Performance and Progress Report

NOAA Grant No: NA15NOS4000200

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

Lead Principal Investigator: ***Larry A. Mayer***

Principal Investigators

Brian Calder
John Hughes Clarke
James Gardner
David Mosher
Colin Ware
Thomas Weber

Co-PIs

Thomas Butkiewicz
Jenn Dijkstra
Semme Dijkstra
Paul Johnson
Thomas Lippmann
Giuseppe Masetti
Shachak Pe'eri
Yuri Rzhanov
Val Schmidt
Briana Sullivan
Larry Ward

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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 2016, a Federal Funding Opportunity was 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 a five-year award, funding the Center for the period of 1 January 2016 until December 2020. This report represent the progress on the first year of effort on this new grant (NA15NOS4000200). It should be noted that during the course of calendar year 2016, efforts also continued under the previous grant (NA10NOS4000073) under a no-cost extension. Progress for work under the previous grant has been presented in a separate report (available on the CCOM website – http://www.ccom.unh.edu) and thus this report represents only part of the work done at the Joint Hydrographic Center for NOAA in 2016.

This report is the twenty-second in a series of what were, until December 2002, semi-annual progress reports. Since December 2002, the written reports have been produced annually. Copies of previous reports (from NA10NOS4000073 and all previous grants to the Joint Hydrographic Center) and more detailed information about the Center can be found on the Center's website, http://www.ccom.unh.edu.

More detailed descriptions of many of the research efforts described herein can be found in the individual progress reports of Center researchers, which 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 an 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 *Fairweathe*r 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 eight 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 12,000 sq. 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 ft.) 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 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 and 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 54 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.

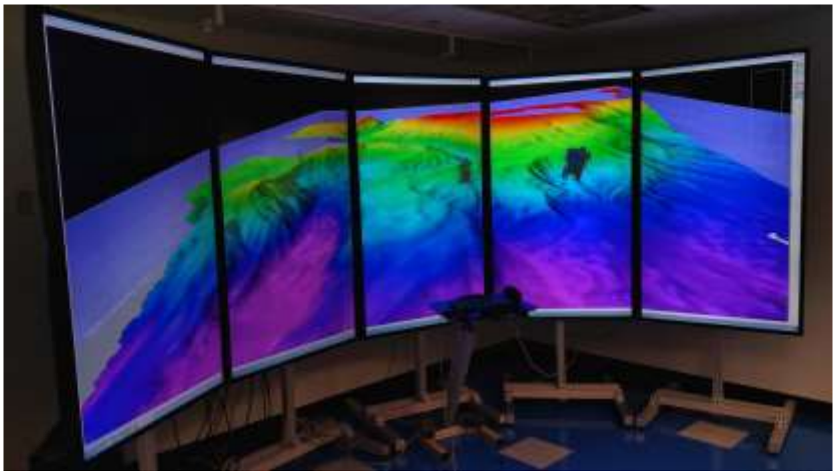

Figure 1-4. Semi-Immersive Large-Format Tiled Display.

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.

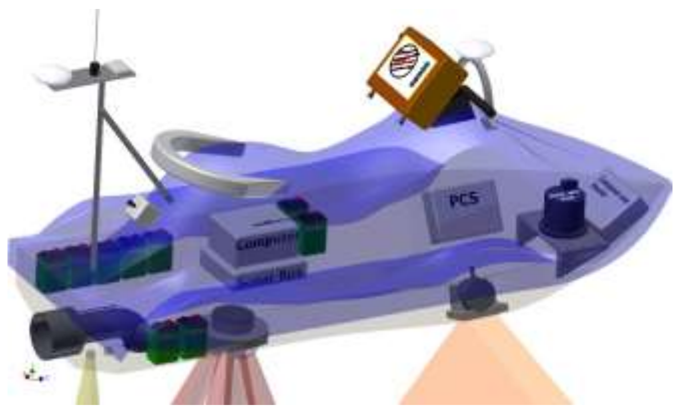

Figure 1-11. CBASS in action surveying in New River Inlet NC (left) and CAD drawing (right) showing the location of the MBES (peach), SBES (yellow), ADCP (red) with acoustic beam patterns on the CBASS. Also shown are the location of the POS MV IMU and PCS, onboard computers and LAN router, internal battery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

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*;

(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 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 2011-2015 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; (*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*)

The Federal Funding Opportunity (FFO) for the newest grant, NA15NOS4000200, competitively awarded to the Center for the period of 2016-2020, defined four programmatic priorities:

1) *Innovate Hydrography*
2) *Transform Charting and Change Navigation*
3) *Explore and Map the Continental Shelf*
4) *Develop and Advance Hydrographic and Nautical Charting Expertise*

Under these, 14 specific research requirements were prescribed (our short name for each research requirement follows the description in bold italics):

1) INNOVATE HYDROGRAPHY

a. *Improvement in the effectiveness, efficiency, and data quality of acoustic and LIDAR bathymetry systems, their associated vertical and horizontal positioning and orientation systems, and other sensor technology for hydrographic surveying and ocean and coastal mapping, including autonomous data acquisition systems and technology for unmanned vehicles, vessels of opportunity, and trusted partner organizations –* ***“Data Collection.”***

b. *Improvement in technology and methods for more efficient data processing, quality control, and quality assurance, including the determination and application of measurement uncertainty, of hydrographic and ocean and coastal mapping sensor and ancillary sensor data, and data supporting the identification and mapping of fixed and transient features of the seafloor and in the water column – “****Data Processing.”***

c. *Adaption and improvement of hydrographic survey and ocean mapping technologies for improved coastal resilience and the location, characterization, and management of critical marine habitat and coastal and continental shelf marine resources – "**Seafloor Characterization, Habitat, and Resources.**"*

d. *Development of improved tools and processes for assessment and efficient application to nautical charts and other hydrographic and ocean and coastal mapping products of data from both authoritative and non-traditional sources – "**Third Party and Non-traditional Data.**"*

2) **TRANSFORM CHARTING AND CHANGE NAVIGATION**

a. *Development of improved methods for managing hydrographic data and transforming hydrographic data and data in enterprise GIS databases to electronic navigational charts and other operational navigation products. New approaches for the application of GIS and spatial data technology to hydrographic, ocean, and coastal mapping, and nautical charting processes and products – **"Chart Adequacy and Computer-Assisted Cartography."***

b. *Development of innovative approaches and concepts for electronic navigation charts and for other tools and techniques supporting marine navigation situational awareness, such as prototypes that are real-time and predictive, are comprehensive of all navigation information (e.g., charts, bathymetry, models, currents, wind, vessel traffic, etc.), and support the decision process (e.g., under-keel clearance management) – "**Comprehensive Charts and Decision Aids.**"*

c. *Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, including four-dimensional high resolution visualization, real-time display of mapping data, and mapping and charting products for marine navigation as well as coastal and ocean resource management and coastal resilience – **"Visualization and Coastal Resource Management."***

3) **EXPLORE AND MAP THE CONTINENTAL SHELF**

a. *Advancements in planning, acquisition, understanding, and interpretation of continental shelf, slope, and rise seafloor mapping data, particularly for the purpose of delimiting the U.S. Extended Continental Shelf – **"Extended Continental Shelf."***

b. *Development of new technologies and approaches for integrated ocean and coastal mapping, including technology for creating new products for non-traditional applications and uses of ocean and coastal mapping – **"IOCM."***

c. *Improvements in technology for integration of ocean mapping with other deep ocean and littoral zone technologies such as remotely operated vehicles and telepresence-enhanced exploration missions at sea – "**Ocean Exploration.**"*

4) **DEVELOP AND ADVANCE HYDROGRAPHIC AND NAUTICAL CHARTING EXPERTISE**

a. *Development, maintenance, and delivery of advanced curricula and short courses in hydrographic and ocean mapping science and engineering at the graduate education level – leveraging to the maximum extent the proposed research program, and interacting with national and international professional bodies--to bring the latest innovations and standards into the graduate educational experience for both full-time education and continuing professional development – **"Education."***

b. *Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound from acoustic devices including echo sounders, and for modeling the exposure of marine animals to propagated echo sounder energy – **"Acoustic Propagation and Marine Mammals."***

c. *Effective delivery of research and development results through scientific and technical journals and forums and transition of research and development results to an operational status through direct and indirect mechanisms including partnerships with public and private entities – **"Publications and R2O."***

d. *Public education and outreach to convey the aims and enhance the application of hydrography, nautical charting, and ocean and coastal mapping to safe and efficient marine navigation and coastal resilience – **"Outreach."***

These programmatic priorities and research requirements are not radically different from those prescribed under earlier grants and thus much of the research that will be done under the 2016-2020 grant will represent a continuation of research already underway. Several of the requirements, particularly those involved with cartographic issues and marine mammals represent new directions for the lab.

To address the four programmatic priorities and 14 research requirements, the Center divided the research requirements into themes and sub-themes, and responded with 60 individual research projects or research tasks, each with an identified investigator or group of investigators as the lead (Figure I-13).

PROGRAMMATIC PRIORITIES	RESEARCH REQUIREMENTS	THEMES	SUB-THEMES	PROJECTS	POC
INNOVATE HYDROGRAPHY	DATA COLLECTION	SENSOR CALIBRATION AND SONAR DESIGN	SONAR	Tank Calibrations	Lanzoni
				PMBS Evaluation	Schmidt
				Circular Array Bathymetric Sonar	Weber
				Synthetic Aperture Sonar	Weber and Lyons
			LIDAR	Lidar Simulator	Pe'eri
			SOUND SPEED	Distributed Temperature Sensing	Pe'eri
		SENSOR INTEGRATION and REAL-TIME QA/QC		Deterministic Error Analysis/Integration Error	Hughes Clarke
				Data Performance Monitoring	Calder
				Auto Patch Test Tools	Calder
		INNOVATIVE PLATFORMS	AUVs	Nav Processing and Boat Camp	Schmidt
			ASVs	Add-on Sensors and Hydro Applications	Schmidt
		TRUSTED PARTNER DATA		Trusted Hardware	Calder
	DATA PROCESSING	ALGORITHMS and PROCESSING		CHRT and Expanded Processing Methods	Calder
				Multi-Detect Processing	Weber and Calder
				Data Quality and Survey Validation Tools	Calder
				Phase Measuring Bathymetric Sonar Processing	Schmidt
				Automatic Processing for Topo-Bathymetric LIDAR	Calder and Pe'eri
		FIXED AND TRANSIENT WATERCOLUM AND SEAFLOOR FEATURES	SEAFLOOR	Hydro-significant Object Detection	Calder and Masetti
			WATER COLUMN	Watercolumn Target Detection	Weber
	SEAFLOOR CHARACTIZATION, HABITAT and RESOURCES	COASTAL AND CONTINENTAL SHELF RESOURCES		Mapping Gas and Leaky Pipelines in Watercolumn	Weber
				Identification of Marine Mineral Deposits	Ward
		SEAFLOOR CHARACTERIZATION	SONAR	GeoCoder/ARA	Masetti
				Singlebeam Characterization	Lippmann
				Multi-frequency Seafloor Backscatter	Hughes Clarke and Weber
			LIDAR and IMAGERY	Lidar Waveform Extraction	Pe'eri
			CRITICAL MARINE HABITAT	Object Based Image Analysis	J. Dijkstra
				Video Mosaics and Segmentation Techniques	Rzhanov
				Margin-wide Habitat Analysis	Mayer, J.Dijkstra, and Mosher
			COASTAL RESILIENCE and CHANGE DETECTION	Shoreline Change	Pe'eri
				Seabed Change	Hughes Clarke
				Change in Benthic Habitat and Restoration	"Sandy Team"
				Marine Coastal Decision Support Tools	Butkiewicz and Viz Lab
				Temporal Stability of the Seafloor	Lobecker
	THIRD PARTY and NON-TRADITIONAL DATA	THIRD PARTY DATA		Assessment of Quality of 3rd Party Data	Calder
		NON-TRADITIONAL DATA SOURCES	ALB	Assessment of ALB data	Pe'eri
			SDB	Development of Techniques for Satellite Derived Bathymetry	Pe'eri
TRANSFORM CHARTING AND NAVIGATION	CHART ADEQUACY and COMPUTER-ASSISTED CARTOGRAPHY			Managing Hydrographic Data and Automated Cartography	Calder and NOAA HRG
				Chart Adequacy and Re-survey Priorities	Calder, NOAA HRG, and Masetti
				Hydrographic Data Manipulation Interfaces	Calder, Hughes Clarke, Butkiewicz, and Ware
	COMPREHENSIVE CHARTS AND DECISION AIDS	INFORMATION SUPPORTING SITUATIONAL AWARENESS		Currents Waves and Weather	Ware, Sullivan, and Viz. Lab.
				Under-keel Clearance, Real-time and Predictive Decision Aids	Calder and Viz. Lab.
		CHARTS and DECISION AIDS		Ocean Flow Model Distribution and Accessibility	Sullivan
				CHUM	Sullivan
				Augmented Reality Supporting Charting and Nav	Butkiewicz
	VISUALIZATION AND RESOURCE MANAGEMENT	GENERAL ENHANCEMENT OF VISUALIZATION		Tools for Visualizing Complex Ocean Data	Ware and Viz. Lab.
				New Interaction techniques	Butkiewicz
EXPLORE AND MAP THE EXTENDED CONTINENTAL SHELF	EXTENDED CONTINENTAL SHELF			Lead in Planning, Acquiring and Processing ECS	Gardner, Mosher, and Mayer
				Extended Continental Shelf Taskforce	Mosher, Gardner, and Mayer
				Best Approaches for Legacy Data: Delineation Techniques	Mosher, Gardner, and Mayer
	OCEAN EXPLORATION			ECS Data for Ecosystem Management	Mayer, Mosher, and J. Dijkstra
				Potential of MBES Data to Resolve Oceanographic Features	Weber, Mayer, and Hughes Clarke
	TELEPRESENCE AND ROVS			Immersive Live Views from ROV Feeds	Viz. Lab.
HYDROGRAPHIC EXPERTISE	EDUCATION			Revisit Education Program	Hughes Clarke and S. Dijkstra
	ACOUSTIC PROPAGATION AND MARINE MAMMALS			Modelling Radiation Patterns of MBES	Weber and Lurton
				Web-based Tools for MBES Propagation	Johnson and Arsenault
				Impact of Sonars on Marine Mammals	Miksis-Olds and Eibs
	PUBLICATIONS AND R2O			Continue Publication and R2O Transitions	Lobecker
	OUTREACH			Expand Outreach and STEM Activities	Hicks-Johnson and Mitchell
DATA MANAGEMENT	EXTENDED DATA MANAGEMENT PRACTICE			Data Sharing, ISO19115 Metadata	Johnson and Chadwick
				Enhanced Web Services for Data Management	Johnson

Figure I-13: Breakdown of Programmatic Priorities and Research Requirements of FFO into individual projects or tasks

This and subsequent progress reports for Grant NA15NOS4000200 will address progress on a task by task basis. It must be noted, however, that the grant extends over five years (2016-2020) and there will not necessarily be progress on every task every year. This is particularly true for this year's report where efforts for 2016 were split between the previous grant (NA10NOS4000073) and the current grant (NA15NOS4000200), and the progress for each grant has been detailed in separate reports. It should also be noted that as our research develops, we may find that some tasks that do not warrant continuation while new directions or combinations of efforts may evolve that lead to changes in emphasis or the evolution of new tasks. This is what differentiates a research grant from a contract, and is essential to allow innovation to flourish.

