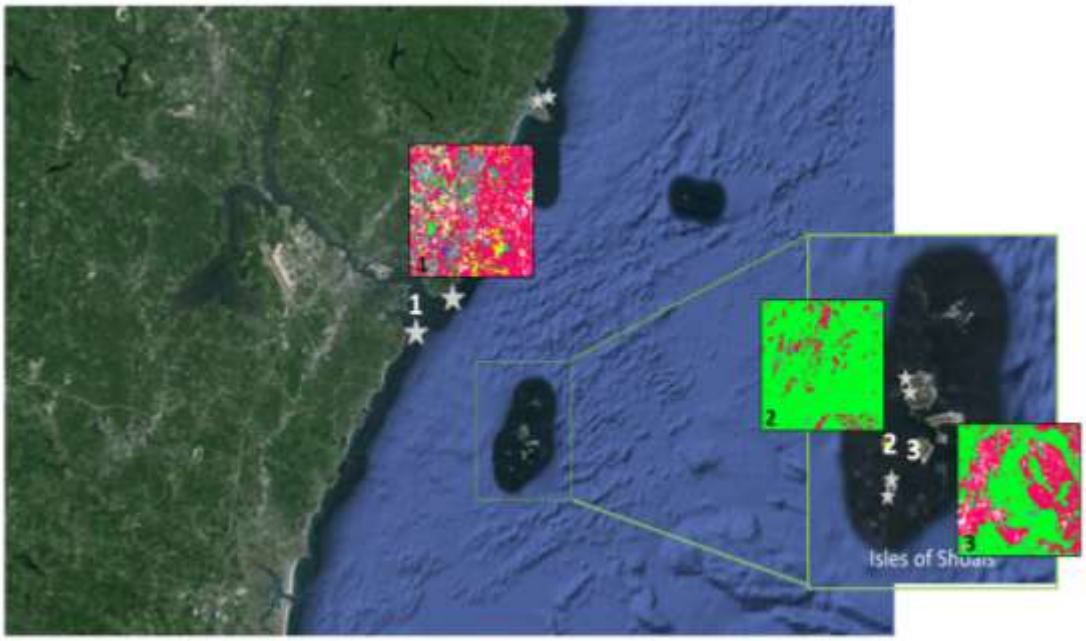


Figure 5-26: Sites of data collection (gray stars) and three seascapes (numbers) of seaweed assemblages and substrate within a 100m^2 section of the seafloor: Introduced seaweed assemblage (1), kelp bed (2) and mixed assemblage (3). Numbers in the seascape image correspond to the numbers of the site of data collection. Each color within the mosaics denotes substrate or a particular seaweed species. Spatial analysis to investigate patchiness, fragmentation, diversity and other seascape variables were determined.

Figure 5-27: Juvenile Pollock (left) and Flounder (right). Both species use seaweed habitats to forage for food and refuge from predators.

MODELLING MACROALGAE AND HABITAT MAPPING

Marine benthic habitats are made-up of species that form complex 3D structures providing habitat and refuge for a wide variety of commercially important invertebrate (e.g., crabs) and vertebrate (e.g., fish) species. Along with seafloor mapping technologies such as high frequency sonar, lidar, and photographic methods that are used to characterize and segment benthic habitats into 2D space, Colin Ware and Jen Dijkstra are developing new techniques for defining the 3D structure of seaweed species. These methods promise to provide a bridge between mapped areas of macroalgae and the habitat they afford for associated species with a goal of developing this method and its associated metrics into a tool for analyzing the role of spatial architecture in mediating the coastal food web.

A new method, called *spherical space analysis* is being developed to estimate the volume of free habitat for organisms of different sizes within the interstitial spaces of difference species of seaweed. The method can be used to estimate the *inaccessible volume* as a function of size for different species using computer generated models rendered volumetrically. A similar metric: *inaccessible surface area* is calculated in parallel.

Figure 5-28 illustrates a new model of the invasive seaweed *Dasysiphonia Japonicus*. The yellow regions represent inaccessible volumes for organisms of different radii. As can be seen most of this seaweed is only accessible by small organisms. Figure 5-29 shows the inaccessible volume and inaccessible area curves for both *Codium* and *Dasysiphonia*. These reveal very different distributions of available space. In the near future we plan to add a model of Kelp (*Saccarina*) to the analysis (Figure

5-30). This was formerly the dominant species in the Gulf of Maine and it has been displaced by invasive species.

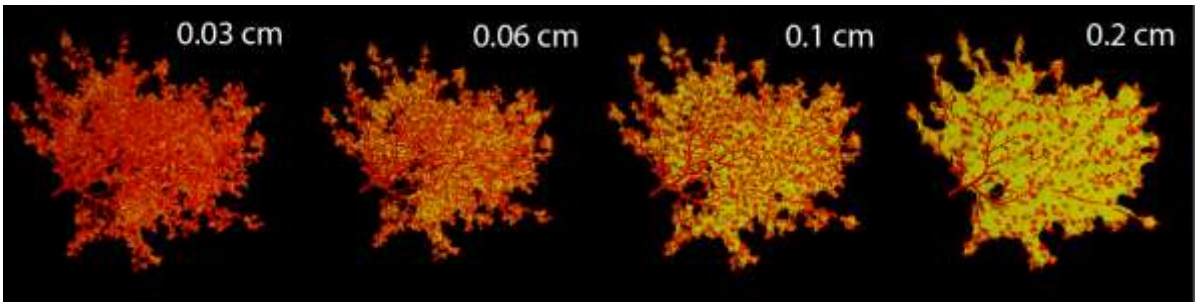


Figure 5-28: A model of Dasysiphonia Japonicus showing the volume accessible by organisms having different radii.

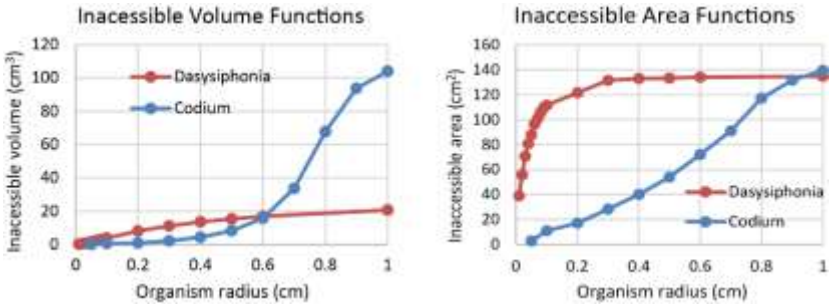


Figure 5-29: The left hand plot shows inaccessible volume functions for dasysiphonia and codium. Dasysiphonia has more volume of refuge for small organisms and less for large organisms relative to codium. The right hand plot shows that dasysiphonia has a much larger surface area accessible only by organisms.

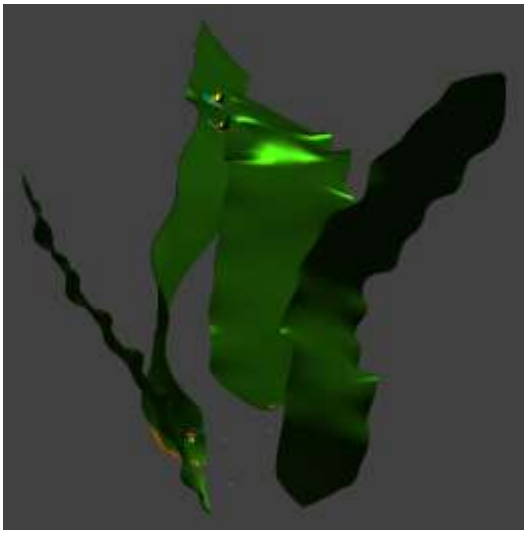


Figure 5-30: A new model of kelp seaweed (saccarina latissima) developed by Drew Stevens and Colin Ware

SEDIMENTOLOGY LAB

The interaction of both sound and light with the seafloor is often dependent on the nature of the seafloor and, in particular, the distribution of grain size in the sediment. In 2013, the Center contributed to an upgrade of the Sedimentology Lab at the UNH Jackson Lab so that we would have assured access to sediment analysis facilities. The laboratory utilizes standard sieve and pipette techniques to determine grain size. We also have access, through a collaborative agreement with the Dept. of Earth Sciences, to a Malvern Mastersizer Hydro 2000-G Laser Particle Size Analyzer. Routine sediment analyses for grain size have been conducted for the NEWBEX study (~170 samples analyzed), for Tom Lippmann, and particularly in support of the projects directed at understanding the distribution of sediment offshore New Hampshire.

WATER COLUMN MAPPING

Although fisheries sonars have imaged the water column for some time, this capability is new to multibeam sonars. The ability to simultaneously image the water column and the seafloor over wide swaths with high-resolutions offers great opportunities for new applications and increased survey efficiencies. The Center has been very active in developing tools to capture, analyze and visualize water-column data and these tools proved extremely valuable in our efforts to map the deep oil plume and monitor the integrity of the Macondo well-head during 2010's Deepwater Horizon crisis (see the 2010 annual report for a full description of our activities related to Deepwater Horizon). Our demonstration of the viability of using sonar systems for mapping natural gas seeps and leaking well-heads in the Gulf of Mexico during the Deepwater Horizon spill have led to several follow-up studies aimed at moving these techniques from qualitative descriptions to quantitative assessments.

SEEP MAPPING ON THE *OKEANOS EXPLORER* IN THE GULF OF MEXICO

Immediately following the Deepwater Horizon explosion and leak of the Macondo well head, we proposed the use of a 30-kHz multibeam sonar with water-column mapping capability (Kongsberg Maritime EM302) as a tool for mapping deep oil and gas spills and monitoring the well head for leaks. Such a system was not available at the time of the spill (the NOAA Ship *Okeanos Explorer*, equipped with an EM302, was deployed in Indonesia) and thus we used 18- and 38-kHz fisheries sonars. These sonars proved very effective for the identification of gas seeps and leaks but have limited areal coverage and limited spatial resolution as compared with the multibeam sonar. We finally had the opportunity in August/September 2011 to bring *Okeanos Explorer* to the Gulf of Mexico in order to test the EM302 water-column mapping capability to detect and characterize methane gas seeps. We also carried out comparisons with data collected with a Simrad 18-kHz EK60 split-beam echosounder, a system known for finding seeps in the Gulf of Mexico, which was purchased and installed on the *Okeanos Explorer* for this cruise. During this relatively short cruise (less than two weeks of active mapping), a Center team led by Tom Weber that included Jonathan Beaudoin, Glen Rice, Kevin Jerram and Maddie Schroth-Miller, mapped 17,477 km^2 of the northern Gulf of Mexico and made observations of 573 seeps (some of which were repeat observations of the same seep) with the EM302. Weber developed seep-detection algorithms for water depths of 1200 to 2500 m, while Beaudoin developed software that allowed the precise geo-location of the targets for presentation in a 3D context. We found that we were able to most reliably detect seeps over a swath that was approximately twice the water depth; farther ranges encountered reverberations from the seafloor that tended to dominate the return from the seep and significantly reduced the likelihood of detection. The results from this cruise demonstrated a new mid-water mapping technology for the *Okeanos Explorer*, and also suggested that wide-scale mapping of seeps in the deep Gulf of Mexico is viable, an objective that is important for both scientific and industry management perspectives.

We followed up these studies in 2012 with another program on the *Okeanos Explorer* where Tom Weber, Larry Mayer and Kevin Jerram, guided (from shore) the science behind ROV dives that were aimed at ground-truthing the mid-water acoustic-mapping efforts. Center involvement led to the development of a direct methane flux-measurement device that was successfully deployed during the cruise from Little Herc (thanks to some outstanding engineering efforts by the NOAA Office of Ocean Exploration ROV team), as well as a calibrated bubble grid for the measurement of bubble sizes and general methane gas-seep exploration from EM302 and EK60 data that were used as acoustic ‘guides’ for the ROV expeditions. Data collected during this cruise greatly increased our ability to properly interpret and analyze acoustic data collected during mid-water mapping expeditions in the same area.

In 2013, we continued to analyze acoustic and ROV data collected with the *Okeanos Explorer* in our attempts to further our capabilities to detect, localize, and quantify gas seeps with both split-beam and multibeam echosounders. These systems provide complementary data: we exploit the multibeam for its wide field of view and accurate positioning capability in order to examine the locations, morphologies and rise heights of the plumes and we exploit the split-beam echosounder to provide calibrated measurements of seep target strength that can be related to gas flux if we know the distribution of bubble sizes. A comparison of estimates of gas fluxes made from acoustic and ROV direct-capture methods has shown a remarkably close agreement (within 20%) from a seep on the Pascagoula Dome in the Gulf of Mexico, which was an encouraging result.

Another aspect of this work is the variability of the observed seeps, both in terms of the seep presence and absence and also in terms of the variations in flux. Graduate student Kevin Jerram worked to improve the localization of plumes and the estimation of associated seep source locations on the seafloor by employing attitude-compensation and refraction-correction methods similar to those used in multibeam echosounder processing routines. Estimates for installation offsets of the EK60 transducer relative to the vessel inertial navigation system are of critical importance for accurate seep localization.

Jerram's master's thesis (under the supervision of Weber) focused on the estimation of angular offsets by comparing seeps observed with the split-beam EK60 to simultaneous 'benchmark' observations made with the *Okeanos Explorer*'s Kongsberg EM302 multibeam echosounder (for which all offsets have been determined by patch testing). He has been able to localize seeps within the split-beam's 11° beam to an accuracy that is similar to that achievable with the 1° x 0.5° EM302. Seep locations in approximately 1600 m water depths were estimated using the resulting EK60 transducer offsets agreed to within ~15 m of those determined from patch-tested EM302 data and fell within the 'scatter' of EM302 location estimates of the seep for repeat observations.

Analyses of acoustic and ROV data collected with the *Okeanos Explorer* aimed at the detection, localization and quantification of gas seeps were completed with the acceptance of a manuscript in G^3, the M.S. defense of Jerram early in the 2014 spring semester. In January 2015, Jerram published a peer-reviewed article with Weber and Beaudoin describing methods for detecting, georeferencing, and characterizing plumes of gas bubbles rising from natural methane seeps. This article provides a basis for acoustical comparison of gas plumes observed with different survey configurations, such as EK60 data from other studies and other NOAA vessels. At present, EK60 echosounders with frequencies of 18-200 kHz are widely installed among NOAA vessels, enabling detection of bubbles in diverse size distributions and water column conditions. Many of the data processing concepts developed with the EK60 will apply to work with broadband EK80 echosounders; these broadband systems will expand the useful frequency bands for existing transducers, improve the range resolution of midwater measurements, and possibly provide information on bubble size distributions. To help maximize the utility of EK60 data collected aboard the NOAA Ship *Okeanos Explorer* during the 2015 season, Jerram joined Weber and NOAA personnel in Rhode Island in February to conduct a series of beam pattern measurements with a calibration sphere of a known acoustic target strength. The results of these measurements yielded an *in situ* calibration to improve target strength measurements of water column features, such as methane bubbles, observed with the EK60.

The tools developed for mapping oil and gas, originally in response to the Deepwater Horizon spill, have attracted much interest from the community and have fostered a number of follow-on studies. Epitomizing the role of the Ocean Exploration Program, this initial work on seep mapping and analysis has led to follow-up funding from several other agencies including NSF, DOE, and the Sloan Foundation. These follow-up projects each seek to look deeper into our ability to be quantitative about the flux and fate of the oil and gas that have been the target of our seep mapping.

We have already developed a suite of tools that have been actively used to identify and locate gas seeps in a number of environments. We now are focusing on attempting to use acoustics to understand the fate and flux of gas and oil as it is released into the water column.

QUANTIFYING ACOUSTIC MAPPING OF GAS SEEPS

As discussed above, we have recently undertaken a more quantitative look at the efficacy of MBES for detecting seeps. To do so, we have deployed a synthetic seep generator (constructed by Kevin Rychert, with funding external to the JHC grant), as shown in Figure 5-31, ready to deploy on the R/V Gulf Surveyor near the Isle of Shoals, and tested our ability to detect the seep with a MBES at different across-track distances. Figure 5-32 shows 12 sequential water column images of the seep as it is traversed with an EM2040p. These data were only recently corrected, but we will be working to quantify our ability to detect seeps (of known size) in the presence of seafloor reverberation. Most importantly, Tor Inge Birkenes Lønmo, a visiting scientist from Kongsberg, was able to collect simultaneous element-level data while we conducted these tests, and will be working on adaptive beamforming approaches for increased resolution and detectability of these water column targets.

Figure 5-31: A synthetic air bubble seep generator ready for deployment on the R/V Gulf Surveyor.

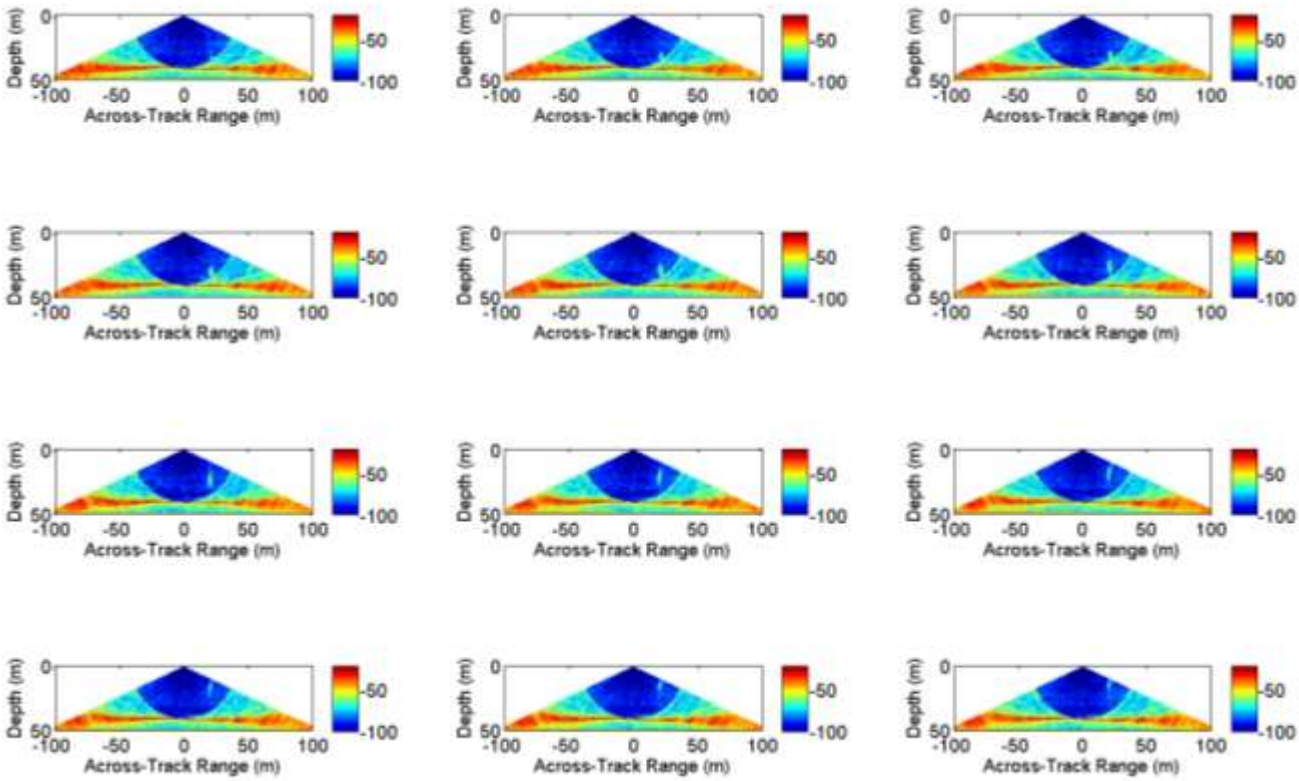


Figure 5-32: A synthetic seep imaged with an EM2040 at an offset distance of 20 m.

TARGET STRENGTH OF OIL DROPLETS

The seeps we map may consist of oil droplets, gas bubbles or both. In order to discriminate between oil and gas and to better understand how we can use acoustics to map and monitor subsurface dispersed oil droplets, a better understanding is required of the acoustic response of oil droplets. Under the supervision of Tom Weber, graduate student Scott Loranger has built an apparatus to create oil droplets of varying size and density. The instrument is designed to provide researchers and oil spill responders with crucial information about the fate and movement of oil in the environment. By detecting oil droplets in the water column it should be possible to trace surface sheens to their source and to determine the location and extent of plumes of oil at depth. Methods of detecting oil currently exist, for example mass spectrometers and fluorometers, but they are limited to detecting oil that is at sub-meter range from the instrument. Using broadband high frequency (30-500 kHz) acoustic echosounders it is possible to not only detect oil droplets from a greater distance (10s of meters for individual droplets, depending on the background noise) but to quantify the physical properties of the oil, including the size of droplets. Droplet size is an important factor in determining the likely location of submerged plumes and surface sheens, the rate of biodegradation, and rise rate of oil.

Laboratory measurements of the broadband response of three different crude oils have been made in the engineering tank at UNH. Data for the crude oil experiments is currently being processed. Figure 5-33

shows the response of diesel oil compared to a model by Anderson (1950) from previous data as an example. The acoustic data are also used to determine a detection range limit for different droplet scenarios. Results from scattering experiments were presented at the Acoustical Society of America Conference in Salt Lake City Utah as well as Gulf of Mexico Oil Spill and Ecosystem Science Conference in Tampa Florida.

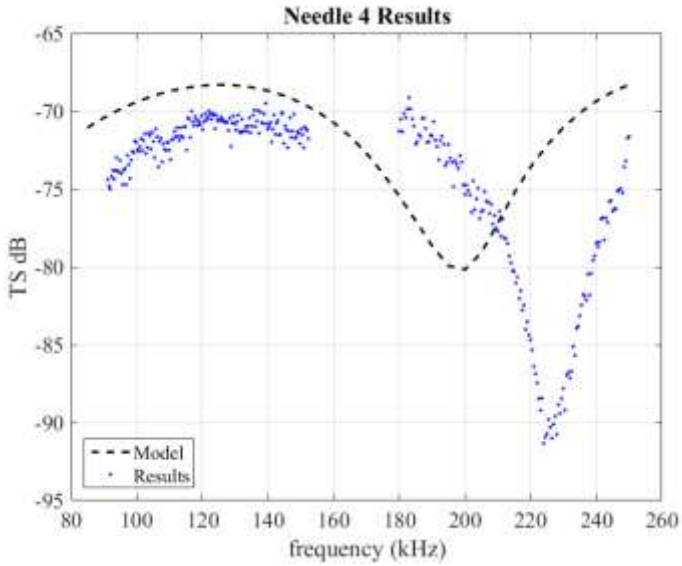


Figure 5-33: Broadband acoustic response of diesel oil

The two most important inputs for models of acoustic scattering of oil droplets are density and sound speed. While measurement methods of density are relatively simple and well established, sound speed measures on complex mixtures, such as crude oil, are more complicated to make. A literature review of sound speed data for complex hydrocarbon mixtures was conducted and it was determined that there is insufficient data in the primary literature to predict the sound speed of crude oil at oceanographically relevant temperatures and pressures. A sound speed chamber (Figure 5-34), specifically designed to accurately measure the sound speed of fluids while minimizing the volume of fluid needed (a crucial consideration for crude oil experiments) has been constructed. Experiments measuring the sound speed of crude oils will begin in the early part of 2017, and these results will inform models of acoustic scattering from fluid targets. For the initial tests of the sound speed measurement device, oil samples have been donated to us by Exxon-Mobil. The design of the chamber and results of the literature review were presented at the Acoustical Society of America Conference in Honolulu, Hawaii. As a result of this presentation, a new collaboration with researchers in Norway who are modeling acoustic scattering from non-spherical targets has been initiated.

Other note-worthy aspects of this project are that 1) Loranger has been playing an advisory role to the U.S. Coast Guard regarding the downed Taylor platform in the Gulf of Mexico particularly during the first half of the year; 2) we have received funding from BSEE to conduct work at Platform Holly, and this funding will pay for a good portion of Loranger's GRA over the next year or two, and 3) Loranger

won the Best Student Paper award for Acoustical Oceanography at the most-recent Acoustical Society of America conference.

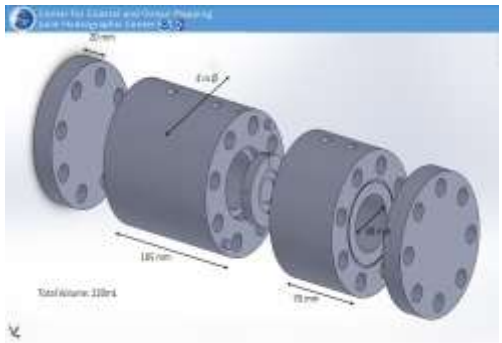


Figure 5-34: Acoustic sound speed chamber

FATE OF METHANE EMITTED FROM DISSOCIATING MARINE HYDRATES:

(For information – funded by non-NOAA sources - DOE)

One of the Center's goals has been to refine the use of acoustic echosounder measurements of methane gas seeps in order to more accurately assess the flux of methane gas exiting the seabed and rising through the water column. This has been the subject of several recent externally funded proposals, not least of which is this DOE funded project which funded Tom Weber and Liam Pillsbury's graduate work (graduated December 2015). Weber has continued Pilsbury's work comparing modeled and observed acoustic profiles of gas seeps (Figure 5-35). This project also incorporates a laboratory component that requires trapping a gas bubble in a flow in order to watch it dissolve while collecting acoustic echoes from the bubble. This capability was demonstrated this spring using a UNH prototype (Figure 5-36) which is being used to help design a high-pressure version at the USGS.

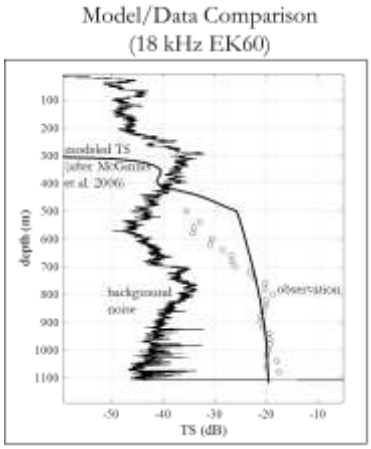


Figure 5-35 Modeled (black line) and observed (open circles) acoustic profiles of the backscatter from a gas seep in the Gulf of Mexico. Work continues to reconcile these two profiles.

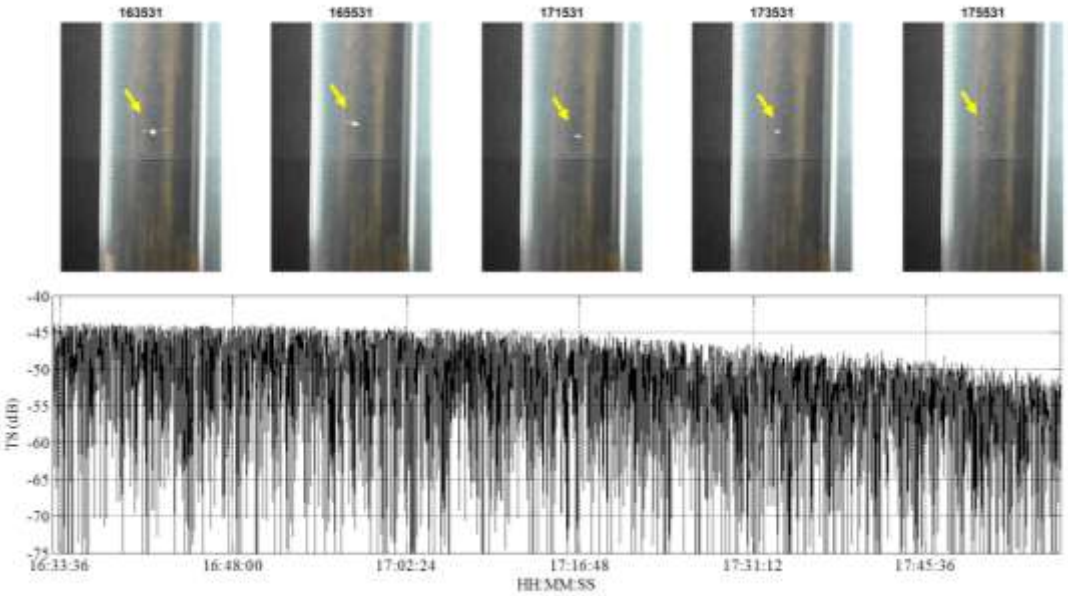


Figure 5-36: Images of a single air bubble trapped in the UNH flow loop as it dissolved over 1.4 hours (top). The acoustic target strength (TS) of the bubble insonified from below as the bubble dissolved (bottom). The acoustic measurements, collected well above bubble resonance at 150 kHz, are noisy due to the lateral movement of the bubble within the flow loop, but show an overall decrease of 8 dB as the bubble decays.

QUANTIFICATION OF GAS FLUX: EAST SIBERIAN MARGIN - SWERUS

(For information – funded by non-NOAA sources -NSF)

With guidance from Mayer and Weber, Elizabeth Weidner (ESCI M.Sc. student) is analyzing data collected from the Icebreaker *Oden* collected on the East Siberian Margin during one of the SWERUS-C3 (Swedish, Russian, U.S. Climate, Carbon, Cryosphere) cruises. Weidner is working an analyzing broadband EK80 data to estimate bubble size and gas flux, and is also working on developing the geological setting for the seeps observed during this cruise in Herald Canyon.

Flux measurement methodology is based on the broad bandwidth of the EK80 spilt-beam echosounder. The broad bandwidth allows for excellent discrimination of individual targets in the water column, allowing individual bubble scatterers to be distinguished from the EK80 data set (Figure 5-37). The identification of individual bubbles allows their acoustic properties to be determined. A well-established theory exists for the acoustic response (target strength) of an individual bubble as a function of the environmental conditions (pressure, temperature, and salinity), ensonification frequency, and of the physical properties of the bubble (gas composition and radius). Therefore we can model the expected frequency modulated target strength of bubbles of different radii in specific oceanographic conditions over the utilized bandwidth of 15 to 30 kHz (Figure 3-38).

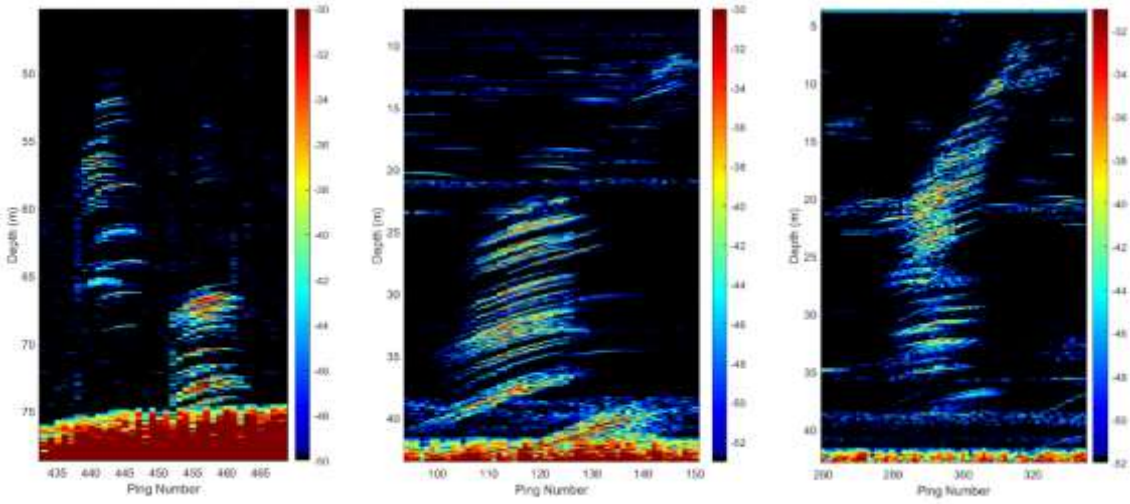


Figure 5-37: Examples of individual bubble traces in SWERUS EK80 data.

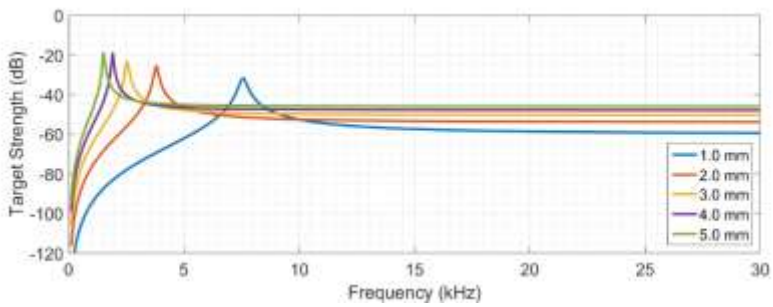


Figure 5-38: Frequency modulated target strength for methane bubbles in typical Arctic Ocean conditions at 50 meters depth.

The approach to analyzing the SWERUS EK80 data can be broken down into five major steps: (1) data extraction and calibration, (2) seep data sampling, (3) bubble size distribution estimation, (4) rise velocity calculations, and (5) methane flux calculation. Calibration scripts which provide corrections for the SWERUS EK80 seep data have been developed (Figure 5-39). The calibration is applied to the target strength curves for each bubble as it rises through the water column. The location of the bubble (electrical phase angle) is determined from the split-aperture calculation and then the appropriate offset values are applied in frequency space. Acoustic measurements of individual bubble can then be changed from sound pressure values to target strength values, permitting us to compare the target strength of bubbles are they move through the EK80 beam (Figure 5-40).

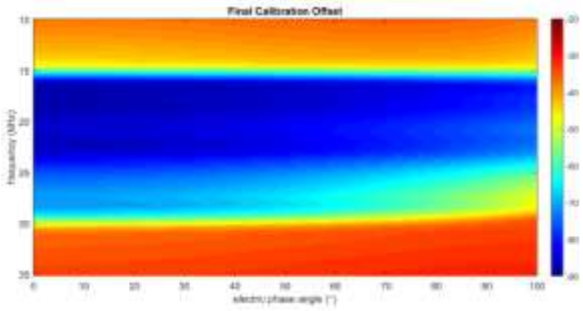


Figure 5-39: Final calibration offsets for the SWERUS EK80 data set.

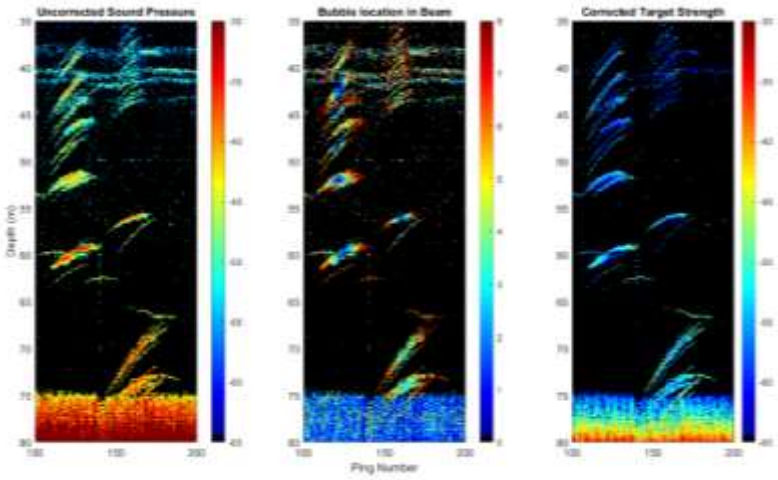


Figure 5-40: Seep with: (left) sound pressure measurements, (middle) bubble location in beam, (right) target strength measurements.

Once the calibration offsets were calculated individual bubble traces were identified and sampled. Each bubble in a seep was identified and assigned a number within the sample data structure. Then each individual ping where the bubble was found was sampled (20 samples are chosen before/after the peak intensity value for the bubble) and the target strength curve was saved, along with all other pertinent data (Figure 5-41).

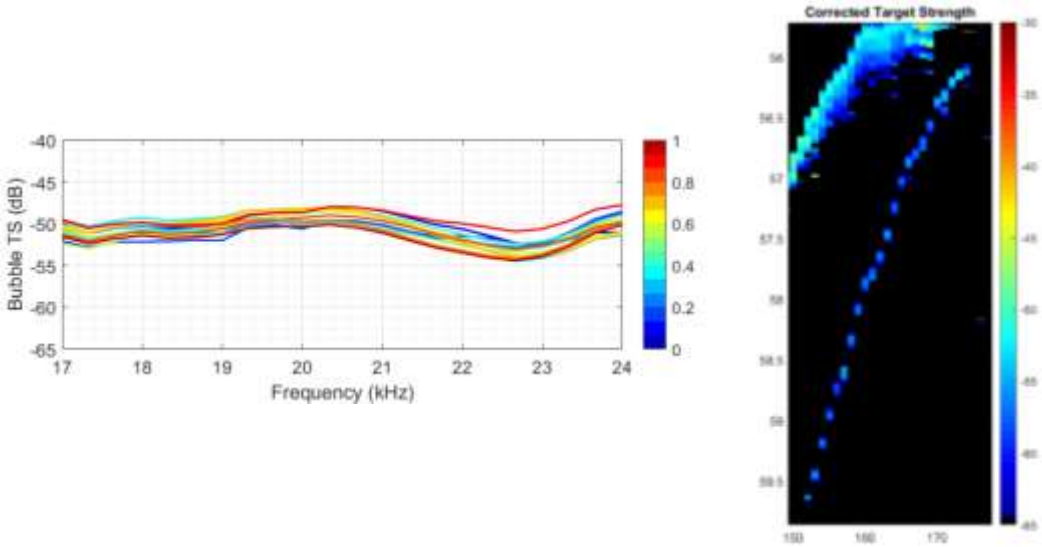


Figure 2-41: Frequency modulated target strength curves (left) for a bubble as it rises through the water column (right).

The probability of occurrence of specific bubble radii is a function of the bubble size distribution. The bubble size distribution of a seep is determined by modeling the size of each bubble sampled. This is done by comparing the frequency modulated target strength to the modeled acoustic response for the specific environmental conditions from which the bubble was sampled (Figure 5-42).

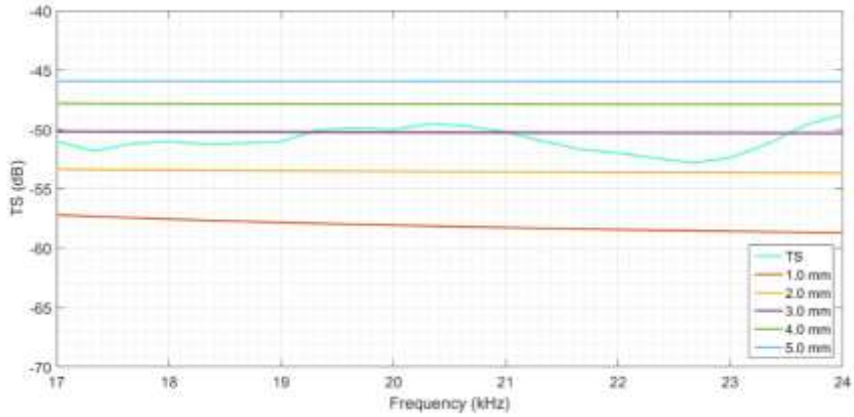


Figure 5-42: Target strength measurements from a SWERUS bubble compared against modeled curves.

The bubble size distribution of a full seep as a function of depth was plotted once every bubble size had been modeled and from these values a probability of occurrence was determined for the full seep as well (Figure 5-43).

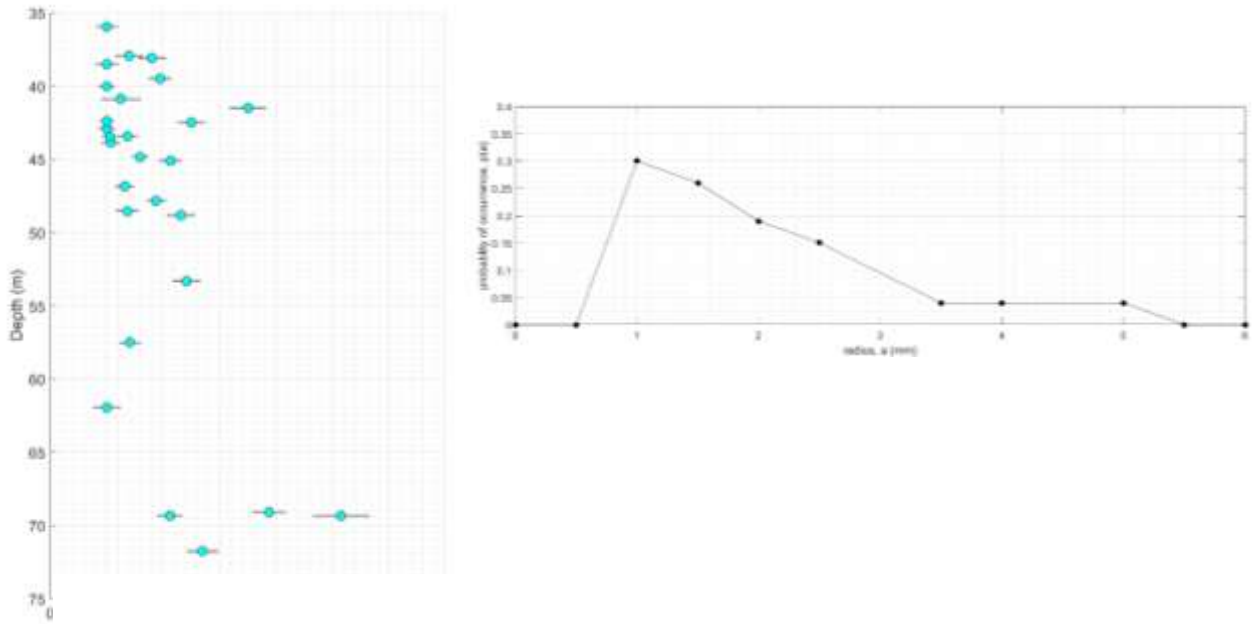


Figure 5-43: Bubble size distribution (left) and probability of occurrence (right) for example SWERUS seep.

In addition to the bubble size distributions it is necessary to calculate bubble rise velocity to estimate methane flux. The bubble position in the first and second ping is first determined (depth and time stamp) and a simple linear rise velocity is then computed (Figure 5-44). For a given seep the rise velocities for each bubble are plotted as a function of depth (Figure 5-45). In the future these calculations will be made for each bubble in every seep while accounting for the ship motion.

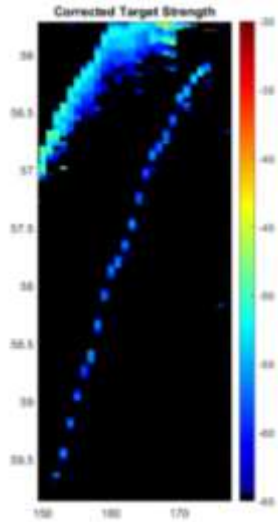


Figure 5-44: Rough rise velocity calculation for example SWERUS seep.

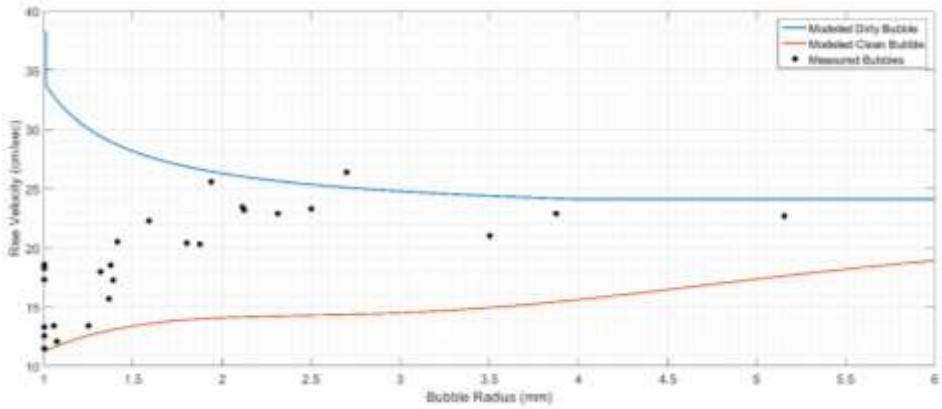


Figure 5-45: Rough rise velocity calculations for SWERUS example seep, plotted against modeled rise velocities for dirty and clean bubbles

MID-WATER MAPPING IN PETERMANN FJORD GREENLAND USING A WIDE-BAND TRANSCEIVER

(For information – funded by non-NOAA sources -NSF)

The summer of 2015 Larry Mayer, and Kevin Jerram participated in an NSF-sponsored cruise aboard the Icebreaker *Oden* to Petermann Fjord, northwest Greenland (Figure 5-46). The cruise was designed to understand the history of the Petermann Glacier (through seafloor and land mapping and coring) and the processes responsible for its rapid degradation.

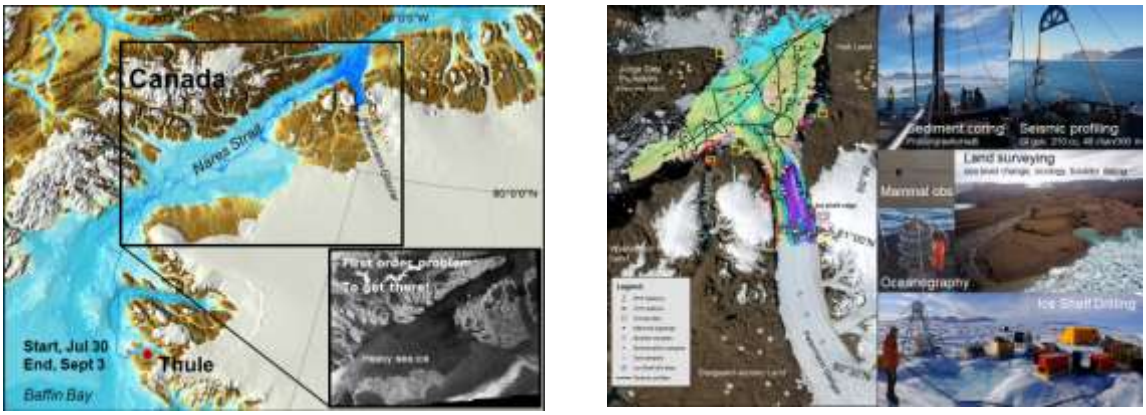


Figure 5-46. Location of Petermann Fjord and Glacier in northwestern Greenland (left); overview of mapping and other programs during the Petermann 2015 expedition (right).

Our component of the program focused on the Kongsberg EM122 multibeam echosounder, the Simrad EK80 wideband split-beam echosounder, and the SBP120 subbottom profiler providing the first high-resolution maps of the seafloor and water column in this remote region. Preliminary water column results

suggest the presence of several possibly fresh-water plumes and a widely distributed scattering layer whose depth appears to correlate with changes in water masses. Erin Heffron will be mapping the distribution of these scattering layers as part of her M.Sc. thesis to better understand if we have an acoustic tool that can track the oceanographic dynamics of the fjord system (Figure 5-47).

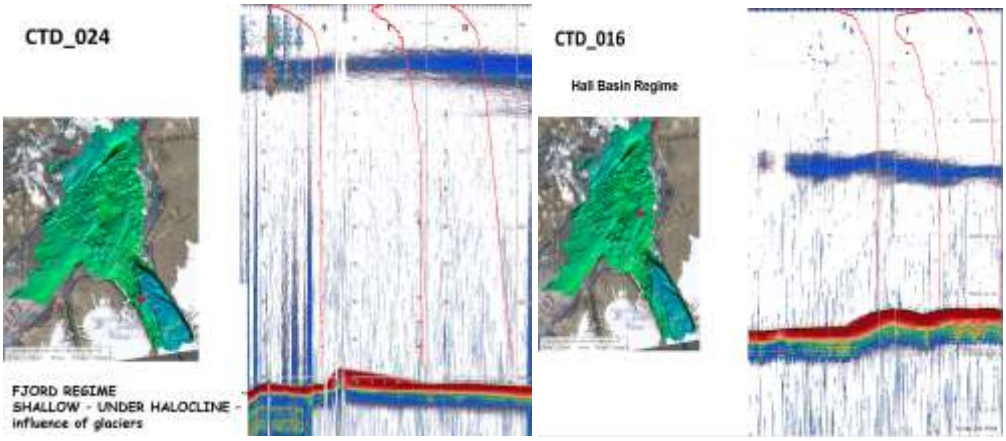


Figure 5-47. Example of scattering layer seen on EK-80 in Petermann Fjord, This layer was mapped continuously for 30 days but showed a distinct change in depth associated with different geographic regions of the fjord that appears to be associated with different water masses.

THEME 4: DEVELOPING TOOLS, PROTOCOLS, NON-STANDARD PRODUCTS, AND APPROACHES THAT SUPPORT THE CONCEPT OF "MAP ONCE – USE MANY TIMES," I.E., INTEGRATED COASTAL AND OCEAN MAPPING

Short name: **IOCM**

A critical component of the Center's effort has been to maintain an Integrated Ocean and Coastal Mapping Processing Center that would support NOAA's new focused efforts on Integrated Ocean and Coastal Mapping as outlined in the Coastal and Ocean Mapping Integration Act of PL-111-11. The IOCM Center brings to fruition years of effort to demonstrate to the hydrographic community that the data collected in support of safe navigation may have tremendous value for other purposes. It is the tangible expression of a mantra we have long espoused; "map once–use many times." The fundamental purpose of the Center is to develop protocols that turn data collected for safety of navigation into products useful for fisheries habitat, environmental studies, archeological investigations and many other purposes, and conversely, to establish ways to ensure that data collected for non-hydrographic purposes (e.g., fisheries, ocean exploration, etc.) will be useful for charting. Our goal is to have NOAA employees from several different NOAA lines and divisions (NOS Coast Survey, Sanctuaries, Fisheries, Ocean Exploration, etc.) at the Center and have them work hand-in-hand with Center researchers to ensure that the products we develop at the Center meet NOAA needs. The NOAA employees will develop skills in the use of these products so that they can return to their respective divisions or the field as knowledgeable and experienced users.

Working under contract to NOAA, a team led by Juliet Kinney have been partnering with a number of Center staff members to design workflows for IOCM products and to provide a direct and knowledgeable interface with the NOAA fleet to ensure that we address high-priority issues and that the tools we develop are relevant for fleet use. This effort received a boost from a separate grant and contract directed to look at the impact of Super Storm Sandy and brings much greater depth to our IOCM efforts as almost all of the work of the Super Storm Sandy teams fits well within the context of the IOCM theme. This pairing really epitomizes the concept of IOCM and of bringing research to operations. The Super Storm Sandy Grant team built on research already being done in the Center to develop algorithms and protocols specifically designed for the Super Storm Sandy effort. The Super Storm Sandy Contract Team have applied these tools to produce a series of products of direct relevance to NOAA charting.

In 2016 our IOCM efforts focused on collaborations with the Office of Coast Survey, Office of Ocean Exploration and Research, National Marine Fisheries Service and with NOS's Marine Modeling and Development Office. Many of the efforts previously described (particularly those described under HABITAT, MIDWATER MAPPING, LIDAR AND DATA PROCESSING themes) can just as easily be listed under the IOCM theme; below we focus on those projects that, for the most part, have been specifically incorporated into NOAA's IOCM projects and in particular outline some of the IOCM-relevant results of the Super Storm Sandy Contract team. We only describe them briefly here; more detailed descriptions of these projects can be found in the Super Storm Sandy final reports (http://sandy.ccom.unh.edu/).

BACKSCATTER FROM HYDROGRAPHIC VESSELS

NOAA continues to require seafloor acoustic backscatter as a deliverable for all hydrographic surveys yet there are still questions about the current approach to collecting and processing backscatter. Under the leadership of Glen Rice and with input from many members of the Center, information is being gathered and synthesized to develop a "business case" for how Coast Survey deals with backscatter. These efforts are aided by the Center's (and Rice's) involvement in the GeoHab Conference Backscatter Working Group, where an international team is looking at both the use of, and needs for, backscatter data as well as developing optimal protocols for the collection of high-quality backscatter data. In 2016 Larry Mayer presented a keynote on backscatter applications at the annual the annual GeoHab Meeting and Massimo di Steffano presented a paper outlining a new tool for integration and fusion of backscatter data with video and environmental data at the same conference. At this conference the Backscatter Working Group met with active participation from a number of Center people (Weber, Rice, Mayer, Heffron) and affiliates (Lurton, Beaudoin).

BATHYMETRY AND BACKSCATTER FROM THE NOAA FSVS

The collection of multipurpose data from NOAA hydrographic vessels (e.g., backscatter data that can be useful for habitat mapping) is only one aspect of the IOCM effort. Just as importantly there is the design of protocols to ensure that as the fisheries vessels use their multibeam sonars they produce bathymetry and other outputs that can serve hydrographic and other purposes. This effort was epitomized in 2011 when Tom Weber, Jodi Pirtle and Glen Rice demonstrated that the fisheries sonar on the NOAA Ship *Oscar Dyson* designed for mid-water fisheries studies, could also be used to provide hydrographic quality bathymetry, map the seafloor for trawlable/untrawlable habitat (see HABITAT Theme), and identify gas seeps. In one example, during a pollock survey, a Danger to Navigation (DTON) was identified from the data collected by the fisheries sonar (see 2011 Progress Report).

The approaches developed at the Center are now being put into practice. Simrad ME70 fisheries multibeam echosounders (MBES) are now installed on each of five NOAA Fisheries Survey Vessels (FSVs). Weber's ME70 software for producing bathymetry and seafloor backscatter has been integrated with the Hypack acquisition software that is standardly used on these vessels. This integration enables the ME70 sonar to simultaneously collect water column and bathymetric data, improving survey operations aboard the FSVs by increasing data collection, enabling visualization of ME70 bathymetry in real-time, and providing mapping and data processing tools. We (UNH) have not been heavily involved with the Hypack development apart from the initial algorithm development (as it should be), but in 2015 we had the opportunity to test Hypack's development in June on the *Oscar Dyson*. The Hypack development has progressed nicely.

Using the same ME70s, NOAA Alaska Fisheries Science Center (AFSC) is exploring new ways to assess rockfish in untrawlable habitats in the Gulf of Alaska. These efforts are based in part on past studies for which the Center has played a role (Jones et al., 2012; Weber et al. 2013; Pirtle et al. 2015). During the past few years of acoustic/trawl survey for walleye pollock in the Gulf of Alaska (nine total weeks of survey per year), 5 km^2 regions that have been historically classified as either trawlable or untrawlable

are being randomly revisited. In each 5 km^2 region, an ME70 survey (not full coverage) is run followed by 15 minute drop camera transects in 2-3 surveyed parts of the grid. The Center is playing a supporting role for the analysis of the ME70 data, using algorithms previously written for generating bathymetry and seafloor backscatter and two new metrics selected by Pirtle et al. [2015] in her general linear model (GLM) that was used to classify the seabed as trawlable or untrawlable based on ME70 data alone. Pirtle et al. [2015] used two topographic metrics: bathymetric position index (BPI) which essentially classifies a location as a bathymetric high or low, and a vector ruggedness measure (VRM) that looks at how the orientations of the cells in gridded bathymetry are distributed. CCOM has provided MATLAB code and help with interpretation to AFSC, which is leading the ME70 data analysis. Examples of the seafloor characterization metrics from a 5 km^2 grid are shown in Figure 6-1. AFSC is also analyzing the camera drop data to help identify the substrate, enumerate species present, etc.

This effort has mostly transitioned to AFSC (Sarah Stienessen), and the Center is now playing a supporting role in the analysis.

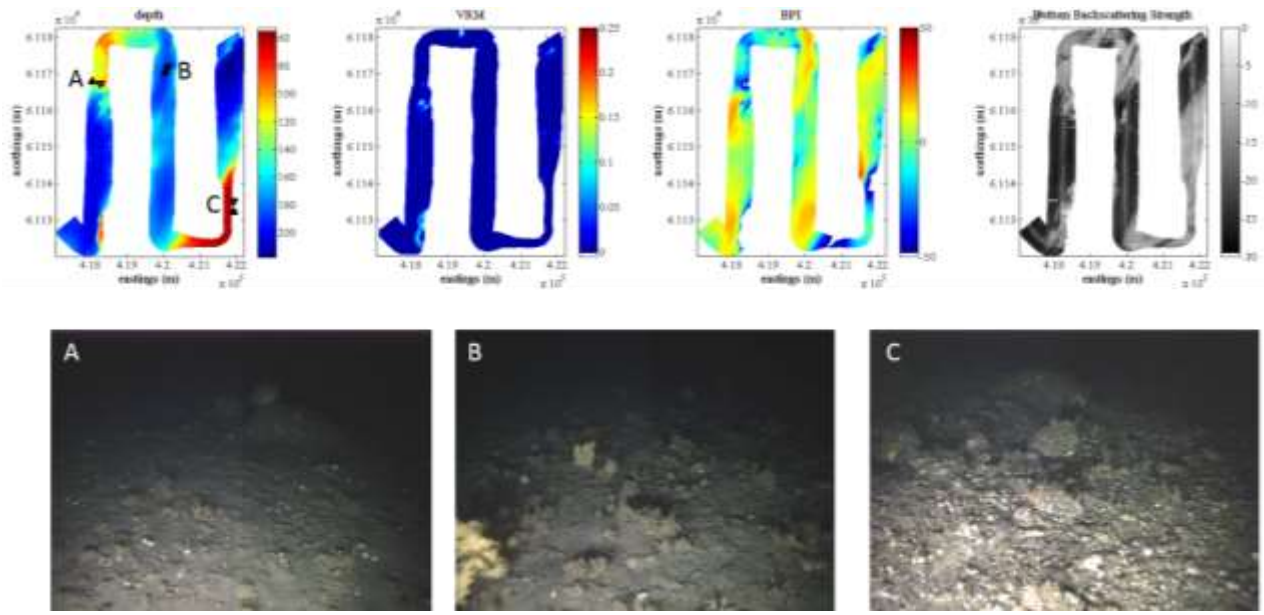


Figure 6-1. Seafloor backscattering metrics from Pirtle et al [2015] extracted from a survey grid during cruise DY1506 on the Oscar Dyson in June 2015. The metrics are derived from Simrad ME70 data and include bathymetry, a vector ruggedness measurement (VRM), bathymetric position index (BPI), and bottom backscattering strength. Camera drops (bottom) are conducted in 2-3 locations in each grid.

Both of these efforts represent prime examples of the transition from Research to Operations (R2O).

SUPER STORM SANDY IOCM EXAMPLES

As discussed earlier, Super Storm Sandy supplemental funding provided an accelerated opportunity to turn many of the on-going research projects in the lab into products needed to help understand and mitigate the impact of one of the worst storms recorded in U.S. history. This was achieved through

funding of a research team (the Sandy Grant team under the supervision of Brian Calder) who developed a number of algorithms and processes specific to the Sandy need based on on-going research in the lab, and a production team (the Sandy Contract team under the leadership of Juliet Kinney and supervision of Andy Armstrong) that applied these algorithms to generate products that were designed to help NOAA and others measure the impact of the storm and design mitigation processes. Common to many of these procedures was the concept of using the data sets available for as many applications as possible – i.e., the concept of IOCM. Here we summarize some of the most relevant IOCM products than came out of this effort. More detailed discussion of these topics can be found in the documents provided at: http://sandy.ccom.unh.edu/.

ASSESSMENT OF EXISTING POST SANDY MAPPING DATA SETS

DEVELOPMENT OF A GIS DATABASE OF SANDY MAPPING DATA

The Sandy IOCM group is utilizing several data types; Lidar: topographic & topobathymetric (topobathy), acoustic bathymetry, sidescan sonar, aerial imagery and other data such as marine debris removal information, location of grab samples, Secchi depths. Most of these data sets are provided as shapefiles or have been converted to shapefiles representing coverage. Organizing large data sets and their products into a geodatabase is an important means for planning and executing projects. Our GIS database is being updated with both raw and processed data coverage(s) throughout the project cycle.

All the Super Storm Sandy data obtained from NOAA's web portal and other supporting data from NOAA partners are maintained on the Center's network in a geodatabase as grids, features, and attribute tables with a direct relationship to feature elements representing their physical location and extent along the east coast of the USA (Figure 6-2). The GIS database is proving very useful for NOAA's Marine Charts Division's (MCD) Composite Coastal Bathymetry Project, under the supervision of Shachak Pe'eri. The IOCM team is experimenting with putting coverage information directly into an internal NOAA geoplatform with the aim of making sharing of data even easier, though this has been a challenge, especially for projects that are continuously being updated. NOAA OCS Operations have also requested coverages be shared.

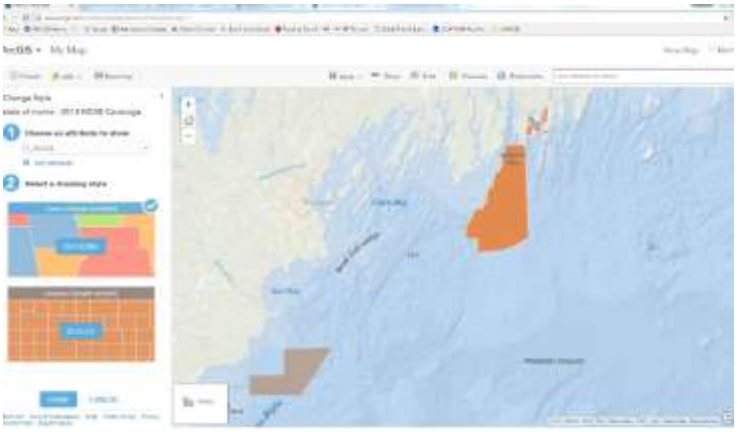


Figure 6-2: Example of NOAA ESRI Geoplatform survey coverage being loaded for previous State of Maine surveys.

USE OF NON-TRADITIONAL DATA SOURCES

A. ACOUSTIC DATA TO THE CHART

1. USGS Interferometric Sonar Data to the Chart

Many surveys collected by the USGS in recent years have been identified as being in high-priority survey areas for NOAA where the nautical charts are in need of updates. Many of these surveys are particularly valuable due to their proximity to the shore, where safety of NOAA personnel in small craft becomes a concern. The overall goal of this project is to assess the chartability of the USGS interferometric data including the assessment of data quality and the ability to meet NOAA specifications and deliverables as well as IHO requirements. A thorough workflow for future ingestion of interferometric data into the OCS pipeline is anticipated upon completion of the analysis of USGS data. The fundamental objectives of NOAA and USGS surveys are different, raising the question of whether each group can adjust their acquisition procedures (within reason) to better suit the needs of the other. The secondary goal to this evaluation is to identify areas of concern for each group for possible adjustments and eventual recommendations.

Assessment of USGS Interferometric Data for Charting:

Analysis of Buzzard's Bay, MA

In order to meet NOAA and IHO standards as closely as possible, the data were trimmed to 1.73x water depth in the across-track distance (see PMBS processing section) resulting in a swath-limited surface with ~50m gaps between each survey line. These surfaces are similar in nature to skunk-stripe single beam surveys, which ultimately influenced how these data were analyzed.

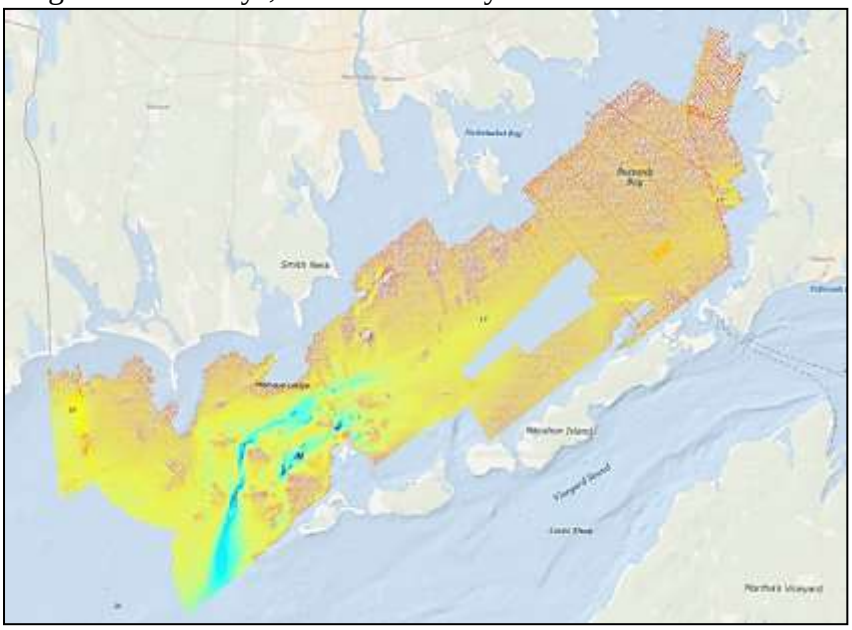


Figure 6-3: Buzzards Bay data collection area for the USGS and MA Coastal Zone Management Organization. Collected from 2009-2010.

To maintain consistency between NOAA ship *Thomas Jefferson*'s 2015 reconnaissance work and these data, the NOAA TCARI tide model was applied to both data sets. The tide application smoothed out errors from both USGS and the TJ's previously applied tidal models.

Additionally, the sonar system was changed in CARIS from the original "SEA SwathPlus" option to "UNKNOWN." This was predicated by previous research by Schmidt, which indicated that selecting "SEA SwathPlus" results in TPU calculations based on a multibeam algorithm, which creates an incorrect "Uncertainty" layer upon surface creation. By selecting UNKNOWN for the sonar type, the uncertainty can instead be ascertained by the "Standard Deviation" layer upon surface creation.

A conservative estimate of the Buzzards Bay uncertainty was achieved by combining the standard deviation from the 1m CUBE grid with other uncertainty sources such as tide, heave, and draft in a root-mean-square sum. Later, an additional and separate component was included to accommodate the residual roll bias discovered through the analysis of reconnaissance crosslines acquired by NOAA ship *Thomas Jefferson*.

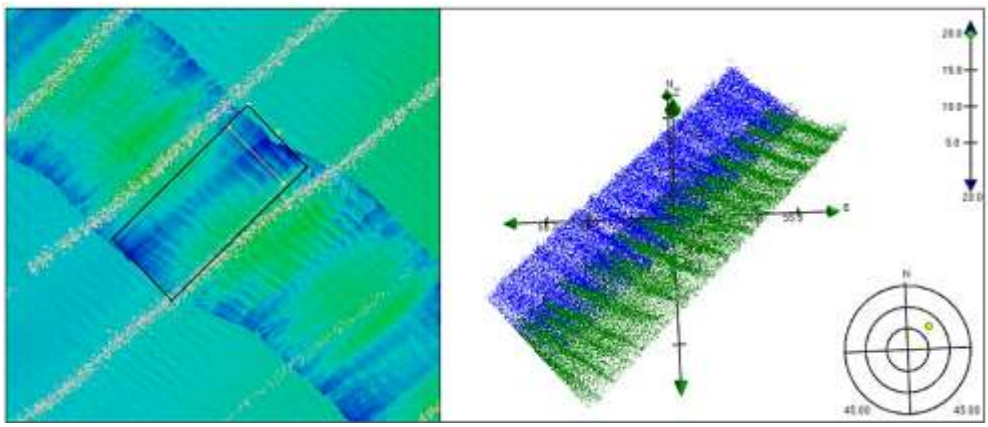


Figure 6-4: A. The crossline difference surface displayed over the 1m CUBE surface. The black box denotes the CARIS Subset Editor box. B. The 3D subset editor view of the black box in 6A. The blue and green represent soundings from two separate lines.

These data were found to meet the NOS density requirement of 80% of all nodes have at least 5 soundings. Furthermore, had the identified roll bias been fixable, these data would have also met the 0.5m uncertainty requirement. However, the roll bias contribution made the uncertainty closer to a meter.

The accompanying USGS Klein sidescan data were used to identify significant features such as large rocks and wrecks. After more than of 9,000 contacts were identified, the nature of the area became clear and additional contact identification ceased. Instead, a general analysis of the USGS 1m sidescan mosaic was performed. Areas which included excessive rocks were identified as "caution" areas in the submitted feature file. It was recommended that these locations be used to update the rocky areas designated on the chart.

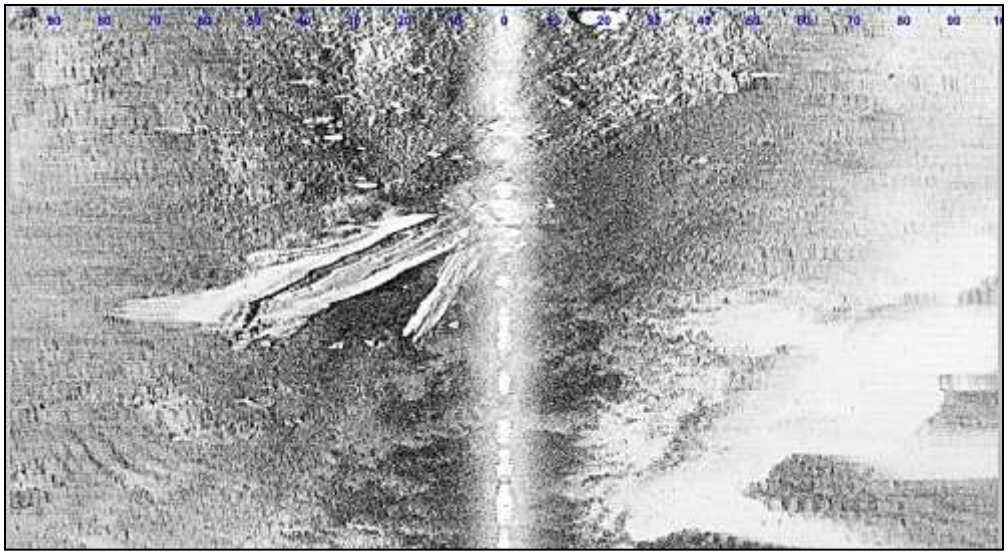


Figure 6-5: Additional uncharted wreck found in Buzzards Bay data that was not part of the NOAA reconnaissance effort.

Through the Klein sidescan waterfall analysis, nine uncharted wrecks were also identified. Five were found in time for the *Thomas Jefferson* reconnaissance effort and were resurveyed for more accurate least depths. The remaining four (along with additional navigationally significant rocks) were sent to NOAA project managers as suggestions for additional work.

After thorough analyses, the Buzzards Bay data were determined adequate to supersede prior data and are intended for chart compilation. These data meet the horizontal and vertical requirements for CATZOC (Categorical Zone of Confidence) A2 but lack the additional coverage and accurate least-depths over all identified significant features, making these data CATZOC B. Details on where further investigations are needed have been shared with NOAA OCS Operations to plan for the NOAA ship Thomas Jefferson. These data have been submitted to AHB.

Findings from the analyses of these data were presented at both the NOAA Field Procedures Workshop in January 2016 and the Canadian Hydrographic Conference in May 2016 with JHC researcher Val Schmidt. Best practices from the analyses of these data will be compiled into a standard operating procedure (SOP) document for future interferometric data analysis and integration.

Analysis of Chincoteague Inlet:
Similar to the Buzzards Bay data, the same USGS group acquired data over two years off the Delmarva Peninsula. The best practices learned from processing the Buzzards Bay data set were utilized on these data.

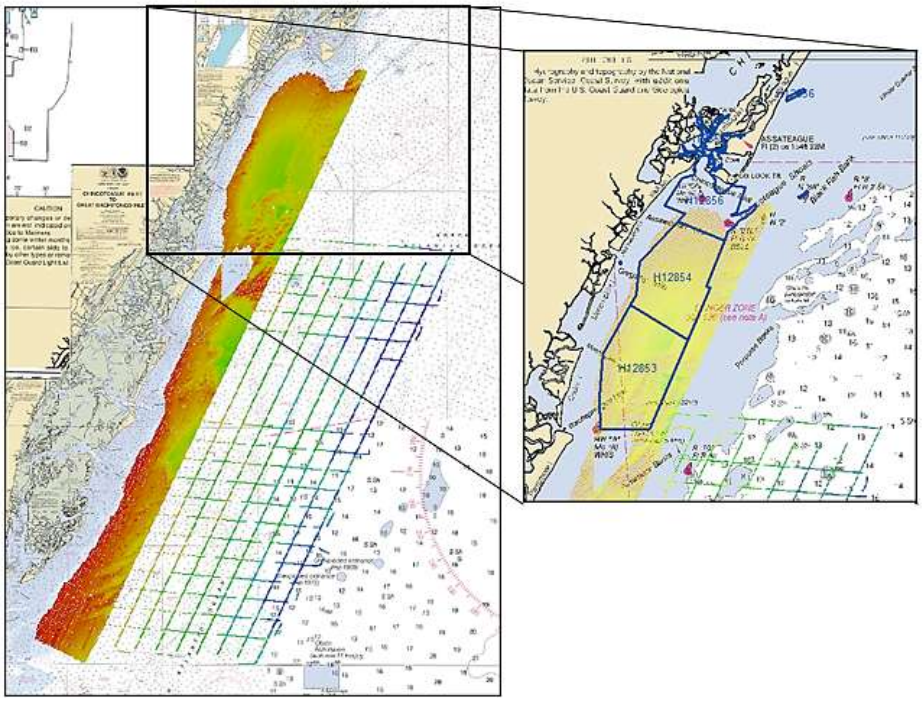


Figure 6-6: USGS Chincoteague 2015 survey over charts 12210, 12221, 12211, and 12200. Subset: Chincoteague 1m grid with Thomas Jefferson 2015 field sheets (blue).

The dynamic environment of the Delmarva Peninsula caused refraction problems to be consistently present yet randomly distributed throughout the bathymetric and sidescan data. It is for this reason that these data have been recommended to be used solely for general trends in bathymetry and reconnaissance work.

Environmental challenges may have prevented the bathymetric data density from meeting NOS standards. Only 60% of these data had five soundings per node. Previously analyzed USGS interferometric data had density problems only with the areas nearest nadir – a common problem amongst all interferometric systems. However, these data had density problems primarily found on the outer edges of the swath. This data quality degradation is likely due to rough survey conditions.

In comparison with recently collected NOAA ship *Thomas Jefferson* bathymetric surveys H12854 & H12856, the USGS Chincoteague data were found to be consistently deeper by ~0.25m. The most notable differences between the TJ data and the USGS Chincoteague data were the lack of evidence for known features and additional proof of refraction artifacts. A closer look at the missed feature revealed that it was not only missed in the surface/soundings, but nothing of significance was found in the Edgetech sidescan mosaic. This is likely due to the feature's proximity to nadir.

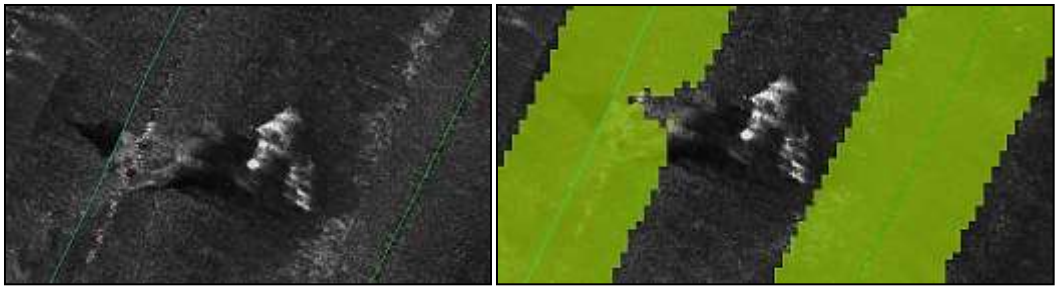


Figure 6-7: Left image represents the shipwreck feature in the sidescan mosaic and the image is of the same object with the 1m bathymetric surface over the backscatter mosaic.

As no raw sidescan files were provided for this analysis, only a visual analysis of the published USGS sidescan mosaic coupled with the bathymetry was done. A number of potential features and one definite wreck were identified through this method. Additional coverage and investigations were recommended to NOAA Operations project managers.

It was recommended that these data be solely used for charting reconnaissance and general trends in bathymetry. The refraction problems found throughout these data could prove to be too risky for chart compilation. Best practices from these data will be compiled into a standard operating procedure (SOP) document for future interferometric data analysis and integration.

Analysis of Cuttyhunk:

In addition to Buzzards Bay, the USGS acquired data in and around Cuttyhunk, Elizabeth Islands, and Vineyard Sound. These data have been processed using the techniques developed from previous analyses and submitted for review (Figure 6-8).

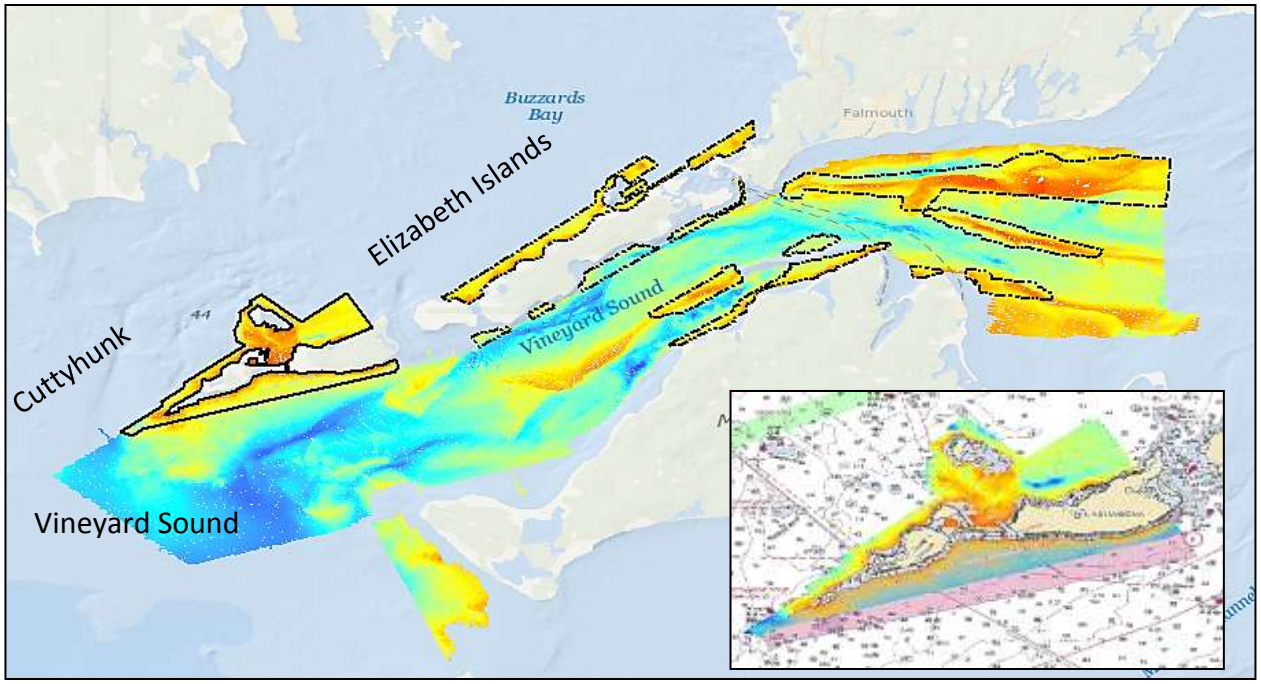


Figure 6-8: The additional areas collected by USGS. Solid outline area is Cuttyhunk, dotted outline areas are the Elizabeth Islands, and the rest of the bathymetric coverage falls under Vineyard Sound. The subset image is of the Cuttyhunk 2m grid and the NOAA ship Thomas Jefferson's 2008 H11921 survey represented by the pink polygon.

Analyses of Cuttyhunk shows that the region of the chart over the Northern section of Cuttyhunk has not been updated since 1976 thus the USGS data coverage will be useful. The South Cuttyhunk USGS data overlaps with NOAA ship *Thomas Jefferson* H11921 survey two years prior to the USGS survey, which provides a great opportunity for comparison. However, the southern Cuttyhunk USGS data is not likely to be recommended for chart updates due to the proximity in time of the surveys, higher quality of the 50cm H11921 grid, and previous application to the chart. The TJ bathymetry along the south side of Cuttyhunk was consistently ~0.20m shoaler than the USGS data.

Similar to the Buzzards Bay data, individual contact identification from the sidescan waterfall has been deemed too time consuming. Instead, only the largest contacts in rocky areas have been identified and general caution areas are to be included in feature file compilation. From the sidescan analysis, one uncharted shipwreck was identified and considered a DTON due to the shallow nature of this survey. Interference is also clearly present throughout the survey and is seen in both the sidescan waterfall and the published USGS mosaic.

Multiple large rocks were identified in the sidescan, but accurate least depths were not able to be identified due to noise. It was recommended that additional coverage be collected over these designated areas.

Improving Communication/Reuse of Data:
The results of the above analyses were compiled into multiple documents and reports upon completion of this project:

- Reports describing the individual data sets including the analyses and results and overall recommendations for each survey area that will be sent to the Atlantic Hydrographic Branch with accompanying data files.
- A standard operating procedure (SOP) was created to aid in the analyses of future outside source interferometric data intended for chart compilation. This document incorporated the lessons and techniques learned from all interferometric data processed during this project and was sent to the appropriate NOAA personnel for distribution.
- A brief document describing recommendations on future projects for both the USGS and NOAA to mutually benefit each other's priorities was created and is under review. This report will be shared with both parties with the hope of beginning discussions about approaches to collecting mutually beneficial data sets.

State of Maine Multibeam Data Assessment and Processing for Application to the Nautical Chart

The JHC IOCM Group is working to repurpose multibeam data collected by the State of Maine Coastal Mapping Program (MCMP) (Figure 6-9). The bathymetric data was originally collected for beach sand renourishment post-Super Storm Sandy and is being post-processed for ingestion into the Office of Coast Survey charting pipeline and application to the chart. Some regions of the chart have not been updated since before 1900 and were mapped with lead line. Data were collected with an Kongsberg Maritime EM2040c as part of a multiyear mapping cooperative agreement between the State of Maine and the Bureau of Ocean Energy Management.

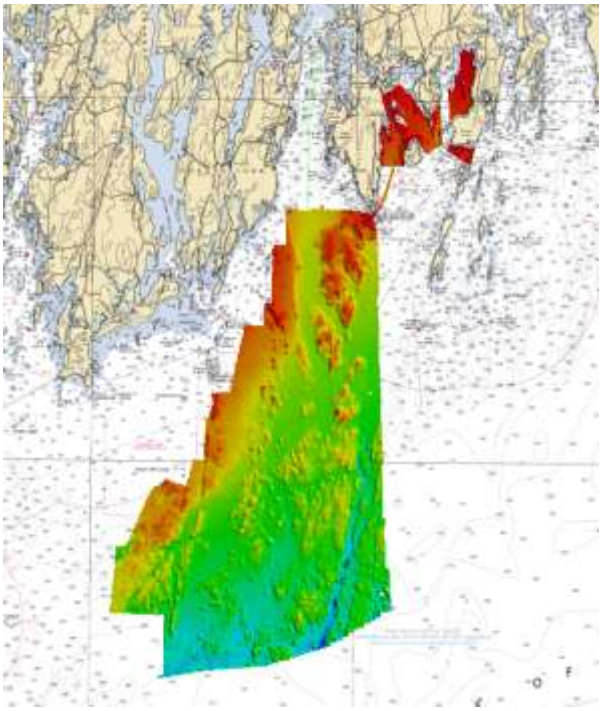


Figure 6-9: EM2040c multibeam coverage in Booth Bay, Sheepscot Bay and the Gulf of Maine to be submitted to the Office of Coast Survey.

The IOCM center has received the 2015 data submission from the State of Maine and coordinated between QPS and CARIS the development of a reformatted GSF file compatible with both software packages. The Center has received the reformatted data, analyzed, cleaned, computed TPU, and created surfaces to best meet formats and standards for ingestion into OCS pipeline.

NJ/ NY: FEMA & State/Local Funded Sidescan & Single Beam to Chart

The tremendous amount of post-Super Storm Sandy acoustic data collected for the purpose of determining if channels needed dredging and debris detection presents an excellent opportunity to update charts in these areas. A large amount of sidescan and single beam data were collected with Federal Emergency Management Agency (FEMA) funds to states and local communities, and many state and local agencies will be continuing to collect at least single beam data in the future. While some agencies may have interacted with NOAA in the past, the effort to bring the Sandy data to the chart is an opportunity to coordinate with state and local communities.

A. New York

Single beam data exists for the Town of Hempstead Bay, NY that they would like applied to the chart. The IOCM team has given MCD the first phase of the Coastal Composite Bathymetry (CCB) Project for New York.

B. ***New Jersey Department of Transportation Data to the Chart***

New Jersey plans to perform repeat acoustic surveys of all of its more than 200 state maintained channels on a regular basis, and will be dredging as needed. Initial data collection started as of November 20, 2014. A conference call with New Jersey Department of Transportation (NJ DOT) in February relayed recommendations on how to ease ingestion into MCD in the future. Post-Sandy NJ DOT data has made its way through MCD's Nautical Data Branch and a decision on how best to apply it to the chart has been made. MCD was nearing completion of charts updates for New Jersey in late Fall 2016.

C. ***New Jersey Department of Environmental Protection Marina Data to the Chart***

New Jersey Department of Environmental Protection (NJ DEP) contracted bathymetry surveys of ~30 marinas impacted by Sandy. Pre- and post-dredge single beam surveys were conducted throughout the eastern portion of the state. These data were received after the initial data was processed for the CCB Project for New Jersey, and thus it was suggested that these data be submitted separately through the hydrographic processing branch (in this case Atlantic Hydrographic Branch). These data are in areas heavily used by vessels, but deeper than the typical LIDAR coverage for turbid New Jersey bays.

MARINE DEBRIS CHARTING WITH OUTSIDE DATA

Super Storm Sandy created a great deal of marine debris in navigable waters, especially in New York and New Jersey. Different agencies and groups within the Sandy-affected region received FEMA funds to map debris, and to remove the debris that was considered a navigational hazard. The Sandy IOCM contract team has been conducting assessments of FEMA and/or state-funded marine debris identified but not removed for updating navigational charts. Additional reports and analyses collected and analyzed by the Sandy IOCM team are discussed in the marine debris reports section.