PROGRAMMATIC PRIORITY 1: INNOVATE HYDROGRAPHY

RESEARCH REQUIREMENT 1.A: DATA COLLECTION

FFO Requirement 1.A: "*Improvement in the effectiveness, efficiency, and data quality of acoustic and LIDAR bathymetry systems, their associated vertical and horizontal positioning and orientation systems, and other sensor technology for hydrographic surveying and ocean and coastal mapping, including autonomous data acquisition systems and technology for unmanned vehicles, vessels of opportunity, and trusted partner organizations.*"

THEME: 1.A.1: SENSOR CALIBRATION AND INNOVATIVE SENSOR DESIGN

Sub-Theme: SONAR

TASK 1: *Continue to develop approaches for* ***sonar calibration*** *that can be transferred to the fleet rather than require each sonar to be brought to the tank.* ***Carlo Lanzoni***

Project: **Sonar Calibration Facility**
JHC Participants: Carlo Lanzoni, Tom Weber, Paul Lavoie
Other Participants: Various Industrial Sponsors

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 1-1).

Figure 1.1. Upgraded vertical target positioning system on bench

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 1-2). 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 1-2. 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.

Project: **Field Calibration of EK80** (partially supported by other sources – NSF)
JHC Participants: Tom Weber, Kevin Jerram, Larry Mayer
Other Participants: NSF, Univ. of Stockholm, Swedish Polar Secretariat

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 1-4). 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.

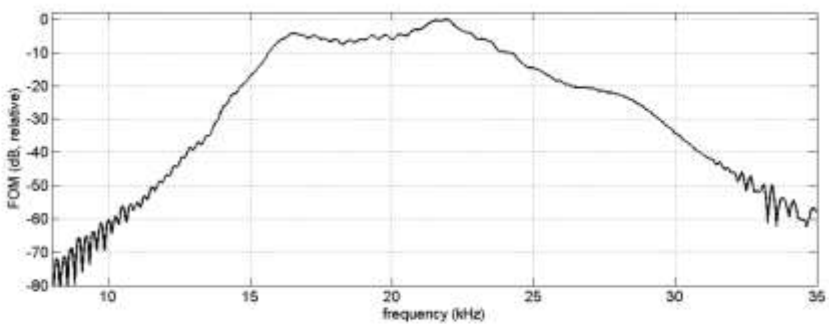

Figure 1-4. Figure of merit (combined transmit/receive response) of ES18 using WBT in decibels, relative to its peak value.

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.

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TASK 2: *Evaluate the capabilities and limitations of the current and future generation of* ***Phase Measuring Bathymetric Sonars (PMBS)*** *in order to better understand their potential as hydrographic tools.* ***Val Schmidt***

Project: **Capabilities and Limitations of PMBS**
JHC Participants: Val Schmidt
Other Participants: N/A

Phase-measuring bathymetric sidescan (PMBS) sonar systems can provide an inexpensive way to achieve the coverage efficiency of a dual-head multibeam system. As part of our ongoing efforts to understand the capabilities and limitations of PMBS systems Val Schmidt has been evaluating the trade-offs of maximizing the swath width of a system. To address this question, Schmidt has built a simple model of coverage rate as a function of various swath widths and at various water depths. The model provides answers that were not wholly anticipated.

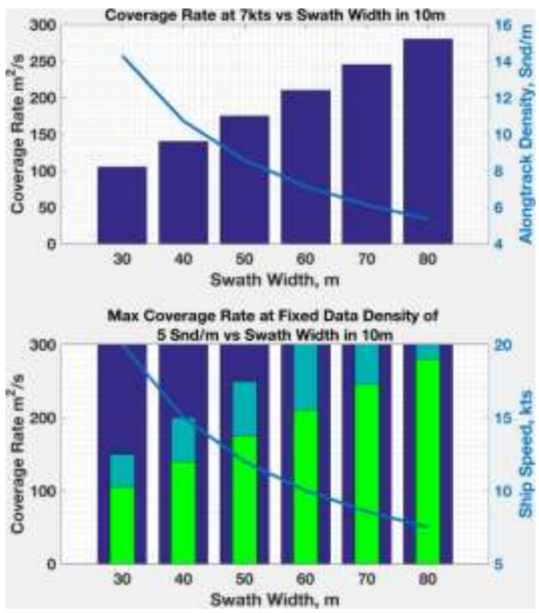


Fig. 2-1: Results of a simple model in which the coverage rate is calculated for various swath widths under the constraint of a fixed speed of 7 knots (upper plot), or a fixed along-track ping density (lower plot). Additional bars are provided in the lower plot in which both the ping density and ship's speed are constrained (to 7 knots and 10 knots in green and teal bars, respectively). Details are provided in the text.

Figure 2-1 illustrates a result of the model run for a system operating at 10 m water depth. The assumption is made in the model that refraction and other conditions are sufficiently benign that the full swath widths considered can be achieved without artifacts or exceeding vertical uncertainty limits. Given those assumptions, one may consider the coverage rate achievable under two additional constraints: a nominal survey speed of seven knots, and an along-track ping density of five pings per meter. In the upper plot, where survey speed is fixed at seven knots, the blue bars indicate that real increases in coverage rate can be had by increasing the swath width up to about eight times water depth, at which point the along-track ping density (blue line) drops to the five pings per meter limit. If instead the along-track ping density is fixed at five pings per meter, then any increase in swath coverage requires a commensurate decrease in ship speed to allow for the increased two-way travel time of the signal (blue curve). Therefore, somewhat surprisingly, no increase in coverage rate is seen, and the maximum theoretical coverage rate is achieved at any swath width, as indicated by the blue bars. However, at narrow swath widths the ship speeds required to achieve this maximum coverage rate at no more than the desired five pings per meter density are unrealistic, quickly exceeding 10 knots. Coverage rates for more practical speeds of seven knots or perhaps 10 knots in fair weather, are shown in the green and teal bars respectively. Similar models run in five meters of water and 20 meters of water show that in water shallower than 20 m, and, in particular, water shallower than 5-10 m, one should endeavor to operate with the widest swath width possible, as real gains in coverage rate are possible. However, in depths deeper than 20 m, an increase in swath width provides no increase in coverage rate.

TASK 3: ***Cylindrical Array Bathymetric Sonar***. ***Tom Weber***

Project: **CABS**
JHC Participants: Tom Weber, Glen Rice
Other Participants: Kongsberg Maritime

Acoustic seafloor mapping systems have relied mainly on sonar systems that employ either a Mills cross array topology, as is the case for most multibeam echo sounders, or a parallel sidescan stave topology, as is the case for phase measuring bathymetric sonars. We are currently exploring a novel array topology which utilizes a cylindrical array to form a transmit beam that is omnidirectional in azimuth and narrow in elevation (4-5˚), and is steered down 30˚ or so from the horizontal. This generates a beam footprint that is described by an annulus on the seafloor (Figure 3-1). The same cylindrical array would then be used to form narrow (ideally 1˚ or smaller) beams upon reception. Using phase differencing, multiple independent soundings would be generated for each beam on a single ping, with a resolution constrained by the pulse length in the radial direction and the azimuthal beam-width in the circumferential direction. This approach offers several potential advantages. Chief amongst these is that it is inherently a multi-look bathymetric system, given the overlap between pings, offering a more statistically robust measure of seafloor bathymetry by generating multiple soundings for the same spot on the seabed. Advantages should also be realized for seafloor imagery: the intensity returns with this type of system would be constrained to a narrow range of oblique-incidence angles, thereby reducing the nadir artifacts that are ubiquitous in traditional seafloor mapping systems.

An opportunistic proof-of-concept test for this bathymetric mapping concept was conducted in the spring of 2016 during a short experiment conducted by Kongsberg Maritime in Horten, Norway. Glen Rice (CCOM Ph.D. candidate and NOAA Office of Coast Survey employee) and Tom Weber participated in this experiment[1] and collected element-level data from a Simrad fisheries Omnisonar SU90. Although this SU90 does not have the azimuthal beamwidth that would be needed to generate high-resolution bathymetry, this test was still useful as a conceptual test for generating bathymetry from cylindrical array sonars. Beamforming, phase differencing, and bottom detection algorithms were generated for the element-level data, and the raw bottom detects were merged with motion and positioning data. A bathymetric grid was generated from the resulting soundings, and shows reasonable agreement with data collected from a much higher resolution Kongsberg EM2040 (Figure 3-2). This

[1] Funding provided by grant NA10NOS4000073.

test represents a first test of the cylindrical array bathymetric sonar (CABS), and over the coming year these results will be further analyzed to generate a roadmap for the continued development of this sonar concept.

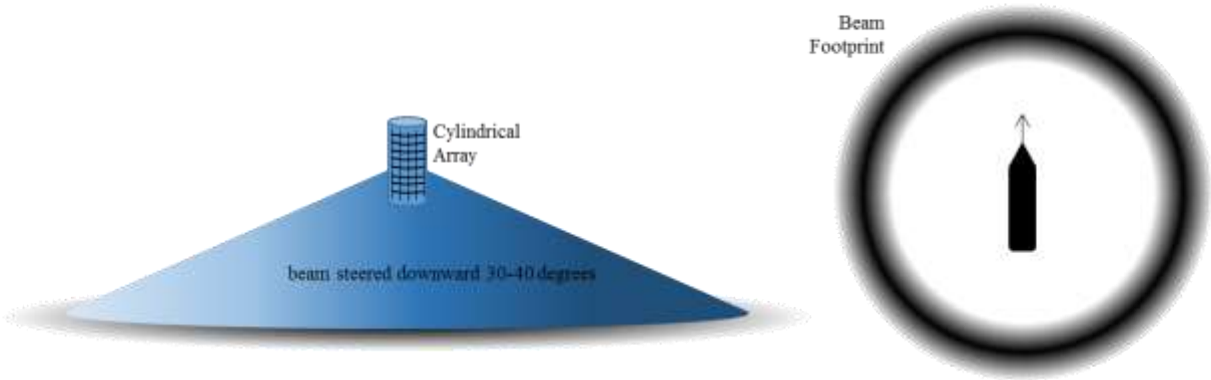


Figure 3-1: A conceptual diagram showing a cylindrical array and its field of view.

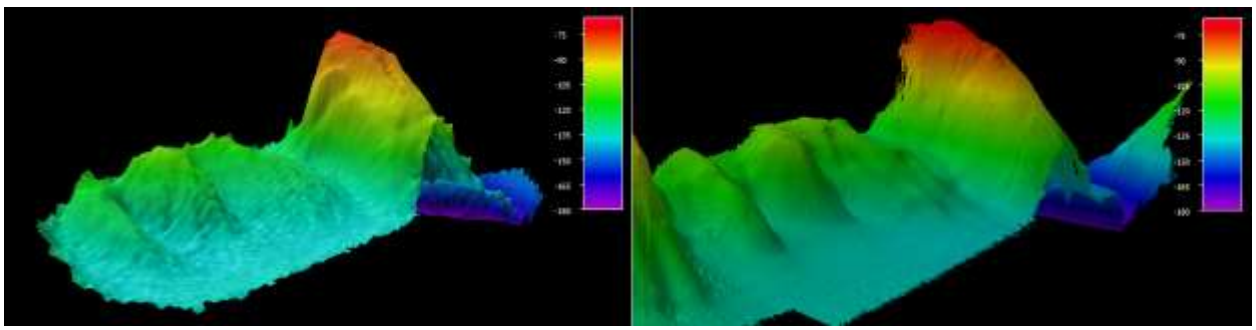


Figure 3-2. Bathymetry from a single line collected with a Simrad Omnisonar (left) and from several lines over the same area collected with a Kongsberg EM2040 (right).

TASK 4: ***Synthetic Aperture Sonar****: Deriving hydrographic-quality phase difference bathymetric solutions with parallel synthetic staves.* ***Tom Weber and Anthony Lyons***

Project has not yet started under this grant.

Sub-Theme: LIDAR

TASK 5: *Develop a* ***LIDAR simulator*** *which will allow us to better understand the interaction of airborne bathymetric LIDAR (ALB) with the sea surface and what happens to the beam once it enters the water column* ***Shachak Pe'eri and Firat Eren***

Project: **ALB Uncertainty Derivation Using a Detector Array**
JHC Participants: Firat Eren, Matt Birkenbak
NOAA Collaborators: Shachak Pe'eri
Other Collaborators: Chris Parrish (Oregon State University)

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 waveform time series (Figure 5-1**)** 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 TASK 17).

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 5-1). 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 5-2. It has been seen that the capillary waves cause a beam shift of up to 0.05m at a depth of 0.25m.

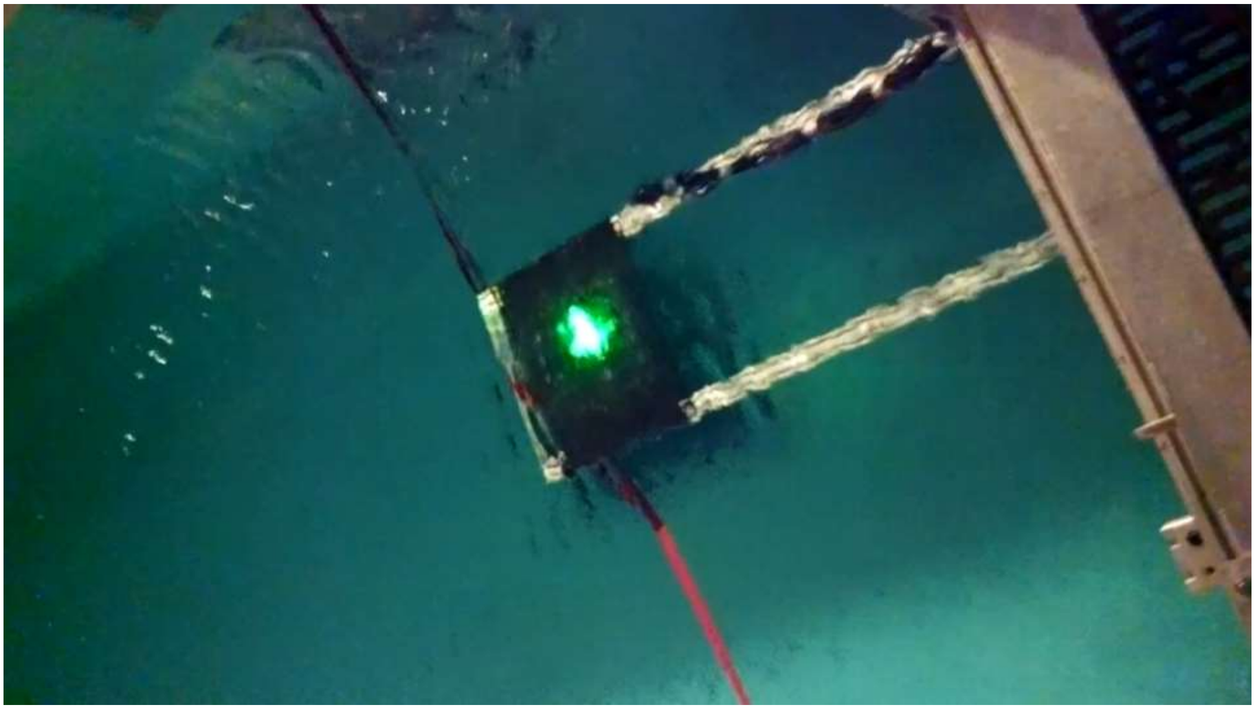


Figure 5-1: Optical detector array submerged in the water. The waves alter the shape and position of the beam.