Marine Debris Accounting:
Over the past two years work-flows have been developed to account for marine debris through the extraction of information from databases or documents. These were presented at the 2016 ESRI Oceans Conference by Michael Bogonko, where he highlighted workflows developed in ArcGIS along with other debris related workflows and recommendations. One of the challenges of implementing and making recommendations for improved data collection standards is understanding how different groups record data on debris. The types of debris information collected with NOAA marine debris funds tends to pertain to debris found along the shore rather than debris completely submerged in deeper vessel traffic areas, and grant recipients focus funds on removal of known debris, not surveys of submerged debris. This is in contrast to professional sidescan surveys designed to find submerged debris, which are integral to the removal process. Each state and/or local entity applies for funds through FEMA, but there has been little guidance on recommended practices of how to share data and what formats would be useful. Thus many groups only produce textual documentation of work completed, and formats vary widely even within a single project. The IOCM team has been working on example templates of how to provide data, as well as SOPs and best practices to share with FEMA and other marine debris response stakeholders through the NOAA Marine Debris Program. In the future it would be best if contractors deliver detailed data attributes and provide data in a GIS format, with tables easily ingestible for analysis in ArcMap or by other programs and scripts (e.g., Excel, Python, or Matlab, etc.) in addition to Adobe PDF reports.

The IOCM contract team has also continued to make suggestions to the terminology used (ontology), through the use of a marine debris markup language developed by Giuseppe Masetti and Brian Calder.

B. LIDAR DATA TO THE CHART

1. Composite Coastal Bathymetry Project

The massive post-Super Storm Sandy response, and the data collection associated, has provided an opportunity to update small craft charts through the Coastal Composite Bathymetry (CCB) Project. Many of the contours and morphology depicted on small craft charts throughout the Intracoastal Waterway of the eastern U.S. are out of date. In the case of the Delmarva Peninsula many of the back-bay chart soundings date from the 1800s. Most of these charts do not have source diagrams and the CATZOC for much of the data, with the exception of more recently charted dangers to navigation, is unknown. The CCB Project, spearheaded by Shachak Pe'eri and NOAA's Anthony Klemm has brought the efforts of the IOCM team's data assimilation procedures into a new workflow. Using the data coverage found by the IOCM team as part of its GIS database effort, a new collaborative workflow has been developed. The composite bathymetry and original data are shared directly with the NOAA Marine Chart Division (MCD) for their evaluation and use in improving the adequacy of the 1:40000 scale charts of New Jersey and New York.

The CCB project collaboration has resulted in a NOAA Technical Memorandum drafted by Pe'eri and Klemm in collaboration with IOCM and MCD. Products delivered to MCD include bathymetric digital elevation models (DEM) or grids of data collected within chart boundaries accompanied by shapefiles of coverage areas with associated attribute tables containing information related to the quality of the data. These attribute tables or M_QUAL (mandatory quality of data attribute) tables contain critical data adequacy information such as category of zone of confidence (CATZOC). The IOCM Center organized and provided all supporting documents gathered to determine M_QUAL information (Figure 6-10). A final merged grid will also be provided. Features/debris information is being handled as a separate analysis when appropriate data is available.

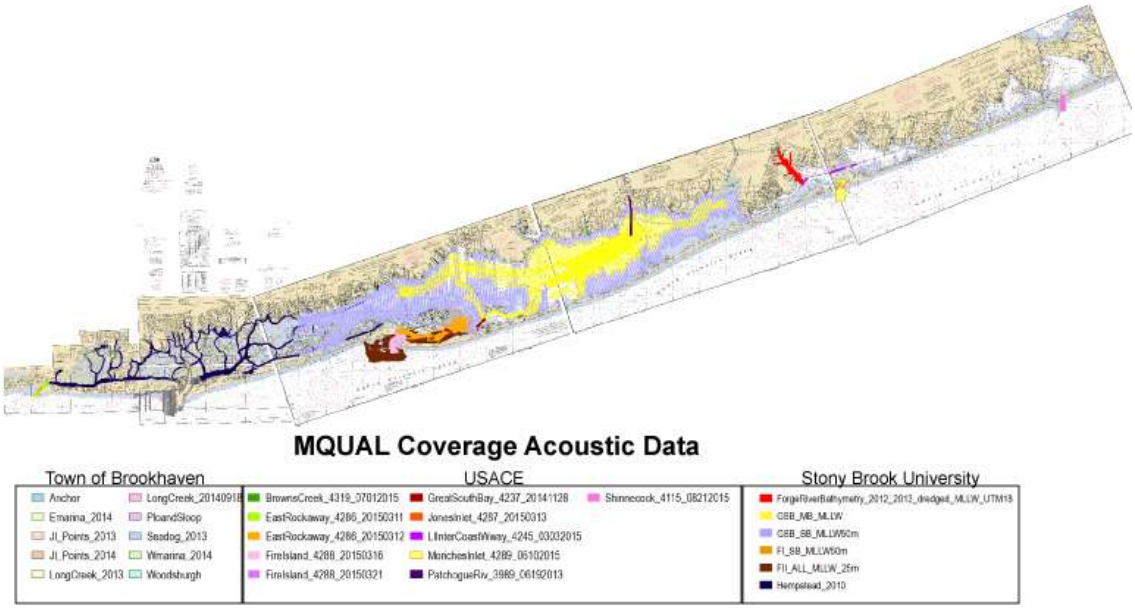


Figure 6-10: Coverage Map showing polygon coverage of data sets used in the CCB Project for Long Island, NY.

2. Remote Sensing Division LIDAR to Office of Coast Survey for Charting

In response to Super Storm Sandy, NOAA's Remote Sensing Division (RSD) collected topo-bathymetric LIDAR data along the eastern seaboard, from South Carolina to New York to update the National Shoreline. We have collaborated with RSD and NOAA's Office of Coast Survey (OCS) to process the bathymetric LIDAR so that it could be used to update the chart and make recommendations on tools and procedures to help OCS process future LIDAR data.

We received RSD LIDAR, imagery and shoreline data that covered the outer coast and inlets. This was broken down into four sections: New York, New Jersey, Delmarva Peninsula, and South/North Carolina (Figure 6-11). All four regions have been processed and submitted to the Atlantic Hydrographic Branch. Two workflows were documented, one using CARIS HIPS that could be utilized by the hydrographic branches and one using LP360 for ArcGIS for internal

reference. Observations regarding processing and data quality have been documented to share with partners and to aid management in decisions on how RSD LIDAR should best be applied to the chart.

In addition to the South Carolina to New York dataset, RSD collected data in Fisher's Island, NY post-Sandy with a Riegl VQ820G. This dataset was collected in a more sheltered environment and had different settings resulting in lower water column noise, and provided better illumination of submerged features. This led to the development of an alternative method to highlight and identify features based on filtering and gridding the data by class and height (Figure 6-12).

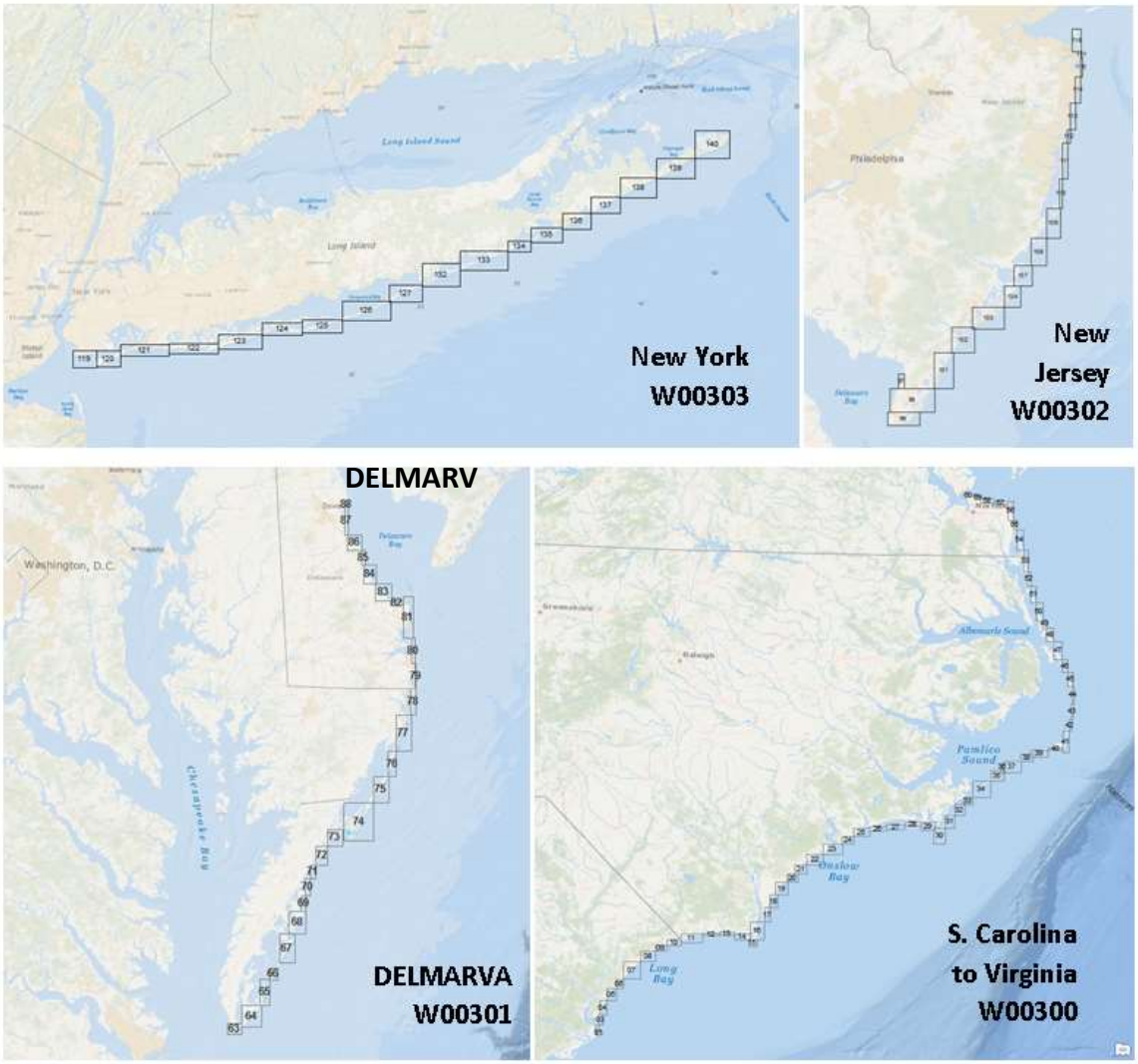


Figure 6-11: The four regions of outer coast and inlet data examined and processed for charting by the Sandy IOCM Group.

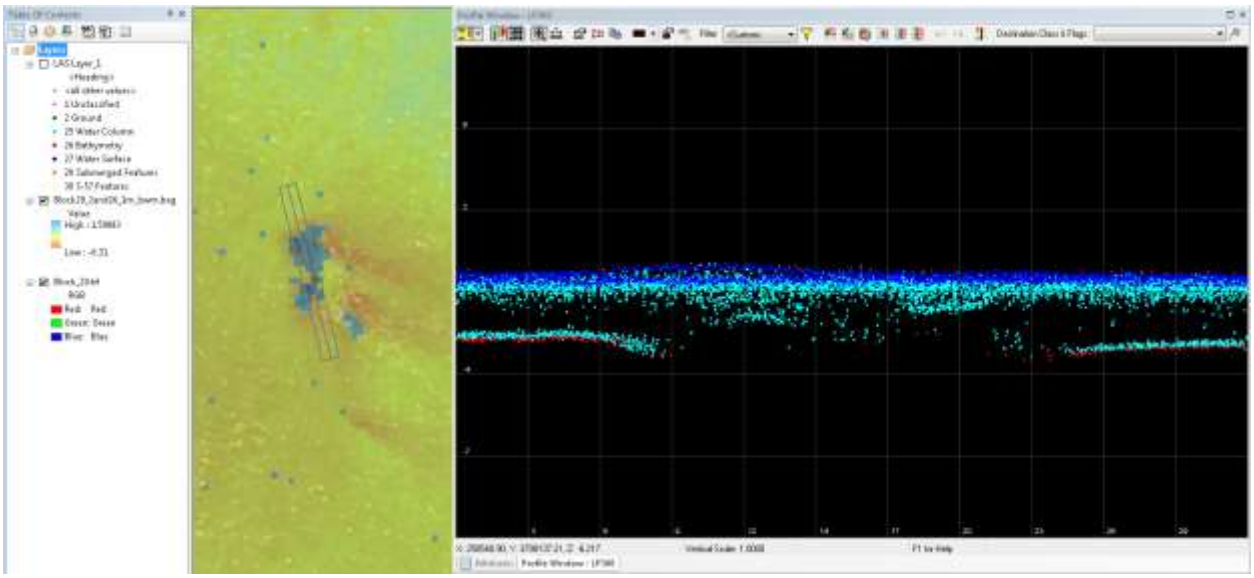


Figure 6-12: Example of submerged feature detected by lidar. The feature is included in the watercolumn class (turquoise points) and is therefore excluded from the grids created from the bathymetry class (red points), hence the hole in the surface on the left.

C. GENERATION OF HABITAT/SEDIMENT MAPS, BACKSCATTER & REFLECTIVITY MAPS

1. Acoustic Backscatter and LIDAR Reflectivity Maps

The Sandy IOCM team is using OCS-collected bathymetric data and USGS EAARL-B bathymetric LIDAR data to create acoustic backscatter and reflectivity maps. It is the intention that these map products be used as a more accurate overall representation of the seafloor and eventually lead to the creation of seafloor characterization for specific areas of interest.

1.2: USGS EAARL-B Processing Waveforms/ "Reflectivity"

This project focuses on processing waveforms statistics and extracting information from the ALPS software system that is not found in the published LAS files and DEMs for the USGS EAARL-B LIDAR surveys. Workflows and SOPs have been generated by Juliet Kinney in collaboration with the USGS and Center affiliate Chris Parrish, and Erin Nagel for using ALPS on EAARL-B data. The focus for this exercise has been a pre- and post-Sandy data set from Barnegat Bay where ground truth data also exists (Figure 6-13).

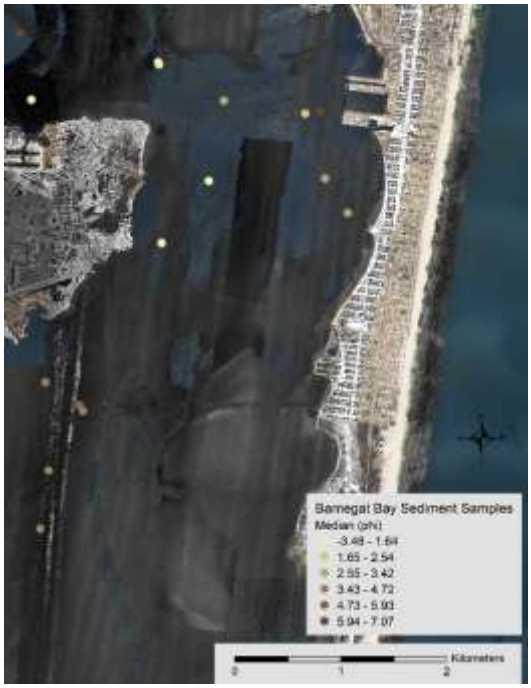


Figure 6-13: North Barnegat Bay EAARLB Channel 4 Reflectance Output with location of USGS Sediment Samples. Background imagery is NOAA RSD imagery flown in 2014 within approximately two weeks of the LIDAR collection.

1.3: RSD LIDAR Intensity/ "Reflectivity"

The goal of this project is to generate intensity/reflectance grids for post-Sandy affected areas and to make them available to users for different mapping purposes (Figure 6-14). The RSD 2014 data were collected using a Riegl VQ820G system. The data coverage was along the Atlantic coast covering 2,775 square miles from New York to South Carolina. White and Bogonko have developed a reflectance processing protocol for the RSD Riegl data (collected by Dewberry) with assistance from Parrish. This builds on previous work done by Jenn Dijkstra, Parrish and others at the Center in conjunction with the Sandy Grant.

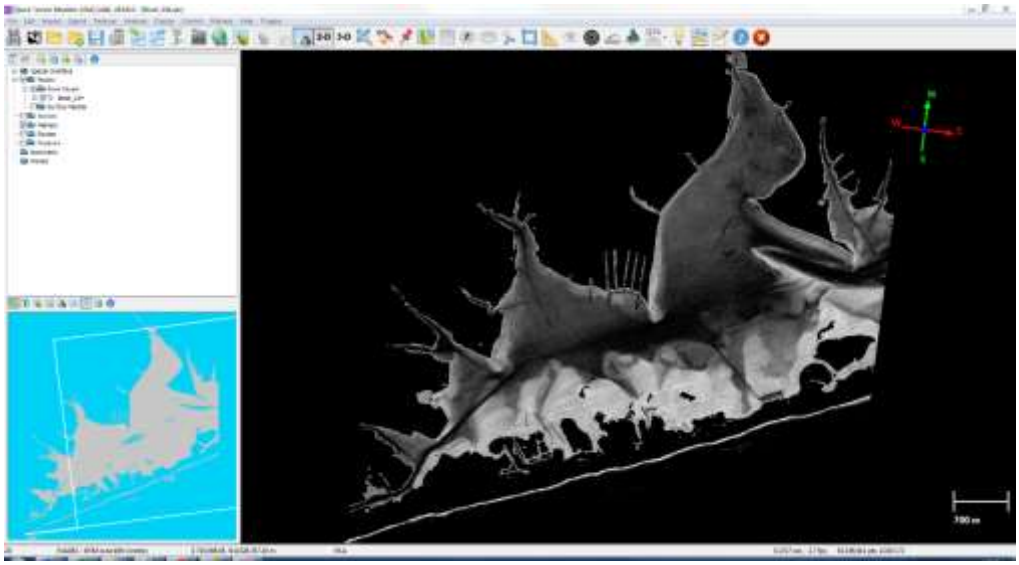


Figure 6-14: Example of Intensity of seabed from Eastern Long Island, NY that is uncorrected for depth and attenuation in Quick Terrain Modeler.

D. Development of Other Mapping Products: Marine Debris

1. Marine Debris Identification using Lidar Data

The NOAA Marine Debris Program (MDP) works to assist states and local entities to remove debris from their waterways quickly after storms and other disasters. They are particularly interested in removing debris, both submerged and above the low tide line, that otherwise would not be removed by another responsible party. Often only debris in channels identified as a danger to navigation is removed by municipalities, largely using FEMA funds. The IOCM Center is attempting to support the work of the MDP by creating workflows that outline approaches to identifying debris in LIDAR data using tools available to local resource managers.

The team has acquired debris data from: New York State, Town of Hempstead, NY, Nassau County, NY, New York City Parks through NOAA MDP, data directly from FEMA, NJ and NY National Wildlife Refuges, and Connecticut Department of Energy and Environmental Protection to help with this task. Work has focused on a narrow strip within Jamaica Bay in New York City that had a great deal of large debris along the shoreline and in the marshes (boats and docks) that are visible in satellite imagery (Figure 6-15). One of the challenges is finding ways to highlight the proper height range of the data to visualize debris, and how to best trim data sets to regions of interest. Intensity is another variable that may be useful for marine debris detection above mean lower low water.

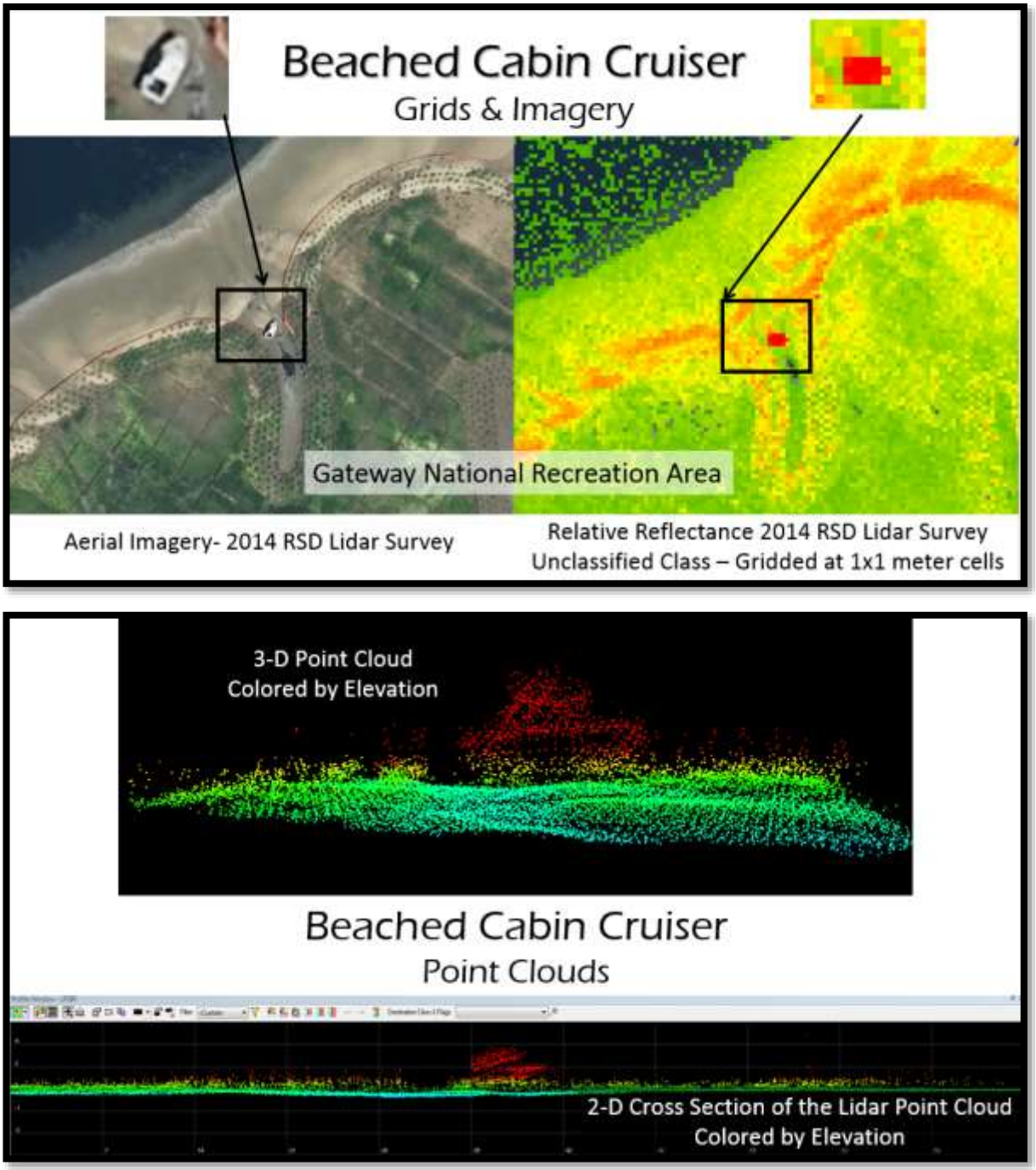


Figure 6-15: Methods to visualize debris include optimizing color scales of elevation point clouds as with this beached Cabin Cruiser.

E. Other IOCM Interactions

1. Seasketch Update

NOAA's Interagency Working Group on Ocean and Coastal Mapping, in conjunction with 3DEP (the 3D Elevation Program), currently uses an ESRI SeaSketch site to manage and plan the mapping efforts of participating state and federal agencies in order to fulfill their goal of interagency cooperation and coordination. The IOCM team has kept the site up-to-date by publishing all current and future mapping projects as well as maintaining the ones already on the site. This is done by processing shapefiles in ArcMap, editing their symbology, and publishing to NOAA's public server. The goal is to have each shapefile use a standard set of schema that will include a point of contact and data type in order to better communicate and organize plans across agencies. This year saw the incorporation of NOAA's 2016-2017 Fleet Allocation Plans to the site (Figure 6-16).

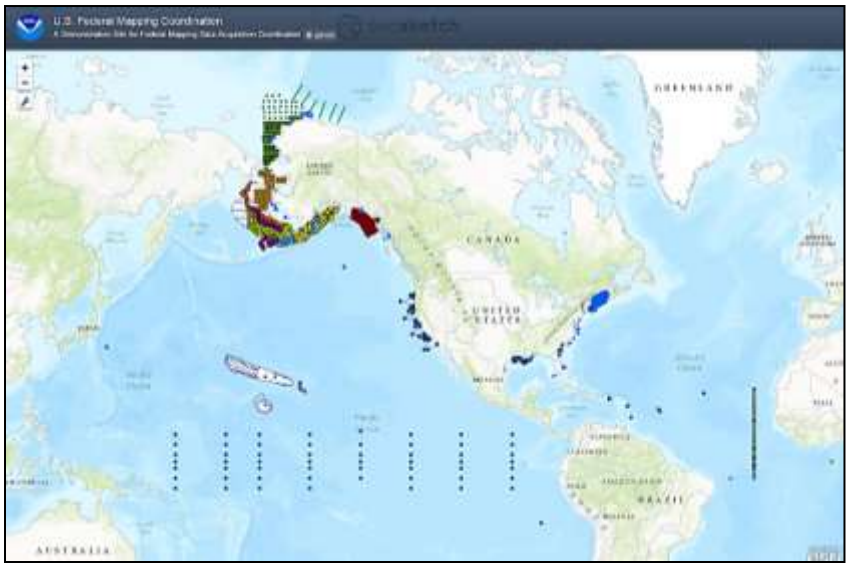


Figure 6-16: NOAA 2016-2017 Fleet Allocation Plans on the SeaSketch Site.

2. NOAA CO-OPS Tide Zone Maps for Public Access

The IOCM team is working with the NOAA Center for Operational and Oceanographic Products (CO-OPS) on ways to visualize and share tidal zone data online. In support of the Sandy contract analyses, the NOAA Center for Operational and Oceanographic Products (CO-OPS) provided tide zones, co-tidal, and co-range lines for the Sandy-impacted region. Using these data, a prototype was developed by the IOCM team that would enable public sharing these data via a web interface (Figure 6-17). CO-OPS has reviewed the prototype internally and decided to move forward with a modified product that contains only recently updated zones. CO-OPs will develop this product by late January, 2017.

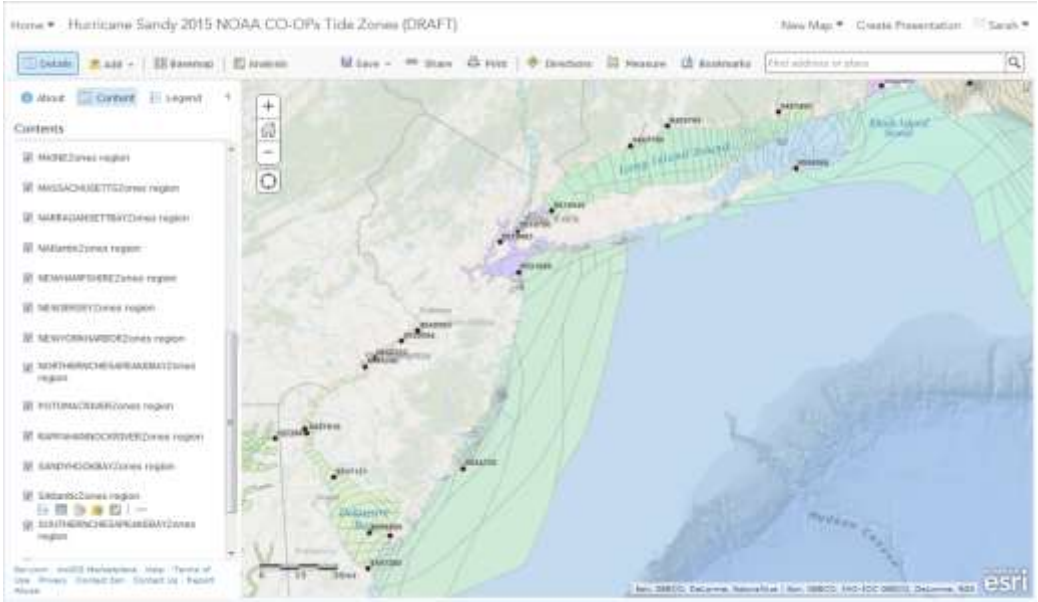


Figure 6-17: CO-OPS tide zone data and active water level stations for Hurricane Sandy effected region.

2. CMECS and the OCS bottom sample archive

The IOCM team has been working with NOAA on the implantation of the Imaging Grab Sampler (see HABITAT theme) and its application to habitat mapping. A specific focus of the effort is to incorporate the imagery collected into the NOAA-accepted habitat classification scheme, CMECS. The IOCM team has been working on this task with others in the IOCM community. In collaboration with Mark Finkbeiner, Melody Ovard, and Jay Lazar and others, the IOCM team helped to assess overlap between CMECS and S-57 definitions. Finkbeiner and Lazar were able to generate a crosswalk based on S-57 definitions provided by Kinney, White and Ovard (Figure 6-18). The first goal is to agree upon a set of file formats, with metadata, naming conventions, and inputs specified that is compatible with OCS workflow, National Centers for Environmental Information needs, and in a format that stakeholders can utilize.

S57 to CMECS Crosswalk	
Nature of Surface	**CMECS**
Mud	**Mud Substrate** - *Substrate Group* (SC)
Clay	**Clay Substrate** - *Substrate Subgroup* (SC)
Silt	**Silt Substrate** - *Substrate Subgroup* (SC)
Sand	**Sand Substrate** - *Substrate Group* (SC)
Stone	**Gravel Substrate** - *Substrate Group* (SC)
Gravel	**Pebbles Substrate** - *Substrate Subgroup* (SC)
Pebbles	**Granule Substrate** - *Substrate Subgroup* (SC)
Cobbles	**Cobbles Substrate** - *Substrate Subgroup* (SC)
Rock	**Rock Substrate** - *Substrate Class* (SC)
Lava	**Rock Substrate** - *Substrate Class* (SC)
Coral	**Coral Substrate** - *Substrate Class* (SC)
Shells	**Shell Substrate** - *Substrate Class* (SC)
Boulder	**Boulder Substrate** - *Substrate Subgroup* (SC)

Figure 6-18: Crosswalk Table by Mark Finkbeiner of S-57 and CMECS definitions of seafloor substrate composition. The hope is that such a conversion could become an automated step within Pydro.

THEME 5: NEW AND INNOVATIVE APPROACHES FOR THE 3D AND 4D VISUALIZATION OF HYDROGRAPHIC AND OCEAN MAPPING DATASETS, INCLUDING BETTER REPRESENTATION OF UNCERTAINTY AND COMPLEX TIME- AND SPACE-VARYING OCEANOGRAPHIC, BIOLOGICAL AND GEOLOGICAL PHENOMENA

Short name: **VISUALIZATION**

The Center continues to have a very strong focus on the development of innovative approaches to data visualization and the application of these approaches to ocean mapping and other NOAA-related problems. Over the past few years, the visualization team (Arsenault, Butkiewicz, and Sullivan), under the leadership and direction of Lab Director Colin Ware, have produced a number of novel and innovative 3D and 4D visualization tools designed to address a range of ocean-mapping applications (see earlier progress reports). Efforts this year (under this grant) have focused on the research designed to enhance the display and understanding of environmental (currents, flow, etc.) data including uncertainty, and innovative approaches for interacting with complex ocean mapping data sets,

VISUALIZING CURRENTS, WAVES AND WEATHER:

The Center is continuing to work on portrayal of meteorological data for the navigator, including currents from operational flow models, sea state from the Wavewatch III model and weather from NOAA Mesoscale operational forecast models. This work has been bolstered by a substantial grant from ONR to supply these sorts of data to the submarine community in compact form.

Based on earlier work of the Center in collaboration with the NowCoast project, the capability to display *animated* harbor and near-shore flows patterns from operational forecast models is now available even with low end laptop and desktop computers, tablets, and even some smart phones. The same technologies can be used to portray wind and wave forecasts. However, the best way to use an animation to portray this information has received little attention by the community.

Animation has two major advantages: it can be used to portray dynamic changes in flow patterns over time, and animated transparent flow patterns generate less interference with the visibility of other chart information. Work on the theory of flow portrayal (Ware and Plumlee 2013; Ware et al., 2014) suggests that visual channel theory can be applied to the problem. Different regions of the brain's visual cortex are devoted to static and moving patterns. This allows a person, when looking at a display that has both static and moving elements, to focus attention on either the moving elements or the static elements.

FLOW PATTERN IDENTIFICATION STUDY: ANIMATED VS STATIC PORTRAYAL

The visualization of 2D vector fields has applications including surface ocean currents, surface winds and waves. Significant effort has gone into determining the most effective method for *statically*

representing these patterns but the use of animation to show flows and other vector fields has not been previously evaluated despite this being a common practice. The fact that flow patterns inherently involve movement suggests that animation should be an intuitive model of representation. Also, it is possible that an animated version of a pattern may be easier to perceive than a statically represented version of the same pattern.

We now have completed two experiments comparing the best static flow visualization methods with animated streamlets. The results (summarized in Figures 7-1 and 7-2) strongly support using animation to show 2D flow patterns. Both of the animated methods cut error rates roughly in half in a pattern search experiment (Figure 7-1) and one of the animated methods was also the best in an advection path tracing task (Figures 7-2 and 7-3).

What these results mean is that the best possible representation of flow data is likely to be animated. This supports previous work we have done showing that animated transparent flow patterns interfere less with underlying data layers.

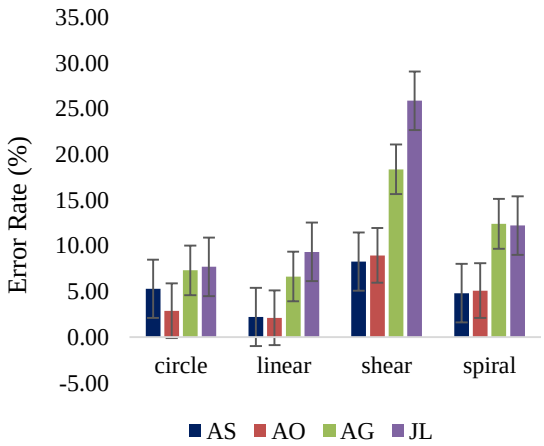


Figure 7-1: Results. Mean error rates for Experiment 1, comparing different methods for visualization of vector flow. AS: Animated streamlets. AO: Animated orthogonal particles. AG: Arrow Grid. JL: Equally spaced streamlines using the Jobard and Lefer algorithm.

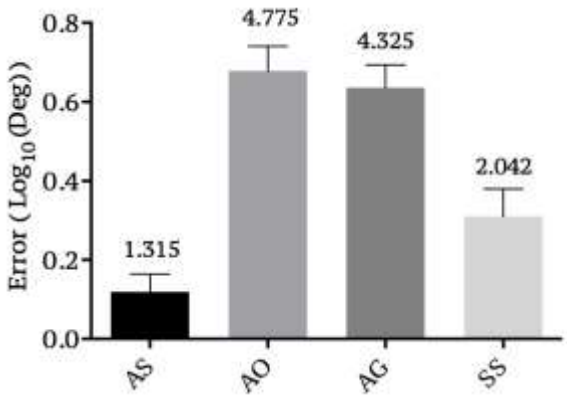


Figure 7-2: Mean log errors for Experiment 2, showing lower error rate for Animated Streamlines) Anti-log values are provided above each bar. AO: Animated orthogonal particles. AG: Arrow Grid. JL: Equally spaced streamlines using the Jobard and Lefer algorithm.

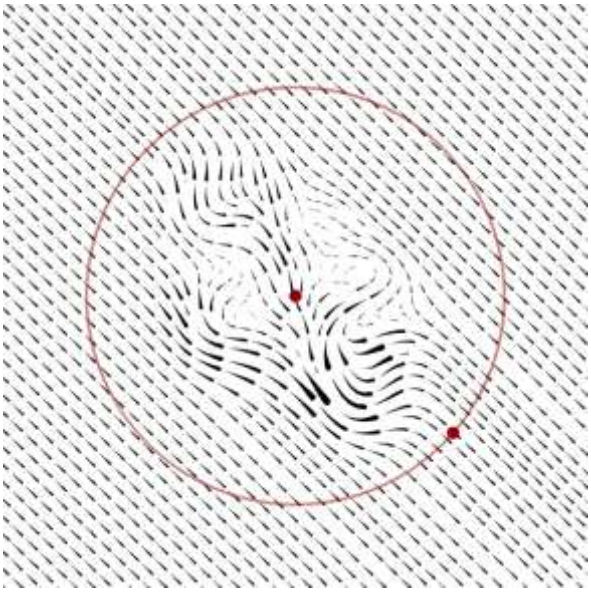


Figure 7-3: A screen from Experiment 2. The participant has placed the dot on the circumference of the circle to indicate where a particle dropped at the center would exit the circle.

LIMITS OF INFORMATION DISPLAYED BY VECTOR FIELDS

There is increasing interest in smaller visualization-optimized data products that will be easier to load on devices such as cell phones and tablets. Most mariners have data bandwidth restrictions meaning that more compact data will have a greater chance of being used. Unfortunately, many weather and current models produce very large files as output (e.g., hundreds of megabytes) making them inaccessible to the mariner due to bandwidth limitations. The cognitive costs in terms of efficient decision making for even short delays in access to information have been well documented. A solution to this is data compression, combined with extraction of the components of files most relevant to safety of navigation.

How do we decide what is an acceptable loss from compression or sampling? There are a number of possible criteria based on perception. The most stringent is the just noticeable different (JND). If an image is degraded by less than a JND then it is reasonable to argue that no information is lost. However, there are also cases where we are willing to accept visualizations where there is some loss in quality if the features of scientific interest are preserved. For example, many scientific videos shown on YouTube are highly compressed but still useful.

In the case of vector fields, it seems likely that different methods of representation are capable of showing different amounts of detail in a flow pattern. But currently we do know whether a conventional arrow grid, a method using parallel streamlines, or a method based on particle traces will provide the most detail. In addition, we do not know how much compression can be applied to the data before compression artifacts will become visible for different types of visualization. It is notable that the arrow grid method (still the most commonly used) reveals far less detail than the other two methods.

We are developing both a methodology and a series of studies to look at perceptually lossless compression for visualization using both Amazon Mechanical Turk (AMT) and conventional laboratory experiments.

Figure 7-4 shows an example of ocean flow model data that has been compressed approximately 100x (blue lines) compared to the original model data (red). The actually amount of data that would be required to transmit this sample is only 8kB. This would make it possible to transmit a time series of winds, currents, or waves from a two day forecast.

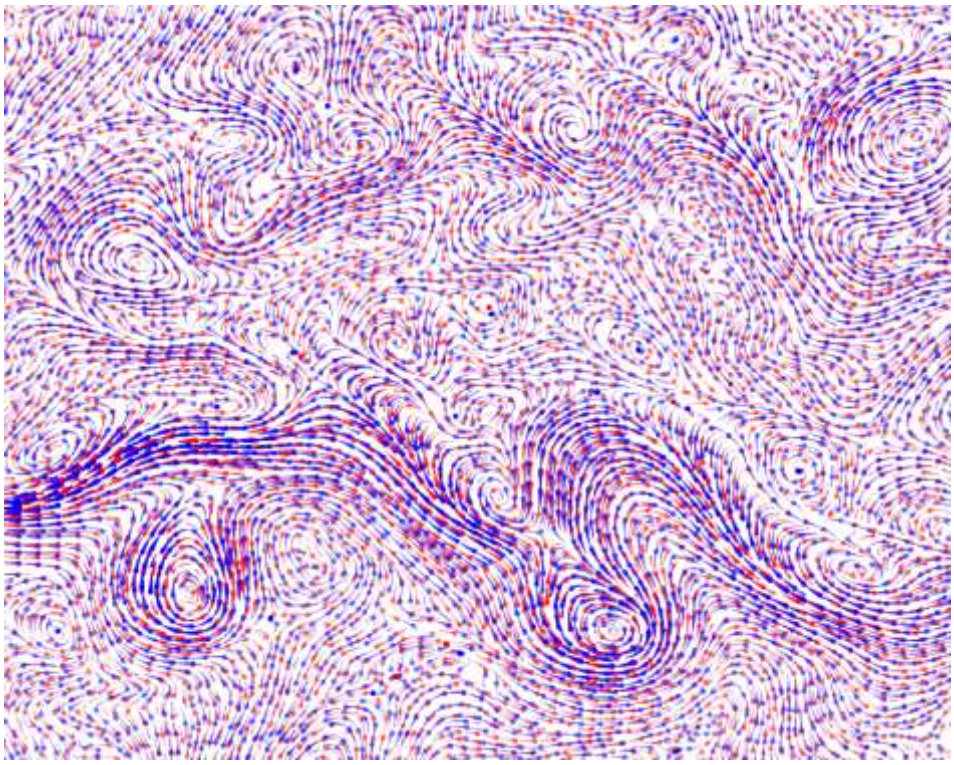


Figure 7-4: Part of an ocean flow model showing the Kuroshio Current. The red streamlines were computed using the uncompressed data. The blue lines were computed with approximately 100x compression applied.

HAIRY SLICES

Three-dimensional vector fields are common datasets throughout the sciences. Visualizing these fields is inherently difficult, due to issues such as visual clutter and self-occlusion. Cutting planes are often used to overcome these issues by presenting more manageable slices of data. But, although existing literature provides many techniques for visualizing the flow through these cutting planes, there is a lack of evidence regarding which are the most effective. We have carried out a quantitative human factors study to evaluate static monoscopic depth and orientation cues in the context of cutting plane glyph designs for exploring and analyzing 3D flow fields. The goal of the study was to ascertain the relative effectiveness of various techniques for portraying the direction of flow through a cutting plane at a given point, and to identify the visual cues, and combinations of cues involved, and how they contribute to accurate performance in identifying flow direction. It was found that shaded tubular structures convey orientation better than lines and increasing their diameter intensifies this benefit (Figure 7-5, furthest right)). These tube-based glyphs were also less sensitive to visual clutter issues at higher densities. Adding shadows to lines was also found to increase perception of flow direction.

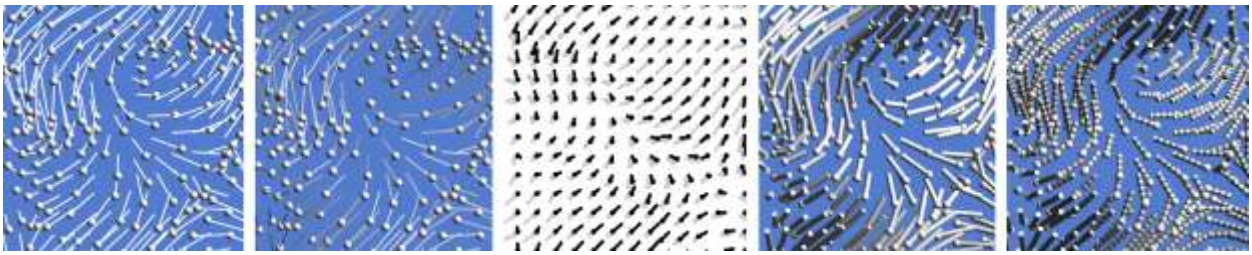


Figure 7-5: Hairy Slices though a vector field portrayed in five different ways.