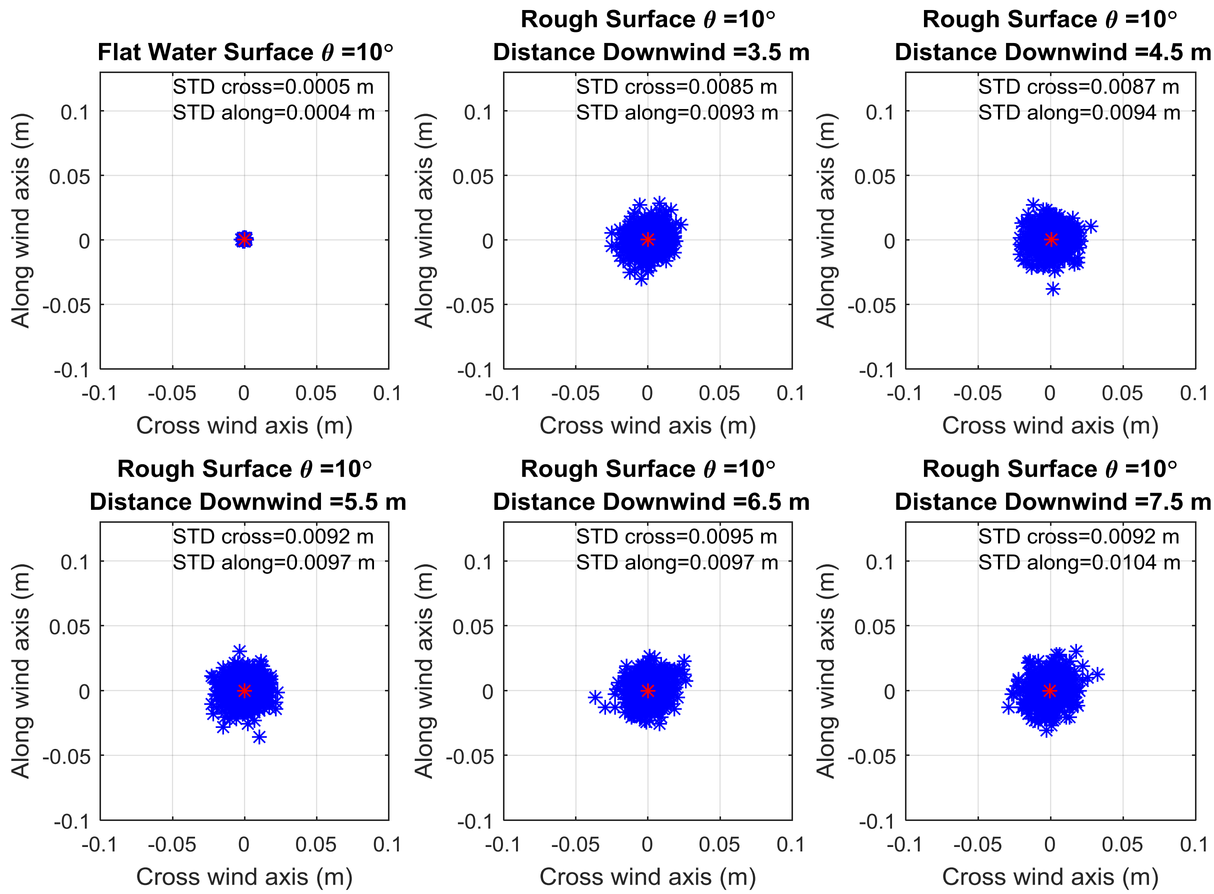


Figure 5-2: The varying location of beam center over time. The still water beam center remains very constant. Once waves are introduced the beam center is constantly shifting by ~0.05m.

Water column experiments:

The laser beam ray path in the water column was measured in the tow tank (Figure 5-3). 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 5-3: 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 5-4. 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.

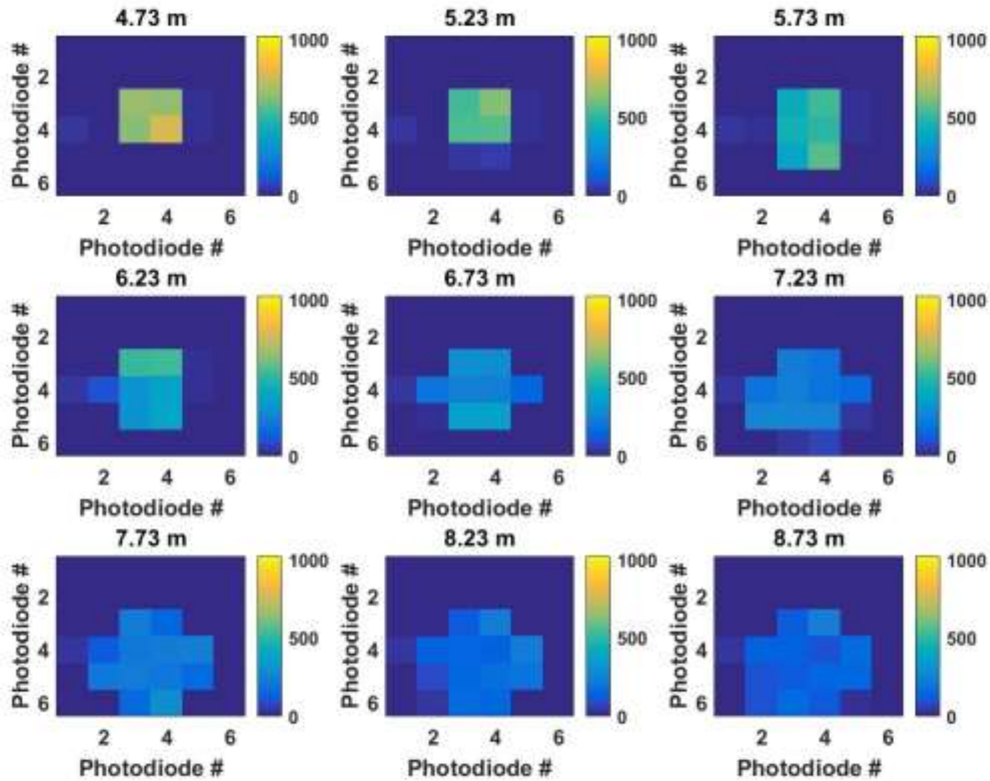
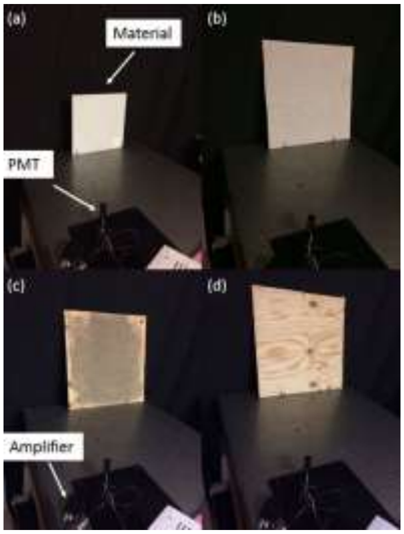


Figure 5-4: The laser beam footprint at distances from 4.73m to 8.73m at varying distances.

Bottom characteristics measurements:

The final part of the environmental interaction of the laser beam is with the sea floor. 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 5-5, left). A photo-multiplier tube (PMT) was used as the receiver, simulating the typical setup for ALB systems. For the bottom characteristics experiments, the bottom return waveforms from four different materials (whiteboard, sand, concrete, and wood) were measured by the PMT unit (Figure 5-5, right). The waveforms recorded from these materials can be seen in Figure 5-6.



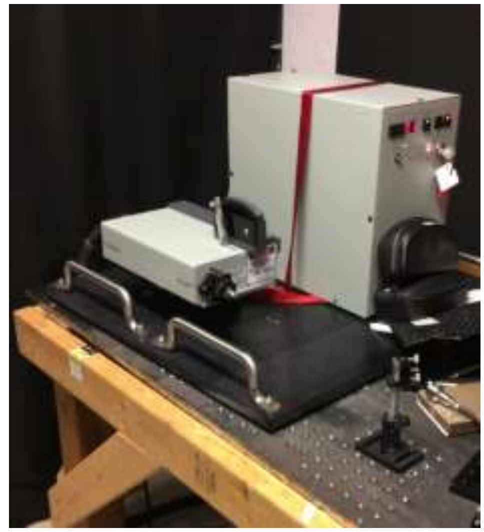


Figure 5-5: Right: The green pulsed Nd:YAG laser unit (Continuum Minilite) used in the bottom return experiments with mirror guides used for alignment. Left: Materials that were used in the bottom return calculations. (a) whiteboard (b) concrete (c) sand (d) wood

The bottom return measurements from these four materials show different reflectivity values for the same laser power. Whiteboard 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 whiteboard and sand.

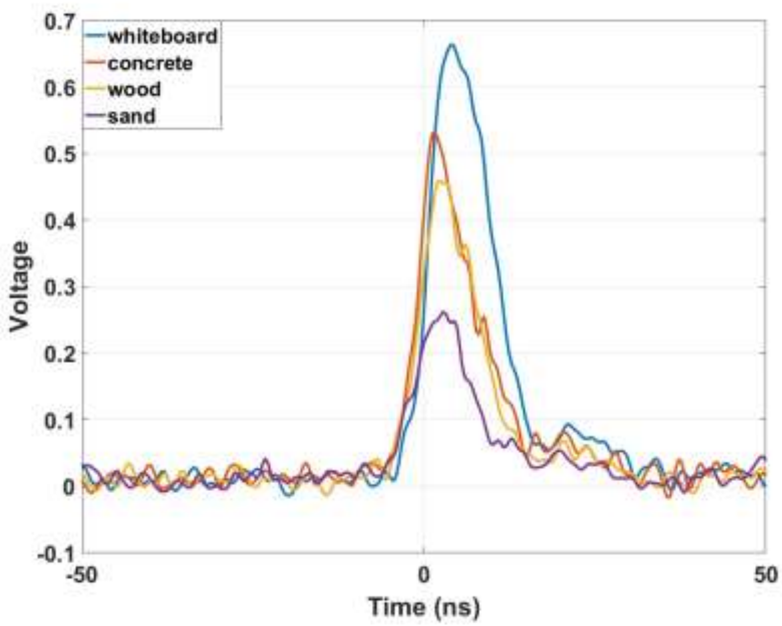


Figure 5-6: Return signal amplitudes from four different materials as measured by the PMT.

Sub-Theme: Sound Speed

Task 6: ***Distributed Temperature Sensing*** *using Raman scattering (RS) for rapid, continuous underway measurements of the sound speed profile.* ***Shachak Pe'eri***

Project has not yet started under this grant.

THEME: 1.A.2 Sensor Integration and Real-Time QA/QC

Task 7: ***Deterministic Error Analysis Tools:*** *Further develop a suite of real-time and post-processing analysis tools to help operators see systematic integration problems in their configuration, e.g., wobble analysis tools including separating motion latency/scaling issues from surface and near-surface sound speed modulations, the use of water column information as a tool for identifying interference, noise sources, and bottom-detection issues. Improved low grazing angle bottom detection for more robust target detection, and tools to assure optimal quality of backscatter data, as well as tools to extract angular response curves that feed into our seafloor characterization developments.* ***John Hughes Clarke***

Project has not yet started under this grant.

Task 8: ***Data Performance Monitoring:*** *Investigate algorithms that could be used for real-time, or near real-time, monitoring of multibeam data, including methods for establishing a baseline performance metric for a class of systems, comparison methods for individual systems, and means to allow tracking of performance over time. We will also consider common methods pioneered through our NSF-funded Multibeam Advisory Committee for adaptation into shallow water environments, and visual feedback mechanisms that allow for clarity of real-time alerts for the operator.* ***Brian Calder***

Project has not yet started under this grant.

Task 9: ***Automated Patch Test Tools:*** *Investigate the development of automated patch-test procedures including the estimation of the uncertainty inherent in the parameters estimated.* ***Brian Calder***

Project has not yet started.

THEME: 1.A.3: Innovative Platforms

Sub-Theme AUVs

Task 10: ***AUVs****: build upon the work done by others in both correcting navigation and assessing navigation uncertainty using the sonar data itself. Continue AUV Hydrographic Bootcamp.* ***Val Schmidt***

Project has not yet started under this grant.

Sub-Theme: ASVs

TASK 11: ***ASVs:*** *develop a suite of add-on sensors and payload processors capable of sensing the ASVs environment and the quality of its survey data in real-time, and adjusting its behavior (course, speed, etc.) to ensure safe, efficient operation. Also the use of ASVs for applications beyond hydrography, for example as smart mobile buoys. Applications include long-term monitoring of extreme weather events from within a storm, gas flux from seafloor seeps, monitoring of marine mammals, or dynamic and subsurface mapping of algal blooms. We also propose the development of a mission planning and vehicle monitoring application.* ***Val Schmidt***

Project: **Hydrographic Surveying with Autonomous Surface Vehicles**
JHC/CCOM Participants: Val Schmidt, Andy McLeod, Sam Reed
Other Participants: ASV Global Ltd.

In order to explore approaches to increasing operational survey efficiency and the quality of hydrographic survey data, the Center has created a new laboratory focused on autonomous marine systems. The lab is both a physical space within the Chase Ocean Engineering building and a team of engineers and graduate students whose research goals are solving problems related to the practical aspects of operating autonomous marine systems for hydrographic survey. The autonomous vehicle lab is led by Val Schmidt with assistance from Andy McLeod and others.

The Center has acquired a C-Worker 4 autonomous surface vehicle from ASV Global Ltd. The C-Worker 4 is the result of a design collaboration with ASV Global to provide a platform whose sea keeping, endurance, and payload capacity are suitable for production survey operations and whose interfaces are adaptable for academic research. The vessel is approximately 4 m in length, is powered by a diesel jet drive, has a 16 hour design endurance, a 1kW electrical payload, and is outfitted with a central sea-chest with retractable sonar mount (Figure 11-1).

Figure 11-1: CAD rendering of UNH C-Worker 4

Figure 11-2: A collage of photos taken during the manufacturing process of the UNH C-Worker 4.

Manufacturing of the C-Worker 4 was begun in March 1st (Figure 11-2), factory acceptance testing occurred the first week of July, with final sea acceptance testing in New Hampshire the week of September 12th.

Much of the fall was spent learning to operate the C-Worker 4 and outfitting the vehicle with sensor payloads (Figure 11-3). Various power conversion and monitoring systems have been put in place to meet the power requirements of various payloads. Linux and Windows computers have been installed to host data acquisition software for the sensors and to host "back-seat driver" capability for the ASV (more on this below). These systems will allow engineers and students at the Center to build new control algorithms and autonomy packages for the ASV beyond those provided by the factory. An Applanix POS/MV inertially-aided GPS positioning system has been installed to provide precise positioning and attitude, and a Kongsberg EM2040p multibeam echo-sounder, graciously provided by Kongsberg through the Center's industrial partnership program, has been installed for seafloor survey. Integration of these systems has been ongoing throughout the fall.

While the larger vessel will provide a seaworthy platform for production survey operations, smaller, more easily deployed vessels can be more suitable for algorithm testing and very shallow water survey operations. In July, Industrial Partner Teledyne Oceansciences loaned the Center a demonstration "Z-boat" equipped with MB-1 multibeam echo-sounder for field trails in Portsmouth Harbor (Figure 11-4) as well as follow-on work at the Autonomous Systems Bootcamp in August, a workshop hosted by Art Trembanis at the University of Delaware (affiliate faculty at the Center).

Figure 11-3: The C-Worker 4 operating at the mouth of Portsmouth Harbor during operational testing this fall.

Figure 11-4: The Teledyne Oceansciences "Z-boat" fitted to a wheeled cart typically used for jet-ski deployment from beaches. The cart was found to make for easy transport around the lab and from the Center's truck to various small boats used for deployment.

The Autonomous Systems Bootcamp Workshop was an opportunity to operate various robotic marine and aerial systems, field test and develop new add-on systems, and collect various kinds of mapping data over a common area. The event was attended by more than 30 participants from academia, government and industry, and provided a week of intense learning and collaboration with exposure to a diverse group of scientists, engineers, and systems (Figure 11-5). Schmidt and Mcleod attended along with graduate students Sam Reed and Coral Moreno, and with Chelsea Fairbank from Teledyne Oceanscience. Our work was focused on integration of a back-seat driver into the Teledyne Z-boat.

Figure 11-5: Andy Mcleod and Sam Reed tending to the Teledyne Oceanscience Z-boat off Broadkill Beach, Delaware Bay, during the Autonomous Systems Bootcamp workshop at the University of Delaware.

In September, the Center was given a Teledyne Oceansciences "Z-Boat" (Figure 11-6), donated under the Center's industrial partnership program. The Z-boat is equipped with an Odom CV100 single beam echo-sounder and Trimble GPS and heading system and will be outfitted with a back-seat driver providing a convenient platform for shallow water survey and research into new behaviors and levels of autonomy for ASVs.

Figure 11-6: A Teledyne Oceanscience Z-boat, donated to the Center under the industrial partnership program.

Increasing the self-awareness of robotic vessels is critical to their operation without continuous supervision, but surprisingly, many ASVs have no ability to simply control and monitor the power consumption of individual loads within the vessel. Therefore, McLeod has developed a power monitoring package capable of reporting voltage and current levels for up to eight devices that is easily deployed aboard any vessel.

Several robotic message-passing architectures are commonly used within the academic community and the group has begun analysis of how to best leverage those architectures. The interface to the C-Worker 4 vehicle will be through the "Robotic Operating System" (ROS.org) while the development for new behavior algorithms will be through the Interval Programming Helm of MOOS-IvP (www.moos-ivp.org). These message-passing middle-ware architectures will provide a basic infrastructure on which to quickly build new capability.

As an example, graduate student Sam Reed has begun development within the MOOS-IvP Helm framework to make an ASV nautical chart-aware. The goal of his research is to use ENCs to provide guidance to the helm when its intended path is unsafe due to known hazards to navigation. To accomplish this task, the information from an ENC is translated into a spatial database to be used for obstacle avoidance, and to provide a prior probability distribution for the likely locations of objects in a sensor's field of view.

During the reporting period, algorithms were developed to read and interpret ENCs into a spatial database where they are encoded with a “threat level” based on the feature type and vessel dimensions as well as quantitative and, where necessary, qualitative measurements of the estimated depth of the object. Using the spatial database, algorithms were then developed to avoid known hazards from the ENCs. Figures 11-7 and 11-8 show a simulation of the ASV dynamically changing its course around a rocky area in Portsmouth Harbor. Figures 11-9 and 11-10 show a simulation of the ASV dynamically changing its course around White Island in Kittery, Maine. Another aspect that was added during this reporting period was the incorporation of tidal predictions, which temporally change the threat level of all objects. The next step for this project is to field test these algorithms.

The developments on this project have been presented at the 2016 Canadian Hydrographic Conference on May 18th and at the 2016 IEEE Oceans Conference in Monterey, CA on September 21st.

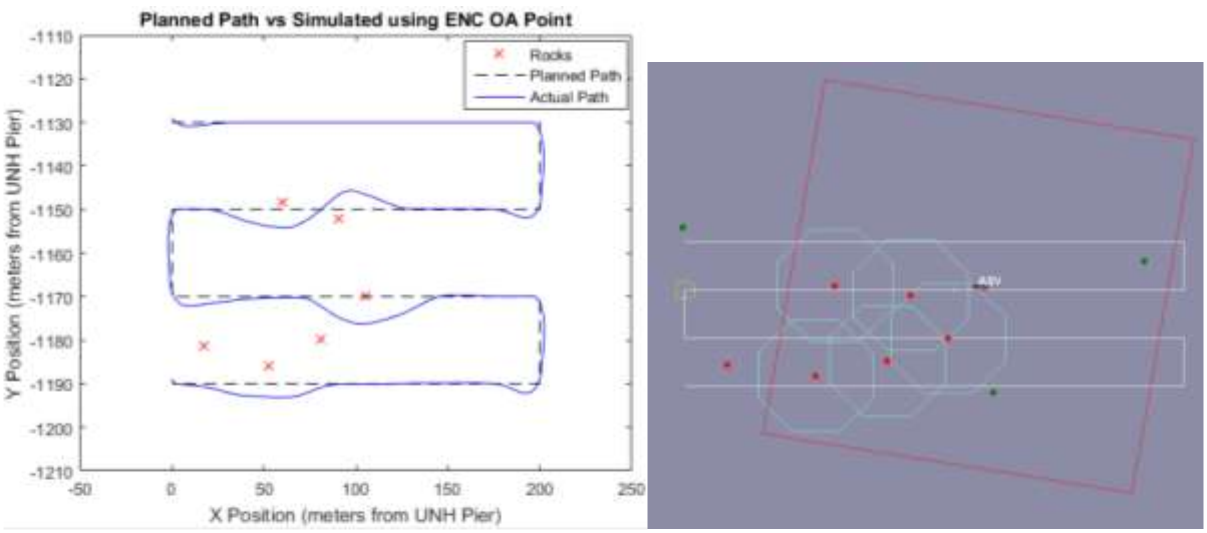


Figure 11-7: Plan-views of a mission in a rocky area in Portsmouth, NH using MOOS’s pMarineViewer where the ASV reactively changes its course away from the planned path around the rocks.

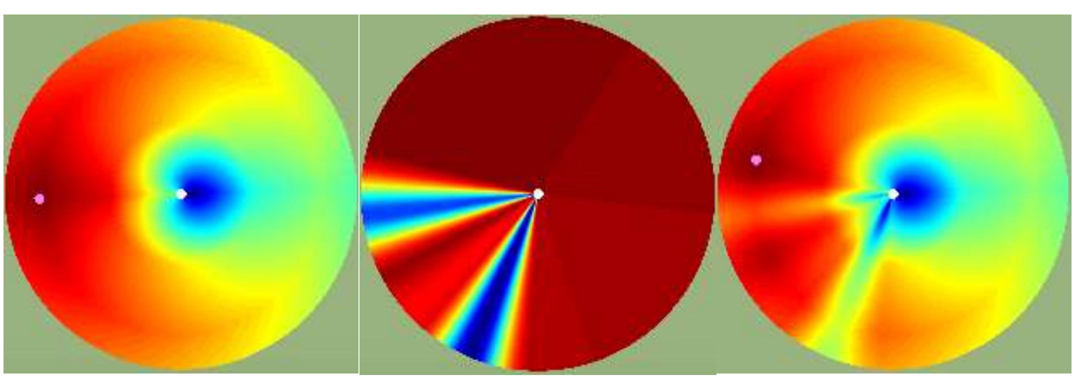


Figure 11-8: Utility functions for the MOOS behavior for the simulated mission shown in Figure 11-7 (Left: Utility Function for the Waypoint/Planned Path Behavio;, Middle: Utility Function for the Obstacle Avoidance Behavior; Right:

Combined Utility Function for both behaviors) where the radial axis is speed and the azimuthal axis is heading. The pink dot in the left and right images show the optimal speed/heading choice

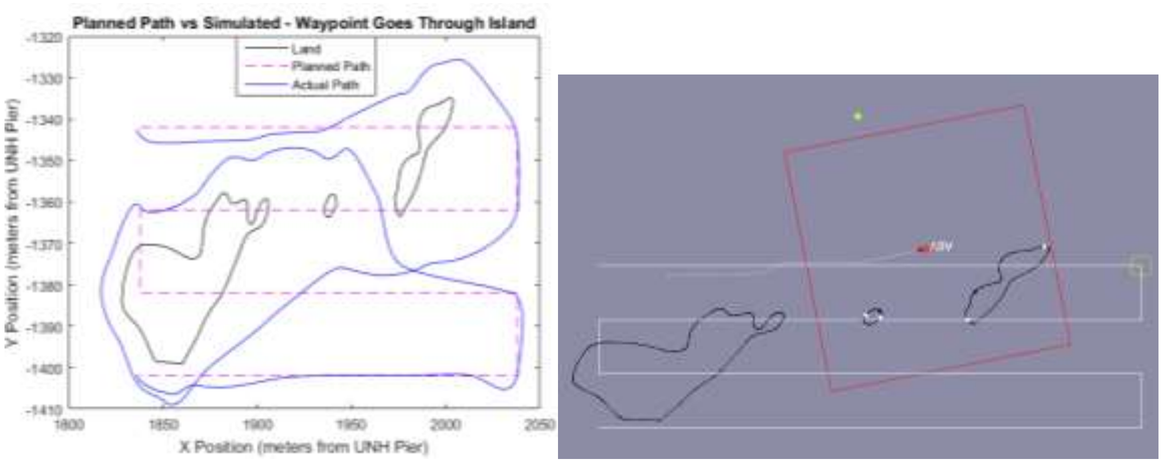


Figure 11-9: Plan-views near White Island, ME using MOOS's pMarineViewer where the ASV reactively changes its course away from the planned path around the islands.

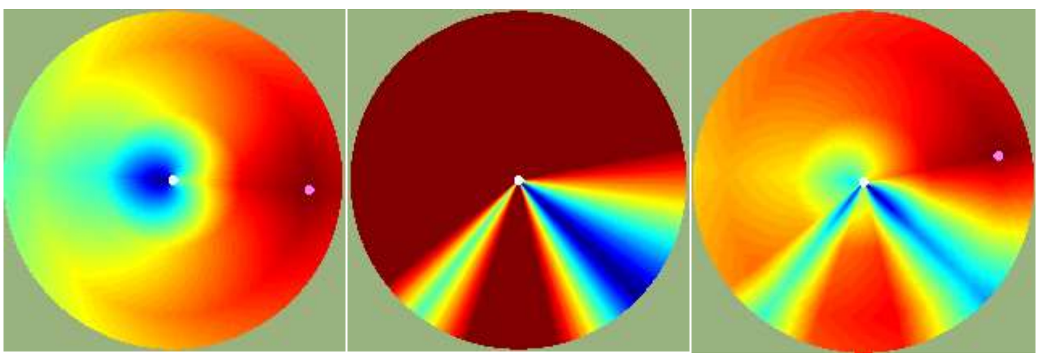


Figure 11-10: Utility functions for the MOOS behavior for the simulated mission shown in Figure 11-9 where the radial axis is speed, the azimuthal axis is heading and the pink dot in the left and right images show the optimal speed/heading choice. (Left: Utility Function for the Waypoint Behavior; Middle: Utility Function for the Obstacle Avoidance Behavior; Right: Combined Utility Function for both behaviors)

Project: **Autonomous Surface Vehicle 3-D Visualization**
JHC/CCOM Participants: Roland Arsenault and Val Schmidt
Other Collaborators: ASV Global Ltd.

MOOS-linked Mission Simulator: The Mission Oriented Operating Suite (MOOS) middleware is being used at the Center for Autonomous Surface Vehicle efforts. To explore potential visualization applications, a proof of concept tool was created by Roland Arsenault that links a MOOS simulation to the Flight Gear Flight Simulator (FGFS) software in order to display the results in a 3D environment (Figure 11-11). FGFS has been used in the past at the Center to simulate a shipboard environment by replacing the aircraft flight and display models by ship models. The display of MOOS data in FGFS may have limited uses outside of outreach scenarios, but the knowledge of interacting with MOOS may be used in future mission monitoring and planning applications.

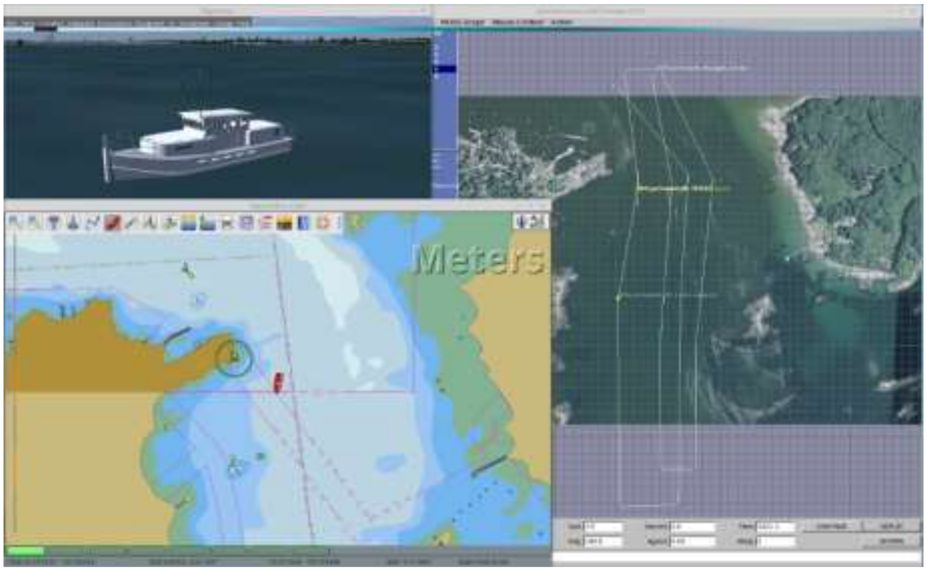


Figure 11-11: MOOS simulation is being portrayed in 3D using Flight Gear Flight Simulator while also being displayed in OpenCPN.

Interactive Autonomous Mission Planner: Software to plan missions for autonomous vehicles is being developed by Roland Arsenault with testing by Val Schmidt. Autonomous vehicles are typically supplied with a custom mission planning and monitoring application specific to that vehicle. Many of these applications have limited capability and limited applicability. Our goal is to develop a cross-vehicle mission planner that will:

- Support multiple vehicle types, such as ASVs and AUVs, and provide a global coherent interface for managing missions composed of a heterogeneous mix of autonomous vehicles.
- Be cross-platform, working on Linux, OSX and Windows.
- Display background data such as charts and previous survey data.
- Be a platform that evolves with the progress made at the Center with autonomous vehicles.

Various approaches for modifying existing applications were explored including the idea of extending an existing nautical chart display application, OpenCPN. This open-source charting software has the ability to display both vector and raster nautical charts and allows routes to be planned. However, it proved difficult to add additional data layers, such as existing survey data, via its plugin API. The API could also prove limiting as the platform evolved with the vehicles.

Another approach explored was to use an open source GIS system (QGIS) as a base. Experiments with displaying raster nautical charts uncovered performance issues while interacting with the display. Such user interface slowdowns would be a detriment to the smooth operations of a mission planning application.

Not finding a suitable software package available, a C++ application is being written using the QT5 framework for the user interface, and the GDAL library for loading geographical data and handling cartographic projections. Incremental steps are being made to allow the loading of a background chart and the plotting of a track line (Figure 11-12).