WINDVIS2

Butkiewicz created a new version of Ware and Plumlee's WindVis2 weather visualization that is intended to generate live streaming video broadcasts rather than interactive local display. The visual elements, labels, and content have all been carefully simplified to better cooperate with video compression algorithms, which have difficulty compressing high-frequency elements and layered opacities. Visual simplification also reduces the required bandwidth for both the transmission and reception of the live stream. The automatic update functionality was improved and the build is very stable, running for weeks at a time without error. A leftover workstation was converted to a dedicated streaming machine, which sits in the Center Visualization Lab. It captures the visualization on screen, compresses it, and streams it to YouTube's servers. The live stream is available through the CCOMLive YouTube page and can be embedded into any website. We continue to live stream via CCOM's live YouTube account, and there have been a couple small server side fixes made to address stability issues.

NEW TOOLS AND APPROACHES FOR INTERACTING WITH COMPLEX DATA SETS

PANTOGRAPH MULTITOUCH STUDY

Butkiewicz and Ware previously developed the Pantograph multitouch technique for positioning and selection in stereoscopic 3D environments. In pursuit of providing a more comprehensive evaluation, Butkiewicz and Stevens modified Ware and Aygar's Halos visualization application to support Pantograph multi-touch interaction for 3D positioning (Figure 7-6). Specifically, a Pantograph 3D cursor widget allows the user to select "filaments," dense clusters of points along curvy paths. This task is inherently 3D and clumsy to use with traditional 2D interaction devices like a mouse. Task performance was compared between a mouse (using a scroll wheel to control cursor z-position/depth), Pantograph, and a Polhemus hand-held electromagnetic 3D tracked joystick. The Polhemus tracker was the highest scoring interface, presumably because of its one-to-one matching of 3D movement in front of the screen to cursor movement on the screen, however such devices are generally prohibitively expensive. Combined with previous evaluations which showed the Pantograph to be superior to other multi-touch 3D positioning techniques, we can conclude that although multi-touch is not the best way to position in 3D, for multi-touch interfaces the Pantograph technique is the best choice for 3D positioning.

Outside of the evaluation itself, we also experimented with extending the functionality of the Pantograph in Halos by utilizing its 4th degree of freedom (inter-finger angle) to intuitively change the tilt of the axis around which the point clouds rotate (to produce motion parallax visual cues).

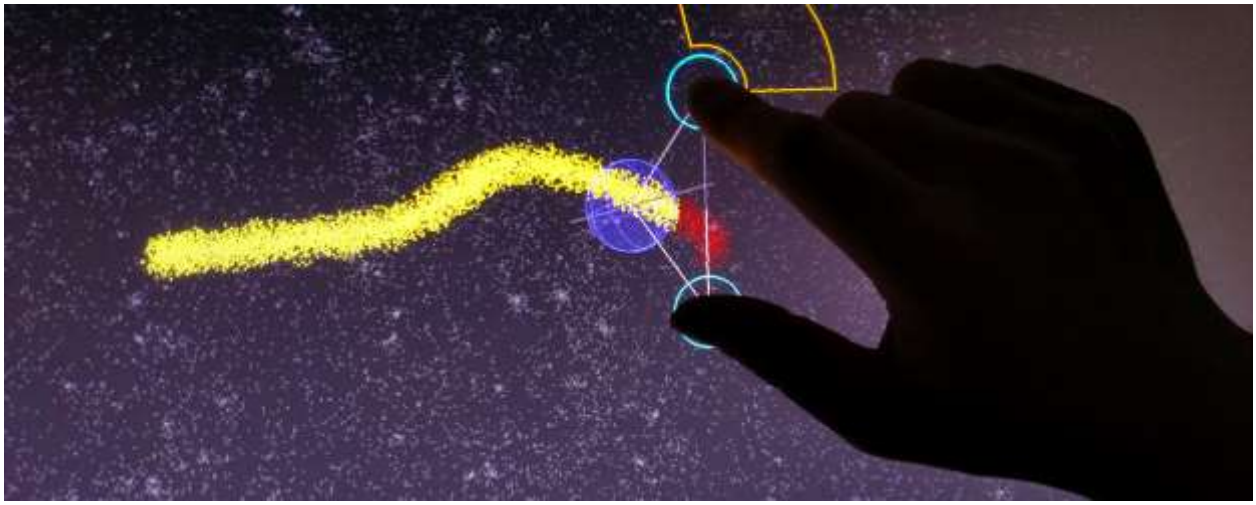


Figure 7-6: The Pantograph multi-touch cursor being used within the Halos application to select a filament of points.

THEME 6: DEVELOPING INNOVATIVE APPROACHES AND CONCEPTS FOR THE ELECTRONIC CHART OF THE FUTURE AND E-NAVIGATION

Short name: **CHART OF THE FUTURE**

The Chart of the Future project is an effort to define the components of the electronic chart of the future by taking advantage of our expertise in visualization, data processing, and navigation. We are taking a two-pronged approach to trying to define the electronic chart of the future. One track of this project is an evolutionary approach to see how additional, non-standard layers (e.g., the navigation surface bathymetric grid, real-time tide information, etc.) can be added to existing electronic charts. This approach requires careful attention to present-day standards and the restrictive constraints of today's electronic charts. This work is being done in conjunction with the standards committees (represented by Center researcher Briana Sullivan) 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 are pursuing a revolutionary development approach with researchers in our Visualization Lab exploring new paradigms in electronic chart design, unconstrained by existing standards or concepts. This exercise takes full advantage of the psychology-based human-computer interaction expertise of our visualization researchers to explore optimal designs for displays, the role of 3D or 4D flow visualization, stereo, multiple windows, etc. From this research, we hope to establish a new approach to electronic charts that will set the standards for the future. Throughout this project (both the evolutionary and revolutionary efforts), experienced NOAA mariners are playing a key role, ensuring that everything that is developed will be useful and functional.

EVOLUTIONARY

An Electronic Chart Display Information System (ECDIS) is no longer a static display of primarily chart-related information. Instead, it has evolved into a decision-support system capable of providing predicted, forecast, and real-time information. To do so, Electronic Nautical Chart (ENC) data is being expanded to include both vertical and time dimensions. Using ENC data produced from high-density hydrographic surveys (e.g., multibeam sonar), a tidal value can be applied to ENC depth areas or contours at arbitrarily fine intervals. The ENC data is not changed, only the display of safe or unsafe water depending on under-keel clearance of the vessel (a parameter set by the ECDIS user) or changes in water levels (e.g., predicted or real-time values). Briana Sullivan and Brian Calder are working with various standards bodies to better understand current constraints and to offer evolutionary suggestions to align the ENC with modern capabilities.

OPEN NAVIGATION SURFACE

Efforts continue to standardize formats for the distribution of full-density bathymetric data to be included in ENCs through the Open Navigation Surface Working Group. Brian Calder serves as the Chair of the Open Navigation Surface (ONS) Working Group and as a member of its Architecture Review Board. His role is primarily as facilitator, but he also serves as release manager for the library and keeps the

website updated as appropriate. The ONS Working Group has continued to develop the Bathymetric Attributed Grid (BAG) format since its adoption as S-102 in 2012.

In 2015, Brian Calder implemented an extension to the BAG library that supported the variable resolution extensions first proposed by Calder and Wade Ladner (NAVO) in 2014. The proposed extensions were specific to the type of variable resolution surfaces generated by the CHRT algorithm, then the only algorithm capable of generating such surfaces. After comments from the ONSWG Architecture Review Board (ARB), however, Calder added facilities to prospectively support more general variable resolution surfaces (i.e., which do not have the same simplifications that are possible due to the axiomatic definitions used in CHRT), in order to provide for other vendor algorithms. The adjusted implementation underwent code review early in 2016, and was accepted at the ONSWG meeting in Halifax, NS, in May.

Calder, as Chair of the ONSWG, also facilitated inclusion of the work of Roland Arsenault on the bagViewer application (a 3D viewer with capabilities for variable-resolution BAG visualization) into the BAG library; approval was granted at the ONSWG meeting in Halifax, NS in May, and the application was merged into version 1.6.0 of the library. Calder also facilitated the inclusion of the work of Giuseppe Masetti on porting the library to Microsoft Visual Studio 2015.

During the course of the current reporting period, it became evident that the definitions of "product uncertainty" used in the current implementation of the BAG library were not entirely consistent across vendors. Calder therefore led a survey of the library developers to pull together a list of available definitions, leading to the recommendation that the current system be refined, and new metadata tags be added to provide better consistency across implementations. These recommendations will be addressed at the next working group meeting during the U.S. Hydrographic Conference in March 2017.

The candidate release for version 1.6.0 of the BAG library was packaged by Calder and released on the project website on June 10, 2016, and became the official release on July 5, 2016. Binary builds of 1.6.0 were added to the website on August 8, 2016, and a patch release of 1.6.1 was made on November 28, 2016 in order to address an obscure Linux bug.

COMPOSITE-SOURCE SAFETY CONTOURS

(For information – funded by non-NOAA sources - ONR)

Funded by a separate grant from the Office of Naval Research, Brian Calder, Giuseppe Masetti, and Colin Ware have worked with Paul Elmore (NRL), Wade Ladner (NAVO), and Matt Thompson (NAVO) to investigate the potential to take multiple, potentially inconsistent, sources of charted data, and assemble them into a consistent estimate of the location of a safety contour, along with an estimate of the uncertainty of the product.

The driving use-case for the work is assessment of the navigational envelope for submarine navigation. Here, available sources of data are limited to primarily vector representations of charted data (typically DNCs, but also including some tactical overlays provided by NAVO) along with limited, generally low resolution, gridded data in the form of NAVO's DBDB-V database. Navigators are required to assess

all sources of data in order to determine the safe operating envelope for the submarine, and the inconsistency and volume of data sources makes this process extremely time consuming and error prone.

While Ware has focused on providing visualizations of uncertain scalar data and in particular contours (see 2015 Progress Report), Calder and Masetti have worked on methods for combining uncertainty and potentially inconsistent source data into a coherent output object. Instead of trying to consolidate the data from the individual chart sources and de-conflict the result, the proposed method constructs estimates of "navigable," "not navigable," and "maybe navigable" regions from each source, and then attempts to fuse these ternary categorizations, taking into account relative weights of the sources and prior assessments of reliability, and using the disagreements between the sources as a measure of the reliability of the reconstruction. While Masetti has focused on the bathymetric reconstruction piece of the solution (reported in progress report for NOAA grant NA15NOS4000200), Calder has focused on fusion of the individual chart results. This has resulted in a Bayesian fusion process that considers each source chart as an observation of the distribution of ternary cases (including a "no water" null case, Figure 8-1) at each spatial point of interest, and then fuses the data by estimating the most likely probability mass function for each spatial point. The most likely classification of the region can then be reconstructed directly from the modal class in the estimated probability mass function, and the non-uniformity of the probability mass function (Figure 8-2) can be used to estimate the reliability of the reconstruction (i.e., uniform distributions indicate great confusion in the source data as to the correct reconstruction). An example of the fusion for an area off the coast of Portsmouth, NH is shown in Figures 8-3 through 8-5.

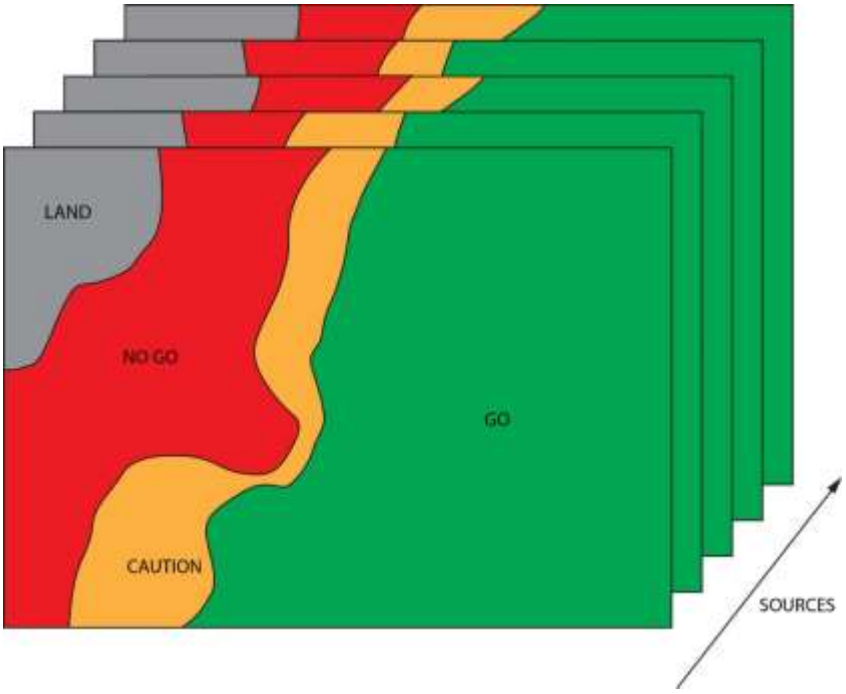


Figure 8-1: Conceptual model of the source data, one from each chart in the area (at any scale), ready for fusion. Generalization as a function of scale, or different source information, can make the classification boundaries different in each source, which the fusion algorithm accommodates through probability mass function estimation at each point.

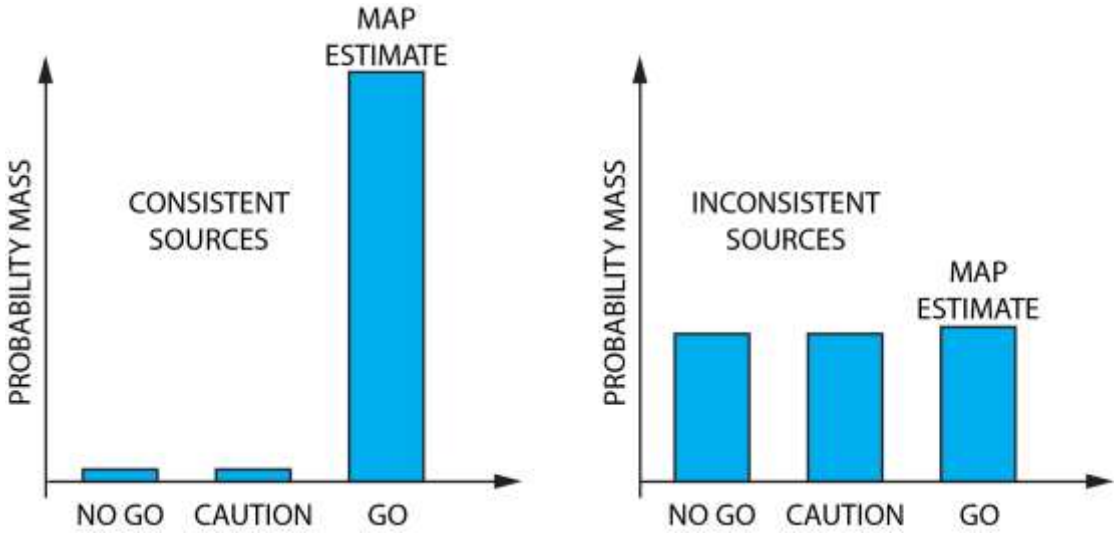


Figure 8-2: Example end-members of fused categorical distributions showing (left) a case with consistent sources and (right) inconsistent sources; in each case, the maximum a posteriori probability (MAP) solution is chosen. Cases where there are inconsistent sources would be displayed to reflect the greater uncertainty in the classification, which would typically occur in border regions between the different classes.

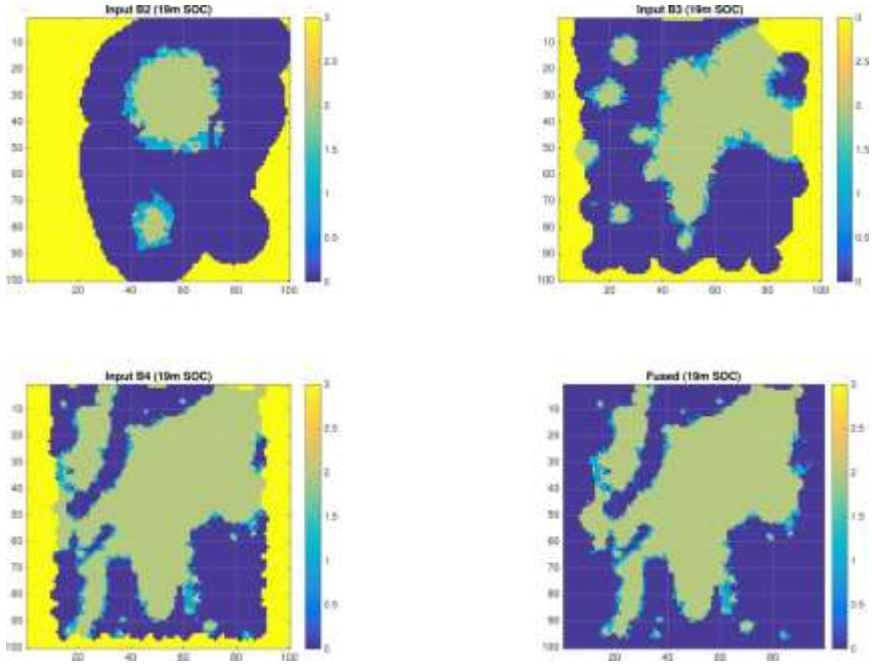


Figure 8-3: Inputs to the fusion algorithm (from SeaDOG) for a nominally simple area of seafloor off Portsmouth, NH, where an arbitrary safety contour of 19m has been specified. The significant difference in scales from ENC band 2 (top left) to ENC band 4 (bottom left) means that the estimate of "navigable" (value 2), "maybe navigable" (value 1) and "not navigable" (value 0) vary widely between inputs. The fused result (bottom right) reflects the largest scale source most strongly due to weighting during fusion.

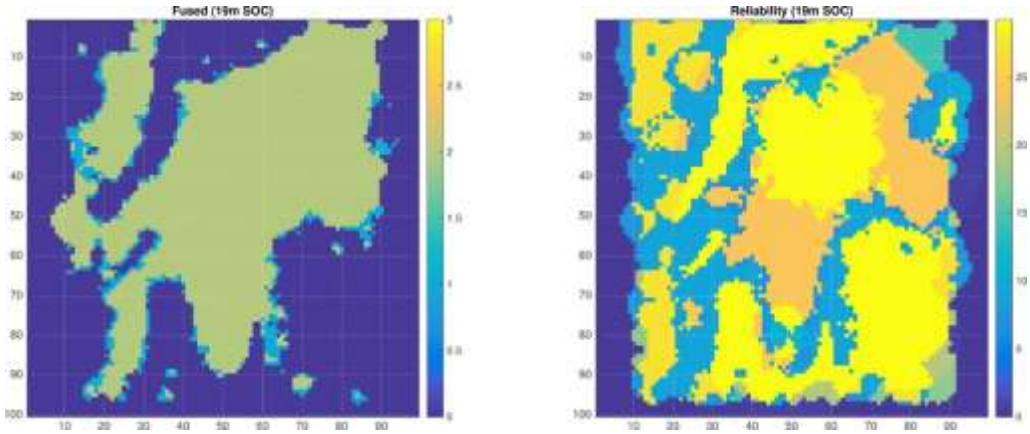


Figure 8-4: Fusion and reliability for Figure 8-3. The confusion of reliability data (right) reflects the radical inconsistency of the inputs, demonstrating that although the area is nominally simple, decisions to navigate in it are not.

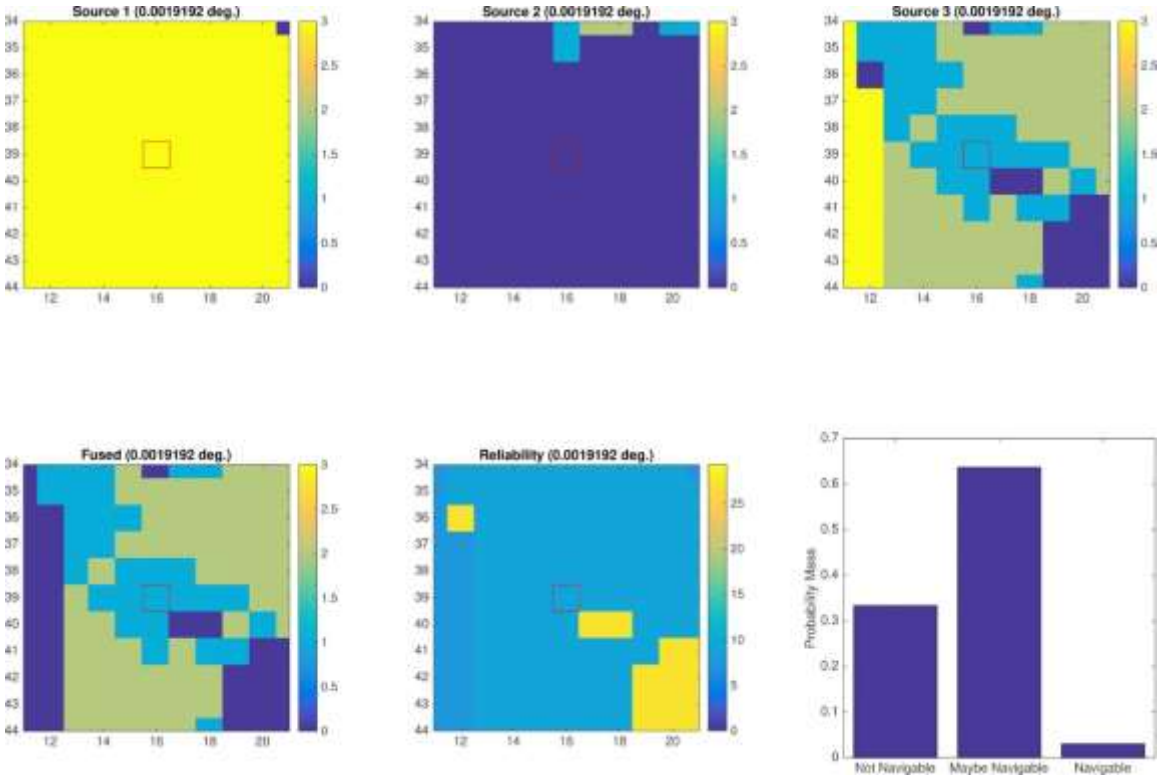


Figure 8-5: Detail of the fusion in the "maybe navigable" region on the western side of the region in Figure 8-3, connecting the channel to the north with the main body of the area. The source data disagree strongly on the correct reconstruction, resulting in a mixed probability mass function, and therefore lower reliability score.

Not all sources of data that inform the decision on navigation are quantitative, however. Consequently, Calder and Masetti are collaborating with Elmore and his colleagues at NRL Stennis on methods by

which linguistic descriptors can be translated to adjust the quantitative reconstruction. The ultimate goal is to combine all of the results together in the ternary field fusion scheme to provide a consistent rendering of the safe navigation envelope.

COAST PILOT DATABASE

In previous years, we have reported on the development of a proof-of-concept of a digital version of the Coast Pilot that provides georeferenced, digital images of coastal features that could be interactively selected to bring one directly to the text description of that target or vice versa – selecting the text describing a feature could bring you directly to an image of that feature. At the end of 2014 Sullivan received a copy of the oracle database that contains information used to generate the Coast Pilot® publications. Sullivan spent time organizing and analyzing the setup/layout of the database to help illustrate that the database has followed the format of the nautical publication, when it needs to be *data-centric* if it is to be "higher quality than the sum of its parts" (former NASA engineer Michael Weiss-Malik, talking about Google Maps data).

In 2015 Sullivan began to share her ideas of the "data-centric" version of the Coast Pilot (versus the "publication-centric" version currently used in the OCS Coast Pilot XML). Since the beginning of 2016, she has been able to hire a database administrator who has been working with the Oracle database and setting up a test environment on internal servers at the Center. Sullivan and the database administrator have created queries that will pick out categories of data and tables that will preserve relationships between content headers and the body, and are working to set up a table of all features within the Coast Pilot data. Sullivan is also finding ways to associate each paragraph in the Coast Pilot with the categories identified as well as geo-referenced data. This will allow the Google Map interface, iCPilot (**i**nteractive **C**oast **Pilot**), to filter the data according to specified areas, specific categories (danger, anchorages, approaches, etc.), as well as their associated charts.

The initial web-based prototype that Sullivan created and demonstrated to Tom Loeper and Scott Sherman from OCS in 2015 was the inspiration for updates to the current web version of the OCS Coast Pilot. (Fig. 8-6). Further examples of the prototype are presented in Figures 8-7 through 8-9.

Figure 8-6. Coast Pilot added menu to jump to chapters after seeing Sullivan's prototype (Figure 8-2).

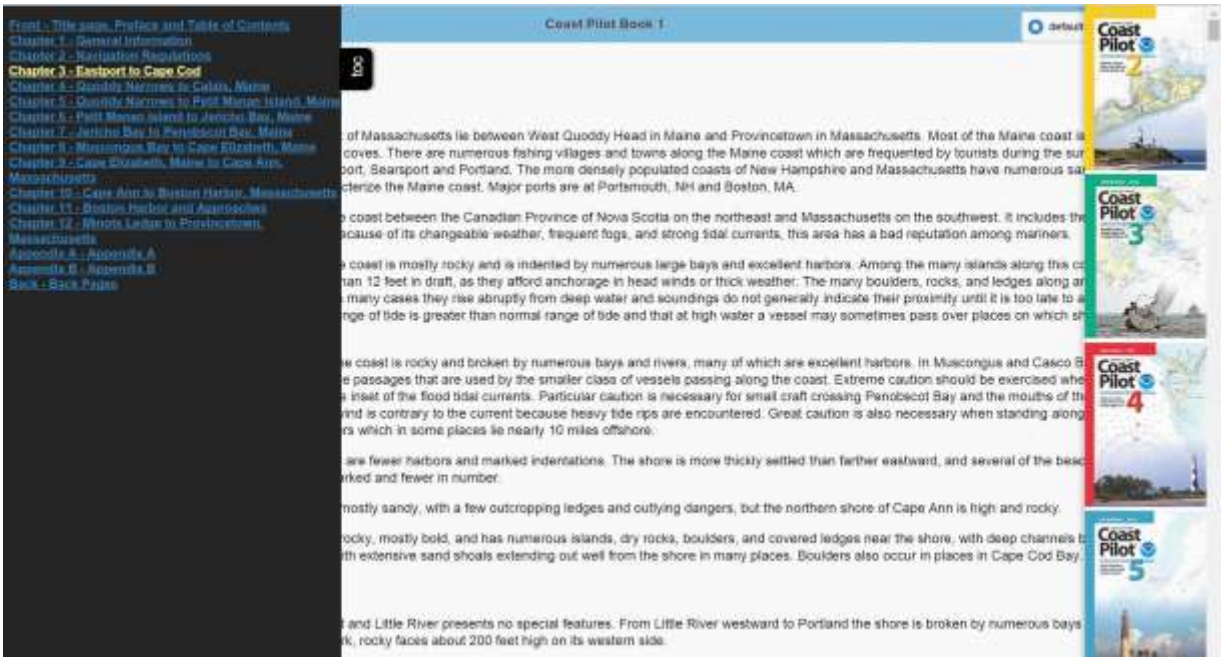


Figure 8-7. Sullivan's 2015 prototype example using jQuery – a more efficient way to navigate within the text-based layout.

Sullivan's work this year has included the "low hanging fruit", i.e., showing how the data can first be filtered by Book (Figure 8-10), then by Chapter and Feature (Figure 8-11), and eventually by Category.

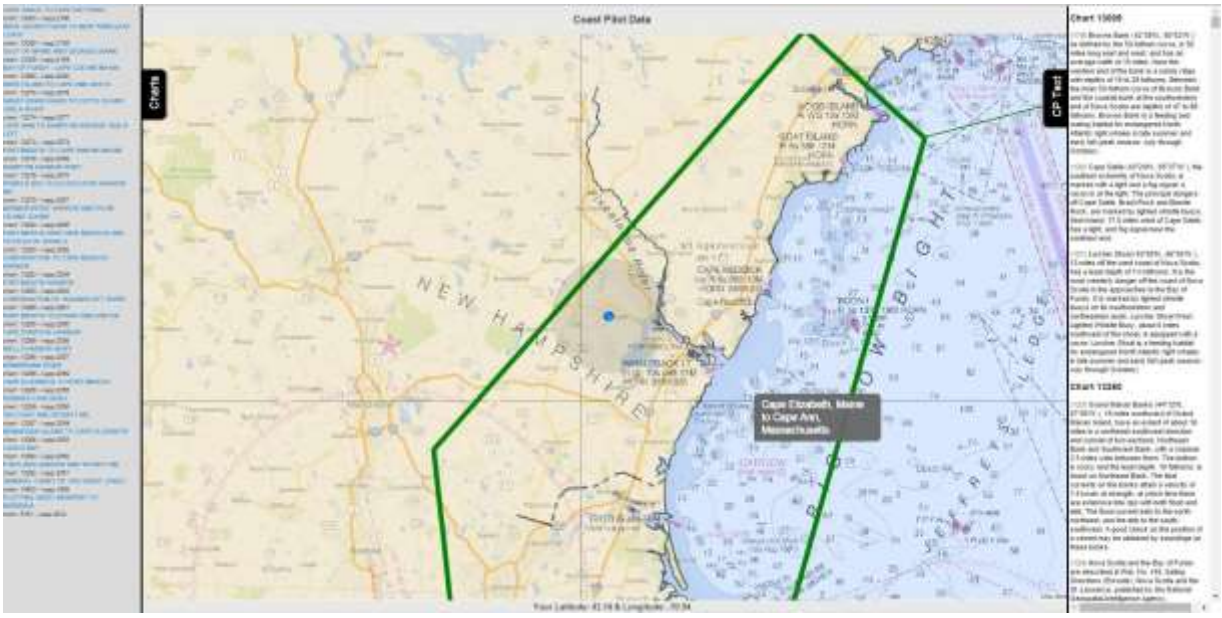


Figure 8-8. iCPilot 2015 Prototype - showing only charts (only tab on the left) within viewport and associated Coast Pilot data.

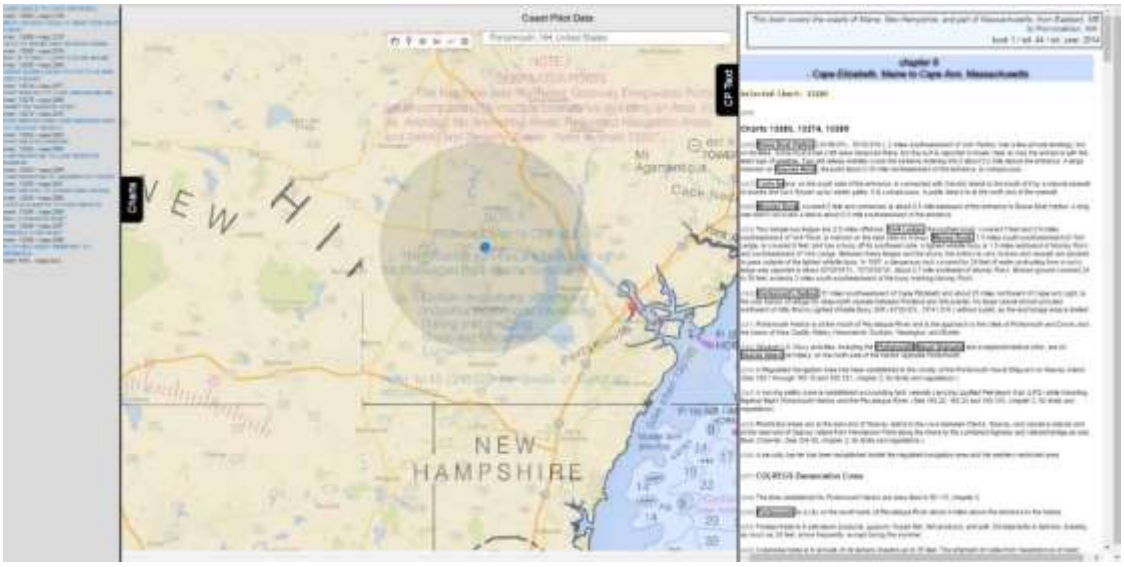


Figure 8-9. iCPilot 2016 Prototype updates: charts tab - showing only first 20 charts within viewport and the associated formatted Coast Pilot data, with the features highlighted.

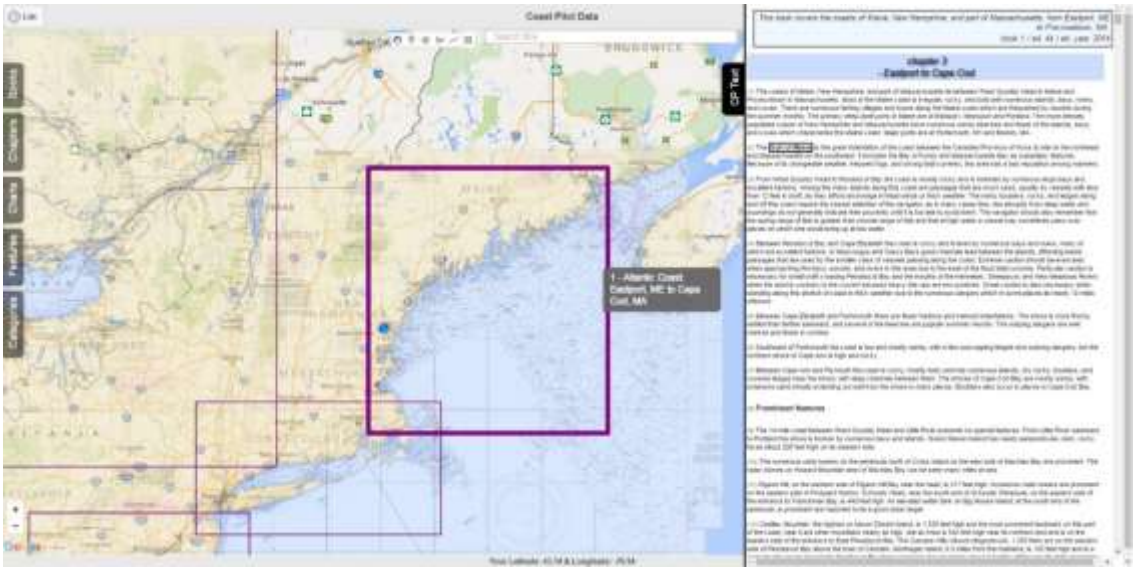


Figure 8-10. iCPilot 2016 Prototype updates: books tab - working tabs (on the left) for Books (book outlines also showing), Chapters, Charts showing only associated Coast Pilot data for each of those geo-referenced areas.

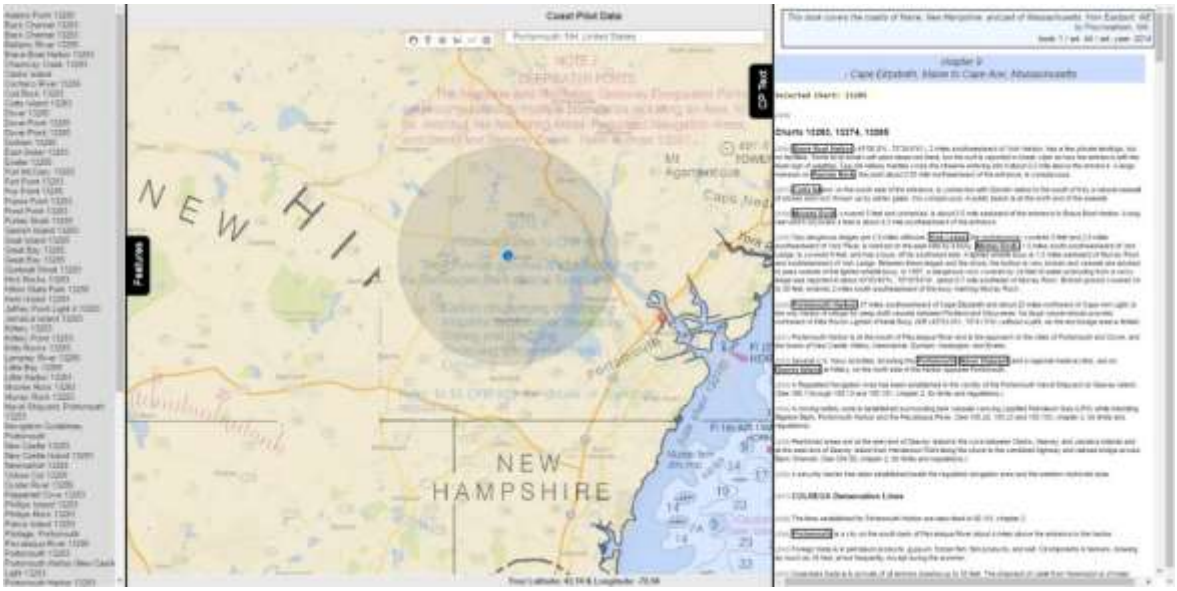


Figure 8-11. iCPilot 2016 Prototype updates: features tab – when the Coast Pilot text is updated (in the CPText tab on the right) the associated features are listed in the Features tab (on the left).

Sullivan's goals with the Books, Chapters, and Charts tabs are to show how the Coast Pilot can be backward-compatible and transition immediately to a better, more useful product. Although still, in essence, "publication-centric", it is a way to ease the user of the data into a more robust interface; exposing them to more options for viewing the data, filtering the data and seeing it within the nautical chart (as it should be viewed).

All of the features in the Coast Pilot text (with black borders around them for visibility) are alphabetized and listed in the Features tab (Figure 8-11). The Features tabs begin the Coast Pilot's transition to the

“data-centric” way of seeing the data. The original version of the Coast Pilot database that we obtained contained about 25,000 features associated with nautical charts, but these items were not necessarily items that were geo-referenced within the Coast Pilot text. In order to make the Coast Pilot data more interactive within the nautical chart context, each element needed to be geo-referenced. A little less than 2,000 items were actually geo-referenced within the Coast Pilot database. With the recent database updates, Sullivan was able to automate linking Coast Pilot keywords to the features in the GNIS database, which successfully geo-referenced almost 21,500 chart features with Coast Pilot text. Figure 8-12 shows circles that represent features that are described within the Coast Pilot text.

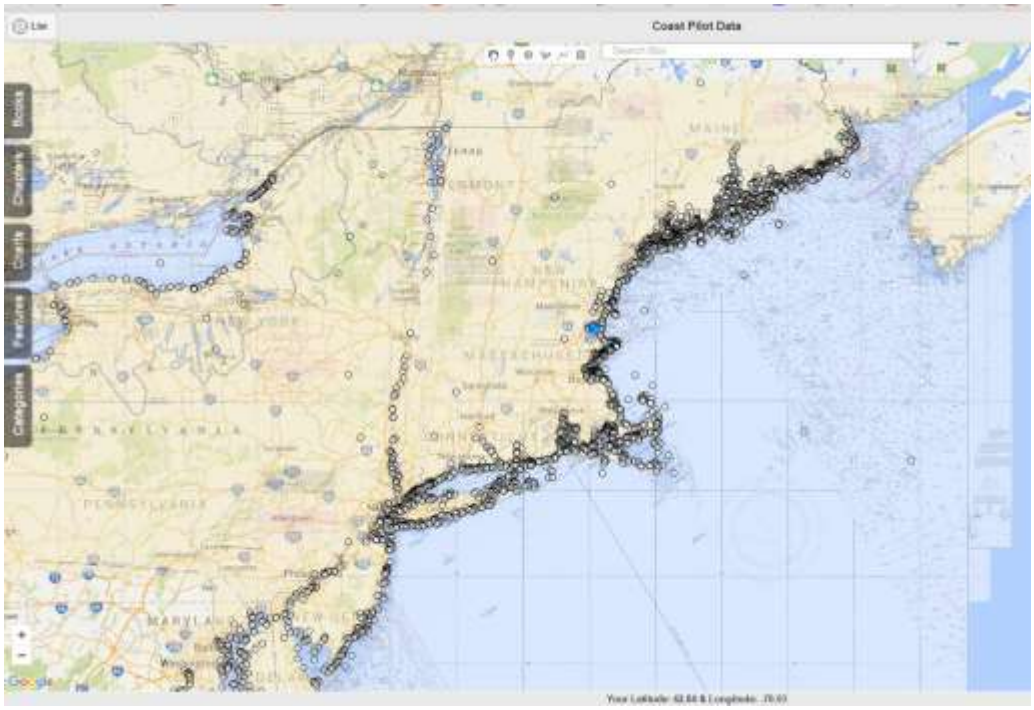


Figure 8-12: Circles representing the chart features that have associated Coast Pilot text

Hovering over a circle will change its color and display the feature’s name (Figure 8-13).

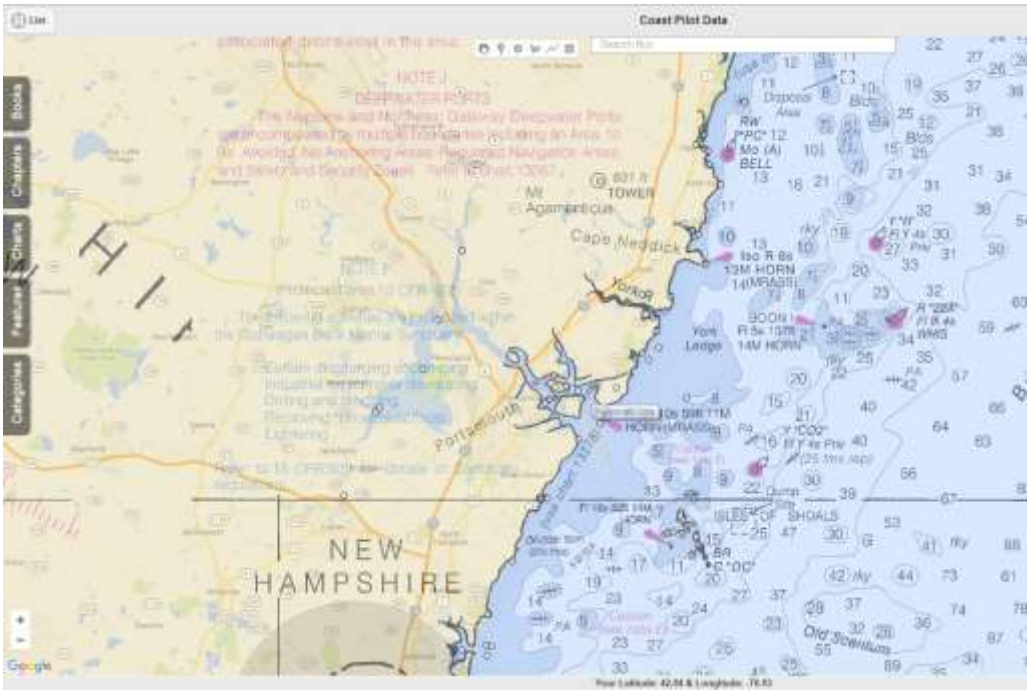


Figure 8-13: Demonstration of hovering over a geo-reference CP-feature

Clicking on the feature will display the associated Coast Pilot text for that feature. (Figure 8-14).