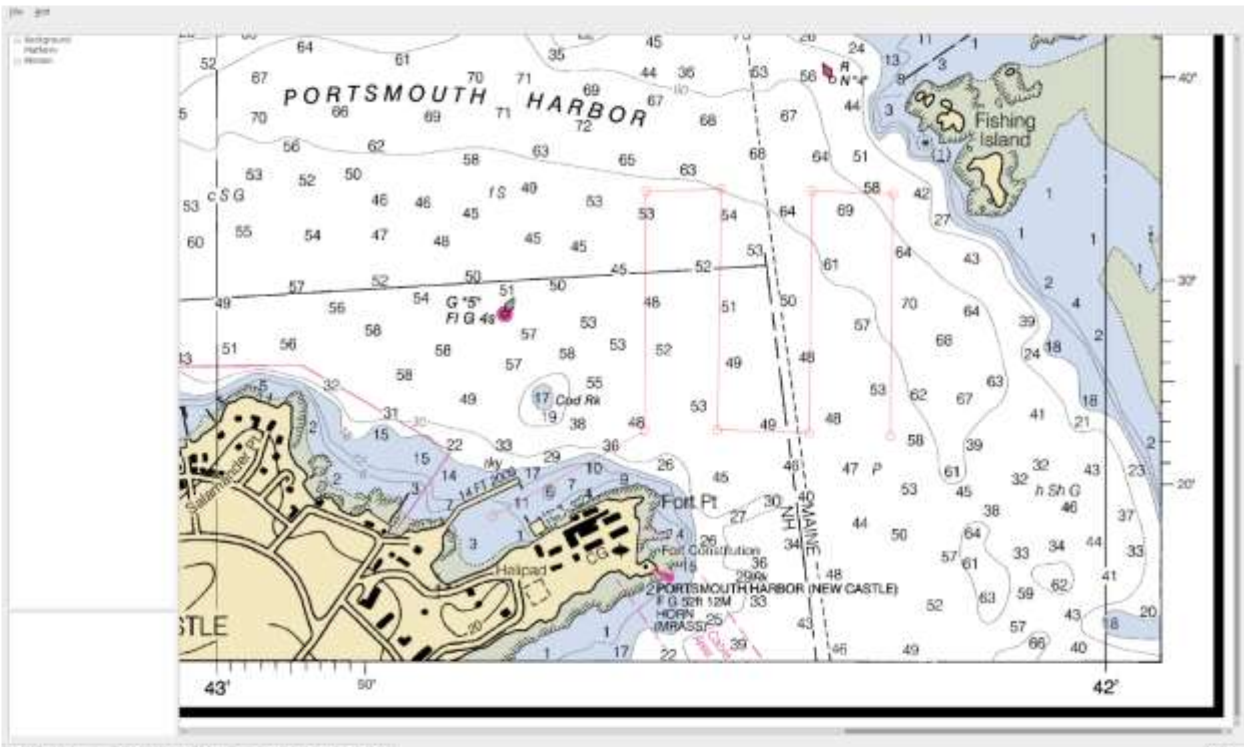


Figure 11-12: The Autonomous Mission Planner application showing a track line plotted on a raster nautical chart of Portsmouth Harbor, NH.

THEME: 1.A.4: TRUSTED PARTNER DATA

TASK 12: *Develop a portable "**trusted system**" capable of generating qualified data using an incremental approach to the problem that would start with a desktop study of capabilities and requirements, followed by the design and build of an appropriate prototype system, and then a demonstration of its ability to interface with appropriate data repositories.* ***Brian Calder***

Project: **Trusted Community Bathymetry**
JHC/CCOM Participants: Brian Calder, Ben Fruth, Semme Dijkstra
Other Collaborators: Ken Himschoot (SeaID)

As an alternate to the unconstrained Crowd Source Bathymetry approaches currently being proposed by a number of researchers, Calder has previously proposed that one way to avoid the inevitable problems of reliability that arise in such data is to build a system that by design will provide guarantees of reliability sufficient for a hydrographic agency to be willing to use the data for charting.

In order to support this alternative proposal of Trusted Community Bathymetry, Calder, Fruth, and Dijkstra have begun work on a desktop design study for the requirements of such a system. Work on data capture using a consumer grade sidescan sonar was conducted in 2015 under grant NA10NOS4000073, which provides valuable insight into source data volumes. In the current reporting period, the work has focused on the requirements for positioning, particularly in the vertical, which will be critical to success of the overall system. At an early stage, the work has Calder and Fruth estimating the volume of data generated by GNSS systems when recording satellite observables suitable for high-precision post-processing for positions, and their potential for data compression. Dijkstra is providing field support, in conjunction with the Center's summer hydrographic field campaign, for real observations with rover GNSS devices.

Meanwhile, Calder has begun a discussion with Ken Himschoot of SeaID, who currently make the data loggers for the IHO's CSB initiative, on the potential for collaboration on this project. Himschoot and his collaborators will visit JHC/CCOM for further discussions early in 2017.

RESEARCH REQUIREMENT 1.B: DATA PROCESSING

FFO Requirement 1.B: "*Improvement in technology and methods for more efficient data processing, quality control, and quality assurance, including the determination and application of measurement uncertainty, of hydrographic and ocean and coastal mapping sensor and ancillary sensor data, and data supporting the identification and mapping of fixed and transient features of the seafloor and in the water column.*"

THEME: 1.B.1: ALGORITHMS AND PROCESSING

Sub-Theme: BATHYMETRIC PROCESSING

TASK 13: ***Continued development of CHRT and like algorithms****, with particular attention to the use of slope information, correlations between measurements, and refinement techniques for variable resolution grids. For alternative bathymetric data processing techniques, we will explore non-parametric methods, non-uniform sampling methods, and non-local context for decision-making. We will also continue our development of parallel and distributed processing schemes, with particular emphasis on practical application of local-network distributed-computing, distributed-storage, and cloud-based environments. Finally, we will investigate better user-level algorithm completeness and skill metrics that provide stable, reliable, and visually impactful feedback for data quality assurance. These efforts will be coordinated with our visualization team to ensure that the final products impart data quality parameters in a manner that is easily interpretable.* ***Brian Calder***

Project has not yet started under this grant.

TASK 14: ***Multi-detect Processing:*** *Develop processing algorithms required to generate multiple detections within a single beam, to appropriately combine their evidence, and to provide qualified detections to the user. We will establish the uncertainty of the measurements determined from the multiple detections, as well as adapt current generation processing algorithms to incorporate the information from multiple detections, and use them to generate the hypotheses being reported while adjusting hypothesis selection to provide more than one "plausible" hypothesis.* ***Tom Weber and Brian Calder***

Project has not yet started.

TASK 15: ***Data Quality and Survey Validation Tools:*** *The development of tools and methods to assess the quality of data during early- and mid-stage processing, primarily to establish a baseline quality standard, assessing the degree to which the data meet the requirements. Additionally, we will develop tools and methods to actively manage the data processing procedure, identifying problem areas in the data, ensuring that objects are appropriately identified and addressed, and keeping track of those objects to ensure that all are addressed before the survey is closed; provide a 'pack and go' option to ensure that the data is complete before the survey is readied for delivery; aggregate information, provide a system-monitoring dashboard, and derive management data. Finally, we will explore the development of tools and methods to support mid-stage office-based data processing: tracking objects,* *assisting with sounding selection, and correlation of hydrographer notes and chart objects.* ***Brian Calder***

Project: **Data Quality and Survey Validation Tools: *QC Tools, SARScan, and HCellScan***

JHC/CCOM Participants:	Giuseppe Masetti, Brian Calder
NOAA Participants:	Matthew Wilson (NOAA OCS AHB physical scientist and Center alumnus), Castle Parker (NOAA OCS AHB physical scientist, Hydrographic Team lead), Edward Owens (NOAA OCS AHB physical scientist, Cartographic Team lead), Barry Gallagher (NOAA OCS/HSTB engineer), Jack Riley (NOAA OCS/HSTB physical scientist), Chen Zhang (NOAA OCS/HSTB IT specialist**)**

In 2015, a collaboration began between Giuseppe Masetti, Brian Calder (JHC/CCOM) and Matthew Wilson (NOAA OCS) to identify challenges and needs, both in the field and in the office, facing those doing hydrographic processing. Addressing these challenges, a series of software utilities were developed within the HydrOffice framework. The framework was designed to lower the barrier for field personnel to develop software utilities to address their specific needs, and, with support from the Center, the utilities became SARScan and HCellScan. These tools are now widely used in the NOAA hydrographic and cartographic communities. Collaboration with NOAA HSTB (Hydrographic Systems Technology Branch) allowed for the incorporation of SARScan and HCellScan into Pydro. This facilitated automatic distribution to all NOAA field units and hydrographic offices, as well as ensuing maintenance and updates. All NOAA hydrographic teams have access to these tools and this has encouraged and promoted their use.

In early 2016, SARScan (Figure 15-1) was presented at the NOAA Field Procedures Workshop, with NOAA hydrography and contractors present. Then, at the Canadian Hydrographic Conference in May, a general overview of SARScan and HCellScan was presented with a preview of the new features. Both presentations garnered significant interest and distribution of the tools became more widespread.

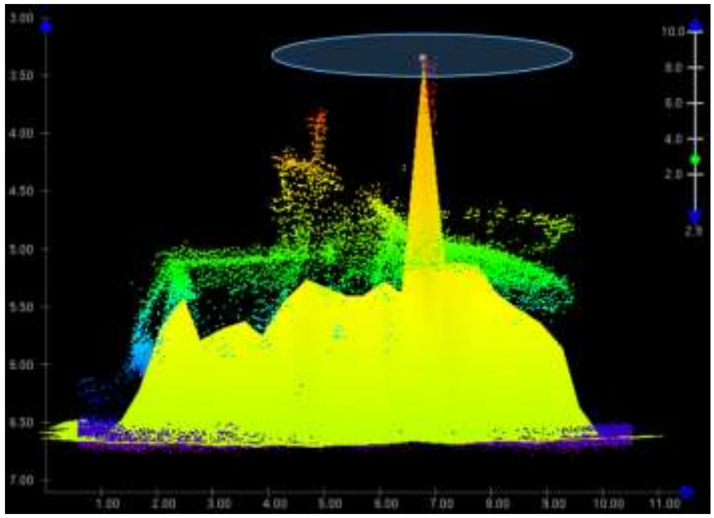


Figure 15-1: A wreck typically has a chosen least depth sounding (orange), which must match the grid (yellow shape), and both of these must match the S-57 feature (blue circle). Currently, the grid to feature check ensures agreement between gridded bathymetry and the corresponding VALSOU attribute of wrecks, rocks, and obstructions, in terms of depth and horizontal position.

SARScan and HCellScan, while effective and widely used in NOAA, also had numerous areas for improvement. The next evolution in their development was QC Tools, which combined the software into a single interface focused on simplicity for the user. The first stable version (1.0) of QC Tools was released in June 2016. In the second half of 2016, the continued development of QC Tools saw its presence and use in NOAA HSD and on NOAA hydrographic vessels increase dramatically. QC Tools has taken the place of both SARScan and HCellScan, with drag-and-drop functionality and direct reading of CSAR, BAG, and S-57 formats. Furthermore, the algorithms were optimized for much faster use and increased efficiency.

QC Tools is distributed (Figure 15-2) to NOAA users via Pydro Explorer, a very convenient delivery system within NOAA that updates automatically on ships and in HSD. In addition, a standalone version of QC Tools is available for download on the HydrOffice website as a click-and-play solution, and is routinely used by NOAA hydrographic contractors. Contractors have shown great interest in the tools for their inherent benefit, but also because the tools are part of HSD policy and workflow.

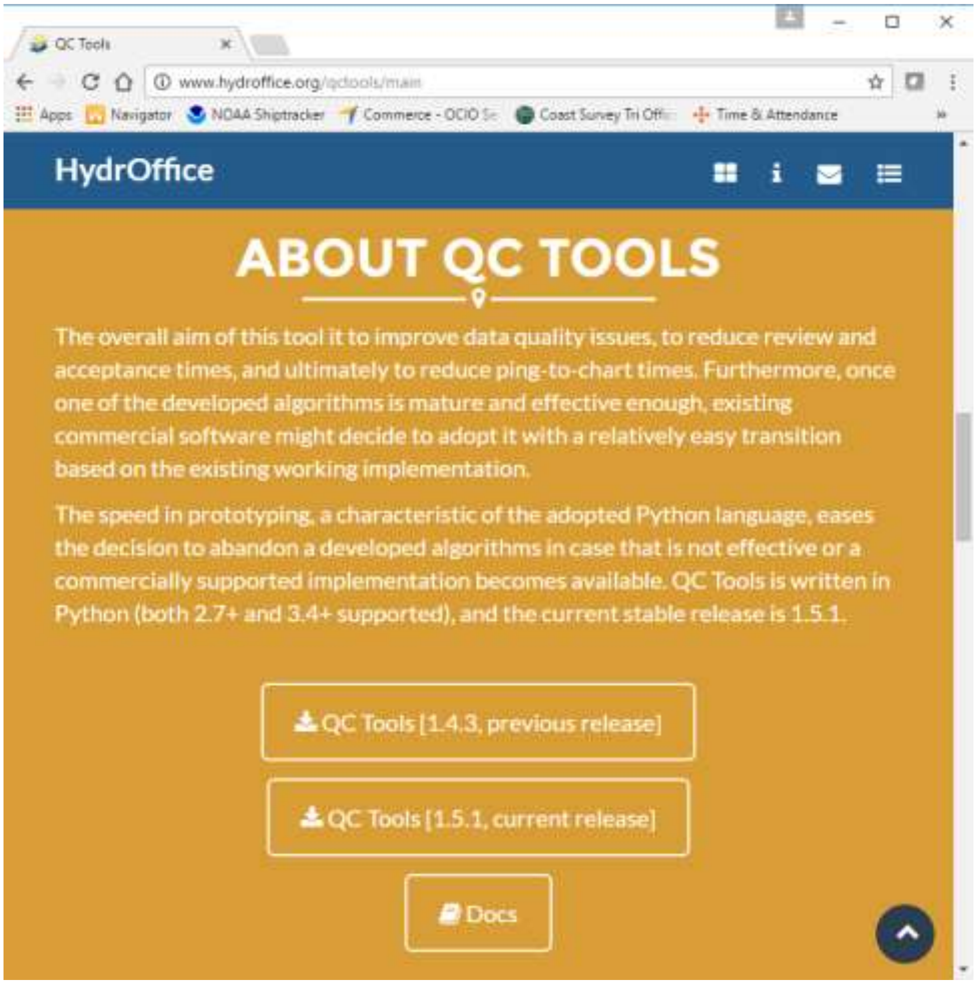


Figure 15-2: The HydrOffice website offers direct download of the QC Tools standalone application, and links to the HTML documentation. After unzipping the package, it is immediately ready for use (no further installation required).

There has been a tremendous amount of user feedback and engagement related to QC Tools, in the form of suggestions, comments, and ideas for new tools. This interaction has been welcomed, and it has also spawned several new tools that have since been added to the software. As shown along the top of the interface in Figure 15-3, QC Tools features separate tabs with tools focused on hydrographic survey review (Survey Review tab), and other tools supporting nautical chart compilation (Chart Review tab).

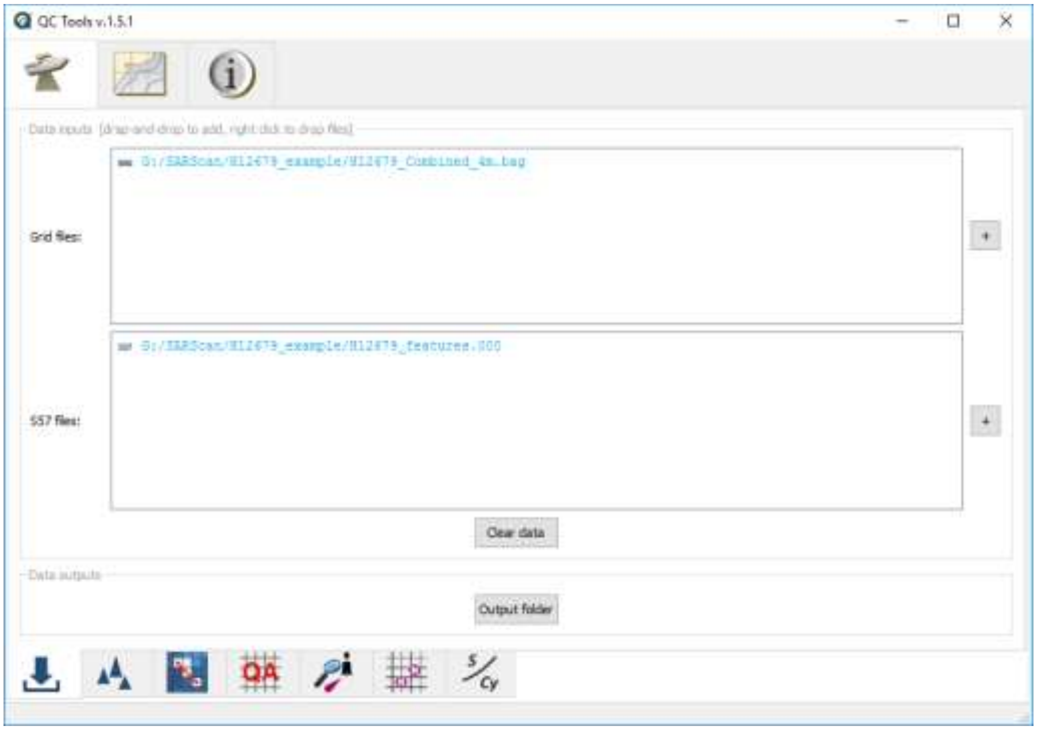


Figure 15-3: The Survey Review tab of QC Tools allows users to import bathymetric grids and S-57 files, and features the following functions (separate tabs along the bottom of the interface) that align to HSD survey review processes: Flier Finder, to detect anomalous grid data; Holiday Finder, to detect unpopulated grid nodes; Grid QA, to evaluate a grid with respect to density and uncertainty requirements; Scan Features, to ensure the correct attribution of submitted S-57 features; VALSOU Checks, to ensure depth and position agreement between submitted bathymetric grids and features, and finally, SBDARE Checks, which ensures the submitted seabed area information is in the proper format for archival.

The new tools added in 2016 are Holiday Finder and Grid QA, for the Survey Review tab; and S-57 Truncate, Triangle Rule, and Feature Scan, each available in the Chart Review tab. In addition, significant enhancements were performed to Flier Finder, a tool built in response to the high occurrence of anomalous grid "fliers" in data received at HSD. One estimate reported up to 25% of surveys received by HSD are affected by fliers, and each requires time and effort to fix. The presence of anomalous grid data is routinely noted as a significant detriment to data quality and a cause for delay in the ping-to-chart process.

Survey QC Tab: Flier Finder

In 2016, QC Tools has taken the place of SARScan in NOAA's Rapid Survey Assessment (RSA) process, and is a critical tool used by ships in the offloading of surveys, and by branches upon their receipt, to quickly and easily detect major errors. Flier Finder plays a major role in the RSA and during survey review, both on the ship and onshore. Because of its critical role in the RSA process, a more standardized basis for flier identification was desired (i.e., setting the height Flier Finder will use when searching for spikes). Rather than the previously used subjectively chosen height, Flier Finder version 3 uses an estimate of height based on median grid depth, depth variability (using the normalized median of absolute deviation), and grid roughness (using the standard deviation of the Gaussian curvature). The user may still input a desired search height manually, for a custom search.

Furthermore, a series of new algorithms were implemented in Flier Finder 3 to greatly reduce false positives, and also to detect the common occurrence of anomalous data on grid edges or isolated from the grid altogether. While there are default algorithms enabled automatically and recommended for standard use, the user may also enable and disable the various algorithms, for a customized search. The various algorithms available are shown in Figure 15-4, and sample Flier Finder output is shown against a grid in Figure 15-5.

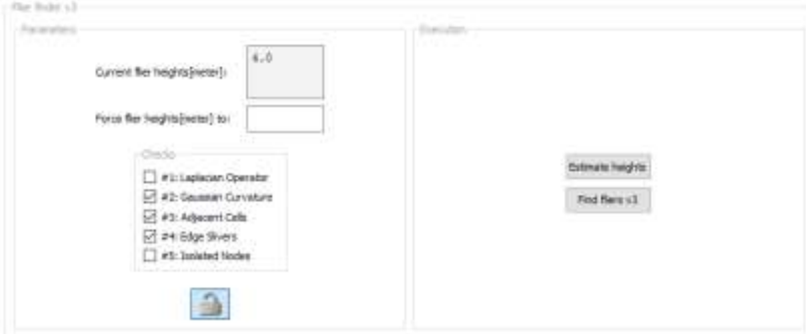


Figure 15-4: Flier Finder 3 offers an automated estimation of search height, to increase standardization of the tool for RSA purposes, though a custom height may be forced. The various algorithms to detect anomalous grid data may be enabled or disabled as desired, but the default algorithms of Gaussian Curvature and Adjacent Cells were built to minimize false positive detections, while Edge Slivers focuses on grid edges where anomalous data is routinely observed. Laplacian Operator may be used as needed for a finer search, and Isolated Nodes with search for grid data far detached from the grid and perhaps unintentionally retained.

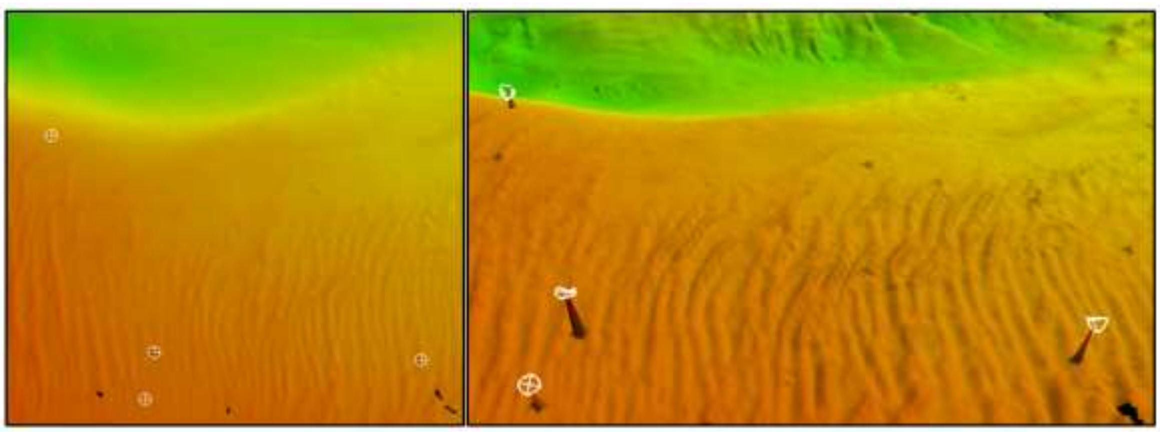


Figure 15-5: Flier Finder output, marking the location of grid data spikes, for fast detection and removal.

Flier Finder routinely detects anomalous grid data during quality review, for removal on the ship before submission; the tool also routinely detects issues during RSA, as survey rejection due to fliers is a common occurrence. This is beneficial because the issues with the grid can be resolved immediately while the survey is still fresh in the mind of the field party, and the data still resides on their data drives. The updates to version 3 have increased standardization, reduced subjectivity in use, and greatly reduced false positive detections, allowing for a faster and easier usage of Flier Finder.

Survey QC Tab: Holiday Finder

Holiday Finder began as a request from the field. NOAA hydrographic specifications strictly define limitations on unpopulated grid nodes (i.e., “holidays”) with regard to coverage requirements. Holiday

Finder thus has settings to identify violations of these limitations, with constraints to what might be included in the search (so islands or areas otherwise unsurveyed may not be flagged), as shown in Figure 15-6. Sample results of Holiday Finder are shown in Figure 15-7.

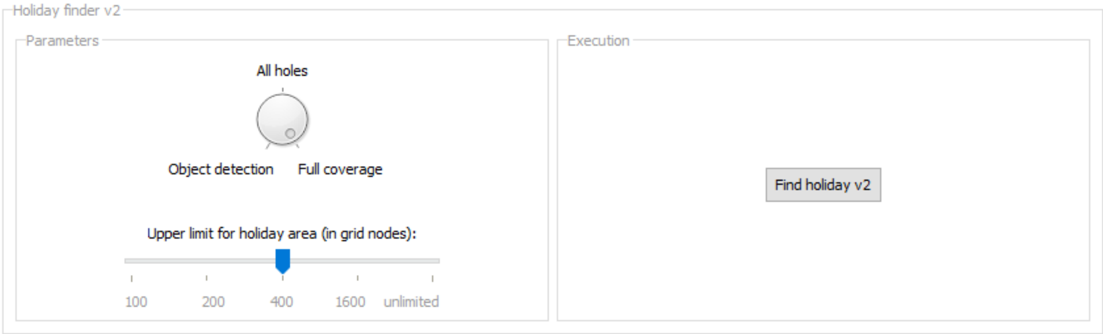


Figure 15-6: Holiday Finder offers a setting to toggle between required NOAA-specific coverage types, and an upper limit, to customize the search.

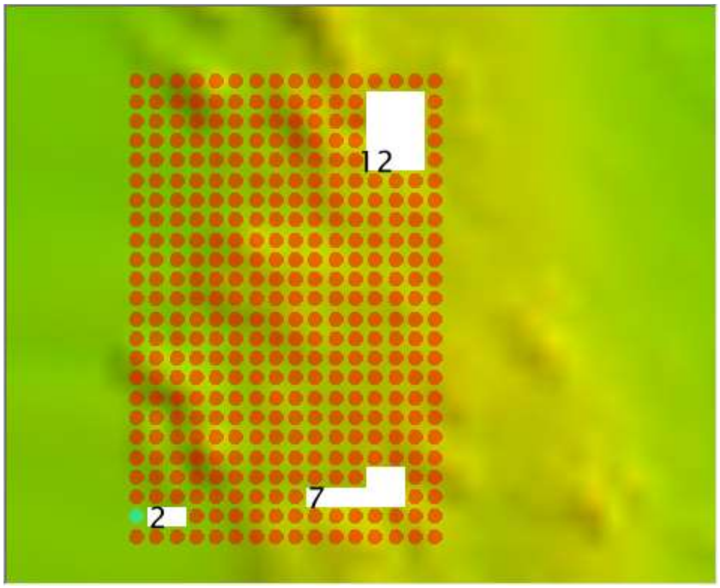


Figure 15-7: When set to find "All holes", Holiday Finder flagged holes in the grid of two, seven, and 12 nodes; when "Object detection", seven and 12 nodes; and, with "Full coverage", just 12 nodes.

Holiday Finder is in standard use by NOAA field parties and visiting scientists during hydrographic data acquisition. It automates and streamlines the process, where previously holidays were located manually, a tedious and challenging task.

Survey QC Tab: Grid QA

A longtime survey review function widely used in NOAA both on ships and on shore, Grid QA, existed as a standalone tool for years. In 2016, it was incorporated into QC Tools, which offers a more streamlined process since grids are already loaded into the software. Furthermore, the capability to accept the BAG format was added, which previously was not available.

With one or more grids loaded, the Grid QA evaluates the input with respect to requirements listed in the NOAA hydrographic specifications with regards to density and uncertainty. The output are plots, routinely used in field descriptive reports and survey acceptance review forms, which have pass/fail criteria for each respective grid. An example is given in Figure 15-8.

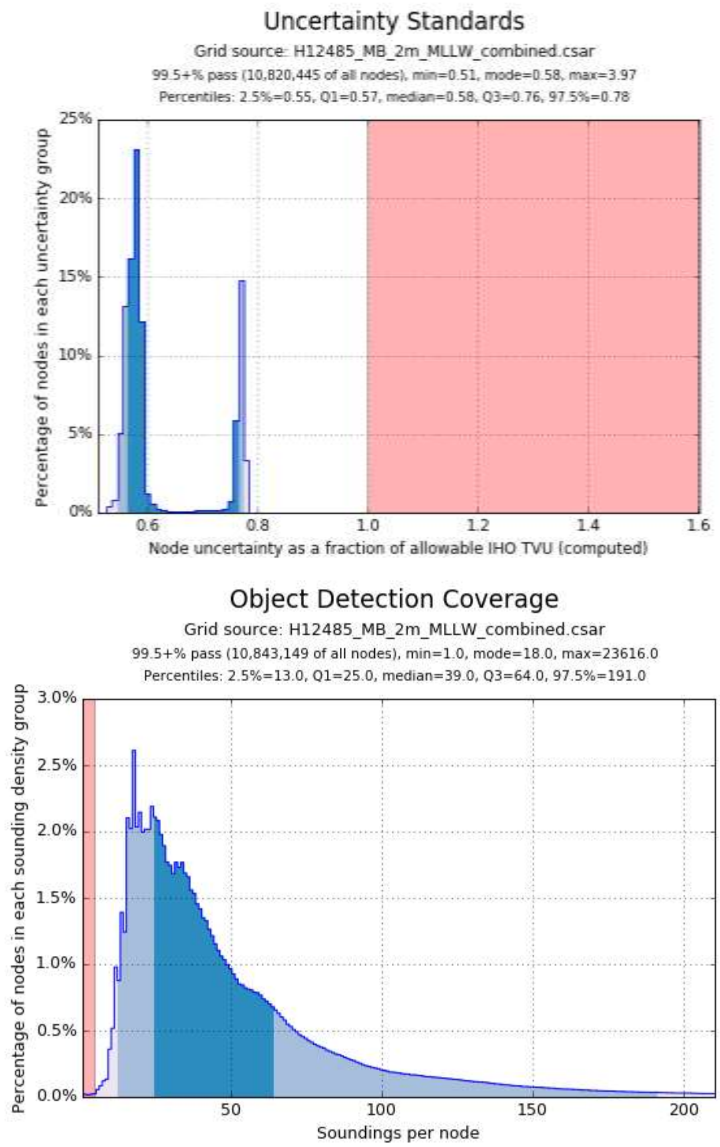


Figure 15-8: The Grid QA ensures 95% of all nodes have uncertainty (top) and density (bottom) that meet NOAA specifications, in easy to read and understand pass/fail plots.

Chart Review

In 2016, developments in QC Tools also addressed a long-neglected, but critically important, part of the ping-to-chart process, which is nautical chart compilation. As the process is evolving considerably, with new NOAA specifications and requirements, there is critical need for process improvement and quality control. The functions created to address chart compilation requirements have been imported from the

HCellScan software, and improved and optimized in a similar manner to the SARScan functions. Data is added with drag-and-drop capability, and there is direct reading and writing of BAG and S-57 files. The updated Chart tab of QC Tools versions 1.5.1 is shown below in Figure 15-9.