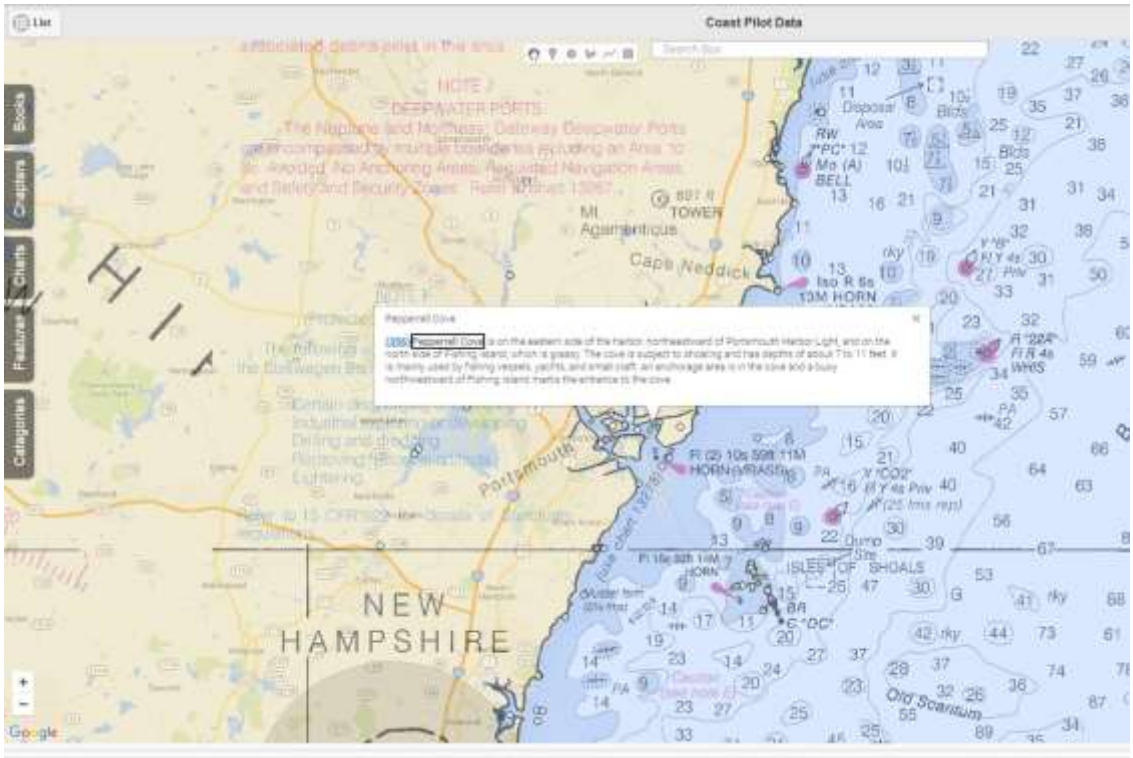


Figure 8-14: Demonstration of click on feature to produce Coast Pilot text

The Categories tab is used to search for weather, anchorages, bridges, dangers and things of a specific nature about the area involved. Updating iCPilot with the geo-referenced features and the categories move the paradigm from a data-centric to an activity-centric interaction.

CHUM – CHART UPDATE MASHUP

Sullivan has worked to upgrade the data structures of the ChUM application, with particular attention to mark-up of the Notice to Mariners (NTM) so that the structure will be more conducive to working with the data for various productsOne example is to drive the ChUM application, while another is to see if this information can be used in Giuseppe Masetti's project for building risk maps associated with marine debris. This work will also lay the foundation for testing to see how the data can be utilized and viewed in relation to the nautical chart.

A new interface for the weekly chart updates for the Office of Coast Survey was released in November that was based on Sullivan's ChUM work. See: https://distribution.charts.noaa.gov/weekly_updates/ (Figure 8-15).

CCOM Industrial Partner Anthropocene Institute connected Sullivan with Jacob Levenson from BOEM who was very interested in the NTM work in both the working group and visual interfaces. Levenson is working with NASA and the Navy hoping they can all be on the same page about the direction the working group is going with the notices as well.

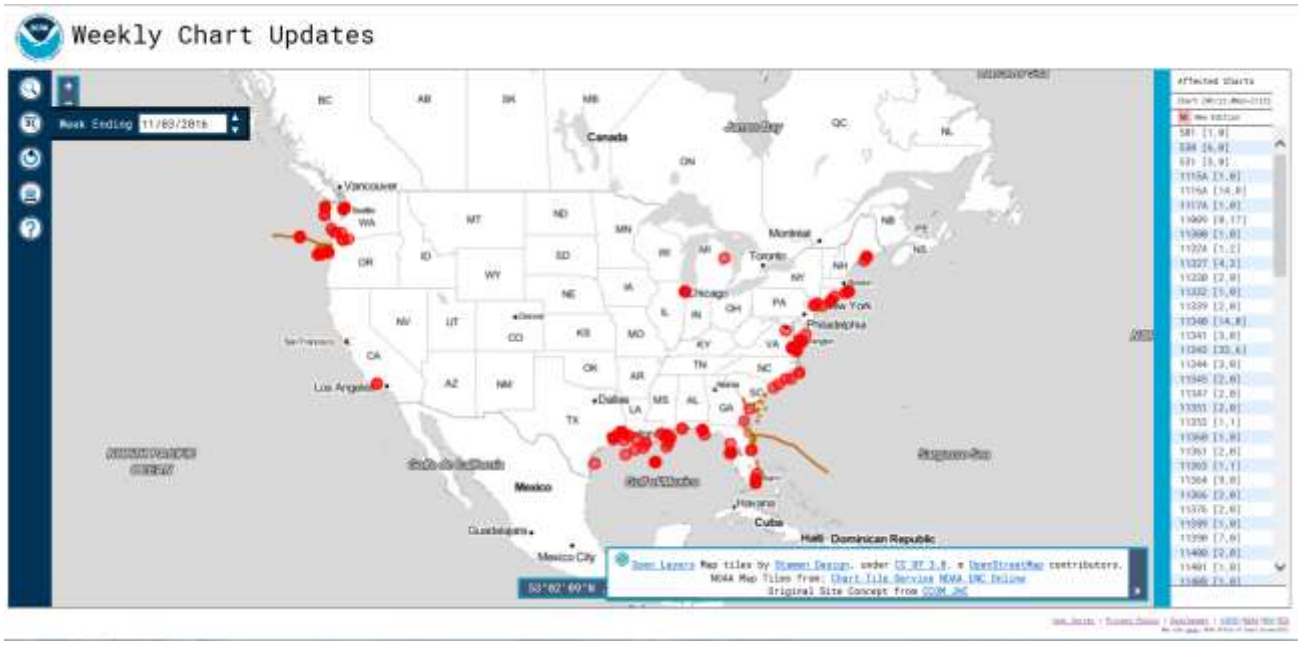


Figure 8-15: OCS Weekly Chart Updates based on the ChuM prototype

REVOLUTIONARY

Within the context of the "revolutionary" effort, Colin Ware, Tom Butkiewicz, Matt Plumlee, Briana Sullivan, and Roland Arsenault have been developing specific visualization applications for the Chart of the Future. This year's efforts are still more within the research realm and can be found described under the VISUALIZATION theme.

THEME 7: BEING NATIONAL LEADERS IN THE PLANNING, ACQUISITION, PROCESSING, ANALYSIS AND INTERPRETATION OF BATHYMETRIC DATA COLLECTED IN SUPPORT OF A POTENTIAL SUBMISSION BY THE U.S. FOR AN EXTENDED CONTINENTAL SHELF UNDER ARTICLE 76 OF THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

Short name: **LAW OF THE SEA**

Growing recognition that implementation of the United Nations Convention on the Law of the Sea (UNCLOS), Article 76 could confer sovereign rights to resources over large areas of the seabed beyond our current 200 nautical mile (nm) Exclusive Economic Zone has renewed interest in the potential for U.S. accession to the Law of the Sea Treaty. In this context, Congress (through NOAA) funded the Center to evaluate the content and completeness of the nation's bathymetric and geophysical data holdings in areas surrounding the nation's EEZ with emphasis on determining their usefulness for substantiating the extension of resource or other national jurisdictions beyond the present 200 nm limit. This report was submitted to Congress on 31 May 2002.

Following up on the recommendations made in the UNH study, the Center has been funded (through NOAA) to collect new multibeam sonar (MBES) data in support of a potential claim under UNCLOS Article 76. Mapping efforts started in 2003 and since then the Center has collected more than 2.65 million square kilometers of new high-resolution multibeam sonar data on 31 cruises including nine in the Arctic, five in the Atlantic, one in the Gulf of Mexico, one in the Bering Sea, two in the Gulf of Alaska, two on the Necker Ridge area off Hawaii, four off Kingman Reef and Palmyra Atoll, five in the Marianas region and two on Mendocino Fracture Zone (Figure 9-1). Summaries of each of these cruises can be found in previous annual reports and detailed descriptions and access to the data and derivative products can be found at http://www.ccom.unh.edu/law_of_the_sea.html. The raw data and derived grids are also provided to the National Center for Environmental Information (NCEI) in Boulder, CO and other public repositories within months of data collection and will provide a wealth of information for scientific studies for years to come.

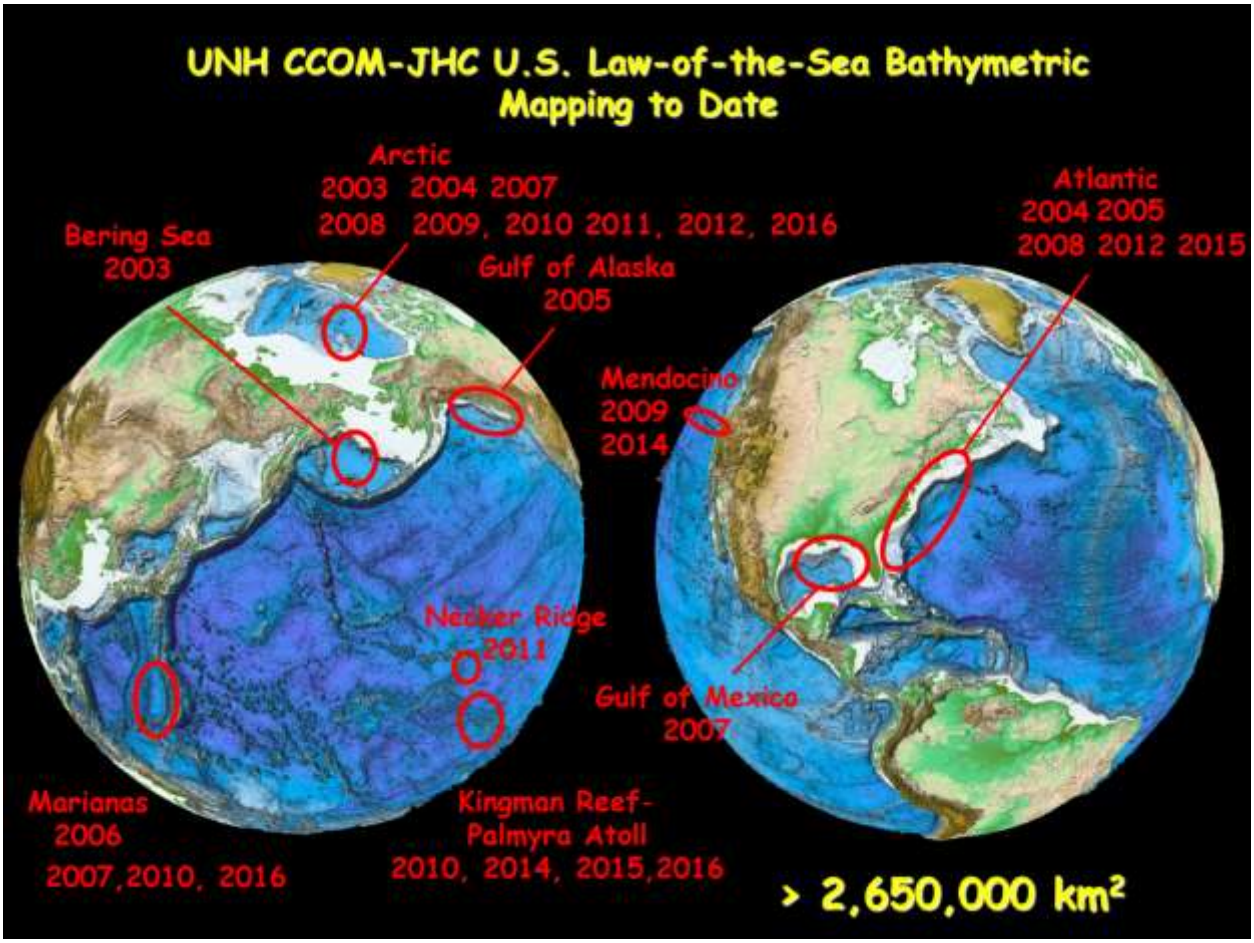


FIGURE 9-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center. To date more than 2.65 million square kilometers of data have been collected.

2016 LAW OF THE SEA ACTIVITIES

Three ECS cruises were competed in 2016, one aboard the NOAA Vessel *Ron Brown* in the Kingman Reef/Palmyra Atoll area, one in the Northern Marianas region aboard the M/V *Fugro Supporter*, and one aboard the USCG Icebreaker *Healy* in the Canada Basin on the southern Alpha Ridge.

NORTHERN MARINAS

A requirement for a 2016 northern Marianas cruise was discussed by the ECS Project Office in May 2016. A small area north of the existing JHC/CCOM ECS multibeam coverage was identified as a target for the cruise. Jim Gardner was asked to develop a cruise plan that included the validation of the legacy multibeam bathymetry in the area and determination of the coverage that could be achieved in a 30-day cruise in the target area. The 2016 cruise was contracted to use the M/V *Fugro Supporter* equipped with a Kongsberg Maritime EM122 MBES and an Edgetech 3300 subbottom profiler. As of this writing, the raw data, bathymetry and backscatter grids, subbottom SEG-Y data and XBT data have been processed and archived at JHC/CCOM, NCEI and the ECS Project Office. The compilation completes the ECS bathymetry mapping in the Marianas area.

The 2016 cruise on the M/V *Fugro Supporter* began in Saipan, CNMI on September 13, 2016 and ended in Saipan, CNMI on October 15, 2016. A total area of 100,072 km^2 (6,408 line kilometers) of multibeam sonar data was collected in the region over a period of 19 days (with 6.75 days of transit). These data have been combined with earlier data to form a single data set that represents a coverage of 627,860 km^2. Figure 9-2 shows the results of the cruise. Large unmapped areas and some areas with sparse multibeam bathymetry coverage were mapped and merged with previous JHC/CCOM multibeam data as well as with multibeam bathymetry provided by NOAA Office of Exploration and Research and the Japanese Coast Guard.

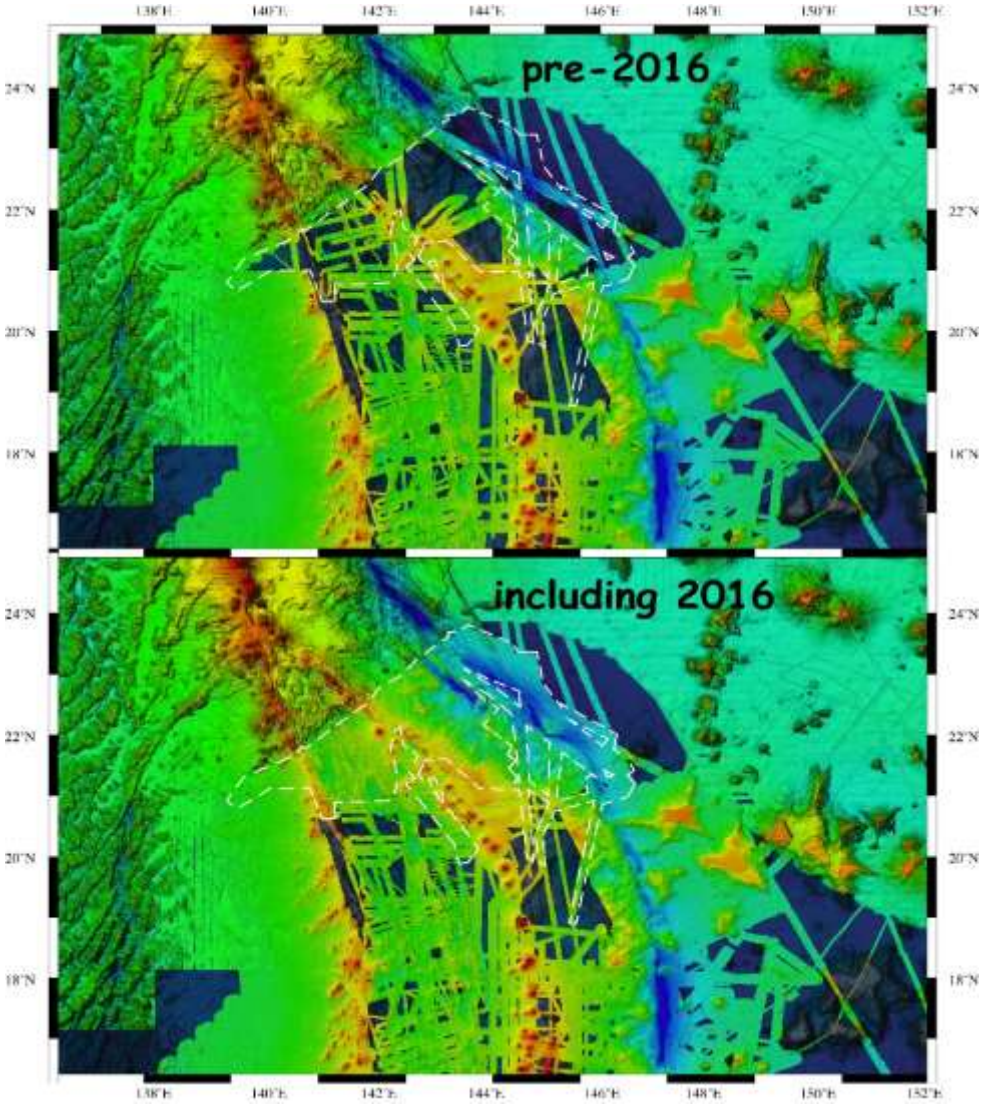


Figure 9-2: Upper panel shows pre-2016 MBES coverage; lower panel shows coverage after the 2016 ECS cruise. White polygon outlines the area mapped in 2016.

KINGMAN REEF-PALMYRA ATOLL, CENTRAL EQUATORIAL PACIFIC

The second ECS cruise for 2016 brought the NOAA Ship *Ron Brown* to the Kingman Reef-Palmyra Atoll region. Before this cruise took place, Center personnel participated in a 4-day test cruise on the *Ron Brown* to analyze ongoing problems with the Kongsberg Maritime EM122 multibeam echosounder aboard the ship prior to ECS mapping. The objectives were to calibrate the multibeam system, integrate the Knudsen subbottom profiler and Sippican XBT/XSV system to the Kongsberg SIS data acquisition system, confirm that the former problems with the POS/MV IMU have been resolved, and ensure that the hull-mounted sound-speed profiler was working properly. The test cruise was conducted at the University of Hawaii's deep-water calibration site located northwest of Honolulu, HI. The test cruise was successful and all systems were performing to specification by the end of the cruise.

Gardner organized, planned, and directed, but did not participate in, a 30-day cruise to complete the ECS bathymetry mapping of the Kingman Reef-Palmyra Atoll area of the northern Line Islands ridge in the central Equatorial Pacific. The objective of the cruise was to gain a regional understanding of the geomorphology of the platform (Fig. 9-3), especially the northern and southern flanks of the ridge. Legacy multibeam bathymetry, as well as a sub-bottom profiles collected across the platform on a JHC/CCOM ECS cruise in 2014, show the platform is elevated as much as 1000 m above the abyssal seafloor (Fig. 9-4). However, the legacy multibeam bathymetry data was not sufficient to meet the areal requirements outlined in the Law of the Sea, Article 76. The 2016 cruise, under the leadership of Andy Armstrong, ran reconnaissance lines across the southeast flank of the ridge as well as collecting data on an excursion into Kiribati's EEZ, at their request. The cruise began in Honolulu, HI, on January 12, 2016 and ended in Honolulu, HI on February 9, 2016. A total area of 166,756 km^2 (10,106 line kilometers) of multibeam sonar data was collected in the region over a period of 29 days (with 4.5 days of transit). These data have been combined with earlier data to form a single data set that represents a coverage of 438,391 km^2.

Although Jim did not participate on the cruise, he handled all post-cruise database archiving (both at JHC/CCOM and NCEI Boulder), generated all the metadata, processed the subbottom profiler data, compiled the three years of data (2010, 2015, and 2015) collected by JHC/CCOM and combined those data with validated legacy multibeam bathymetry from the area, and created derivative bathymetry and acoustic backscatter maps.

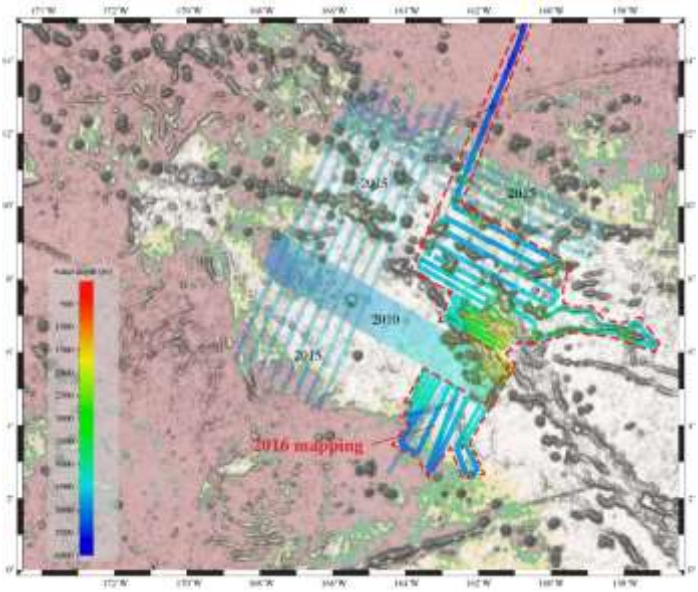


Figure 9-3: JHC/CCOM ECS multibeam bathymetry collected in Kingman Reef-Palmyra Atoll area. Semitransparent multibeam lines collected in 2010 and 2015. Red dashed area outlines data collected in 2016. White area on base map is the Line Islands platform. Base map from Sandwell and Smith v. 18.1.

One of the 2016 cruise objectives was to verify a Project Office interpretation from GLORIA sidescan sonar data that there were a series of submarine channels that trended north off the northern Line Islands ridge, which may have formed a series of submarine fans that coalesced into a continental rise. The 2016 multibeam bathymetry and backscatter show conclusively that no such channel or fan systems occur in the area.

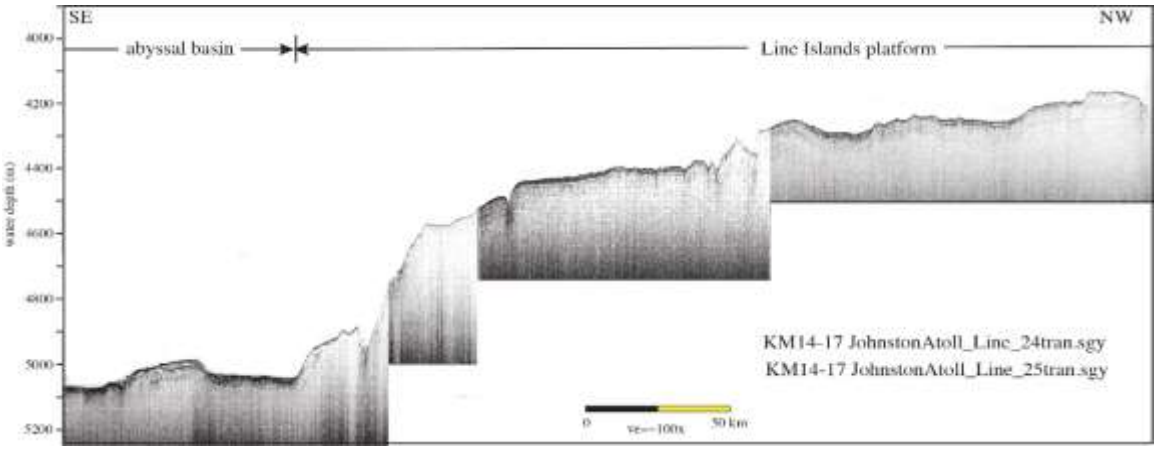


Figure 9-4: Knudsen subbottom profile across the western edge of the Line Islands platform that Kingman Reef and Palmyra Atoll are constructed on.

HEALY 1603 – CANADA BASIN AND SOUTHERN ALPHA RIDGE

Healy-1603 (HLY1603) was the tenth in a series of Healy cruises dedicated to mapping and sampling regions of the Arctic north of Alaska that may qualify as "extended continental shelf" under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). Healy-1603 was a relatively short cruise that was scheduled late in the year when Healy ship time became available due to cancellation of a BOEM cruise. Originally scheduled for 11 days, the primary objective was to collect a few key high-resolution multibeam sonar lines in the region north of the Alaskan north-slope margin and on the Beringian margin in the Bering Sea to verify and further support initial foot of the slope (FoS) picks. With the decision to use Healy for ECS operations this season, discussions also began with the Canadians with respect to a possible two-ship operation with their icebreaker Louis S. St. Laurent (LSL) that was scheduled for a seismic and mapping mission in the vicinity of the North Pole and the Alpha Ridge during August and September. Logistical constraints prevented scheduling the ships for joint operations; however, both Canada and the U.S. agreed to extend their respective cruises by five days to accommodate high-priority objectives for each other: the LSSL would attempt to collect a seismic line on the northern extension of Chukchi Cap for the U.S., and the Healy would attempt to dredge on the southern Alpha Ridge for Canada. Thus Healy-1603 was extended five days with the added objective of dredging on the Alpha Ridge. Ancillary projects on Healy-1603 included the deployment of ice buoys under the direction of Ignatius Rigor (University of Washington) and Pablo Clemente-Colon of the National Ice Center (NIC), and the underway real-time isotopic analyses of seawater samples for ocean acidification studies under the direction of Jonathan Wynn from the University of Southern Florida.

Healy-1603 was originally scheduled to depart Nome, AK on 18 Sept. 2016 but when the chief scientists arrived in Nome on the 16th of Sept., the *Healy* was already anchored offshore and requested that the small boat transfer to the *Healy* take place on the 17th. With the arrival of the last of the incoming scientific party at 1945L on the 17th, the final small-boat transfers were made and *Healy* immediately departed Nome at 2130L on the 17th. Given the very tight schedule, long transit distances, and unknown ice and weather conditions, the *Healy* transited at best speed towards Chukchi Plateau, with a line planned *en route* to collect a Foot of the Slope crossing at a location selected by the ECS Planning Office in Boulder, CO.

Despite a series of technical issues with the state of the multibeam on board HEALY, we were able to accomplish most of the mission requirements. We arrived in Dutch Harbor at 1800Z on 5th October, having collected a total of 7,771 linear km (4,196 linear nautical miles) of multibeam sonar and chirp sonar data (representing approximately 14,000 sq. km, or 5400 square miles) of multibeam sonar coverage in support of U.S. ECS activities, including several key Foot of Slope crossing lines (Figure 9-5). In the course of this work, we collected 65 XBTs, and recovered approximately 60 pounds of dredged rock from the southern Alpha Ridge in support of both U.S. and Canadian ECS efforts. Ancillary projects during the leg included the launch of three Seasonal Ice Buoys (XIBs) by a team from the International Arctic Buoy Program and four Surface Velocity Profilers (SVP-Bs) in the Beaufort and Chukchi seas, and three SVP-Bs in the Bering Sea. Additionally, the University of South Florida carried out a program of underway real-time seawater isotopic analyses to evaluate changes in freshwater sources and surface-water carbonate chemistry and the role of changes in the freshwater budget on ocean

acidification and the carbon cycle in the western Arctic Ocean, all without any interruption to the mapping and dredging program.

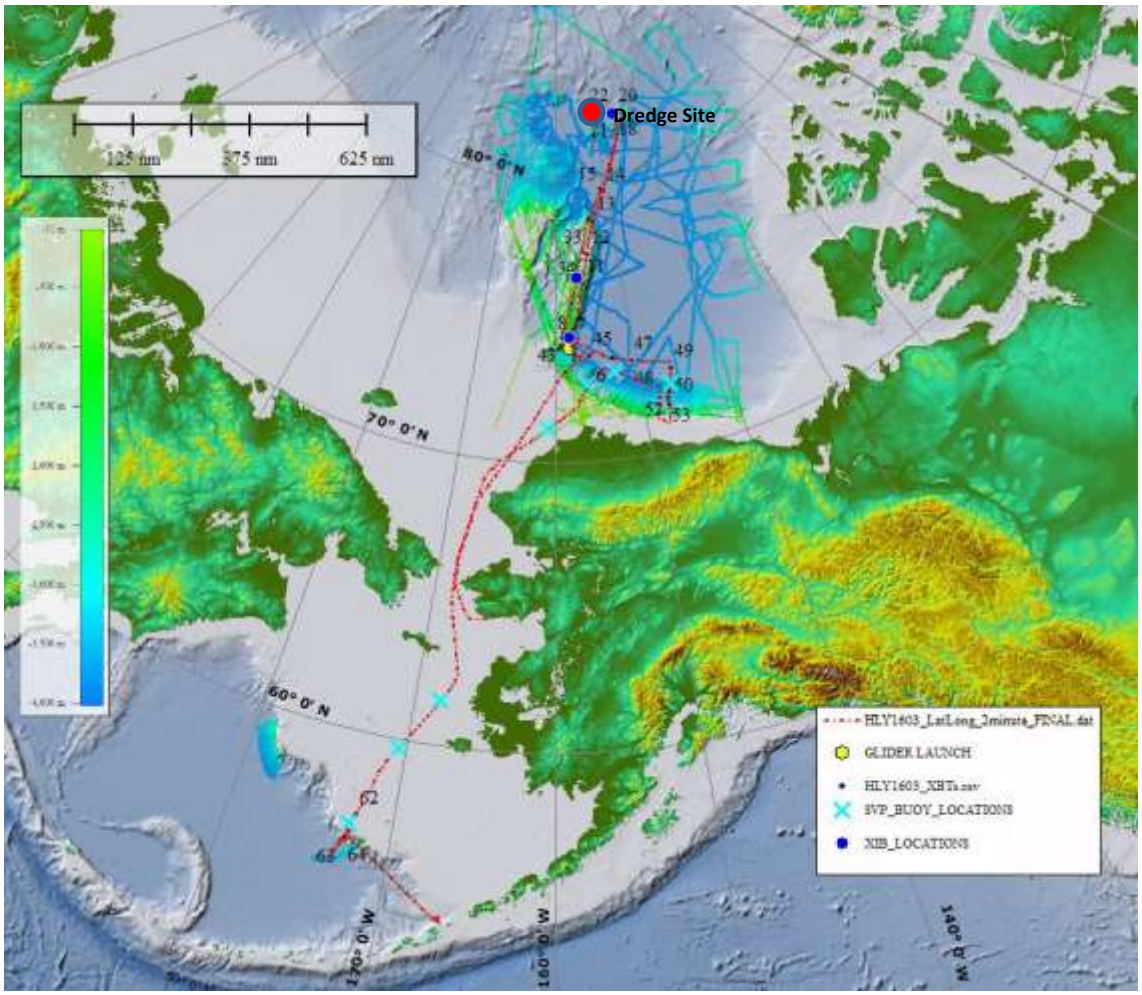


Figure 9-5: Trackline for HEALY 1603, 2016 ECS cruise in the Arctic. Red circle represents location of dredges collected for Canada.

OTHER ECS ACTIVITIES

GENERATION AND VALIDATION OF NEW LAW OF THE SEA BATHYMETRY AND BACKSCATTER GRIDS AND DERIVATIVE PRODUCTS.

Over the course of 2016, Gardner and Paul Johnson continued the process of generating and validating bathymetry and backscatter grids for each of the core Law of the Sea areas as identified by the Program Office. These sites included the Arctic, the Atlantic Margin, the Gulf of Mexico composed of the Eastern and Western Gap, the Mendocino Ridge, and the Bering Sea composed of the Beringian Margin and Bowers Ridge (see Figures 9-6, 9-7, and 9-8). Prior to gridding the bathymetry and backscatter data for each area, it was necessary to conduct a complete inventory and data quality review of all files that

were contributing to the grids. This became especially important as this round of grid generation involved merging data from outside sources (NOAA Ship *Okeanos Explorer*, NOAA Ship *Ronald H Brown*, and the R/V *Kilo Moana*) which were not collected as primary Extended Continental Shelf datasets by the Center. As part of this data completeness review, navigation from each survey was extracted and transformed into a queriable Geodatabase.

Figure 9-6: Location map showing the final bathymetry over each of the core Law of the Sea sites, except for the Arctic.

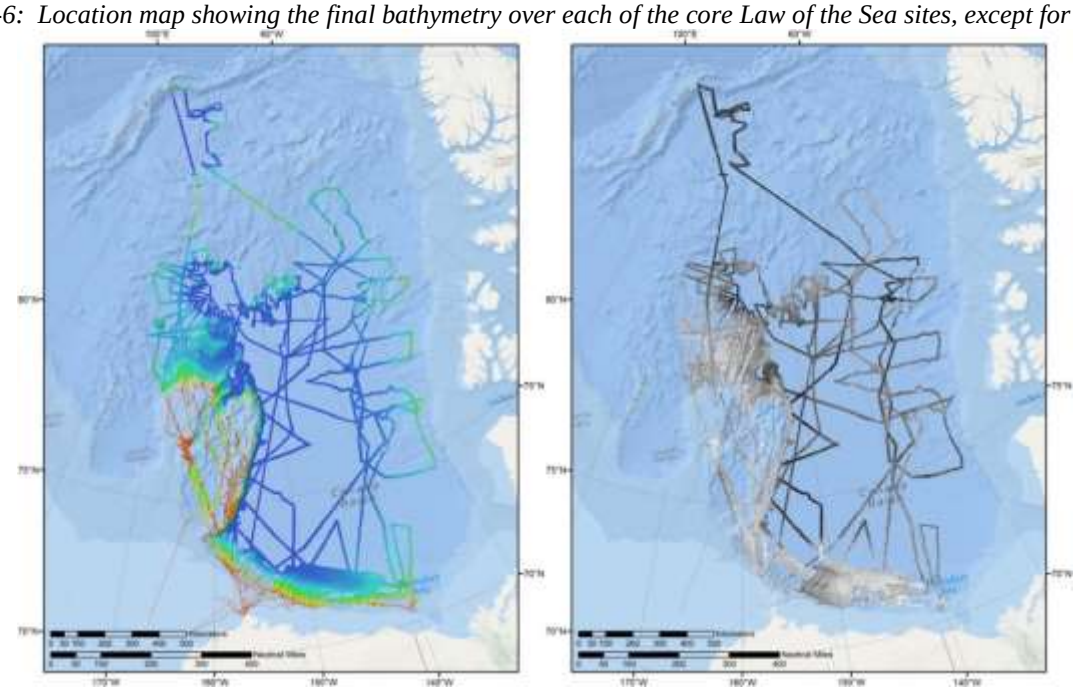


Figure 9-7: Final Arctic bathymetry and backscatter grids as submitted to the Law of the Sea program office.

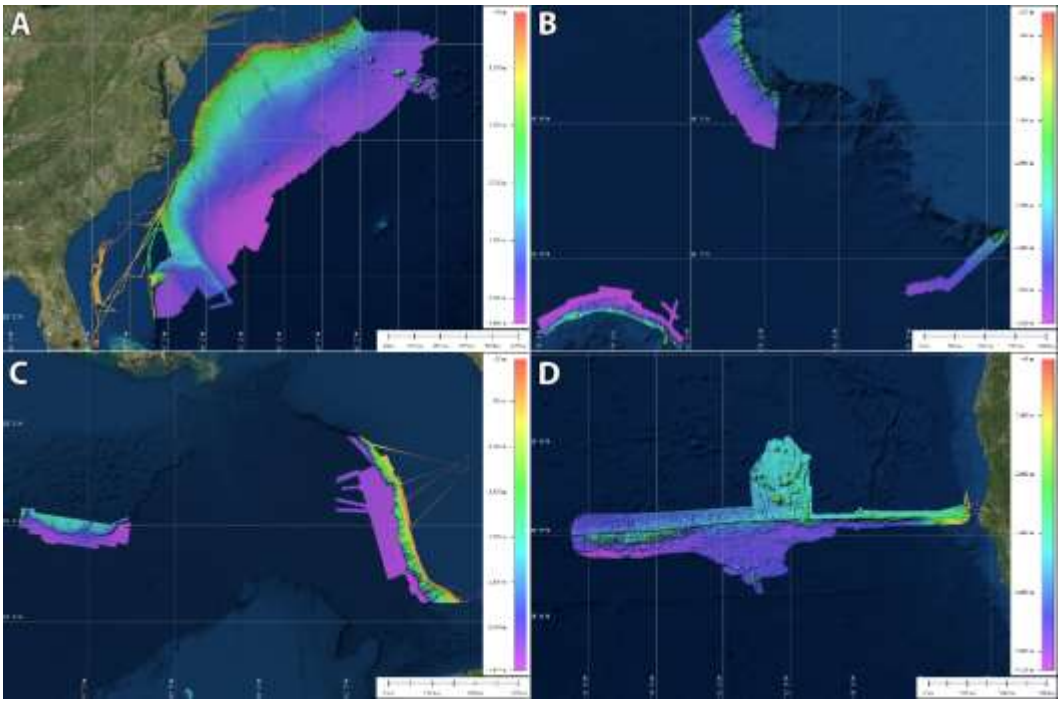


Figure 9-8: Final core area bathymetry grids for the Atlantic Margin (A), the Bering Sea including the Beringian Margin and Bowers Ridge (B), the Gulf of Mexico including the Eastern and Western Gaps (C), and Mendocino Ridge (D).

For the generation of each bathymetric synthesis grids, cleaned data were exported from CARIS HIPS, UNB SwathEd, or QPS Qimera, and loaded into the QPS DMagic program with a Lambert Conformal Conic projection, supplied by the Program Office and optimized for the core area, designated as the gridding projection. A line prioritization was then determined to select designated surveys lines vs. cross cutting lines, lines with partially compromised data due to ice conditions (Arctic surveys), and lines from non-ECS cruise data. The prioritization resulted in the generation of two separate grids, one containing all data files for a region, the second only utilizing files deemed to be primary lines contributing to the survey. The two resulting grids were then fused into a final bathymetric synthesis grid (e.g., Figure 9-7, left) by overlaying the grid with the select survey lines on top of the grid composed of all of the data.

The backscatter synthesis did not require quite as many steps to produce a final gridded backscatter data product for each area. As was the case for the bathymetry processing, the first step involved verifying that all files were being included into the gridding process. Each survey's backscatter grid was then adjusted (a positive or negative shift in backscatter level for the whole grid) to allow for a better match between the different surveys. Finally, a ranking was performed to determine an overlay order for each survey's backscatter. Grids were then fused based on this ranking into a single backscatter grid file (e.g., Figure 9-7, right).

Following completion of the bathymetry and backscatter gridding, metadata were generated for each of the grids, raster domain (survey area) shapefiles were generated, and the final grids and associated data products were submitted to the NCEI Law of the Sea Project Office. The submittal process became

much easier in 2016 due to the newly installed Science DMZ at the University of New Hampshire campus, which allows for high speed transfer of files directly from a University of New Hampshire data transfer node at the national archive at NCEI.

The final core area backscatter and bathymetry grids, navigation shapefiles, and surveys domains are currently in the process of being loaded on to the Center's GIS server where they will be accessible as dynamic maps through the Center's various web mapping services, and GIS services are being developed using a combination of the Center's GIS server and GIS portal (Figure 9-8; see discussion in Data Management section of DATA PROCESSING Theme). The core area data products are also currently being bundled into a downloadable package which will be made available through the Center's website in the spring of 2017.

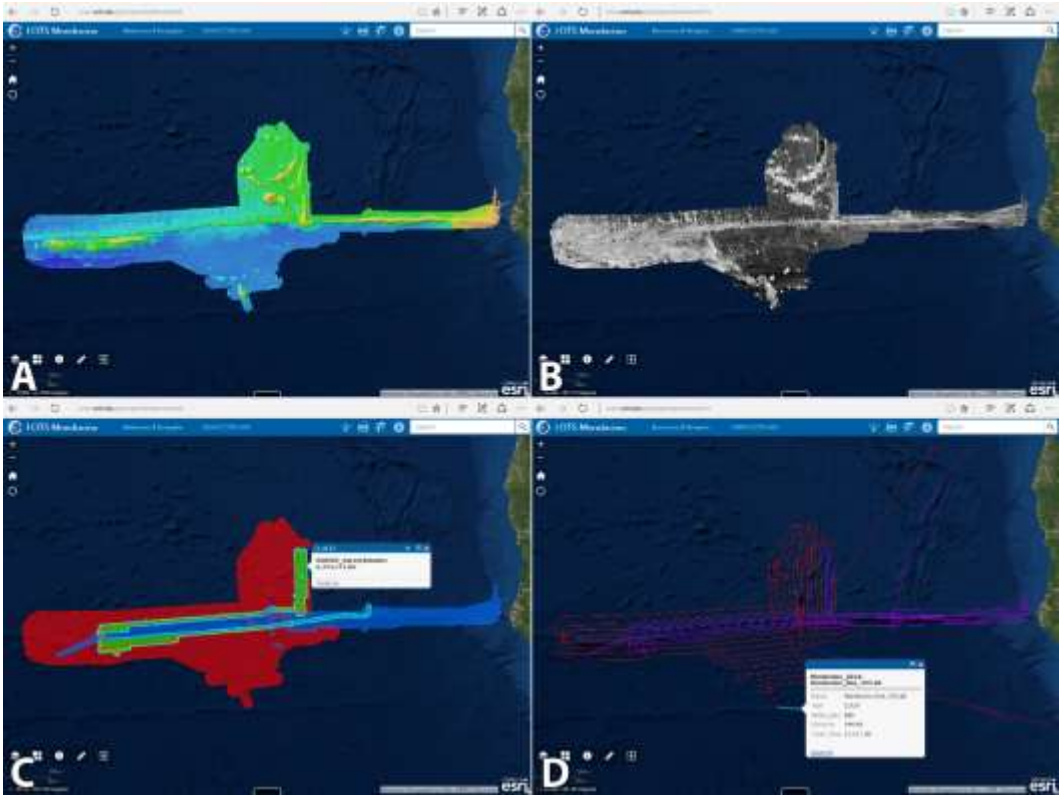


Figure 9-8. Mendocino Ridge bathymetry (A), backscatter (B), survey bounds (C), and navigation (D) dynamic maps available through the Center's website at http://ccom.unh.edu/gis/maps/Mendocino2016/

2016 ECS MEETINGS AND BATHYMETRY ANALYSES

Numerous ECS conference calls, videoconferences, and IRT calls occurred throughout the year. Monthly ECS Working Group conference calls were scheduled to review overall ECS progress, supported by unscheduled phone calls and videoconferences to discuss specific IRT details.

As discussed above, the Project Office requested the creation of new bathymetry and backscatter grids for all ECS cruises for the 12 core and non-core areas. The requested analysis grids include grids of

bathymetry and backscatter in both ESRI ASCII and plain ASCII formats, comprising four grids for each area. An added requirement of the Project Office was that each grid must be built in a projection specified by the Project Office. The Arctic grids were rebuilt and projected in Polar Stereographic and sent to the Project Office early in the year, with projections from the five other core areas, and non-core areas being provided in May and November, respectively.

During the year, Gardner completed cross-swath analyses for all cross lines in each of the 12 ECS areas of interest. The task involved identifying each cross-swath junction in each area, performing a cross-swath analysis and recording the statistics of each analysis. Figures 9-9a and 9-9b are examples of a cross-swath histogram and analysis for each of the six core areas. The result was more than 100 cross-swath analyses from the six core areas. In addition, Calder documented bathymetric uncertainty which was then applied to each of the 12 areas of ECS interest, and the resulting histograms and statistics have been sent to the Project Office.

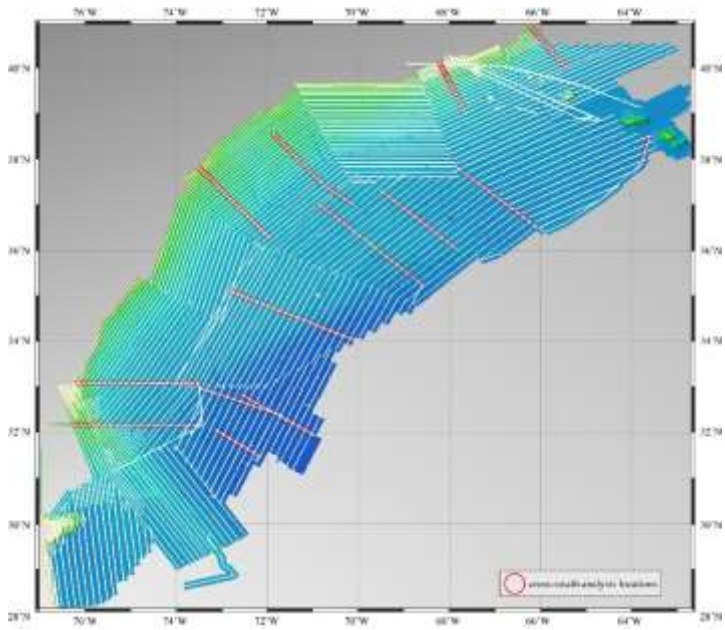


Figure 9-9a: Map of the JHC/CCOM ECS multibeam survey tracklines showing each swath crossing (red circles) where a cross-swath analysis was performed.

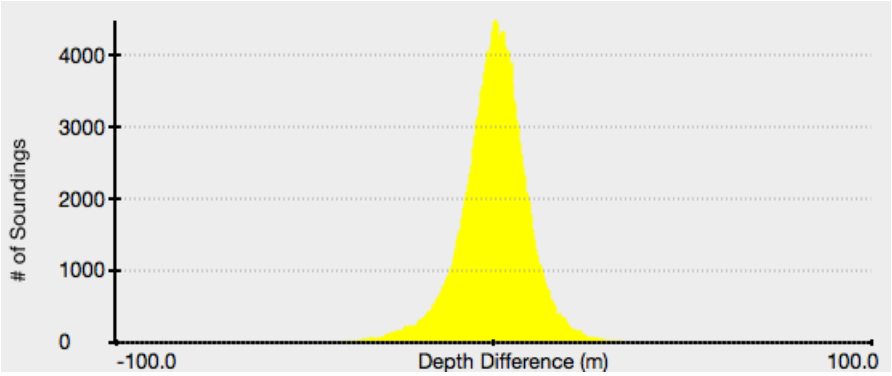


Figure 9-9b: Histogram of sounding-depth differences from cross-line check of Atlantic Line 25 and Dipline 16 (fairly smooth bathymetry). Kongsberg Maritime EM121a.

Cross check statistics

Line 25 vs dipline 16	Mean water depth	3395 m
	Mean Z difference	-2.51 m
	Standard deviation	9.87 m
	Number of samples	17,975
	Percent of water depth	0.5% at 2σ

A time frame for completion was developed between JHC/CCOM and the Project Office with the aim of completing the analyses by the end of August 2016. Some delays were experienced in obtaining projection parameters, which have of necessity pushed back the completion of some of the work. However, as of this writing, all of the ECS core areas (Arctic, Gulf of Mexico Florida Escarpment and Sigsbee Escarpment, Bering Sea Beringian margin and Bowers Ridge, Eastern Pacific Mendocino Ridge and the U.S. Atlantic margin) have been completed and transferred to the Project Office. New projected grids will be constructed for the six non-core regions (central Pacific Necker Ridge, Pacific Kingman-Palmyra area, Johnston Island area, western Pacific West Mariana Ridge and Mariana Trench and the north Pacific Gulf of Alaska) in 2017.

EXTENDED USE OF ECS DATA

SURFICIAL GEOLOGY MAP OF THE ARCTIC

Kimberly Baldwin, under the supervision of David Mosher, is working on compiling existing near-surface geophysical and geological data in the Arctic in order to produce a surficial geology map to complement the current International Bathymetric Chart of the Arctic Ocean (IBCAO). Along with its scientific merits, this map can serve as a tool for environmental and resource management and geohazard risk assessment. It can also be applied to Extended Continental Shelf (ECS) arguments to define the "base of the continental slope" (as defined in the Law of the Sea Treaty) along with other features. Further, this map will be important in presentations to the Commission on the Limits of the Continental Shelf (CLCS).

To produce this map, all subbottom data publicly available were acquired and processed using software developed by Natural Resources Canada (NRCAN). This software allowed Baldwin to combine multiple SEGY files; clean navigation and simplify the trackline (Figure 9-10) to reduce complexity that often occurs while icebreaking, also known as speed correction (Figure 9-11); and export SEGY files to JPEG2000 format in order to work with subbottom data in an ArcGIS environment. To date, 54 subbottom profiler datasets collected by nine different research vessels were processed and added to the subbottom compilation. A compilation of the location of sediment cores throughout the Arctic was also created for this project to provide ground-truthing. Further, Baldwin created an IHS Kingdom project with available subbottom data to complement the ArcGIS project, as the seismic interpretation software has extra features for working with seismic data that ArcGIS does not, which may prove useful further into the mapping process.

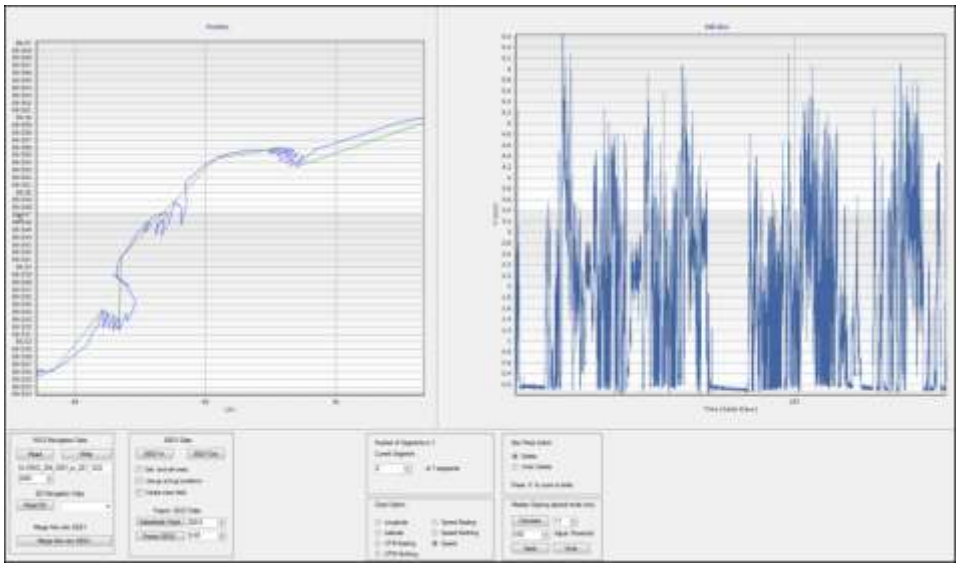


Figure 9-10: Screenshot of the NRCAN program NavClean. The left side of the program shows a plot of the subbottom tracklines (in blue). The green line is the defined interpolated track that data will be subsampled to in order to reduce the overall complexity caused by icebreaking. The right shows a plot of speed vs. distance.

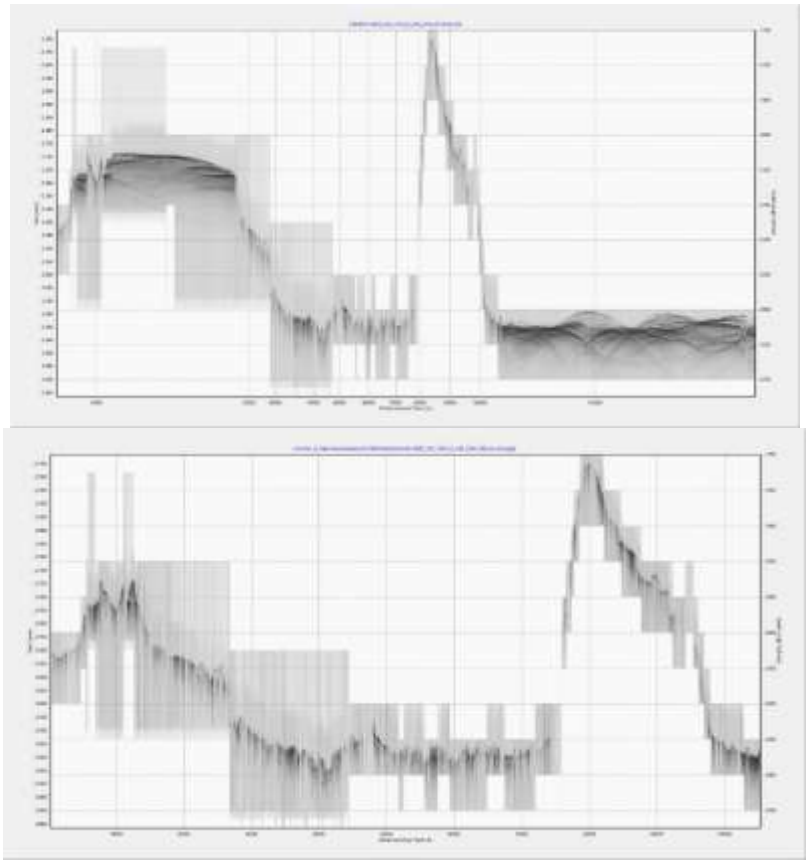


Figure 9-11: Comparison of two subbottom images without speed correction (top) versus with speed correction (bottom). Notice how the speed corrected plot has equidistance spacing.

A meeting with international collaborators was held in Bremerhaven, Germany on 23-24 May, 2016 in order to assess international data holdings and develop an acoustic facies schema (Figure 9-12). All existing processed data along with tracklines showing data holdings of other countries were compiled onto one ArcGIS project (Figure 9-13). In this reporting period, several additional cruises (Healy and Sikuliaq) were added to the subbottom profiler compilation, including the most recent Healy ECS cruise that occurred in October, 2016 (Figure 9-14). Current data holdings, mapped acoustic facies units, and acoustic facies mapping concept were presented by David Mosher at the IBCAO meeting in Monaco on 12 June, at the Royal Society, London on 18 October, the Arctic Council meeting on 6-8 December, and at the Fall American Geophysical Union (AGU) meeting on 16 December.

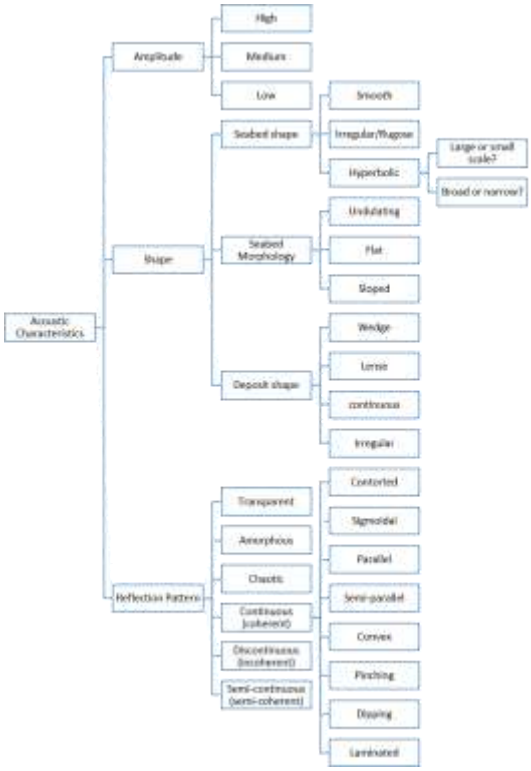


Figure 9-12. Acoustic facies classification schema, developed at the working meeting in Bremerhaven on 23-24 May, 2016.

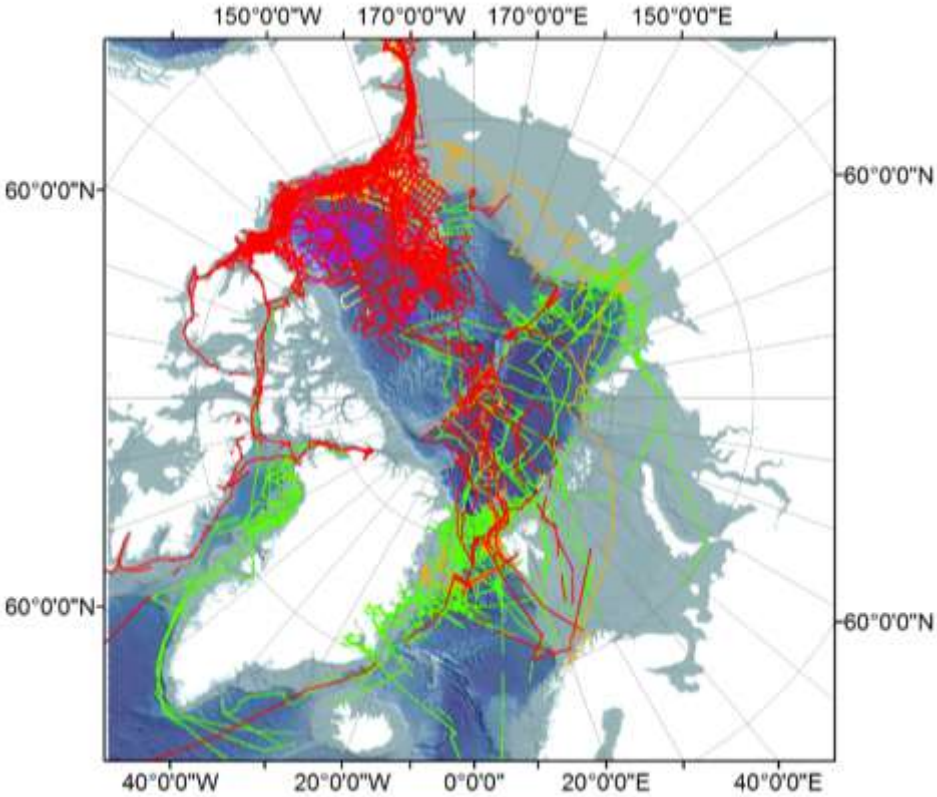


Figure 9-13: Tracklines showing the compilation of existing subbottom data holdings (red) as well as tracklines of subbottom data holdings not currently in the project from other countries (green= Germany; orange= Sweden; purple= Canada; yellow= US). Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

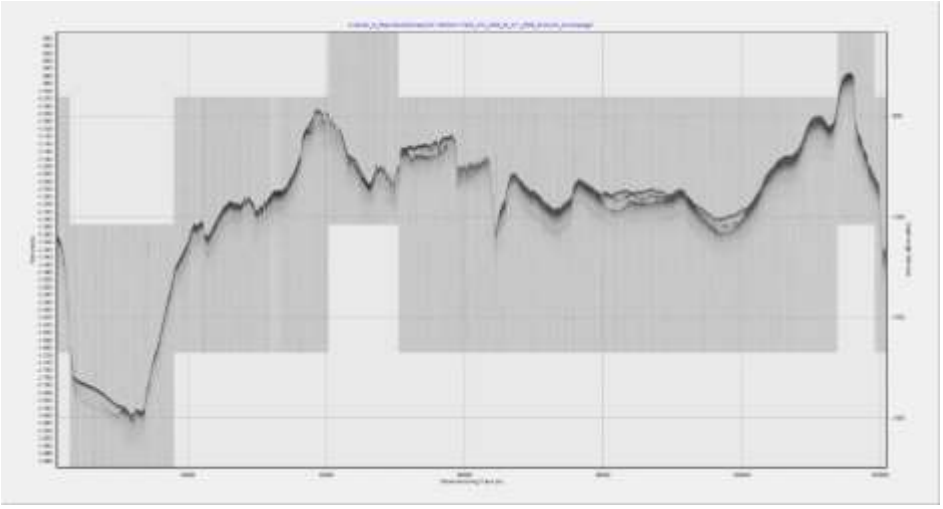


Figure 9-14: An example of processed subbottom data collected on the most recent USCGC Healy ECS Cruise in October, 2016. This line extends across the Northwind Ridge and shows a variety of acoustic facies including 5c, 5e, 6a and 10a, among others (see Figure 9-19 for legend).

The various seismic facies (e.g., Figure 9-15) are currently mapped on an ArcMap project (Figures 9-16, 9-17, 9-18 and 9-19). This is done by characterizing acoustic facies units in the subbottom profiles, and correlating units across additional seismic lines. The seafloor morphology found in the United States Arctic Multibeam Compilation (Flinders et al., 2014) as well as the underlying IBCAO map are used to extend acoustic facies units where no subbottom data is available.

Currently, only acoustic facies are mapped in areas of the Arctic where there is a dense amount of freely available subbottom profile data (Figures 9-16, 9-17, 9-18 and 9-19), specifically in the Chukchi Borderland (Figure 9-16, 9-19) and Alaskan Margin (Figure 9-17, 9-19). Attempts have been made to map acoustic facies of the entire Arctic region (Figure 9-18, 9-19), however a lack of available data and time restrictions have precluded an entire compilation at this time. Additionally, all units mapped so far are acoustic facies, and facies have not yet been interpreted to their seafloor geology unit. The end goal of this project will be to provide a publicly accessible compilation of all open source data with interpreted surficial geology among other features. This will require cooperation with other nations, especially those with large data holdings in the Arctic.

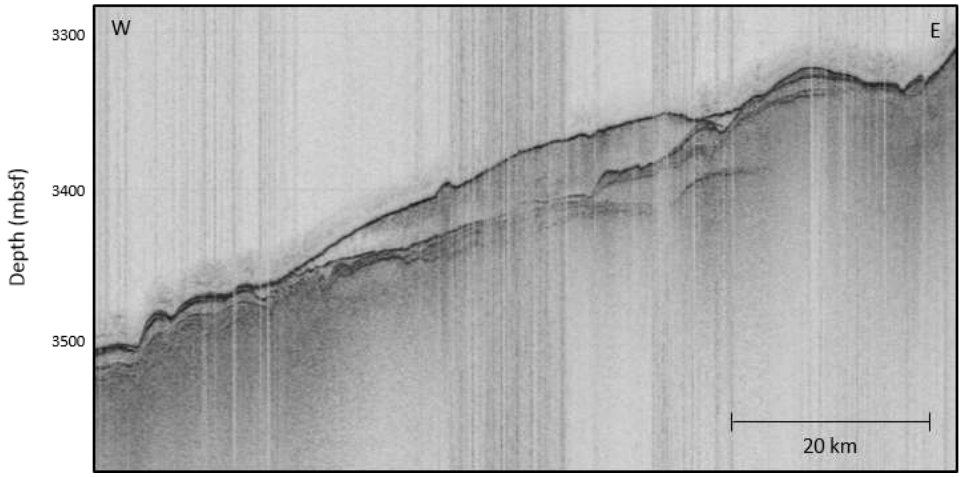


Figure 9-15: One of the acoustic facies (6a) identified in the Arctic subbottom profiler data set (high amplitude, smooth bottom echo with unconformable, stacked, transparent, wedge-shaped deposits). The facies identified will be used to interpret the depositional process and develop a surficial geology map for the Arctic Ocean.

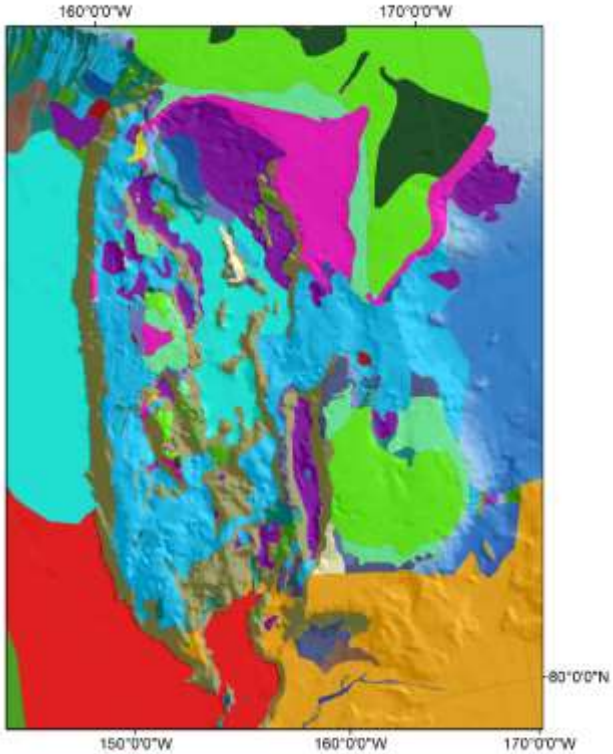


Figure 9-16: Acoustic facies mapped to date of the Chukchi Borderland. See Figure 9-19 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

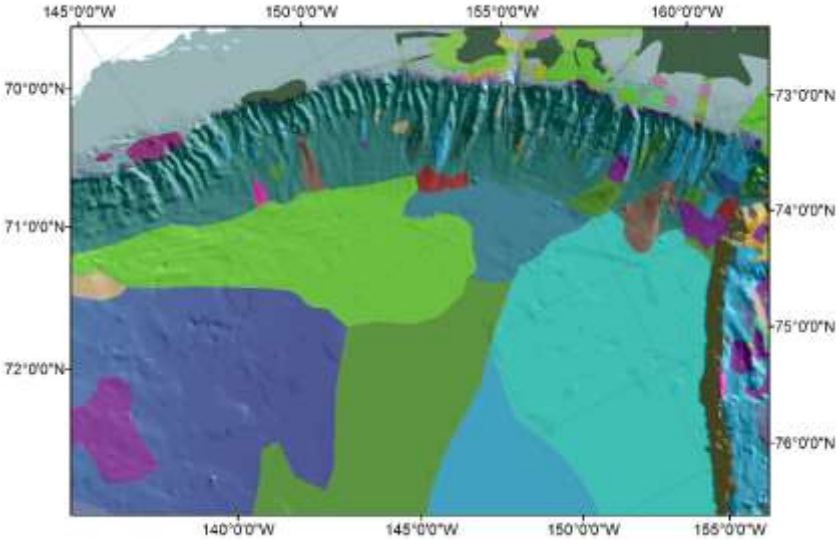


Figure 9-17: Acoustic facies mapped to date of the Alaskan Margin. See Figure 9-19 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

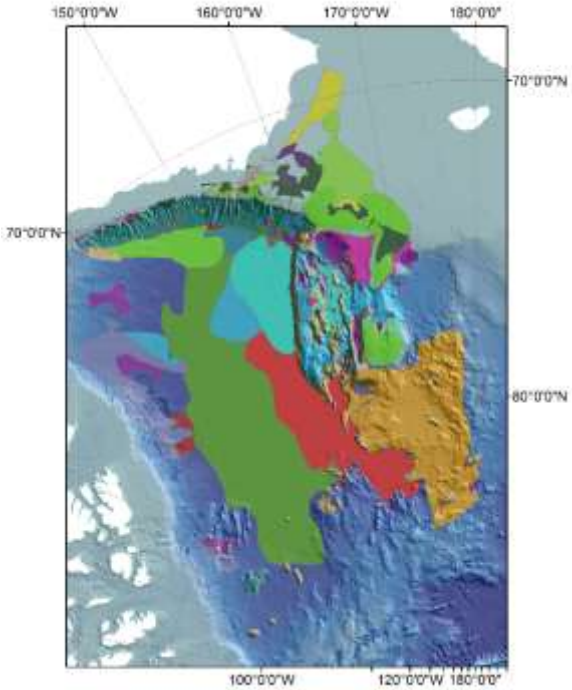


Figure 9-18: Acoustic facies mapped to date of the entire Arctic. See Figure 9-19 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

Figure 9-19: Acoustic facies legend to date, developed by the acoustic facies classification schema (Figure 9-12). Refer to Figures 9-16, 9-17, and 9-18 for mapped units.

MANUSCRIPTS AND MEETINGS

Demonstrating the value of the ECS multibeam sonar data beyond the establishment of an extended continental shelf, the Center Law of the Sea team have been involved in writing peer-reviewed journal articles. David Mosher is guest editor of a Special Issue in Marine Geology on Deep-water Sedimentary Processes. Deep sea processes are critical in defining the geomorphology of continental margins and therefore are of fundamental importance to ECS mapping. He has submitted a paper (with Jim Gardner as a co-author) to this issue on the Atlantic margin (Figure 9-20). Additionally, he is convening a special session at the European Geosciences Meeting on scientific outcomes of ECS data sets, attracting international participation and encouraging dissemination of ECS mapping results. He is also organizing a meeting and publication of a book on Submarine Mass Movements. The meeting will take place in May of 2018 and the book will be published by the Geological Society of London prior to the meeting.

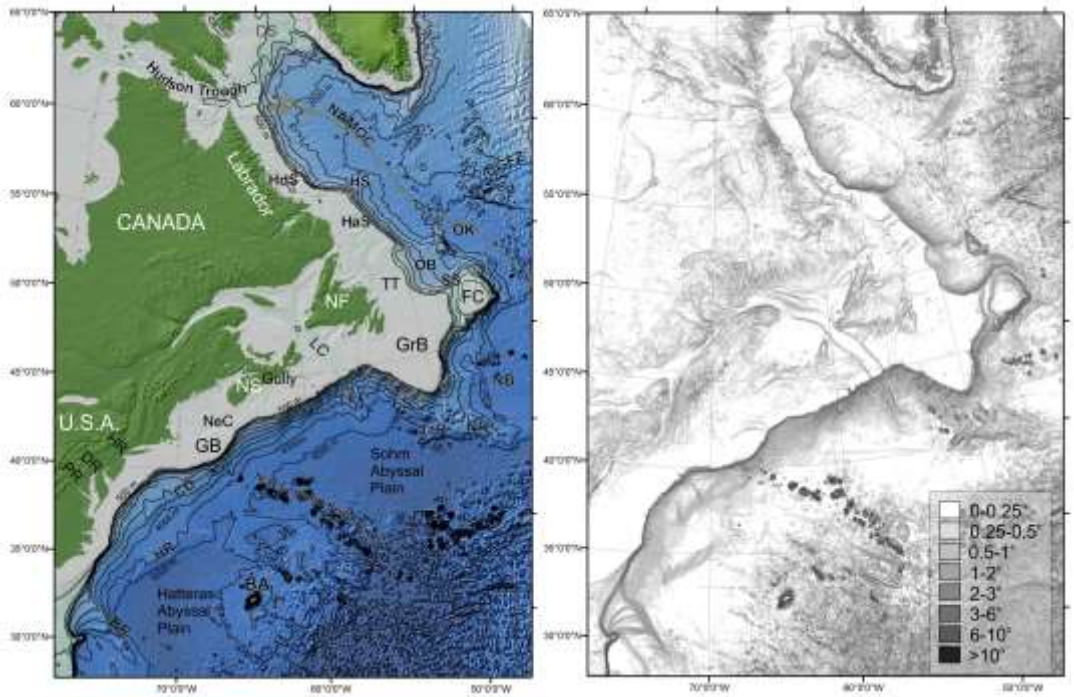


Figure 9-20. Maps of the geomorphology and slope angles of the Atlantic margin – part of the publication on deep water sedimentary processes.

OUTREACH

In addition to our research efforts, we also recognize the interest that the public takes in the work we do and our responsibility to explain the importance of what we do to those that ultimately fund our work. We also recognize the importance of engaging young people in our activities so as to ensure that we will have a steady stream of highly skilled workers in the field. To this end, we have upgraded our web presence and maintained our outreach activities and staff (Tara Hicks-Johnson, an experienced outreach specialist joined our staff in 2011). Tara now coordinates Center activities with UNH Media Relations to collaborate on Center-related news releases and media events and has begun working with NOAA media personnel to prepare releases that feature Center researchers. The Center continues to attract significant media attention, including articles or features this year in Newsweek, The Economist, 60 Minutes, The Sunday Times and the BBC. A partial list of media reports on CCOM activities is provided below:

JHC/CCOM Media Coverage – 2016

2016-01- 31	Greenland	*60 Minutes*
2016-02- 24	R/V *Gulf Surveyor*	*On the Island*, CBC Victoria
2016-03-01	A Hurricane Hits Home!	Seacoast Science Center *Blue Notes*
2016-03-03	There's Noise Deep in the Mariana Trench	*Australia Network News*
2016-03-31	UNH Hosting Underwater Robotics Competition	*Foster's Daily Democrat*
2016-04-03	NOAA Medalists Announced	*UNH Today*
2016-04-05	At SeaPerch, Last-Minute Fixes are Opportunities to Learn	UNH Cooperative Extension
2016-04-13	Zeroing in on Life Around a Hydrothermal Vent	*State of the Planet*, Columbia University
2016-04-15	Department of Marine Science Announces World Leader in Sonar Technology as Annual Wiesenburg Lecturer	*Southern Miss Now*
2016-04-20	Mapping the Depths	*The Guam Daily Post*
2016-05-05	Two GSO Alumnae Receive Presidential Early Career Awards	URI Graduate School of Oceanography
2016-05-05	Four Gulf of Mexico Basins Named for Officers Who Led EEZ Bathymetric Mapping	NOAA's Coast Survey Blog
2016-05-12	Young Guns: Up-and-Coming ONR Talent Honored by White House	Office of Naval Research

2016-05-17	Listening to the Ocean	*UNH Today*
2016-05-24	A Hole in the Bottom of the Sea	*UNH Today*
2016-05-27	Arctic Appointment	*UNH Today*
2016-06-03	Pygmy Blue Whales Deepen Their Moans	*ScienceNews*
2016-06-07	The See-Through Sea	*The Economist*
2016-06-08	8 Breakthrough Innovations Saving Our Ocean	*National Geographic Voices*
2016-06-10	Shepard Smith Named Next Director of Coast Survey	NOAA's Coast Survey Blog
2016-06-16	Mapping the Ocean Floor	BBC *Science in Action*
2016-06-17	Nasa-Style Mission Needed to Map Ocean Floor	BBC
2016-06-18	Why Haven't We Explored the Ocean Like Outer Space?	*Motherboard*
2016-07-03	Mapping Earth's Final Frontier	*Seacoast Online*
2016-07-07	EIVA and UNH/CCOM Enter into Partnership	*Hydro International*
2016-07-19	NOAA Hosts International “Chart Adequacy Workshop”	NOAA's Coast Survey Blog
2016-07-22	I Would Walk 500 Miles, and I Would Walk 500 More, Just to Be the Man Who Walked 1,000 Miles Out on the Ocean Floor	*Atlas Obscura*
2016-07-28	Ocean Floor to be Mapped by 2030	*Hydro International*
2016-08-04	New Hampshire Research Vessel from All American Marine	*WorkBoat*
2016-08-07	Scientists Want to Create Google Maps for the World’s Oceans	*New Delhi News*
2016-08-07	Scientists Want to Create Google Maps for the World’s Oceans	*New York Post*
2016-08-07	Scientists Want to Create Google Maps for the World’s Oceans	*Big News Network*
2016-08-07	‘Gurgle Maps’ to Reveal Sea’s Deep Secret	*The Sunday Times*
2016-08-07	Scientists Unearth the Secrets of the Ocean Using Google Maps-Style Mapping	*International Business Times*
2016-08-08	Scientists Implementing a Google Maps-esque Approach to Unearthing the Secrets of the World’s Oceans	*The Daily Telegraph Australia*

2016-08-08	Scientists Implementing a Google Maps-esque Approach to Unearthing the Secrets of the World's Oceans	News.com.au
2016-08-08	Scientists Want to Create Google Maps for the World's Oceans	*TweakTown*
2016-08-12	President Appoints Engineer Specializing in Sea Ice to Seat on U.S. Arctic Research Commission	KUAC
2016-08-18	The Man Who Would Map the Ocean	*National Fisherman*
2016-08-25	Polar Explorers	*UNH Today*
2016-08-27	Shiny and New	*UNH Today*
2016-08-27	Robots, Scientists Map Broadkill	*Delaware Online*
2016-08-30	Faculty Kudos	*UNH Magazine*
2016-08-30	A Hole By Any Other Name…	*UNH Magazine*
2016-09-29	GEBCO Team Enter Shell Ocean Discovery XPRIZE	*Hydro International*
2016-09-29	A Quest to Map the Seafloor by 2030	*Newsweek*
2016-10-04	Eavesdropping on the Ocean	*UNH Today*
2016-10-05	UNH Receives Multi-Million Dollar Contract for Underwater Acoustic Monitoring Research	*UNH Today*
2016-10-29	In an Octopus's Garden	*The Economist*
2016-11-03	American-Ship-Review 2017 - Research/Survey	*Professional Mariner*
2016-11-28	Mapping the Extended Continental Shelf in the Arctic	*Coast Guard Compass*

OUTREACH EVENTS

The facilities at the Center provide a wonderful opportunity to engage students and the public in the types of research that we do. In 2016 the Center provided individual tours for almost 1000 students and individuals from a number of schools and organizations (see list below):

250 students	Windham School 6th grade
120 students	Oyster River Middle School 8th grade – Spring
80 students	Oyster River Middle School 8th grade – Fall
120 students	Barrington Middle School 8th grade
75 students	Bow Middle School
100 students	McLaughlin School
20 students	St. Thomas Aquinas

20 students	Mast Way Elementary School Science Friday Club
8 students	Mount Prospect Academy High School
10 students	Hampstead Academy
6 students	4H STEM club
6 students	RSEC Academy
10 students	Central High School - Spring
14 students	Central High School – Fall
50 students	Cardigan Mountain School
25 students	Prospect Mountain High School
80 CS students	CS400 students from an Intro to Computer Science Class

In addition to these small groups coming to the lab, we also have hosted several large and specialized events including SeaPerch ROV events, the annual UNH "Ocean Discovery Days" event, and several workshops for educators that have attracted an additional 3000 visitors to the Center.

SEAPERCH ROV

For a number of years, the Center has been working with the Portsmouth Naval Shipyard (PNS) and UNH Cooperative Extension to train and host participating schools, after school programs, and community groups that have built SeaPerch Remotely Operated Vehicles (ROVs) and wish to test them out in our facilities. Local schools have brought their students to the Center to test drive ROVs in our engineering tank, and tour both our Center and the engineering facilities on campus. The interest in these ROVs was so great that PNS and the Center started the Seacoast SeaPerch Regional Competition in 2012. We have continued to host SeaPerch builds, and provide facilities support to participating student groups, throughout this year.

We have many SeaPerch related events throughout the year. In January and October our Seacoast SeaPerch program held educator ROV workshops at the Center. These training programs are open to formal and informal educators, 4-H leaders, afterschool providers, community partners and homeschooling parents. The trainings included building a SeaPerch ROV, a discussion about starting SeaPerch ROV teams, and ways to incorporate ROVs into learning experiences. Each educator was able to take a SeaPerch kit back to their institution. We even worked through power outages in the building (Figure 10-1).

Figure 10-1: SeaPerch educator training at UNH (this one during a power outage).

Participants came from all over the state. Groups represented included afterschool 4H leaders from several counties, UNH Cooperative Extension, homeschool educators, and teachers from 28 different schools and groups from New Hampshire, and Maine.

The SeaPerch program culminates each year in a series of regional and then national competitions for the student groups. The Center, in conjunction with PNS, and the UNH Cooperative Extension Program, host the local Seacoast SeaPerch Competition. The fourth annual event was held on Saturday, April 12, 2016 on the UNH campus (Figure 10-2). Forty-five teams from New Hampshire, Maine, and Massachusetts schools, afterschool programs, and community groups competed in this ROV challenge, using ROVs that they built themselves. A SeaPerch is an underwater ROV made from simple materials like PVC pipe, electric motors and simple switches. While there is a basic SeaPerch ROV design, the children have the freedom to innovate and create new designs that might be better suited for their specific challenge. This year's competition included challenges such as an obstacle course where pilots had to navigate their ROV through five submerged hoops, and an Orbs course where students had to maneuver levers to release floating whiffle balls and return them to submerged cages. "These teams face the same types of challenges as ROV operators the world over: visibility, tether management, vehicle power, and maneuverability," said Rick Cecchetti, the PNS SeaPerch coordinator. "While building and testing the SeaPerch ROV, students learn and apply basic engineering principles and science concepts with a marine engineering theme. Our mission is to inspire the next generation of scientists, engineers, and technologists."

Winning teams this year then went on to represent the Seacoast in the SeaPerch Finals in Baton Rouge, LA, which was a wonderful opportunity for our local students to experience competition on a higher level. Our High School level team, Team SAAM from the Claremont Rogue Robots of 4-H club, did very well, placing 15th overall out of 75 teams, including a 6th place finish in the poster competition.

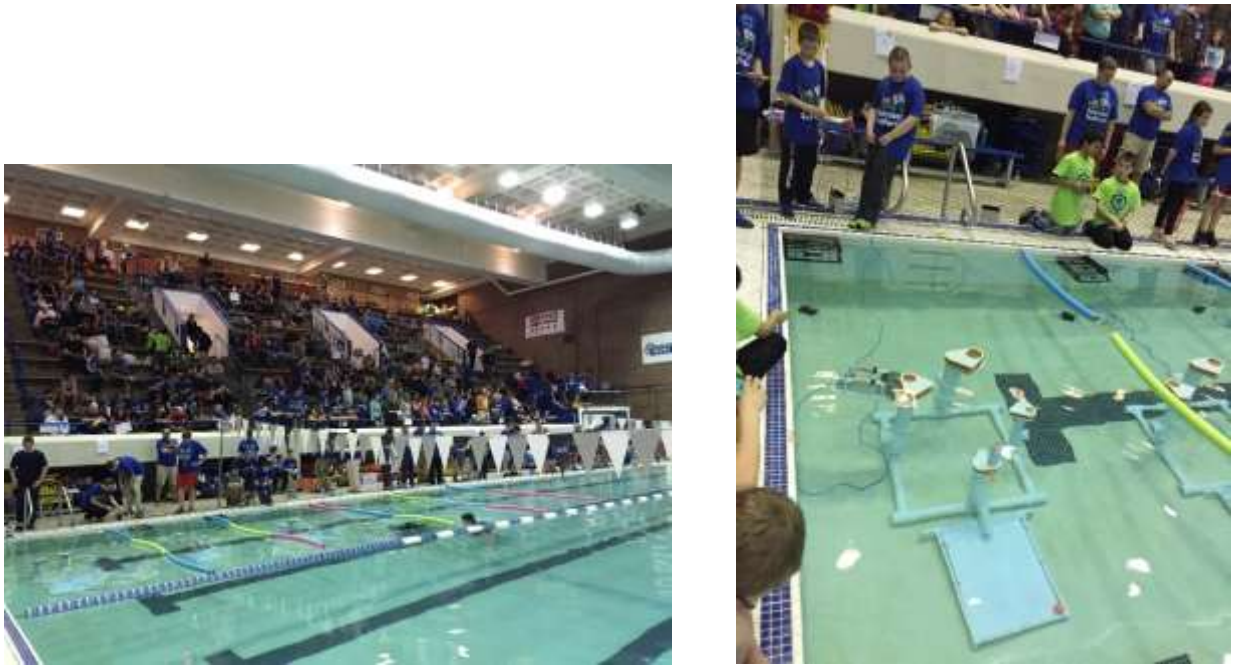


Figure 10-2: Scenes from the 2016 SeaPerch Competition at UNH

The Seacoast SeaPerch program also hosts two strands of UNH Tech Camp. The Tech Camp is a two-week camp for boys and girls that offers two concurrent programs for campus entering grades 7 & 8 and 9 & 10. One week is a basic build week for the younger students where they learn how to build a SeaPerch ROV. This year instead of the SeaPerch advanced strand that we normally do, we tested out a new program called SeaGlide.

The SeaGlide is a miniature underwater glider designed to be built by high school students. It moves by changing its buoyancy, taking in or expelling water. This change in buoyancy causes the glider to rise and sink in the water. As the glider travels up and down, its wings generate lift, which propels the glider forward (Figure 10-3). Students that construct the SeaGliders learn about basic electronics and then progress to circuit board soldering and programming with Arduino Pro Mini microcontrollers. They build servo-driven buoyancy engines with large, 100cc syringes and moveable mass to manage buoyancy and pitch. A critical final step is to ballast gliders for proper underwater flight. The program was popular, and will be repeated again next summer during Tech Camp.

Figure 10-3: Advanced Tech Camp attendees building a SeaGlider – a small autonomous underwater buoyancy-driven vehicle.

OCEAN DISCOVERY DAY

Ocean Discovery Day is an annual two day event held at the Chase Ocean Engineering Lab. On Friday, September 16th over 1500 students from school groups and homeschool associations from all over New Hampshire, Maine, and Massachusetts came to visit our facilities and learn about the exciting research happening here at the Center (Figure 10-4). Activities and demonstrations for all ages highlighted research on telepresence, ocean mapping, Autonomous Surface Vehicles (ASVs), ROVs, ocean engineering, coastal ecology, LIDAR, and ocean visualization. The event was open to the public on Saturday, September 17th, where close to 700 more kids and adults got to learn about the exciting research at the Center.

Students and the public were able to tour our engineering tanks in our High Bay, see video taken on the sea floor in our Telepresence room, and try their hand at mapping the ocean floor. They could see the Zego boat and jet-ski that we use to map shallow coastal areas, learn how we will be using our new ASVs for ocean research, see how scientists explore the ocean using sound waves, and test drive SeaPerch ROVs. Our visualization team showed off their interactive weather map and ocean visualization tools.

Ocean Discovery Day is a joint outreach event run through the Center, the UNH Marine Program, the New Hampshire Sea Grant office, and the School of Marine Science and Ocean Engineering. It relies on faculty, staff, and student volunteers from UNH, and volunteers from UNH Marine Docent program.