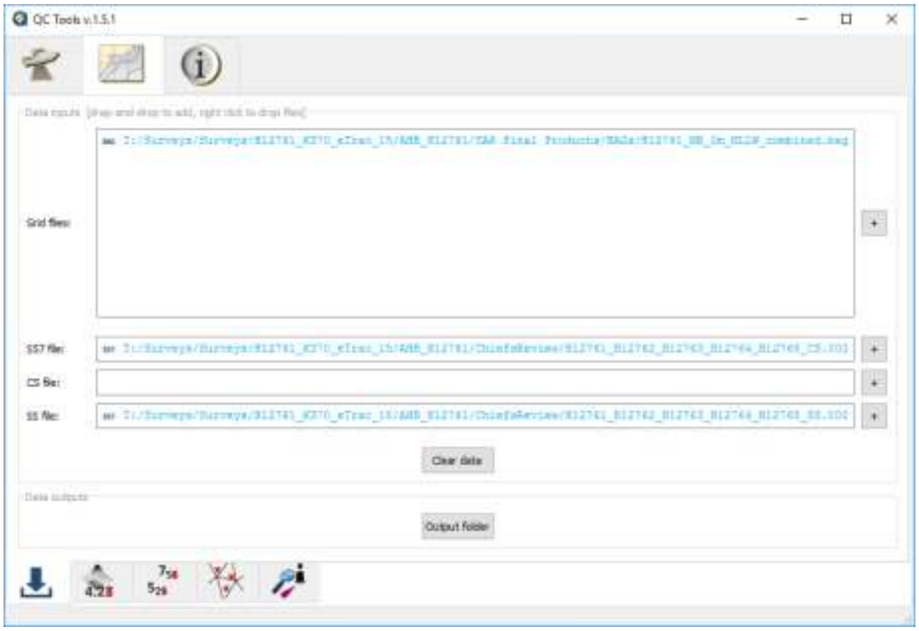


Figure 15-9: The Chart tab features along the bottom of the interface include BAG truncate, so soundings extracted and contours generated thereafter will meet the required units and precision; S-57 truncate, so feature files submitted from the field will also meet these requirements; Triangle Rule, a method of evaluating chart soundings; and Scan Features, which will ensure the proper disposition and attribution of features intended for chart update.

Chart Review tab: BAG and S-57 Truncate

The BAG and S-57 truncate functions are demonstrated in Figure 15-10 and ensure that all ensuing cartographic components used in the chart update will adhere to required units and precision limits. The capability to truncate these data files is a critical step at the beginning of NOAA chart compilation, and use of the QC Tools to accomplish this function has been written into policy at the hydrographic branches.

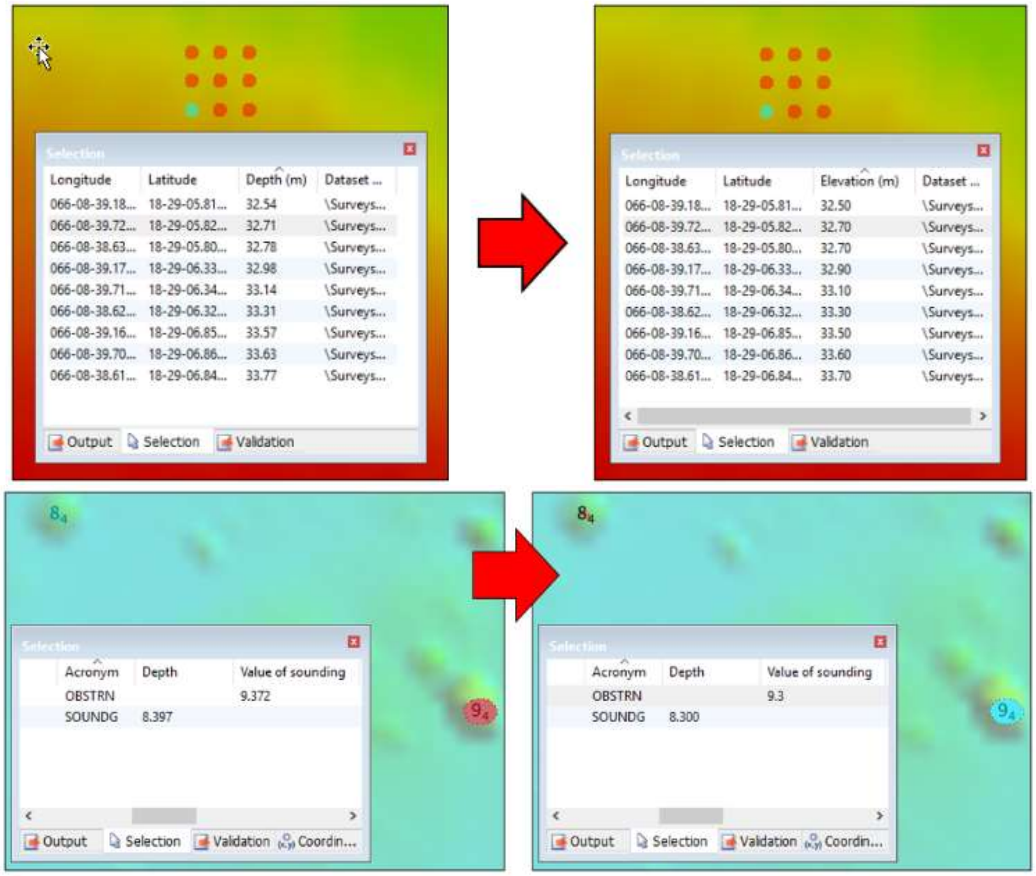


Figure 15-10: The BAG (top) and S57 (bottom) files are truncated to decimeter precision prior to chart compilation, in accordance with current HCell Specifications.

Chart Review tab: Triangle Rule

The Triangle Rule is a longtime NOAA cartographic best practice, once done by hand and now automated in QC Tools. A triangulated irregular network (TIN) is created from a prospective chart sounding selection. The survey soundings are categorized into the triangles of the TIN, and if any survey sounding is shoaler than the three vertices of the triangle it falls within, it is flagged for evaluation. An example is shown in Figure 15-11.

Given the direct reading of S-57 in QC Tools, the Triangle Rule offers additional benefits, such as a unique method of chart comparison that can be utilized at any time during the ping-to-chart process to effectively identify shoaling and dangers to navigation. The Triangle Rule represents the only currently accepted method to directly compare ENC soundings to survey soundings. The output of the Triangle Rule is shown in Figure 15-12, in this case comparing an ENC directly to a survey sounding selection.

The Triangle Rule is thus multi-functional and adds value at multiple points in the ping-to-chart process: during acquisition, to search for shoals and dangers to navigation; during survey review, for standard chart comparison; and during chart compilation, to evaluate a prospective chart sounding selection.

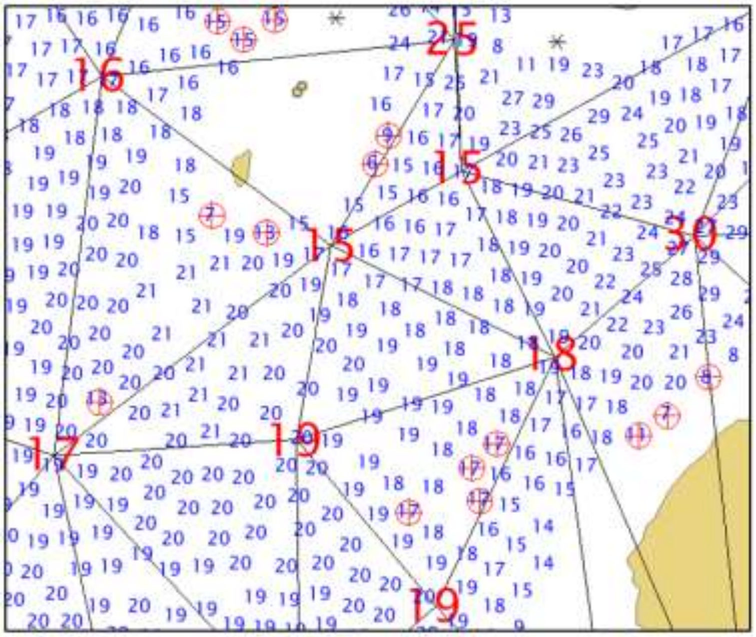


Figure 15-11: A TIN and Triangle Rule application of the prospective chart sounding selection reveals survey soundings that may need additional consideration by the cartographer; in particular, the 13-foot sounding in the southwest (near the 17-foot chart sounding) is dangerous to navigation, as it is not represented in the current chart sounding selection.

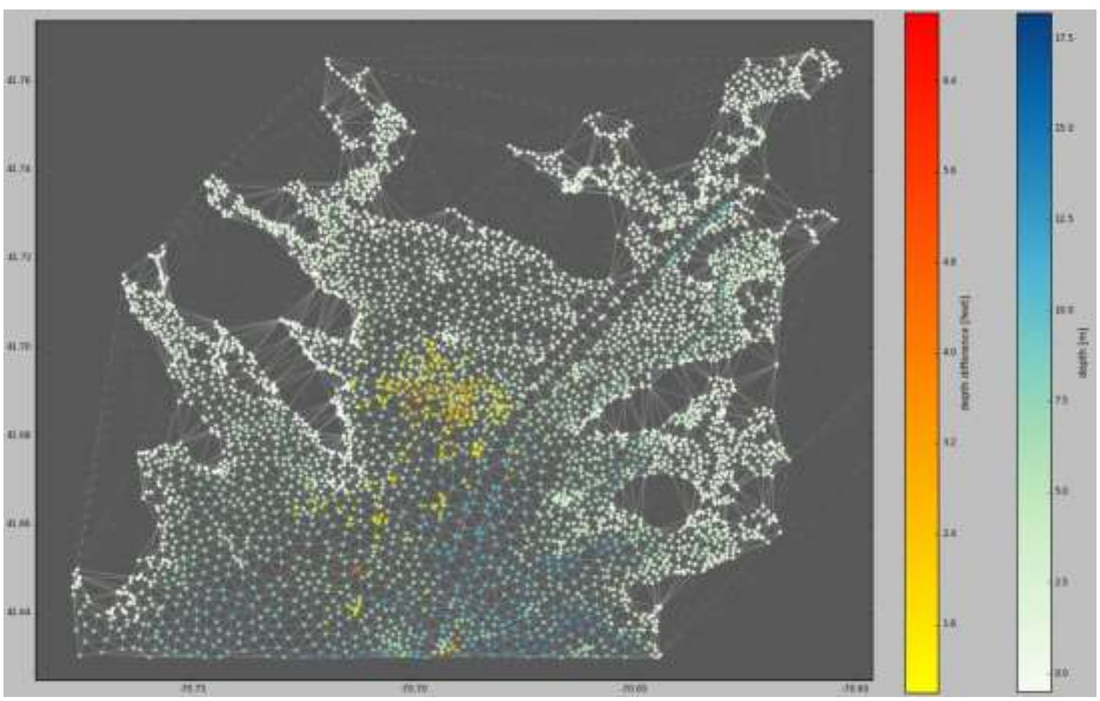


Figure 15-12: The Triangle Rule as applied to an ENC and a dense survey sounding selection offers an effective means of chart comparison and quick identification of dangers to navigation. A TIN is applied to the ENC soundings (depths in blue/green), and any survey soundings shoaler than the three vertices of the triangle they fall within is flagged (shoal discrepancy in red/yellow). Areas of shoaling are quickly evidently, and soundings flagged red might be a danger to navigation.

Chart Review tab: Feature Scan

The Feature Scan function quickly scans all prospective features to be applied to a chart, and ensures their correct disposition and attribution per current HCell Specification. Errors are exported to a GIS overlay, with a summary to PDF for archival. An example is shown in Figure 15-13.

Figure 15-13: Feature Scan of prospective chart components quickly catches a multitude of potential minor errors that frequently occur. The PDF summary shown above serves as a useful record for review.

The QC Tools' Chart Review tab functions have been incorporated into chart compilation workflows at both the Atlantic and Pacific Hydrographic Branches of Hydrographic Surveys Division (HSD). It is effective in quickly alerting the cartographer to minor errors that affect final products. With Feature Scan, the cartographer is relieved of the tedious task of checking potentially hundreds of features. The efficiency and accuracy gained with the automated methods are obvious, and the tool has been written into policy at the hydrographic branches for standard use during chart compilation processes.

A paper with title "Finding Fliers: New Techniques and Metrics" will be presented to the upcoming US Hydro conference. Furthermore, QC Tools is one of the selected topic for the 2017 NOAA Field Procedures Workshop.

TASK 16: ***Phase Measuring Bathymetric Sonar Processing:*** *Continue engineering, evaluation, and post-processing efforts for PMBS systems. Continue development of new signal processing algorithms that provide additional robustness against multipath returns when measuring the direction of arrival of incoming signals.* ***Val Schmidt***

Project has not yet started under this grant.

TASK 17: ***Automatic Data Processing for Topo-bathymetric LIDAR Systems:*** *Investigate automated processing tools for topo-bathymetric LIDAR data, with the aim of providing output products that include uncertainty, metrics for quality assurance, and a strong visual feedback mechanism (again coordinated with our visualization team) to support user manipulation of the data. This process will involve establishing an uncertainty model for topo-bathy LIDAR, adapting current generation processing tools, and exploring the use of waveform shape, reflectance, and other features as aids to processing.* ***Brian Calder and Shachak Pe'eri***

Project: **Topographic-Bathymetric Lidar Total Propagated Uncertainty (TPU)**
JHC/CCOM Participants: Firat Eren, Matthew Birkebak
NOAA Participants: Stephen White (NGS) and Gretchen Imahori (RSD)
Other Collaborators: Chris Parrish (Oregon State University**)**

NOAA's National Geodetic Survey (NGS) Remote Sensing Division (RSD) and partner agencies routinely collect topographic-bathymetric (topo-bathy) LIDAR data in support of coastal mapping programs. The topo-bathy data are used for purposes ranging from mapping the National Shoreline in NGS's Coastal Mapping Program to regional sediment management, flood risk management, and emergency management. If the topo-bathy LIDAR data from these surveys could also be routinely assimilated into NOAA hydrographic processing pipelines and evaluated for application to nautical charts, this could greatly assist in addressing the current lack of data in many shallow and near shore areas. However, the most important challenge facing the ingestion of topo-bathy LIDAR data into OCS workflows is the lack of uncertainty data for the topo-bathy LIDAR data. The objective of this project is to develop Total Propagated Uncertainty (TPU) models for topo-bathy LIDAR data.

The method of uncertainty analysis involves both analytical and Monte Carlo methods. The approach decomposes the measurement model as a sum of two vectors: a sub-aerial (i.e., in-air) vector, and a sub-aqueous (i.e., in-water) component (Figure 17-1). The advantage of this approach is that already available uncertainty data can be integrated into the established geolocation analytical equations for the sub-aerial component. However, the sub-aqueous portion involves radiometric transfer interactions within the water column and are difficult to model analytically. Therefore, in this portion, a Monte Carlo ray-tracing approach is more applicable.