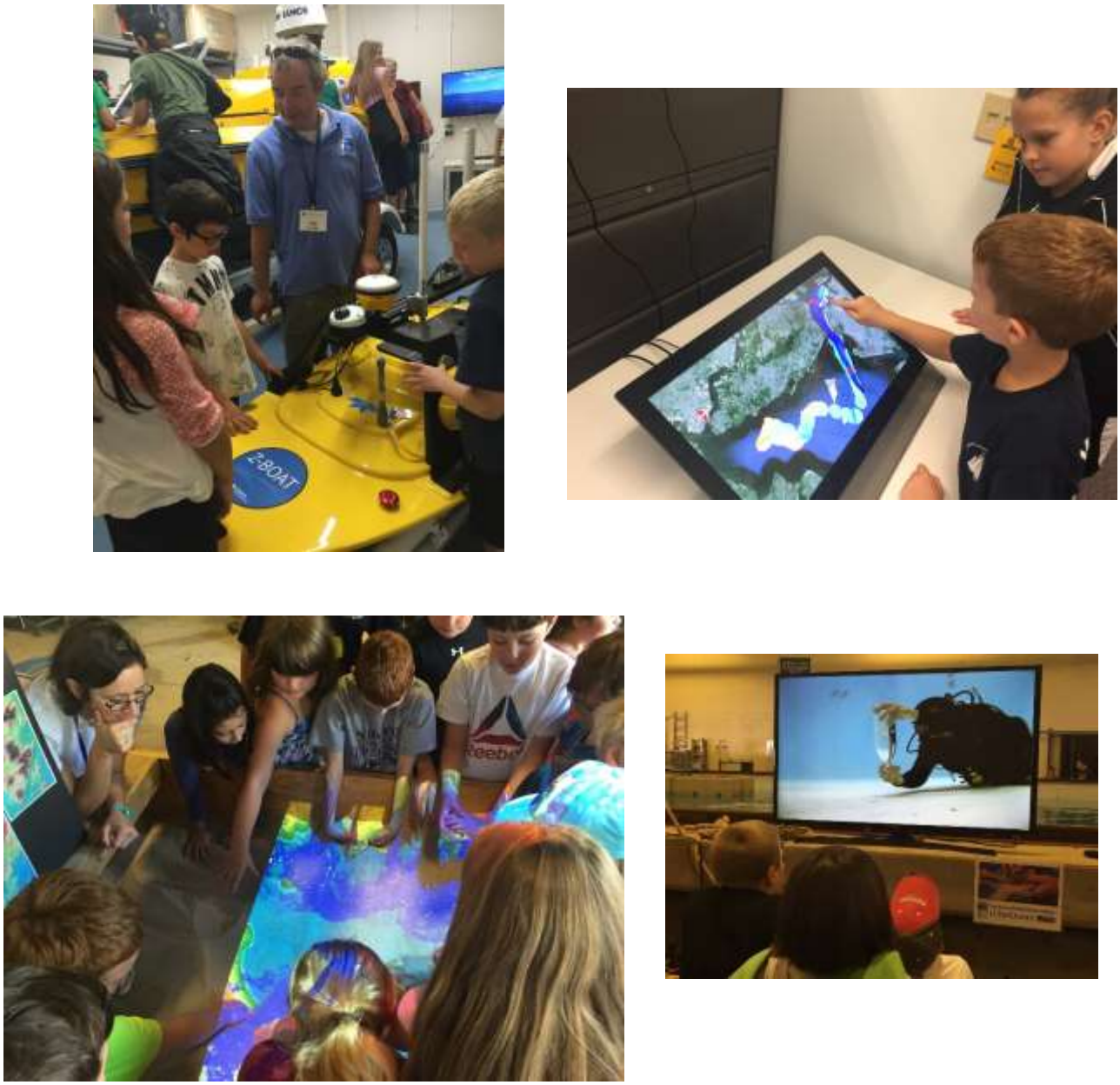


Figure 10-4: 2016 Ocean Discovery Day activities

Other Activities

In addition to the major outreach events that we manage each year, we also participate in smaller events and support smaller groups. For example:

- The Center also hosted a tour of the Center for Members of the Seacoast Science Center (SSC). For April and May, the Seacoast Science Center focused on Ocean Exploration, and did many ocean themed activities. Because of the our partnership with them, we held a "Members Night"

at the Center, where we were able to highlight our research and projects, including the new Ocean Exploration Trust community STEM partnership, and our new Super Storm Sandy exhibit at the SSC (Figure10-5). We also had two live interactions with the *E/V Nautilus* that evening. There was great interest in the event, with over 90 people signing up to attend the event.

Figure 10-5: Seacoast Science Center "Members Night" at the Center

- In support of a Cub Scouts "Floats and Boats" badge, a group of Tiger Cub Scouts from Lee, NH were given a tour of the facilities (Figure 10-6). They toured the Telepresence room, the visualization lab, and the High Bay, and tested out SeaPerch ROVs. Tara Hicks Johnson worked with the scout leaders to prepare activities so the scouts could earn their "Floats and Boats" badge for Tiger Cubs.

Figure 10-6: Cub Scouts"Floats and Boats" badge tour

- We hosted an Ocean Exploration Trust (OET) Educator Workshop at the Center. This one-day hands-on workshop introduced 25 NH educators to the OET program, highlighted ways to get involved in the Community STEM Partnership, provided them with standards-based activities for their learners, and sign-ups for live interactions with the OET Corps of Exploration aboard the E/V *Nautilus*. The workshop was led by the OET Community Stem program.

- The Center participated in the U-Day celebration on campus as part of the School of Marine Science and Ocean Engineering tent (Figure 10-7). Val Schmidt, Andy McLeod and Sam Reed brought the new ASV to the grounds in front of Thompson Hall to show off our newest ocean exploration vessel to students and the UNH community.

Figure 10-7: Center ASV at U-Day celebration

- The Center hosted the Wildcat Friends group, a group of developmentally delayed adults that spend every Wednesday on the UNH campus as college students. We hosted this group of 30 (plus their support staff) and with assistance from the Outreach Team at the Portsmouth Naval

Shipyard did some fun engineering activities (Figure 10-8). We also toured the Center and watched highlight videos in the telepresence room.

Figure 10-8: Center hosting the Wildcats Friends Group

WEBSITE AND OTHER OUTREACH ACTIVITIES

WEBSITE:

The JHC/CCOM website, www.ccom.unh.edu, is the public face of the Center (Figure 10-9).
The website is dynamic, with new content being continually added. Publications, seminars and events, and news articles are updated most frequently. Thirty-two front page slides were featured in 2016, highlighting awards and honors, interviews, news articles, and outreach events.

Figure 10-9: The homepage of the Center's website.

Since January 1, the website has received 57,839 visits from 36,401 unique visitors. 62% of those were first time visitors. The average visit lasted 2 minutes and 31 seconds with an average of 2.71 pages visited. From the distinctive jagged graphing of visits (Figure 10-10) we can surmise that most of these visits are made during the work week.

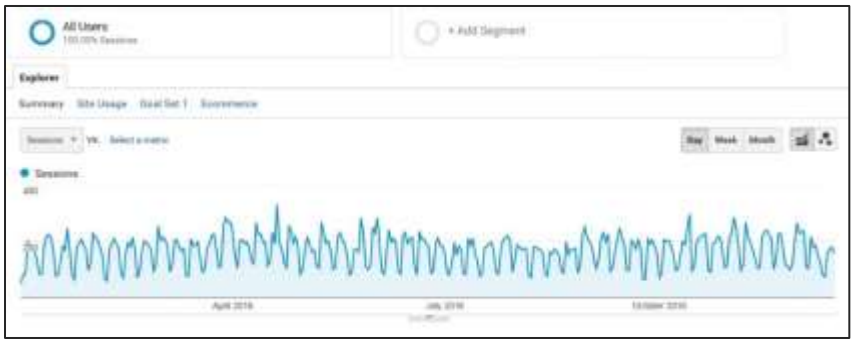


Figure 10-10: Google Analytics graph showing the clear trend of work week visits.

Sixty-one percent of visits originated in the U.S. while the other 39% is spread all over the world. In fact, we have had visits from 186 countries outside the U.S., including such exotic locales as Cote d'Ivoire, Romania, and Qatar.

Eighty-five percent of sessions are on desktop computers with the remaining split between mobile devices (11.5%) and tablets (3.4%). 80% of mobile devices have screen resolutions less than 500x750 pixels. This information will be helpful as we begin to work on making our website more mobile friendly.

Facebook continues to provide the bulk of our social media referrals at 73.7%, followed by LinkedIn at 13.5%, Twitter at 5.4%, and the rest scattered across a variety of other platforms.

Flickr

There are currently 2,312 images in the Center's Flickr photostream (**www.flickr.com/photos/ccom_jhc)**. Flickr has changed their statistics access so the total number of views is unknown. However, as of July 1, 2016, Center images had received a total of 265,834 views since the account was created in August 2009 (Figure 10-11).

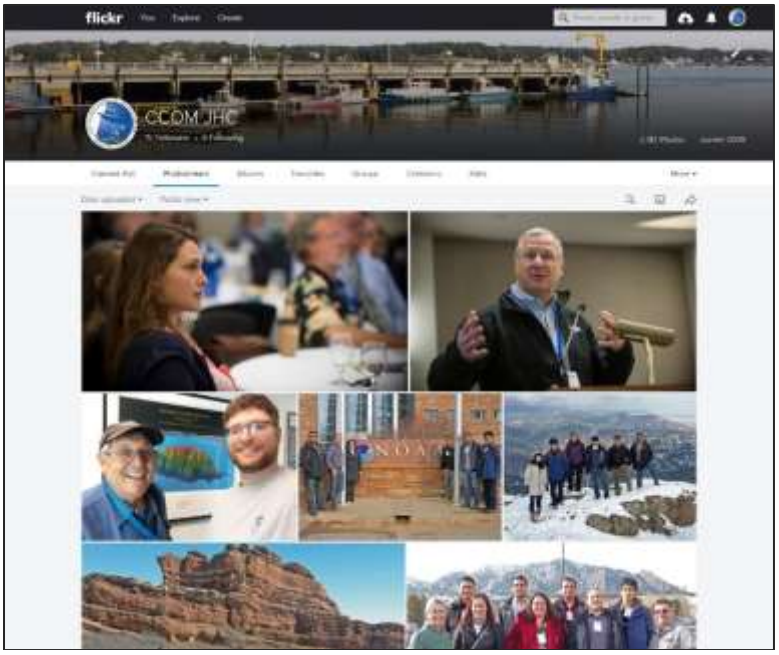


Figure 10-11: The Center's Flickr photostream.

The image that has been viewed the most is a photo of Dr. John Hall as he presented, "Update on the R/H *Sabvabaa*: A hovercraft for marine geophysical research in the most inaccessible parts of the High Arctic," as part of the Center's weekly seminar series on January 22, 2010 (Figure 10-12).

Figure 10-12: Dr. John Hall's photo is the most viewed on Flickr.

Pinterest

The Center's Pinterest page (**www.pinterest.com/ccomjhc**) has a board for faculty members, which serves as a kind of look book for prospective students (Figure 10-13). A board dedicated to the Center's

facilities and a board for research vessels have also been created. Pinterest serves as another social media outlet to enhance the Center's digital presence, particularly as a means to attract graduate students.

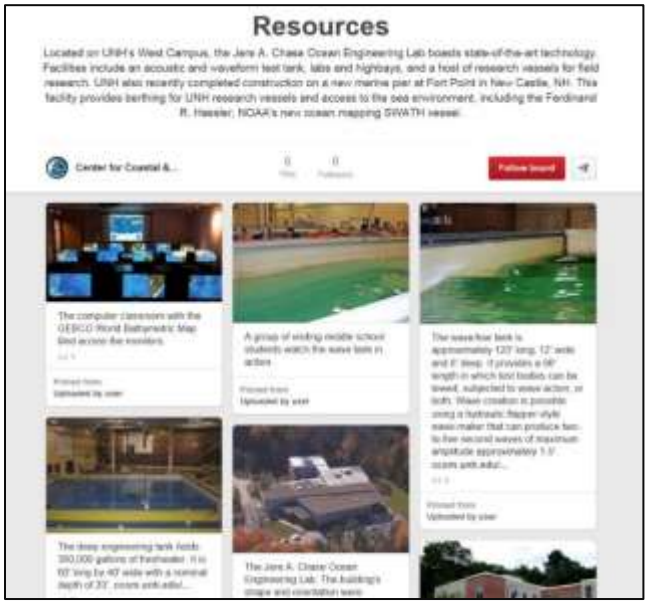


Figure 10-13: The Resources board on the Center's Pinterest page.

Vimeo

The Center's videos are hosted by Vimeo (**vimeo.com/ccomjhc)**. There are currently 101 videos in the Center's catalog. Some of these videos are short clips, such as "Arctic Flyover" or "Creating an AUV Plot with Interactive Visualization Tools." Other videos are full-length recordings of our seminar series. In addition to broadcasting the seminars as webinars, talks are recorded—as long as the speaker is amenable. Will Fessenden and Colleen Mitchell then edit the videos and upload them to the Vimeo site (Figure 10-14).

Figure 10-14: A sampling of the videos available in the Center's Vimeo catalog.

In 2016, the Center's videos were played 6,239 times. While the U.S. is the origin of most plays, Center videos have been viewed in 144 countries, including Turkey, Kenya, and Brunei. The most popular video continues to be, "Mariana Trench Fly Through," with more than 24,800 plays to date. It was created by Research Professor Jim Gardner and has been a featured video on the website.

Seminar Series

Our seminar series featured 29 seminars in 2016. Five of these seminars were master's thesis defenses and the rest were by Center researchers or experts from industry and academia. Graduate students Onni Irish and John Kidd served as seminar coordinators for the spring semester then handed their duties over to Matt Birkebak and Shannon Hoy for the fall semester. Our seminar coordinators do an exemplary job of populating the schedule and interfacing with the speakers. They communicate very well, sharing information and updates with the rest of the seminar team in a timely manner. System Administrator Will Fessenden continues to help the speakers set up their presentations, making sure that the webinars run smoothly and recording the presentations' video and audio. Colleen Mitchell advertises the seminars with customized flyers (Figure 10-15) that are posted on the Center's website and Facebook page, Twitter feed, and appear in the Center's kiosk slideshow in the lobby of Chase.

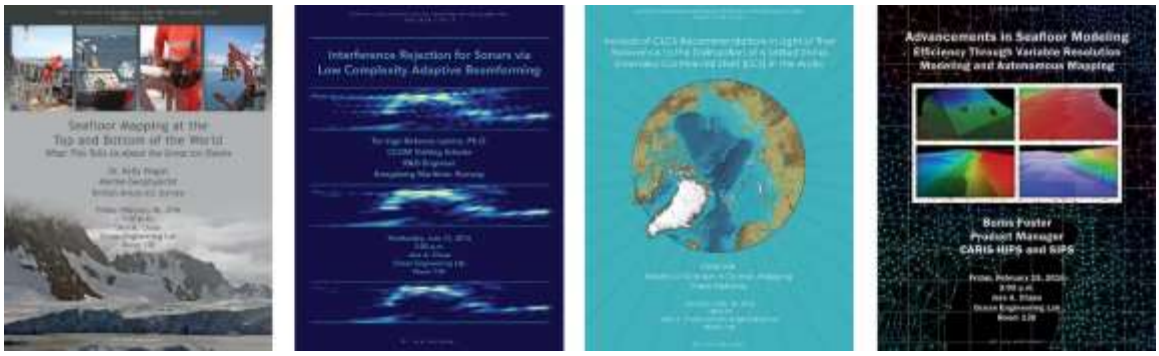


Figure 10-15: A few of the 17 flyers produced for the 2016 seminar series.

Facebook

The Center's Facebook page (**www.facebook.com/CCOMJHC**) mirrors the website and provides a less formal venue for posting Center news, announcements, videos, and photos. The page currently has 968 followers. Colleen Mitchell, who manages the Center's social media, actively sources stories that will interest the Center's Facebook audience. It is clear from our feedback that stories about people are very popular and posts featuring research always create a buzz (see Figures 10-16 and 10-17). And it is also clear, from the feedback the page gets, that the majority of our audience is made up of scientists and researchers all around the world, including Center alumni, GEBCO fellows, and NOAA personnel.

Figure 10-16. The Center's Facebook page.

The most popular post so far this year was on May 26 when we announced that Center Director Larry Mayer was appointed by President Obama to the U.S. Arctic Research Commission (Figure 10-17). The post reached 4,399 people and was liked and shared numerous times.

A post from October 13 that linked to an article on the Center's website written by graduate student Erin Heffron was the second most popular post this year. Heffron was part of a survey team aboard the M/V *Fugro Supporter* on an ECS mapping mission in the Mariana Archipelago (Figure 10-17). The post reached 2,925 people and was liked and shared numerous times.

Figure 10-17. The two posts with the most exposure in the first half of 2016.

Twitter

While the Center's Facebook page is a more relaxed and casual reflection of the website, the Center's Twitter is more relaxed still (Figure 10-18). In some ways, Twitter is more conducive to community-building because it is easier to tag other people and organizations, and responding and retweeting creates a sense of conversation. It also increases the Center's exposure since UNH Media follows our account and is quick to pick up on our news, sometimes giving our stories "legs." To date, we have tweeted 231 times. We are following 47 groups or individuals in the ocean community, and 166 people or groups are following us.

Figure 10-18. The Center's Twitter page.

Videos

The creation of a series of videos to augment the Center's outreach efforts has been a goal of the current reporting period. As an on-going effort, the intent is that these videos will range from short, informative clips about lab-based experiments, *in situ* fieldwork, and pieces of technology, to more in-depth looks at research projects, as well as interviews with Center staff members. The effort was initiated with the hiring of recent American University graduate Emma Asher as a summer intern. Asher's degree in film was useful as she provided guidance in the acquisition of the appropriate equipment and gave instruction to Mitchell in production and editing.

During her tenure at the Center, Asher completed a short clip on the delivery of the Center's new ASV, and two lengthier films: an interview with Jim Gardner (Figuer 10-19), and a tour of the new research vessel Gulf Surveyor with Lee Alexander (Figure 10-20). Both are available on the Center's Vimeo site.

Figure 10-19. Interview video with Jim Gardner.

Figure 10-20: Video tour of the R/V Gulf Surveyor with Lee Alexander.

When the videos are complete, they will be disseminated in our usual way of posting them on Vimeo and announcing them on the website, Facebook page, and Twitter. A webpage featuring all videos, infographic, animations, and photo galleries is also planned, bringing together all of the Center's digital outreach together in one place.

SEACOAST SCIENCE CENTER HURRICANE MARINE DEBRIS EXHIBIT/GAME

As part of the outreach component of the Super Storm Sandy project, the Center partnered with the Seacoast Science Center in Rye, N.H. to develop an interactive museum exhibit that engages the public with a touchscreen based game revolving around the detection and identification of marine debris. "A Hurricane Hits Home" is a multi-station touchscreen exhibit geared towards children, and integrates a portion of a historical wooden shipwreck into its physical design (Figure 10-21 to 10-23).

The game invites museum guests to examine a number of coastal regions and harbors in Sandy affected areas. It teaches visitors about modern mapping technology by having them control boats with multibeam sonars and airplanes with LIDAR sensors. They drag these vehicles around maps to reveal the underlying bathymetry below the satellite photos. They learn the applications and limitations of sonar and lidar by where the vehicles can and cannot collect survey data (e.g. LIDAR does not work in deep water, and the boat cannot go in shallow areas).

As users collect bathymetry data, they occasionally reveal marine debris objects on the seafloor. Once all the debris objects in a level have been located, the game challenges them to identify them based on their appearance in the bathymetry data. They must compare the simulated bathymetry images of the debris targets to photos of possible objects, and choose the correct matches to achieve a high score.

This year Tom Butkiewicz worked with student Ben Fruth to improve the exhibit. Originally a computer science senior project, the software had a number of usability and reliability bugs that needed to be fixed. Based on feedback and suggestions from a UNH educational researcher, vocal prompts/cues were added to encourage and direct users. This improved final version was installed June 2016 and has been stable since. Thus, this project is considered closed.

Figure 10-21: A screenshot of the gameplay in the science museum exhibit, showing the user dragging boats and planes around to reveal bathymetry and find debris targets.

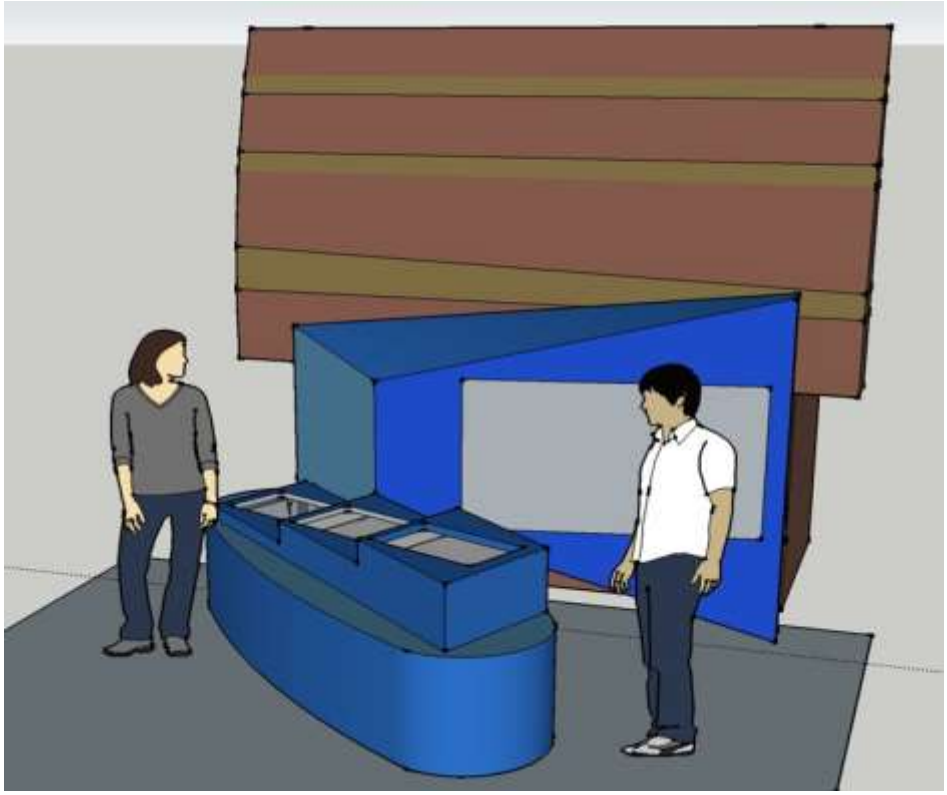


Figure 10-22: Mockup of the final exhibit design, with three touchscreen stations in front of the museums existing piece of a historical shipwreck.

Figure 10-23: Exhibit currently under construction at The Seacoast Science Center.

PARTNERSHIPS AND ANCILLARY PROGRAMS

One of the goals of the Joint Hydrographic Center is, through its partner organization the Center for Coastal and Ocean Mapping, to establish collaborative arrangements with private sector and other government organizations. Our involvement with Tyco has been instrumental in the University securing a $5 million endowment; $1 million of this endowment has been earmarked for support of post-doctoral fellows at the Center for Coastal and Ocean Mapping. Industrial Partner Kongsberg Maritime has also provided $1 million to support the research of John Hughes Clarke. Our interaction with the private sector has been formalized into an industrial partner program that is continually growing.

Acoustic Imaging Pty LTD
Airborne Hydrography AB
Alidade Hydrographic
AML Oceanographic
Anthropocene Institute
ASV Global LTD
Bluefin Robotics
Chesapeake Technologies
Clearwater Seafoods
EarthNC, Inc.
EdgeTech
Environmental Systems Research Institute, Inc. (ESRI)
EIVA Marine Survey Solutions
Exxon Mobil
Fugro Inc. (Pelagos)
Hydroid – subsidiary of Kongsberg
HYPACK, Inc.
IFREMER
IIC Technologies
Kongsberg Underwater Technology, Inc. (KUTI)
Klein Marine Systems, Inc.
Leidos
Norbit Subsea
Novatel
Ocean Aero
Ocean High Technology Institute
Phoenix International
QPS - Quality Positioning Services B.V.
Schlumberger WesternGeco
Sea Machines Robotics
SevenCs
SMT Kingdom
Substructure
Survice Engineering Company
Teledyne Benthos, Inc.

Teledyne Caris
Teledyne Ocean Science
Teledyne Odom Hydrographic
Teledyne Optech
Teledyne-Reson
Triton Imaging Inc.
Tycom LTD
YSI, Inc

In addition, grants are in place with:

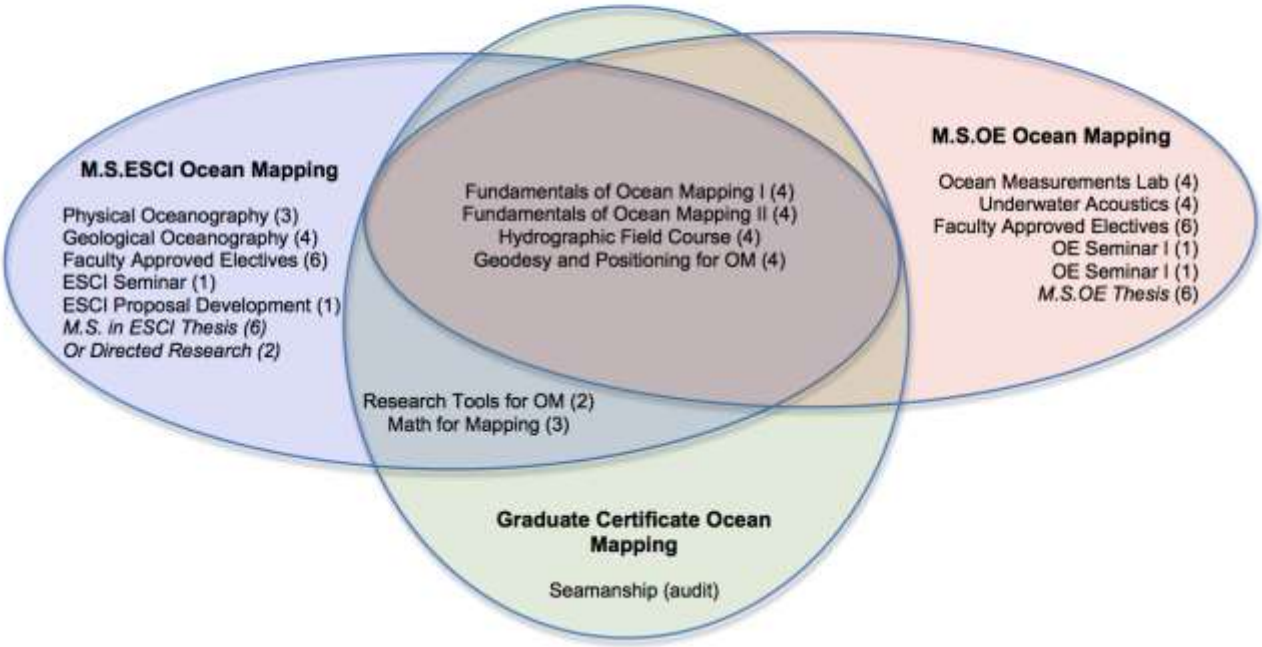
National Science Foundation
Nippon Foundation/GEBCO
NOAA National Marine Fisheries Services
Ocean Exploration Trust
Office of Naval Research
Schmidt Ocean Institute
Systems & Technology Research, LLC
University Corporation for Atmospheric Research
U.S. Geological Survey
Department of Defense
Kongsberg Maritime
Swedish Polar Research Secretariat / Stockholm Univ.
Northeastern Regional Association of Coastal Ocean Observing Systems
International Association of Oil & Gas Producers
Department of the Interior
Department of Energy
Exxon-Mobil Upstream Research
United Kingdom Hydrographic Office

The Center has also received support from other sources of approximately $8.092M for 2016 (see Appendix C).

APPENDIX A: GRADUATE DEGREES IN OCEAN MAPPING

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

Curricula for Masters Degrees and Certificates in Ocean Mapping at UNH CCOM/JHC



REQUIREMENTS FOR MASTER OF SCIENCE IN OCEAN ENGINEERING

OCEAN MAPPING OPTION

CORE REQUIREMENTS			CREDIT HOURS
OE 810	Ocean Measurements Lab	Baldwin	4
OE/ESCI 874	Fundamentals of Ocean Mapping I	Dijkstra/Hughes Clarke/ Calder	4
OE/ESCI 875	Fundamentals of Ocean Mapping II	Dijkstra/Calder Mayer/Armstrong/Weston	4
OE/ESCI 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
OE/ESCI 865	Underwater Acoustics	Weber	3
OE/ESCI 972	Hydrographic Field Course	Dijkstra/Armstrong	4
OE 990	Ocean Engineering Seminar I	Mayer	1
OE 991	Ocean Engineering Seminar II	Mayer	1
OE 899	Thesis		6

In addition one of either ESCI 858 Physical Oceanography or ESCI 859 Geological Oceanography must be taken.

AT LEAST SIX ADDITIONAL CREDITS FROM THE ELECTIVES BELOW

ESCI 858	Introduction to Physical Oceanography	Pringle	3
OE 854	Ocean Waves and Tides	Swift	4
ESCI 859	Geological Oceanography	Mosher	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/EE 985	Special Topics	Many	3
MATH 944	Spatial Statistics	Linder	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
ESCI 898	Directed Research		2
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Remote Sensing of the Environment	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
ESCI 896	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
OE 995	Graduate Special Topics		2-4
OE 965	Advanced Underwater Acoustics	Weber	3
OE 895	Time Series Analysis	Lippmann	4
OE 998	Independent Study		1-4
	Other related courses with approval		1-4

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

REQUIREMENTS FOR MASTER OF SCIENCE IN EARTH SCIENCES

OCEAN MAPPING OPTION

CORE REQUIREMENTS

			CREDIT HOURS
ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Mosher	4
MATH 896	Mathematics for Geodesy	Wineberg	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	Dijkstra/Hughes Clarke Calder	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra/Calder/Armstrong Mayer/Weston	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra/Wigley/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4
ESCI 997	Seminar in Earth Sciences	Mayer	1
ESCI 998	Proposal Development		1
ESCI 899	Thesis		6

APPROVED ELECTIVES

OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 754	Ocean Waves and Tides	Swift	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/EE 985	Special Topics		3
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	3
OE 965	Advanced Underwater Acoustics	Weber	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
ESCI 896	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Nearshore Processes	Ward	4
OE 995	Graduate Special Topics	Many	2-4
OE 895	Time Series Analysis	Lippmann	4
OE 998	Independent Study	Many	1-4

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

REQUIREMENTS FOR MASTER OF SCIENCE IN EARTH SCIENCES (NON THESIS OPTION)

OCEAN MAPPING OPTION

CORE REQUIREMENTS			CREDIT HOURS
ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Mosher	4
MATH 896	Mathematics for Geodesy	Wineberg	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	Dijkstra/Hughes Clarke Calder	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra/Calder/Armstrong Mayer/Weston	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra/Wigley/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4
ESCI 997	Seminar in Earth Sciences	Mayer	1
ESCI 998	Proposal Development		1

AT LEAST FOUR ADDITIONAL CREDITS FROM THE ELECTIVES BELOW

OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 754	Ocean Waves and Tides	Swift	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	3
OE 965	Advanced Underwater Acoustics	Weber	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
ESCI 895,896	Special Topics in Earth Science	Many	1-4
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
ESCI 896	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Near shore Processes	Ward	4
OE 995	Graduate Special Topics		2-4
OE 895	Time Series Analyses		4
OE 998	Independent Study		1-4

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

REQUIREMENTS FOR CERTIFICATE IN OCEAN MAPPING

OCEAN MAPPING OPTION

CORE REQUIREMENTS			CREDIT HOURS
MATH 896	Mathematics for Geodesy	Wineberg	3
ESCI/OE 874	Fundamentals of Ocean Mapping I	Dijkstra/Hughes Clarke Calder	4
ESCI/OE 875	Fundamentals of Ocean Mapping II	Dijkstra/Calder/Armstrong Mayer/Weston	4
ESCI/OE 871	Geodesy and Positioning for Ocean Mapping	Dijkstra	3
ESCI 872	Research Tools for Ocean Mapping	Dijkstra/Wigley/Johnson	2
ESCI /OE 972	Hydrographic Field Course	Dijkstra/Armstrong	4

APPROVED ELECTIVES

ESCI 858	Introductory Physical Oceanography	Pringle	3
ESCI 859	Geological Oceanography	Mosher	4
OE 810	Ocean Measurements Laboratory	Baldwin	4
OE 854	Ocean Waves and Tides	Swift	4
ESCI 864	Data Analysis Methods in Ocean and Earth Sciences	Gopal	4
OE 954	Ocean Waves and Tides II	Swift	4
OE/ESCI 895,896	Special Topics in Earth Science	Many	1-4
MATH 944	Spatial Statistics	Linder	3
OE 865	Underwater Acoustics	Weber	3
OE 965	Advanced Underwater Acoustics	Weber	3
OE/ESCI 973	Seafloor Characterization	Mayer/Calder/Masetti	3
EOS 824	Introduction to Ocean Remote Sensing	Vandemark	3
NR 857	Photo Interpretation and Photogrammetry	Congalton	4
NR 860	GIS in Natural Resources	Congalton	4
GSS 807	GIS for Earth and Environmental Science	Routhier	4
ESCI 896	Bathymetric Spatial Analysis	Wigley	3
ESCI 896	Near shore Processes	Ward	4
OE 995	Graduate Special Topics		2-4
OE 895	Time Series Analyses		4
OE 998	Independent Study		1-4

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

APPENDIX B: FIELD PROGRAMS

Great Bay survey, January 1 - April 30, R/V *Galen J*. Re-survey of the Great Bay with single-beam echo sounder. (Jon Hunt, Tom Lippmann)

RB2016 Leg 1 RB2016, January 5 - 8, NOAA Ship *Ron Brown*. Multibeam shakedown cruise for the NOAA Ship *Ron Brown*. A full multibeam quality assurance visit was conducted during this leg, which included verification of the POSMV and EM122 setup, a patch test, noise testing, swath performance testing, and accuracy testing. (Jim Gardner, Glen Rice, Paul Johnson)

RB2016 Leg 2 Kingman-Palmyra Leg 2, January 12 - February 12, NOAA Ship *Ron Brown*. ECS surveying of area around Palmyra Atoll and Kingman Reef. (Kelly Nifong, Will Fessenden, John Kidd, David Mosher)

PNSY, January 21, recovered ADCP deployed in back channel of Portsmouth Naval Shipyard. R/V *Galen J*. (Tom Lippmann)

RVBG1601 EM302 and EM2040 Shipboard Acceptance Test, January 31 - February 4, R/V *Bat Galim*. Shipboard acceptance test for the R/V *Bat Galim*'s newly installed EM302 and EM2040. Testing included patch tests, accuracy tests, swath performance tests, and noise testing for both the EM302 and EM2040. This field program was paid for through external funding. (Paul Johnson)

EX-16-01 Transit and Mission Patch Test, January 23 - February 7, NOAA Ship *Okeanos Explorer*. Map Molokai Fracture Zone, test and calibrate multibeam and EK60 sonars. (Derek Sowers)

AR0103 R/V *Neil Armstrong* Multibeam Sea Acceptance Trials, February 10 - 17, *R/V Neil Armstrong*. Field program AR0103 involved Multibeam Advisory Committee (MAC) Sea Acceptance Trials (SAT) for new Kongsberg EM710 and EM122 multibeam echosounders aboard the new vessel R/V *Neil Armstrong*. Trials were conducted southeast of Charleston, South Carolina, involving a complete review of vessel geometry and software configuration followed by geometric calibrations (‘patch tests’) and verifications for each multibeam echosounder. Assessments were made of the achieved swath coverage versus depth, sounding accuracy relative to reference surfaces, and vessel noise perceived by the multibeam receivers at a variety of speeds and headings relative to the prevailing swell. (Paul Johnson, Glen Rice, Erin Nagel, Kevin Jerram)

SKQ201602S R/V *Sikuliaq* Multibeam Quality Assurance Testing, March 7 - 12, R/V *Sikuliaq*. Field program SKQ201602S involved Multibeam Advisory Committee (MAC) Quality Assurance Testing (QAT) for the Kongsberg EM710 and EM302 multibeam echosounders aboard the vessel R/V *Sikuliaq* following a shipyard period and relocation of GPS antennas to provide better satellite visibility. The evaluation involved review of an updated vessel survey, software configuration, and geometric calibrations (‘patch tests’) and verifications for each multibeam echosounder off San Diego, California. (Paul Johnson, Kevin Jerram)

HRS1602 R/V *Hugh R. Sharp* Multibeam Quality Assurance Testing, March 21 - 23, R/V *Hugh R. Sharp*. Field program HRS1602 involved Multibeam Advisory Committee (MAC) Quality Assurance Testing (QAT) for the Reson 7125 multibeam echosounder aboard the R/V *Hugh R. Sharp* following reinstallation of the transducer assembly on the vessel's drop-keel. The evaluation involved review of vessel geometry and software configuration, geometric calibration ('patch testing') during a survey at Redbird Reef near Lewes, Delaware, and updating the post-processing parameters for the vessel. (Paul Johnson, Kevin Jerram)

EX001 Vessel Delivery Transit, March 25 - April 21, R/V *Gulf Surveyor*. Delivery of *R/V Gulf Surveyor* to home port in New Castle, NH. Navigation data collection in the intracoastal waterway. (Lee Alexander, Daniel Tauriello)

AR01-07 Armstrong, March 30 - April 6, R/V *Neil Armstrong*. Ship Bad weather resulted in no data acquisition (Larry Mayer, David Mosher)

NA070 E/V *Nautilus* Acoustic Shakedown, April 10 - 15, E/V *Nautilus*. Field program NA070 involved performance testing of the Kongsberg EM302 multibeam echosounder aboard the E/V *Nautilus* off Victoria, British Columbia, ahead of the 2016 mapping season. This ship visit involved review of the vessel geometry and software configuration, geometric calibration ('patch testing') and verification, and assessments of swath accuracy and coverage versus depth. (Paul Johnson, Kevin Jerram)

EX-16-04 NOAA Ship *Okeanos Explorer* CAPSTONE Wake Island Mapping, April 13, *NOAA Ship Okeanos Explorer*. Exploration mapping cruise in the Wake Island Unit of the Pacific Remote Islands Marine National Monument (Derek Sowers)

EX1605 Leg 1 NOAA Ship *Okeanos Explorer* - Deepwater Exploration of the Marianas - Leg 1, April 19 - May 11, *NOAA Ship Okeanos Explorer*. The NOAA *Ship Okeanos Explorer* undertook Leg 1 of the Deepwater Exploration of the Marianas expedition between Guam and Saipan to map and conduct ROV dives in poorly explored areas near the Mariana Trench. The vessel's Kongsberg EM302 multibeam echosounder was used to conduct surveys of opportunity and map ROV dive sites overnight ahead of each day's ROV-centric science and outreach activities. Simrad EK60 split-beam scientific echosounders and a Knudsen subbottom profiler were operated to provide additional data on water column targets (at a variety of frequencies) and sediment structure. (Kevin Jerram)

QINSy Edgetech 6205 Cruise, April 19, R/V *Coastal Surveyor*. QPS and Edgetech tested the acquisition of 6205 data with QINSy on board the *R/V Coastal Surveyor*, while demonstrating their equipment to Center students. (Emily Terry, Daniel Tauriello, Tiziana Munene, Elizabeth Weidner, Erin Heffron, Samantha Bruce, Shannon Hoy, Matthew Birkebak, Semme J. Dijkstra)

Eelgrass Acoustic Field Experiment, May 20 – 31. A multi-beam echosounder, high resolution current profiler and HD camera were deployed on a stationary frame in an eelgrass bed just off the UNH/NOAA pier at New Castle, NH. The purpose of the experiment was to observe how the acoustic response of the eelgrass changes as the morphology of the eelgrass canopy changes with current magnitude. (Semme J. Dijkstra, Jenn Dijkstra, Andy McLeod, Ashley Norton)

R/V *Daiber* Magnetometer Testing w Gavia AUV, May 23 - 25, R/V *Daiber*. Field evaluation and development of a magnetometer integrated into the University of Delaware's Gavia AUV - a collaborative effort with Dr. Art Trembanis. (Val E. Schmidt)

Summer Hydro 2016, May 31 - July 8, R/V *Gulf Surveyor*, R/V *Cocheco*. The 2016 Summer Hydrographic Field Course brought the R/V *Gulf Surveyor*, R/V *Cocheco*, 11 JHC/CCOM students, and several technical staff under the supervision of Semme Dijkstra to the nearshore waters between, North Hampton, NH and Salisbury, NH. The primary objective was to map an area of Salisbury Beach at the request of the Massachusetts Coastal Zone Management (CZM). (Matthew Birkebak, Semme J. Dijkstra, Emily Terry, Daniel Tauriello, Tiziana Munene)

Great Bay ADCP deployment, June 3 - 13, deployed and recovered ADCP and ADV in the Great Bay for sediment flux studies. (Jon Hunt, Tom Lippmann)

EX-16-05 Leg 3 NOAA Ship *Okeanos Explorer* - Deepwater Exploration of the Marianas - Leg 3, June 17 - July 10, ROV and mapping exploration cruise in the Mariana Trench Marine National Monument and CNMI EEZ. (Derek Sowers)

Lake Erie Surveys, June 19 - 23, Surveyed select transects along the southern Lake Erie Shoreline to the east of Cleveland. (Tom Lippmann)

Leg 1 R/V *Gulf Surveyor* - Klein 3500 Testing, July 12 - 14, R/V *Gulf Surveyor*. Field evaluation of the Klein 3500 bathymetric sidescan sonar. (Val E. Schmidt)

MGL EM122 Calibration R/V *Marcus G. Langseth* Remote Patch Test, July 21 - October 24, R/V *Marcus G. Langseth*. The Multibeam Advisory Committee (MAC) assisted the R/V *Marcus G. Langseth* over email and satellite phone with planning two calibrations of the vessel's Kongsberg EM122 multibeam echosounder and troubleshooting a motion sensor communications error. The data acquisition was coordinated remotely, collected by the on-board technicians during a transit, and then analyzed by MAC personnel on shore, drastically reducing the scheduling impact on other Center activities and the vessel's science programs compared to traditional ship visits. (Note that the date range is from first email communication from the ship during planning to completion of the calibration.) (Paul Johnson, Kevin Jerram)

SR1601 R/V *Sally Ride* Sea Trials, July 24 - 29, R/V *Sally Ride*. Shipboard acceptance tests of the R/V *Sally Ride*'s EM712 and EM122 systems. Tests were conducted off of Anacortes, WA. (Paul Johnson)

FS1601, September 13 - October 15, M/V *Fugro Supporter*. FS1601 is a 32-day Extended Continental Shelf-related bathymetry cruise to the Northern Mariana Islands Continental Shelf. Andy Armstrong, Erin Heffron, Tiziana Munene, Michael Smith, Giuseppe Masetti.

HLY16-03 Healy Extended Continental Shelf Project 2016, September 17 - October 6, USCGC *Healy*. USCGC *Healy* program in support of the U.S. Extended Continental Shelf project. (Larry Mayer, Elizabeth Weidner, Shannon Hoy, David Mosher, Kim Baldwin, Massimo Di Stefano, Brian Calder)

ATL EM122 System Review R/V *Atlantis* System Geometry Review, October 6 - December 1, While analyzing Kongsberg EM122 multibeam data from the R/V *Atlantis* to determine swath coverage performance ahead of a mapping expedition, the Multibeam Advisory Committee (MAC) noticed other bathymetric artifacts and reviewed system geometry and motion sensor performance. The multibeam echosounder and motion sensor received hardware and/or software updates from their manufacturers and the MAC is planning to assist remotely with a multibeam calibration after modification of sensor offsets per the system geometry review. (Note that the date range is from early email communication from the ship during planning to most recent updates regarding system performance.) (Paul Johnson, Kevin Jerram)

NOAA Ship *Thomas Jefferson* Acceptance Cruise, October 14 - 21, NOAA Ship *Thomas Jefferson*. Assisted with the shipboard acceptance test of the NOAA Ship *Thomas Jefferson*'s EM710 MKII and EM2040 conducted out of Norfolk, VA. (Paul Johnson)

APPENDIX C: OTHER FUNDING

Project Title	PI	Sponsor	CY Award	Total Award	Length
IT Support for NOAA UNH Employees	Calder, B.	US DOC, NOAA	45,912	45,912	1 year
Development of Theoretical and Computational Methods for Single-Source Bathymetric Data	Calder, B.	Office of Naval Research	94,761	94,761	1.1 year
NOAALink OCS Sandy Task Order	Calder, B.	Earth Resources Technology, Inc.	-	57,002	3 years
IT Support for NOAA UNH Employees	Calder, B.	US DOC, NOAA	-	105,019	2 years
An Annual Cycle of Ice-Ocean Interactions using Autonomous Platforms: Sea Ice Component	Chayes, D.	Office of Naval Research	140,000	509,920	5 years
Autonomous Ice Mapping	Chayes, D.	US DOD, Dept. of Defense	497,183	497,183	1 year
Integrated Multibeam	Hughes Clarke, J.	Kongsberg Maritime	1,000,000	1,000,000	5 years
Geophysical Mapping, Arctic Ocean 2016	Jerram, K	Swedish Polar Research Secretariat/Stockholm U.	20,898	20,898	3 months
Supporting the Multibeam Sonar Systems of the US Academic Research Fleet	Johnson, P.	National Science Foundation	170,815	666,841	3 years
Optimizing Multibeam Data Acquisition, Operations, and Quality for US Academic Research Fleet	Johnson, P.	National Science Foundation	-	420,527	5 years
Improving Coastal Inundation	Lippmann, T	NERACOOS	77,570	77,570	1.5 years
Neracoos Grad Student	Lippmann, T	NERACOOS	8,298	8,298	1 year
Large Scale Observations	Lippmann, T.	Office of Naval Research	-	150,000	2.5 years
3D SAS Wave Measurements	Lyons, A.	US DOD, Dept. of Defense	60,000	60,000	1 year
SAS Analysis, Scattering Mechanisms	Lyons, A.	Office of Naval Research	140,000	449,946	3.5 years
Imaging SAS Performance Estimation	Lyons, A.	Office of Naval Research	24,999	214,998	3 years
NF GEBCO Years 13 & 14 Travel	Mayer, L	GEBCO Nippon-Foundation	171,052	171,052	2 years
NF GEBCO Years 13 & 14 Project	Mayer, L	GEBCO Nippon-Foundation	1,087,345	1,087,345	2 years
GEBCO Yrs. 1-10	Mayer, L.	GEBCO Nippon-Foundation	-	5,383,922	13 years
Indian Ocean Project	Mayer, L.	GEBCO Nippon-Foundation	-	245,269	5 years
Mapping and Quantifying Methane Seeps	Mayer, L.	National Science Foundation	-	290,667	3 years
NF GEBCO Ambassador	Mayer, L.	GEBCO Nippon-Foundation	-	40,500	2 years
NF GEBCO Ocean Floor Forum	Mayer, L.	GEBCO Nippon-Foundation	-	322,788	2.5 years
Petermann Gletscher, Greenland	Mayer, L.	National Science Foundation	-	249,278	3 years
Seafloor Methane Deposits	Mayer, L.	Columbia University/Sloan Foundation	-	46,250	3 years
Support for R/V Falkor Mapping Support	Mayer, L.	Schmidt Ocean Institute	-	83,600	3.5 years
Tyco Endowment	Mayer, L.	TYCO	49,544	-	***in perpetuity***
GEBCO 11th Year & Travel support for Monaco	Mayer, L.	GEBCO Nippon-Foundation	-	630,000	1 year
GEBCO Yr. 12	Mayer, L.	GEBCO Nippon-Foundation	-	604,301	2 years
Monitoring Odontocete Shifts	Miksis-Olds, J.	US DOD, Navy	400,000	800,000	5.4 years
SeaBass 2016: Marine Bioacoustic	Miksis-Olds, J.	US DOC, NOAA	20,000	20,000	6 months
SeaBASS 2016: A Marine Bio-Acoustic Summer School	Miksis-Olds, J.	US DOD, Navy	40,000	40,000	4 months
Large Scale Density Estimation of Blue and Fin Whales	Miksis-Olds, J.	US DOD, Navy	114,453	266,396	1.5 years
Sound and Marine Life Joint Industry Program	Miksis-Olds, J.	Intl Assoc of Oil & Gas Producers	62,000	62,000	1 year
ADEON	Miksis-Olds, J.	US DOI, Department of the Interior	3,131,842	6,092,513	2 years
Seafloor Video Mosaic Research	Rzhanov, R.	US DOI, US Geological Survey	10,000	10,000	5 years
NH Volunteer Beach Profiling	Ward, L.	NH Dept of Environ Services; US DOC, NOAA	31,768	31,768	1 year
Assessment of Offshore Sources	Ward, L.	US DOI, Department of the Interior	200,000	399,997	3 years
Optimizing the Energy Usage	Ware, C.	US DOE, Department of Energy	115,000	345,000	3 years
TrackPlot Enhancement	Ware, C.	US DOD, Navy	-	78,179	2.9 years
Visualization, Human Systems	Ware, C.	Systems & Technology Research, LLC	-	205,000	2 years
Development of a Broadband	Weber, T.	National Science Foundation	85,317	690,785	5 years
Effect of Hydrocarbon Production	Weber, T.	US DOI, Dept of Interior/University of California at Santa Barbara	248,828	248,828	3 years
Fate of Methane	Weber, T.	US DOE, Dept of Energy / Massachusetts Institute of Techn	-	245,788	4 years
Increased Efficiency for Detection of Gas Seeps	Weber, T.	Exxon-Mobil Upstream Research	-	150,000	1.5 years
2nd NOAA Chart Adequacy Eval	Wigley, R	United Kingdom Hydrographic Office	44,960	44,960	1 year
Chart Adequacy Workshop	Wigley, R.	United Kingdom Hydrographic Office	-	39,960	2 years
Total			8,092,545	23,305,021	

APPENDIX D: PUBLICATIONS

Book Sections

L.A. Mayer, “The Arctic Continental Shelf and Its Evolving Morphologic Context,” in Challenges of the Changing Arctic: Continental Shelf, Navigation and Fisheries, vol. 19, M. Nordquist, Moore, J. M., and Long, R. Leiden, The Netherlands: Brill Nijhoff Press, 2016, pp. 17–41.

L.A. Mayer and Gardner, J.V., “Cascades and Plunge Pools in the Gulf of Alaska,” in Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient, Memoir, London, UK: Geological Society of London, 2016. pp. 387–388.

J.V. Gardner and Mayer, L.A., “Chatham Fan and Adjacent Upper Baranof Fan Channels and Levee, U.S. Gulf of Alaska Margin,” in Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient, Memoir, London, UK: Geological Society of London, 2016. pp. 389–390.

J. Miksis-Olds, “Global Trends in Ocean Noise,” in Effects of Noise on Aquatic Life II, vol. 2, A. N. Popper and Hawkins, A. New York, NY: Springer Science & Business Media, LLC, 2016, pp. 713–718.

A. Klemm, Nyberg, J., Pe'eri, S., Wigley, R., Gur-Arieh, L., Kamaruddin, Y., Kimeli, A., Kurita, H., Prasetyawan, I.B., Roperez, J., Samarakoon, N., Vallee-Anziani, M., Roh, J.-Y., and Sydenham, J., “Nautical Chart Adequacy Procedure,” in The IHO-IOC GEBCO Cook Book (IHO Publication B-11 and IOC Manuals and Guides, 63), 11.1.16th ed., Monaco, Monaco Cedex, Monaco: International Hydrographic Office (IHO)/International Ocean Commission (IOC), 2016, pp. 346–422.

J. Miksis-Olds, Van Opzeeland, I.C., Van Parijs, S., and Jones, J., “Pinniped Sounds in the Polar Oceans,” in Listening in the Ocean: New Discoveries and Insights on Marine Life From Autonomous Passive Acoustic Monitors (PAM), W. W. Au and Lammers, M. O. Springer-Verlag, 2016, pp. 257–308.

S. Pe'eri, Madore, B., Alexander, L., Parrish, C. E., Klemm, A., Armstrong, A.A., Azuike, C., and Tetteh, E., “Satellite-Derived Bathymetry,” in The IHO-IOC GEBCO Cook Book (IHO Publication B-11 and IOC Manuals and Guides, 63), 11.1.16th ed., Monaco, Monaco Cedex, Monaco: International Hydrographic Office (IHO)/ International Ocean Commission (IOC), 2016, pp. 346–422.

L.A. Mayer, Gardner, J.V., and Armstrong, A.A., “An Ultrahigh-Latitude Submarine Channel: Northern Chukchi Rise,” in Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient, Memoir, London, UK: The Geological Society of London, 2016.

Journal Articles

C. Ware, “Averaged Propulsive Body Acceleration (APBA) Can Be Calculated from Biologging Tags That Incorporate Gyroscopes and Accelerometers to Estimate Swimming Speed, Hydrodynamic Drag and Energy Expenditure for Steller Sea Lions,” PLOS ONE. PLOS, San Francisco, CA, 2016.

F. Eren, Pe'eri, S., Rzhanov, Y., Thein, M-W., and Celikkol, B., “Detector Array Design for Optical Communication Between Unmanned Underwater Vehicles (UUVs),” IEEE Journal of Oceanic Engineering, vol. 40(1). IEEE Oceanic Engineering Society, pp. 18–26, 2016.

M.R. Carman, Colarusso, P.D., Nelson, E.P., Grunden, D.W., Wong, M.C., McKenzie, C., Matheson, K., Davidson, J., Fox, S., Neckles, H., Bayley, H., Schott, S., Dijkstra, J.A., and Stewart-Clark, S., “Distribution and Diversity of Tunicates Utilizing Eelgrass as Substrate in the Western North Atlantic: A Latitudinal Study Between N 39° and N 47°,” Management of Biological Invasions, vol. 7. pp. 51–57, 2016.

C. St. Jean, Ware, C., and Gamble, R., “Dynamic Change Arcs to Explore Model Forecasts,” Computer Graphics Forum, vol. 35(3). pp. 311–320, 2016.

S. Pe'eri, Morrison, J.R., Frederick, S., Mathieson, A., and Lippmann, T.C., “Eelgrass and Macroalgal Mapping to Develop Nutrient Criteria in New Hampshire's Estuaries Using Hyperspectral Imagery,” Journal of Coastal Research, vol. SI76. pp. 209–218, 2016.

S. Pe'eri, Madore, B., Nyberg, J., Snyder, L.P., Parrish, C.E., and Smith, S.M., “Evaluation of Chart Adequacy Over the Arctic North Slope Using a Satellite-Derived Bathymetry Multi-Temporal Approach,” Journal of Coastal Research. pp. 56–63, 2016.

M. Jakobsson, Nilsson, J., Anderson, L., Backman, J., Bjork, G., Cronin, T., Kirchner, N., Koshurnikov, A., Mayer, L.A., Noormets, R., O'Regan, M.A., Stranne, C., Ananiev, R., Barrientos, N., Chernykh, D., Coxall, H., Eriksson, B., Floden, T., Gemery, L., Gustafson, O., Jerram, K., Johansson, C., Khortov, A., Mohammad, R., and Semiltov, I., “Evidence for an Ice Shelf Covering the Central Arctic Ocean During the Penultimate Glaciation,” Nature Communications, vol. 7. Macmillan Publishers Ltd., 2016.

N.A. Raineault, Ballard, R., Mayer, L.A., Fisher, C.R., Carey, S., Marsh, L., Kane, R., Tüzün, S., Shank, T.M., and Smart, C., “Exploration of Hydrothermal Vents Along the Galapagos Spreading Center,” Oceanography, vol. 29, No.1, Supplement. The Oceanography Society, pp. 35–7, 2016.

A.H. Stevens, Butkiewicz, T., and Ware, C., “Hairy Slices: Evaluating the Perceptual Effectiveness of Cutting Plane Glyphs for 3D Vector Fields,” IEEE Transactions on Visualization and Computer Graphics, vol. 23(1). IEEE Computer Society, 2016.

A. Chase, Dijkstra, J.A., and Harris, L.G., “The Influence of Substrate Material on Ascidian Larval Settlement,” Marine Pollution Bulletin, vol. 106. Elsevier, pp. 35–42, 2016.

J.A. Dijkstra and Simkanin, C., “Intraspecific Response of Colonial Ascidians to Variable Salinity Stress in an Era of Global Change,” Marine Ecology Progress Series, vol. 551. Inter-Research, Oldendorf/Luhe, Germany, pp. 215–225, 2016.

J. Miksis-Olds and Nichols, S.M., “Is Low Frequency Ocean Sound Increasing Globally?” Journal of the Acoustical Society of America, vol. 139. Acoustical Society of America, pp. 501–511, 2016.

N.A. Raineault, Mayer, L.A., Ballard, R., and Irish, O., “Mapping the Eastern Pacific Ocean,” Oceanography, vol. 29, No.1, Supplement. The Oceanography Society, pp. 38–9, 2016.

D.R. Olson, Lyons, A.P., and Sæbø, T.O., “Measurements of High-Frequency Acoustic Scattering from Glacially-Eroded Rock Outcrops,” Journal of the Acoustical Society of America, vol. 139. pp. 1833–1847, 2016.

C. Ware, Rogers, D., Petersen, M., Ahrens, J., and Aygar, E., “Optimizing for Visual Cognition in High Performance Scientific Computing,” Electronic Imaging, vol. 2016. Society for Imaging Science and Technology, pp. 1–9, 2016.

C.E. Parrish, Dijkstra, J.A., O'Neil-Dunne, J., McKenna, L., and Pe'eri, S., “Post-Sandy Benthic Habitat Mapping Using New Topographic-Bathymetric Lidar Technology and Object-Based Image Classification,” Journal of Coastal Research. pp. 200–208, 2016.

C. Simkanin, Fofonoff, P.W., Larson, K., Lambert, G., Dijkstra, J.A., and Ruiz, G.M., “Spatial Extent and Temporal Dynamics of Ascidian Invasions in the Continental United States and Alaska,” Marine Biology. pp. 1–16, 2016.

S.E. Beaulieu, Fox, P.A., Di Stefano, M., Maffei, A., West, P., Hare, J.A., and Fogarty, M., “Toward cyberinfrastructure to facilitate collaboration and reproducibility for marine integrated ecosystem assessments,” Earth Science Informatics, vol. 10. Springer, p. 13, 2016.

T.C. Lippmann and Bowen, T., “The Vertical Structure of Low Frequency Motions in the Nearshore, Part 2: Theory,” Journal of Physical Oceanography, vol. 46(12). American Meteorological Society, Boston, MA, pp. 3713–3727, 2016.

T.C. Lippmann, Thornton, E., and Stanton, T., “The Vertical Structure of Low Frequency Motions in the Nearshore, Part 1: Observations,” Journal of Physical Oceanography, vol. 46(12). American Meteorological Society, Boston, MA, pp. 3695–3711, 2016.

Conference Abstracts

E. Weidner, Mayer, L.A., Jerram, K., Weber, T.C., Jakobsson, M., Chernykh, D., Ananiev, R., Mohammad, R., and Semiltov, I., “Acoustic and Geomorphological Signatures of Gas Seeps on the

East Siberian Margin," 2016 Graduate Research Conference. University of New Hampshire, Durham, NH, 2016.

F. Eren, Pe'eri, S., and Rzhanov, Y., "Airborne Lidar Bathymetry (ALB) Waveform Analysis for Bottom Return Characteristics," SPIE Defense and Commercial Sensing. Baltimore, MD, 2016.

A. Klemm, Pe'eri, S., Sartor, C., Nyberg, J., and Barber, J.E., "Chart Adequacy Procedure Using Publicly-Available Information," 2016 Canadian Hydrographic Conference. Canadian Hydrographic Association, Halifax, Nova Scotia, Canada, 2016.

K. Mello, Dijkstra, J.A., Malik, M., Sowers, D., McKenna, L., and Lobecker, E., "Coarse and Fine Scale Patterns of Community Structure of Benthic Habitats Along the U.S. Atlantic Continental Margin," Benthic Ecology Meeting. Portland, ME, 2016.

S. Loranger and Weber, T.C., "Detection and Quantification of Submerged Oil Droplets by a Broadband, High-frequency Echo Sounder," 2016 Gulf of Mexico Oil Spill and Ecosystem Science Conference. Tampa, FL, 2016.

T.I.B. Lønmo and Lyons, A.P., "Effect of Low Complexity Adaptive Beamforming on Seafloor Backscatter Statistics," 5th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan. Honolulu, HI, 2016.

B. Costa, Battista, T., Parrish, C., and Dijkstra, J.A., "Evaluating the Utility of EAARL-B Lidar Waveforms for Mapping Coral Reef Habitats," JALBTCX. Silver Spring, MD, 2016.

S. Loranger and Weber, T.C., "An Evaluation of the Frequency Response of Hydrocarbon Droplets," 171st Meeting of the Acoustical Society of America. Salt Lake City, UT, 2016.
J.A. Dijkstra, Litterer, A., Mello, K., Rzhanov, Y., and Johnson, P., "A Fish Eyes View of the Impact of Non-native Seaweeds on Temperate Reef Seascapes," Benthic Ecology Meeting. Portland, ME, 2016.

D.C. Mosher, Campbell, D.C., Gardner, J.V., Chaytor, J., Piper, D.J.W., and Rebesco M., "Geomorphology of the Northwest Atlantic Continental Margin: The Role of Deep Sea Sedimentation Processes," 2016 Fall Meeting, American Geophysical Union. San Francisco, CA, 2016.

M. Jakobsson, Hogan, K., Mayer, L.A., Mix, A.C., Jerram, K., Mohammad, R., Stranne, C., and Eriksson, B., "The History of Retreat Dynamics of Petermann Glacier Inferred from Submarine Glacial Landforms," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

L. G. Ward, McAvoy, Z., Olsen, N., Vallee-Anziani, M., Chormann, F., McPherran, K., and Nifong, K., "Integrated Studies of the New Hampshire Shoreline and Continental Shelf: An Important Step Towards Coastal Resiliency," American Shore and Beach Protection Association Annual Meeting. Long Branch, NJ, 2016.

J. Kinney, Bogonko, M., White, M., Nagel, E., Dijkstra, J.A., Parrish, C., Wilson, N., and Armstrong, A.A., "Intensity and Reflectance Mapping for Habitat Mapping and Seafloor Characterization Using the Superstorm Sandy Lidar Data," JALBTCX. Silver Spring, MD, 2016.

S. Pe'eri, Eren, F., Birkebak, M., Pradith, V., Kidd, J., and Riley, J., "Measurement of Dynamic Biases in Hydrographic Surveying Using an Industrial Laser Scanner," 2016 Canadian Hydrographic Conference. Canadian Hydrographic Association, Halifax, Nova Scotia, Canada, 2016.

S. Loranger, Bassett, C., and Weber, T.C., "Measurements of the Acoustic Properties of Crude Oil," 5th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan. Honolulu, HI, 2016.

P. Johnson, Ferrini, V.L., and Jerram, K., "The Multibeam Advisory Committee (MAC): A Search for Solutions for Collecting Consistent High Quality Multibeam Data Across Multiple Ships, Systems, and Operators in the U.S. Academic Fleet," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

J.A. Dijkstra, Litterer, A., Mello, K., Rzhanov, Y., Johnson, P., and O'Brien, B., "Non-Native Species Increase Habitat Heterogeneity to Influence Trophi Interactions in Temperate Reef Seascapes," International Temperate Reef Symposium. Pisa, Italy, 2016.

A.R. Norton and Dijkstra, S.J., "Observations of Acoustic Backscatter and Current Velocity Above an Eelgrass Canopy Over Multiple Tidal Cycles," New England Estuarine Research Society Fall Meeting. Block Island, RI, 2016.

K. McPherran and Ward, L.G., "Observations of Seasonal Changes and Storm Effects on a Bedrock-Influenced, Paraglacial Coastal System: New Hampshire," Geological Society of America Annual Meeting, Northeastern Section. Albany, NY, 2016.

J. Kidd, Pe'eri, S., Eren, F., and Armstrong, A.A., "Performance Evaluation of the Velodyne VLP-16 System for Feature-Surface Surveying," 2016 Canadian Hydrographic Conference. Canadian Hydrographic Association, Halifax, Nova Scotia, Canada, 2016.

A. C. Mix, Jakobsson, M., Andrews, J.T., Jennings, A., Mayer, L.A., Anderson, S.T., Brook, E., Ceperley, E., Cheseby, M., Clark, J., Dalerum, F., Dyke, L.M., Einarsson, D., Erkisson, D.B., Frojd, C., Glueder, A., Hedman, U., Heirman, K., Heuze, C., Hogan, K., Padman, J., Pecnerova, P., Reilly, B., Reusche, M., Ross, A., Stranne, C., Marcott, S.A., Muenchow, A., Stoner, J.S., Andresen, C.S., Nicholls, K.W., Holm, C., Jerram, K., Krutzfeld, J., Nicolas, L., Par, L., Lomac-MacNair, K., Madlener, S., McKay, J., Meijer, T., Meiton, A., Brian, M., Mohammad, R., Molin, M., Moser, C., Normark, E., Trinhammer, P., Walczak, M. H., Walczak, P., Washam, P., Karasti, M., and Anker, P., "The Petermann Glacier Experiment, NW Greenland," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

E. Weidner, Mayer, L.A., Jakobsson, M., Chernykh, D., Ananiev, R., Weber, T.C., Jerram, K., Mohammad, R., and Semiltov, I., "Quantification of Methane Gas Flux and Bubble Fate on the

Eastern Siberian Arctic Shelf Utilizing Calibrated Split-beam Echosounder Data," 2016 Fall Meeting, American Geological Union (AGU). San Francisco, CA, 2016.

V. Jegat, Pe'eri, S., Freire, R., Klemm, A., Castillo, J., and Nyberg, J., "Satellite-Derived Bathymetry: Performance and Production," 2016 Canadian Hydrographic Conference. Canadian Hydrographic Association, Halifax, Nova Scotia, Canada, 2016.

J.E. Barber, Pe'eri, S., Klemm, A., Nyberg, J., and Powell, J., "Sensor-Derived Policy and Localized Chart Updates at NOAA's Marine Chart Division," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

K. Baldwin, Mosher, D.C., and Gebhardt, C., "Surficial Geology Mapping of the Arctic Ocean: Using Subbottom Profiling and Multibeam Echosounding Data Sets to Constrain the Subsea North of 64° as a Layer for the IBCAO," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

Brian R. Calder, "Synoptic Risk Assessment for Ship Passage and Hydrographic Uncertainty Representation," Fourth Biennial Conference on the Marine Transportation System: From Sail to Satellites. Committee on the Marine Transportation System, Washington, DC, 2016.

L.A. Mayer, Jakobsson, M., Mix, A.C., Heffron, E., Jerram, K., Hogan, K., and Muenchow, A., "Towards the Complete Characterization of Marine-Terminating Glacier Outlet Systems," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

S. Pe'eri, Eren, F., Thein, M-W., Rzhanov, Y., and Birkebak, M., "Underwater-Detector Array for Optical Communication and Laser Beam Diagnostics," SPIE Defense + Commercial Sensing. Baltimore, MD, 2016.

R. Freire, Pe'eri, S., Alexander, L., Rzhanov, Y., Parrish, C.E., and Lippmann, T.C., "Use of Satellite Imagery for Monitoring the Mouths of Dynamic Rivers," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

J. Wozencraft, Aslaksen, M., Imahori, G., Pe'eri, S., and Witmer, J., "Using JALBTCX-USACE Airborne Topographic-Bathymetric Lidar to Update Coastal Bathymetry on NOAA Nautical Charts," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

A.P. Lyons and Brown, D.C., "On Using Multi-look Synthetic Aperture Sonar Analysis for the Investigation of Scattering Mechanisms," 5th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan. Honolulu, HI, 2016.

A. Kampia, Klemm, A., Pe'eri, S., Barber, J.E., Merke, D., and Athens, E., "Yukon River Prototype Electronic Charts Using Satellite Derived Bathymetry," 2016 Canadian Hydrographic Conference. Canadian Hydrographic Association, Halifax, Nova Scotia, Canada, 2016.

Conference Proceedings

C. Ware, Bolan, D., Miller, R., Rogers, D.H., and Ahrens, J.P., "Animated Versus Static Views of Steady Flow Patterns," Proceedings of the ACM Symposium on Applied Perception. ACM, Anaheim, CA, pp. 77–84, 2016.

R.E. Hansen, Lyons, A.P., Cook, D.A., and Sæbø, T.O., "Detection of Internal Waves Using Multi-Aspect Processing in Synthetic Aperture Sonar," EUSAR 2016: 11th European Conference on Synthetic Aperture Radar. Hamburg, Germany, pp. 757–760, 2016.

C. Bongiovanni and Schmidt, V., "Evaluating Outside Source Interferometric Data for Chart Updates," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

C. Ware, "Multiple Independent Highlighting Techniques," Conference on Visualization and Data Analysis, vol. 2016(1). San Francisco, CA, pp. 1–9, 2016.

S. Reed and Schmidt, V.E., "Nautical Chart Awareness for Autonomous Surface Vehicles," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

M. Wilson, Masetti, G., and Brian R. Calder, "NOAA QC Tools: Origin, Development, and Future," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

S. Reed, "Providing Nautical Chart Awareness to Autonomous Surface Vessel Operations," OCEANS 2016 MTS/IEEE Monterey. IEEE, Monterey, CA, 2016.

Brian R. Calder, "Risk Models and Survey Completeness," 2016 Canadian Hydrographic Conference. Halifax, Nova Scotia, Canada, 2016.

Conference Posters

A.R. Norton and Dijkstra, S., "Developments in Eelgrass Mapping Methodology Using Hydrographic Multi-beam Sonar," 25th Annual Zosterapalooza. EPA District 1 Offices, Boston, MA, 2016.

K. Hogan, Jakobsson, M., Mayer, L.A., Mix, A.C., Jerram, K., Nielsen, T., Kamla, E., Stranne, C., and Eriksson, B., "The Glacimarine Sediment Budget of the Nares Strait-Petermann Fjord Area Since the Last Glacial Maximum," 2016 Fall Meeting, American Geological Society (AGU). San Francisco, CA, 2016.

N.A. Raineault, Smart, C., Mayer, L.A., Ballard, R., Fisher, C.R., Marsh, L., and Shank, T.M., "Signs of Recent Volcanism and Hydrothermal Activity Along the Eastern Segment of the Galapagos Spreading Center," 2016 Fall Meeting, American Geophysical Union (AGU). San Francisco, CA, p. San Francisco, CA, 2016.

Posters

E. Weidner and Matthew Roy, “Sedimentary Analysis from the Mouth of the Great Bay Estuary: Biogenic Sediment Fraction.” 2016.

E. Weidner and Matthew Roy, “Sedimentary Analysis from the Mouth of the Great Bay Estuary: Lithologic Analysis.” 2016.

Reports

B.D. Andrews, Chaytor, J.D., Brink, U. Sten, Brothers, D.S., Gardner, J.V., Lobecker, E.A., and Calder, B.R., “Bathymetric Terrain Model of the Atlantic Margin for Marine Geological Investigations, Version 2.0,” U.S. Geological Survey (USGS), Woods Hole, MA, 2016.

L.P. Snyder, Nyberg, J., Smith, S.M., Pe'eri, S., Madore, B., Rogers, J., Lowell, J., and DeAngelis, R., “Chart Adequacy Evaluation of the Coastal Water of Haiti Using Satellite-Derived Bathymetry,” National Oceanic and Atmospheric Administration (NOAA), National Ocean Survey (NOS), Silver Spring, MD, 2016.

P. Johnson and Jerram, K., “E/V *Nautilus* EM302 Multibeam Echosounder System Review NA070—April 10–15, 2016,” Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

L.G. Ward, Vallee-Anziani, M., and McAvoy, Z.S., “New Hampshire and Vicinity Continental Shelf: Morphologic Features and Surficial Sediments,” Bureau of Ocean Energy Management (BOEM) Marine Minerals Branch, Herndon, VA, 2016.

L.G. Ward, McAvoy, Z.S., and Vallee-Anziani, M., “New Hampshire and Vicinity Continental Shelf: Sand and Gravel Resources,” Bureau of Ocean Energy Management (BOEM) Marine Minerals Branch, Herndon, VA, 2016.

L.G. Ward, McPherran, K.A., McAvoy, Z.S., and Vallee-Anziani, M., “New Hampshire Beaches: Sediment Characterization,” Bureau of Ocean Energy Management (BOEM) Marine Minerals Branch, Herndon, VA, 2016.

P. Johnson, “R/V *Bat Galim* EM302 and EM2040 Multibeam Echosounder System Review—January 31 to February 4, 2016,” Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

K. Jerram and Ferrini, V.L., “R/V *Hugh R. Sharp* Reson 7125 SVP2 Multibeam Echosounder System Calibration—March 21–23, 2016,” Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

P. Johnson, Jerram, K., Rice, G., Nagel, E., and Zhang, C., "R/V *Neil Armstrong* Multibeam Echosounder Sea Acceptance Trials—February 10–17, 2016," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

K. Jerram and Johnson, P., "R/V *Sikuliaq* EM302 and EM710 Multibeam Echosounder System—March 7–12, 2016," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

L.A. Mayer and Brian R. Calder, "U.S. Law of the Sea Cruise to Map and Sample the U.S. Arctic Ocean Margin, Healy 1603," Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire, Durham, NH, 2016.

L.G. Ward, Johnson, P., Nagel, E., McAvoy, Z. S., and Vallee–Anziani, M., "Western Gulf of Maine Bathymetry and Backscatter Synthesis," Bureau of Ocean Energy Management (BOEM) Marine Minerals Branch, Herndon, VA, 2016.

Theses

O. Irish, "Analysis of CLCS Recommendations in Light of Their Relevance to the Delineation of a United States Extended Continental Shelf (ECS) in the Arctic," University of New Hampshire, Durham, NH, 2016.

D. Manda, "Development of Autonomous Surface Vessels for Hydrographic Survey Applications," University of New Hampshire, Durham, NH, 2016.

A. Peçanha, "Evaluating the Usage of Multi-frequency Backscatter Data as an Additional Tool for Seafloor Characterization," University of New Hampshire, Durham, NH, 2016.

K. Nifong, "Sedimentary Environments and Depositional History of a Paraglacial, Estuarine Embayment and Adjacent Inner Continental Shelf: Portsmouth Harbor, New Hampshire," University of New Hampshire, Durham, NH, 2016.

APPENDIX E: TECHNICAL PRESENTATIONS AND SEMINARS

Jenn Dijkstra, January 21, Mapping the Influence of Anthropogenic Factors on Spatial and Temporal Habitat Structure in Marine Systems, UNH School of Marine Science and Ocean Engineers, Durham, New Hampshire, United States, Marine School Seminar

Paul Johnson, Invited, January 26 - 28, *Multibeam Advisory Committee - Supporting the U.S. Academic Fleet*, NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Seattle, WA, United States, Shared talked with LCDR Samuel Greenaway, OCS, about the importance of having groups tasked with undertaking quality assurance tests and shipboard acceptance test for both the NOAA fleet and the U.S. academic fleet.

Larry Mayer, Invited, February 9, *From Deepwater Horizon to the Arctic Ocean: UNH Exploring the Mysteries of the Deep*, Florida Atlantic University, Harbor Branch Oceanographic Institution, Fort Pierce, FL, United States.

Larry Mayer, Invited, February 15, *Understanding Article 76 and its Application in the Arctic*, Yale School of Law, New Haven, CT, United States.

Colin Ware, Keynote, February 18, *Optimizing for visual cognition in high performance scientific computing*, Human Vision and Electronic Imaging Conference, San Francisco, CA, United States.

Colin Ware, March 16, Kinematics of Foraging: Humpbacks and Sea Lions, NIWA New Zealand, Wellington, New Zealand.

Yuri Rzhanov, Paul Johnson, Jenn Dijkstra, Contributed, March 17, *A fish eyes view of the impact of non-native seaweeds on temperate reef seascapes*, Benthic Ecology Meetings, Portland, Maine, United States, Described the process of collecting underwater video and creating mosaics for seascape classification (spatial analysis).

Semme J. Dijkstra, Ashley Norton, Contributed, March 30, *Developments in eelgrass mapping methodology using hydrographic multi-beam sonar*, EPA District 1, 25th Annual Zosterapalooza, Boston, MA, United States, Presented a poster with updates on the development of eelgrass mapping methods using a multi-beam echosounder, and on data collection in the Great Bay estuary to academic, regulatory and natural resource professionals involved in eelgrass research and monitoring throughout New England.

Matthew Birkebak, Firat Eren, April 1, Attributing Environmental Uncertainty Values to ALB Surveys, JHC/CCOM, Durham, NH, United States.

Larry Ward, Invited, April 6, *Development of surficial geology maps of the New Hampshire and vicinity continental shelf*, New Hampshire Geological Survey, Geologic Mapping Workshop, Concord, NH, United States.

Larry Mayer, Keynote, April 13, *Ocean Mapping: We're Remote Sensors Too!,* American Society of Photogrammetry and Remote Sensing Annual Meeting, American Society of Photogrammetry and Remote Sensing Annual Meeting, Ft. Worth, TX, United States.

Tom Lippmann, April 15, What's Up With Great Bay Bathymetry, Hydrodynamics, and Sediments? JHC/CCOM Seminar, Durham, NH, United States.

David Mosher, Invited, April 18, *Continental Margins of the Arctic Ocean: Implications for Law of the Sea*, European Geosciences Union, General Assembly, European Geosciences Union, Vienna, Austria.

Shachak Peeri, Firat Eren, Contributed, April 19, *Airborne lidar bathymetry (ALB) waveform analysis for bottom return characteristics*, SPIE Defense, Security and Sensing (Ocean sensing and monitoring VIII), Baltimore , MD, United States.

Firat Eren, Yuri Rzhanov, Matthew Birkebak, Shachak Peeri, Contributed, April 19, *Underwater-Detector Array for Optical Communication and Laser Beam Diagnostics*, SPIE, SPIE DCS, Baltimore, Maryland, United States.

David Mosher, Invited, April 26, *Glacigenic Processes: Continental Margins of the Arctic Ocean, Implications for Law of the Sea*, European Geosciences Union, Annual meeting, Vienna, Austria

Larry Mayer, Keynote, May 3, *Ruminations on the Future of Ocean Mapping*, GeoHab Conference, GeoHab Conference, Winchester, United Kingdom, Ruminations on the Future of Ocean Mapping.

Yuri Rzhanov, Jenn Dijkstra, Invited, May 10 - 12, *Collecting underwater video for the creation of video mosaics*, University of Laval, Technical Workshop, Quebec City, Quebec, Canada.

Jenn Dijkstra, Yuri Rzhanov, May 11, Practical mosaicing, University of Laval, Quebec City, Quebec, Canada, Presentation on current state of image mosaicking and software developed at CCOM for this purpose.

Yuri Rzhanov, Jenn Dijkstra, May 12, Mapping the Influence of Introduced Species on Temperate Reef Seascapes, University of Laval, Quebec City, Quebec, Canada, Invited Seminar.

Firat Eren, John Kidd, Matthew Birkebak, Shachak Peeri, Contributed, May 17, *Measurement of Dynamic Biases in Hydrographic Surveying Using an Industrial Laser Scanner*, CHS, Canadian Hydrographic Conference 2016, Halifax, Nova Scotia, Canada,

Ramos Ricardo Freire, Tom Lippmann, Lee Alexander, Yuri Rzhanov, Shachak Peeri, Contributed, May 18, *Use of Satellite Imagery for Monitoring the Mouths of Dynamic Rivers*, CHS, Canadian Hydrographic Conference 2016, Halifax, Nova Scotia, Canada.

Kevin Jerram, Invited, May 31, *From Appledore to the Arctic: Adventures of an Island Engineer*, Shoals Marine Laboratory, 'Rock Talk' Seminar Series, Appledore Island, Maine, United States,

Tom Lippmann, June 7, What's Up With Great Bay Bathymetry, Hydrodynamics, and Sediments?, PREP Executive committee and collaborative public/private organizations, Greenland, NH, United States, Gave seminar to PREP, their board, and the attendees of their regularly scheduled meeting.

Larry Mayer, Invited, June 12, *U.S. Extended Continental Shelf Mapping in the Arctic (and a Bit More)*, IBCAO-IBCSO Meeting, IBCAO-IBCSO Meeting, Monaco, Europe, U.S. Extended Continental Shelf Mapping in the Arctic (and a Bit More)

Larry Mayer, Keynote, June 15, *The Oceans Are So Big But Our Footprints Are So Small*, Forum for Future of Ocean Floor Mapping, Forum for Future of Ocean Floor Mapping, Monaco, Europe, The Oceans Are So Big But Our Footprints Are So Small

Colin Ware, Keynote, June 17, *Visual Thinking about Data: The Cognitive Thread, Interaction and the Visual Query*, Information+ Conference, Vancouver, BC, Canada.

Larry Mayer, Invited, June 21, *Bathymetric Data Collection in the Arctic and the Grounding of the Clipper Adventurer*, IONS Workshop, Arctic Domain Awareness Center, IONS Workshop, Arctic Domain Awareness Center, Anchorage, Alaska, United States.

Yuri Rzhanov, Paul Johnson, Jenn Dijkstra, Contributed, June 24 - July 1, *Non-native species increase habitat heterogeneity to influence trophic interactions in temperate reef seascapes*, International Temperate Reef Symposium, Pisa, Italy.

Larry Mayer, Invited, June 28, *Setting the Context: The Scientific Aspects of Article 76*, UN Convention on the Law of the Sea, United Nations Headquarters, Legal Order in the World's Oceans, NYC, NY, United States.

Larry Mayer, Invited, July 12, *Adventures of Ocean Mapping*, UNH Marine Docents, Newington, NH, United States.

Matthew Birkebak, Contributed, July 18 - 22, *Underwater Detector Array for Optical Communications and Laser Beam Diagnostics*, JALBTCX, Silver Spring, MD, United States.

Matthew Birkebak, Firat Eren, Contributed, July 19, *Analysis of Airborne Lidar Bathymetry (ALB) Bottom Return waveforms for seafloor characterization*, Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), JALBTCX workshop, Silver Spring, MD, United States

Larry Mayer, Invited, August 11, *From Deepwater Horizon to the Arctic Ocean; Exploring the Secrets of the Deep*, Gulf of Maine Marine Institute, Portland, Maine, United States.

Ashley Norton, Contributed, September 30, *Developments in eelgrass mapping methodology using hydrographic multi-beam sonar*, Society for Women in Marine Science (SWMS), SWMS Fall Symposium, Woods Hole , MA, United States.

Larry Mayer, Invited, October 20, *Acoustics/Bathymetry Exploration 2020-2025*, The Rockefeller University, 2016 National Ocean Exploration Forum: Beyond the Ships 2020-2025, NYC, NY, United States.

Igor Kozlov, Yuri Rzhanov, October 20, Pushing the envelope of a 3D scene reconstruction, Computer Science Dept, Durham, NH, United States.

Semme J. Dijkstra, Ashley Norton, Contributed, October 21, *Observations of Acoustic Backscatter and Current Velocity above an Eelgrass Canopy over Multiple Tidal Cycles*, New England Estuarine Research Society (NEERS), NEERS Fall meeting, Block Island, RI, United States.

Thomas Butkiewicz, Colin Ware, Andrew Stevens, Contributed, October 27, *Hairy Slices: Evaluating the Perceptual Effectiveness of Cutting Plane Glyphs for 3D Vector Fields*, IEEE, IEEE Vis 2016, Baltimore, Maryland, United States.

Kevin Jerram, Paul Johnson, Invited, November 2, *Multibeam Advisory Committee Breakout Session*, RVTEC, RVTEC 2016, La Jolla, CA, United States.

Colin Ware, November 10, Visual Thinking about Scientific Data: The Cognitive Processes Whereby We Gain Knowledge. , University of Miami, Miami, Florida, United States.

Larry Mayer, Invited, November 7 - December 11, *Four Lectures: Law of the Sea*, Yeosu Academy of the Law of the Sea, Third Session, 2016, Republic of Korea, Korea.

Colleen Mitchell, Derek Sowers, November 18, "Exploring America's Remote Pacific Marine Monuments: the 2016 Okeanos Explorer Field Season", JHC/CCOM, Durham, NH, United States.

Larry Mayer, Invited, November 21, *Law of the Sea & Mapping in the Arctic*, University of Rhode Island: Marine Policy Program, Kingston, Rhode Island, United States.

Larry Mayer, Invited, November 22, *Law of the Sea & Mapping in the Arctic*, United States Coast Guard Academy, New London, CT, United States.

Larry Mayer, Invited, November 28, *Global Warming and a Bit of Law of the Sea*, University of Virginia School of Law, Charlottesville, VA, United States.

Larry Mayer, Invited, November 29, *Acoustic Mapping of Gas Seeps from Deep Water Horizon to the East Siberian Arctic Ocean*, University of Delaware, Newark, DE, United States.

Larry Mayer, Keynote, November 30, *Arctic Research: A Practitioner's Perspective*, UNLOS 2016 Annual Meeting, Arlington, VA, United States.

Kim Baldwin, December 2, A 2D High-Resolution Seismic Study in the Caroline Basin: Sediment Waves as an Indicator of Long-Term Bottom Current Flow, JHC/CCOM, Durham, NH, United States, JHC/CCOM seminar presented in December on research regarding abyssal sediment waves in the western equatorial Pacific.

Larry Mayer, Invited, December 8, *Update on U.S. Bathymetry Mapping and Sampling Activities in the Arctic*, 2016 Arctic 5 Meeting, Copenhagen, Denmark.

Kevin Jerram, Paul Johnson, Contributed, December 14, *The Multibeam Advisory Committee (MAC): a search for solutions for collecting consistent high quality multibeam data across multiple ships, systems, and operators in the U.S. Academic Fleet.*, American Geophysical Union, 2016 Fall AGU Meeting, San Francisco, CA, United States.