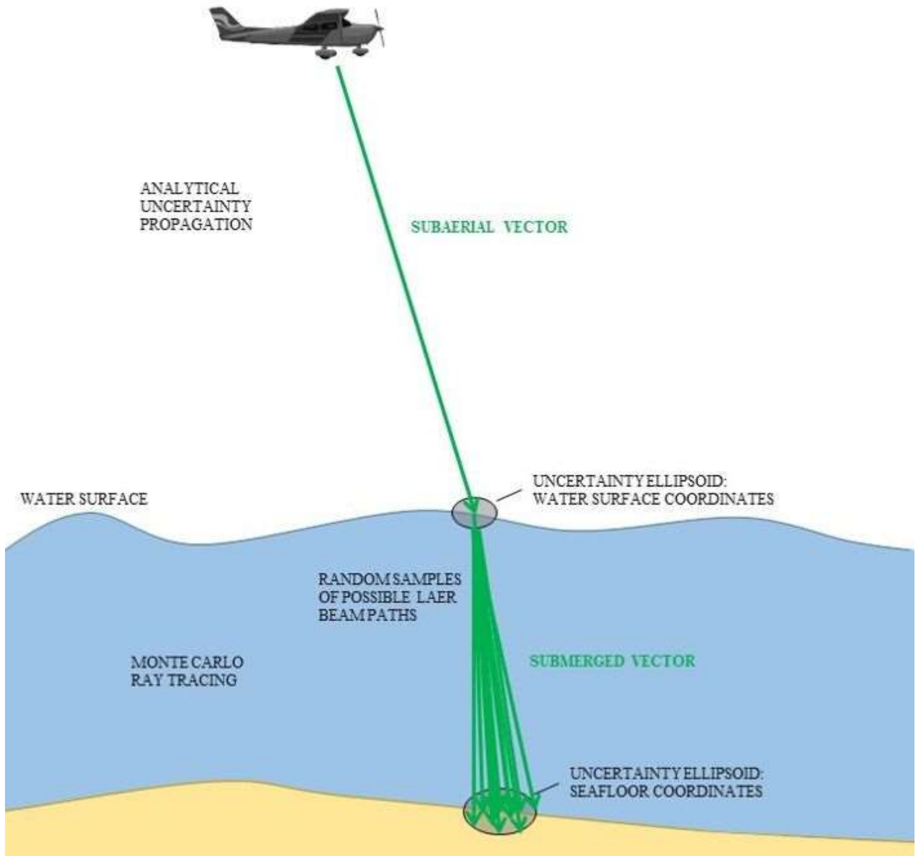


Figure 17-1: The decomposition of the two main uncertainty factors, sub-aerial and sub-aqueous portions.

The main focus of our research has been the sub-aqueous uncertainties of the system. These uncertainties start from the time the laser beam hits the water surface and ends when the laser beam travels back through the water column to the receivers in the air. It includes the uncertainties contributed by the water surface, the water column, and the seafloor. Accordingly, Monte Carlo ray tracing algorithms were developed to understand the effect of these parameters on the laser footprint.

The Monte Carlo ray-tracing algorithms take several variables as inputs including the airplane position in Cartesian coordinates, the number of laser rays, the laser scanner angle, and the laser beam divergence. Laser beam interaction with the sub-aqueous portion starts with refraction into the water column. Here, the laser beam incidence angle changes with respect to the slope of the waves. Once in the water column, the laser beam undergoes scattering and absorption effects. Additionally the pulse shape expands with respect to the water turbidity, which is indicated by the diffuse attenuation coefficient, K_d.

The Monte Carlo ray-tracing has been run based on a flat water surface assumption and a constant K_d. The simulation geometry demonstrated in Figure 17-2 includes an airplane flying at 300m altitude, 1000 rays, 20° scanner angle, 20 milliradian beam divergence angle on a flat surface. The laser refraction and water column scattering are simulated.

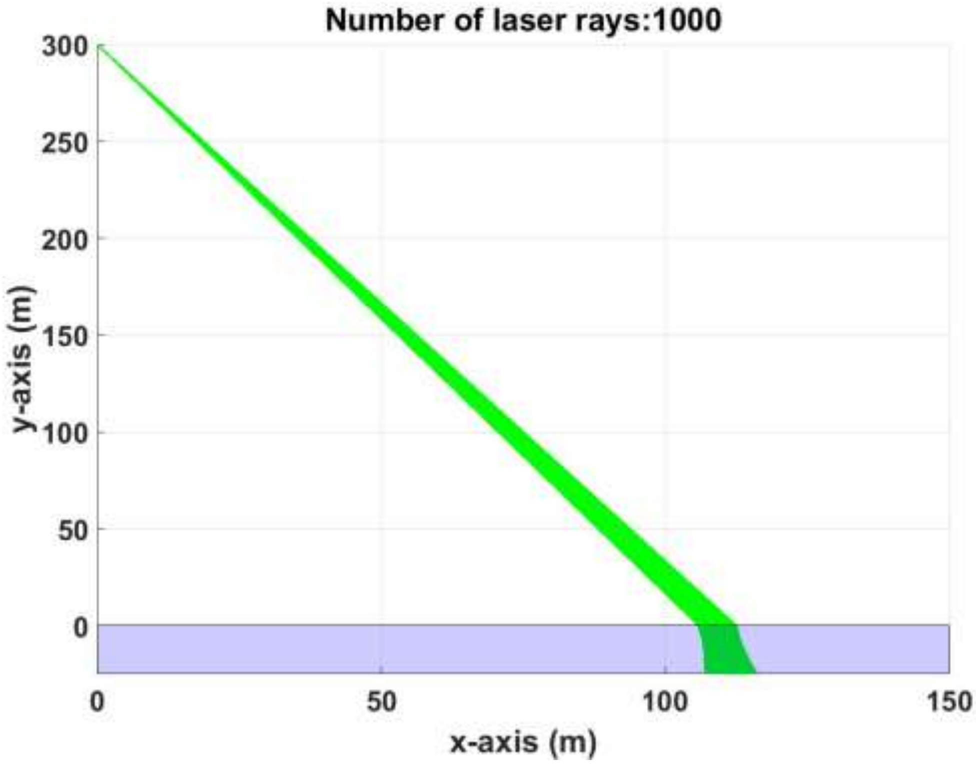


Figure 17-2: Simulated laser beam path geometry in sub-aqueous portion with refraction and scattering effects within the water column.

In order to understand how the laser beam expands in the water column with respect to depth, the laser rays were intersected at 0 m, 7.5 m and 15m (Figure 17-3). The uncertainty ellipsoids were drawn to the intersected laser rays at these depths (Figure 17-4).

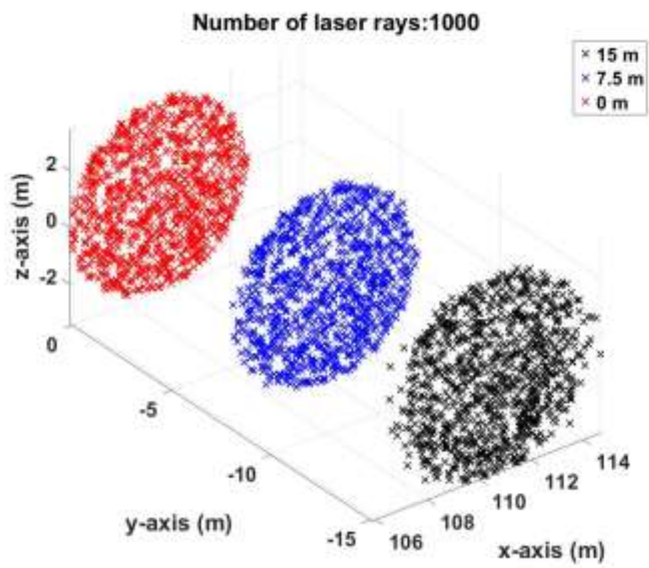


Figure 17-3: Laser rays intersecting the planes at three different depths, i.e., 0, 7.5 and 15m.

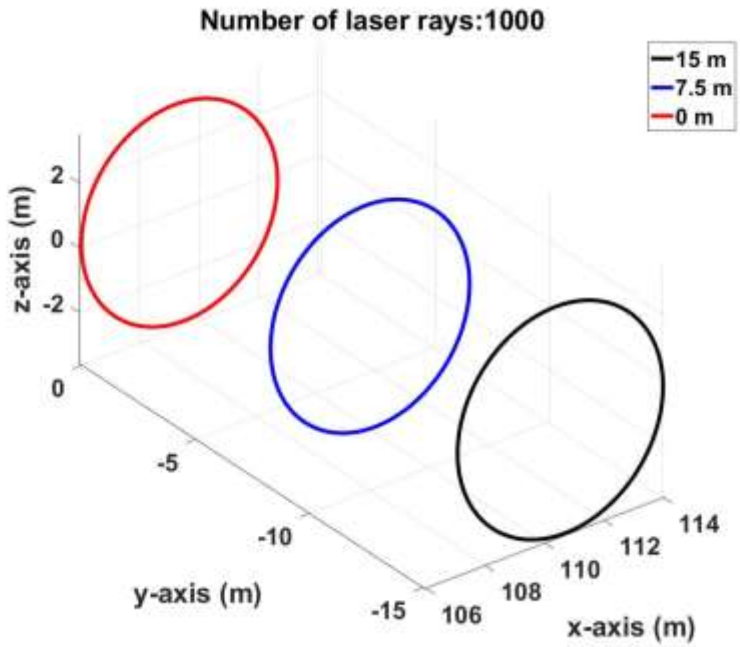


Figure 17-4: Uncertainty ellipsoids (95% CI) at three different depths, i.e., 0, 7.5 and 15m.

The results indicate that the area of uncertainty ellipsoids increased by 4% at 7.5 m and by 10% at 15 m. A similar analysis was repeated for 100 different K_d values in the Monte Carlo simulations. The results showed that the mean and standard deviation of the ellipsoid area increase as the depth increases. The standard deviation increased from 0.004 m^2 to 0.48 m^2 due to the variation in water turbidity, K_d.

As future work, the Monte Carlo simulations will be extended by modeling the water surface, varying water surface parameters such as wave height and understand its contribution to the TPU results. In addition, bottom representations will also be integrated to the Monte Carlo simulations for TPU calculation. Later stages of the project will combine contributions from both sub-aerial and sub-aqueous vectors to the TPU.

THEME 1.B.2: IDENTIFICATION AND MAPPING OF FIXED AND TRANSIENT FEATURES OF THE SEAFLOOR AND WATER COLUMN

Sub-Theme: SEAFLOOR

TASK 18: ***Hydro-significant Object Detection:*** *develop algorithms to automatically detect objects attached to the seafloor that might be hydrographically significant and, if possible, to determine their character (e.g., natural or anthropogenic) using all available sources of data, including information about the local environment. Provide directed visual feedback to the user, ideally in a quantitative manner, on the objects in the area that might be hydrographically significant, preferably in order from most significant to least; and to seed geodatabases with the information in a manner that addresses downstream use of the detections. Investigate the development of tools that address the issue of* *correlation between different data sources for the objects detected, both algorithmically and visually, so that objects can be tracked over time and compared with prior information on location.* ***Brian Calder and Giuseppe Masetti***

This project has not yet started under this grant

Sub-Theme: WATER COLUMN

TASK 19: ***Water Column Target Detection:*** *Continue the development of algorithms for the detection, processing, extraction and visualization of water column targets from the new generation of sonars that provide water column data. Work with our industrial partners to help make this workflow a reality.* ***Tom Weber***

This project has not yet started under this grant

RESEARCH REQUIREMENT 1.C: SEAFLOOR CHARACTERIZATION, HABITAT AND RESOURCES

FFO Requirement 1.C: "*Adaption and improvement of hydrographic survey and ocean mapping technologies for improved coastal resilience and the location, characterization, and management of critical marine habitat and coastal and continental shelf marine resources,"*

THEME: 1.C.1 COASTAL AND CONTINENTAL SHELF RESOURCES

Sub-Theme: RESOURCES

TASK 20: ***Mapping Gas and Leaky Pipelines in the Water Column:*** *Refine and enhance water column mapping tools to better understand our ability to map/monitor leaky systems and dispersed clouds of oil, with a focus on high frequency shelf-mapping systems, which present a more challenging environment with respect to volume reverberation.* ***Tom Weber***

Project: **Broadband Acoustic Measurements of Liquid Hydrocarbon Droplets**
JHC/CCOM Participants: Scott Loranger, Tom Weber, Alex Padilla

Development of instrumentation to detect and quantify submerged oil droplets will 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 oil plumes at depth. Methods of detecting oil currently exist, for example mass spectrometers and fluorometers, however, 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 using novel programming written in MATLAB. Figure 20-1 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.

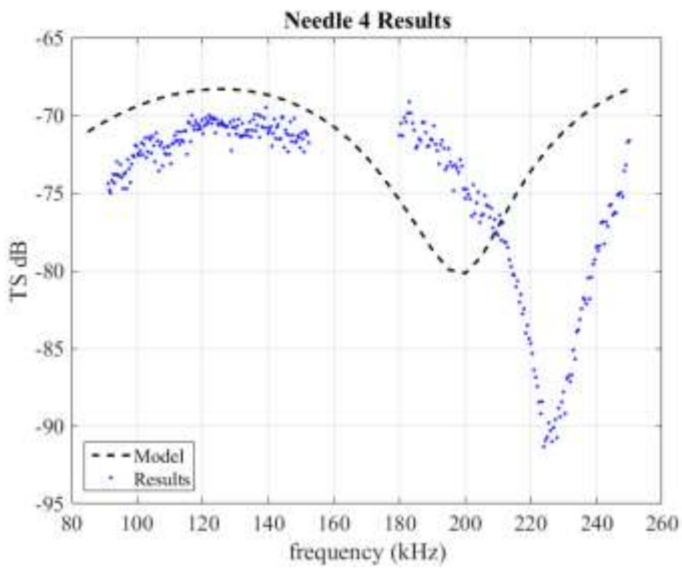


Figure 20-1: Broadband acoustic response of diesel oil compared to Anderson (1950) model

The two most important inputs for models of acoustic scattering are density and sound speed. While measurement methods of density are relatively simple and well established, sound speed measures of 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 not sufficient data in the primary literature to predict the sound speed of crude oil at oceanographically-relevant temperatures and pressures. To address this, a sound speed chamber (Figure 20-2), 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. 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.

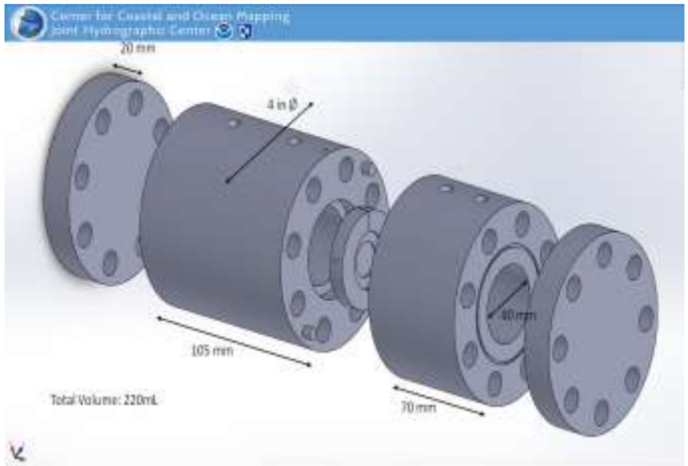


Figure 20-2: Acoustic sound speed chamber

TASK 21: ***Approaches to Identification of Marine Resources and Mineral Deposits**: Develop techniques for combining high-resolution bathymetry, backscatter, and seismic data with ground-truth samples to identify potential marine mineral deposits, as well as collect baseline information needed for environmental evaluations.* ***Larry Ward***

Project: **Developing Tools to Identify Marine Resources on the New Hampshire Continental Shelf** (with additional funding from BOEM)
JHC Participants: Larry Ward, Maxlimer Vallee-Ansiani, Zachary McAvoy

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 data processing 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 21-1 and 21-2) and surficial sediment classifications (Figures 21-3 and 21-4). 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 subjective 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 21-1 through 21-4). 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.

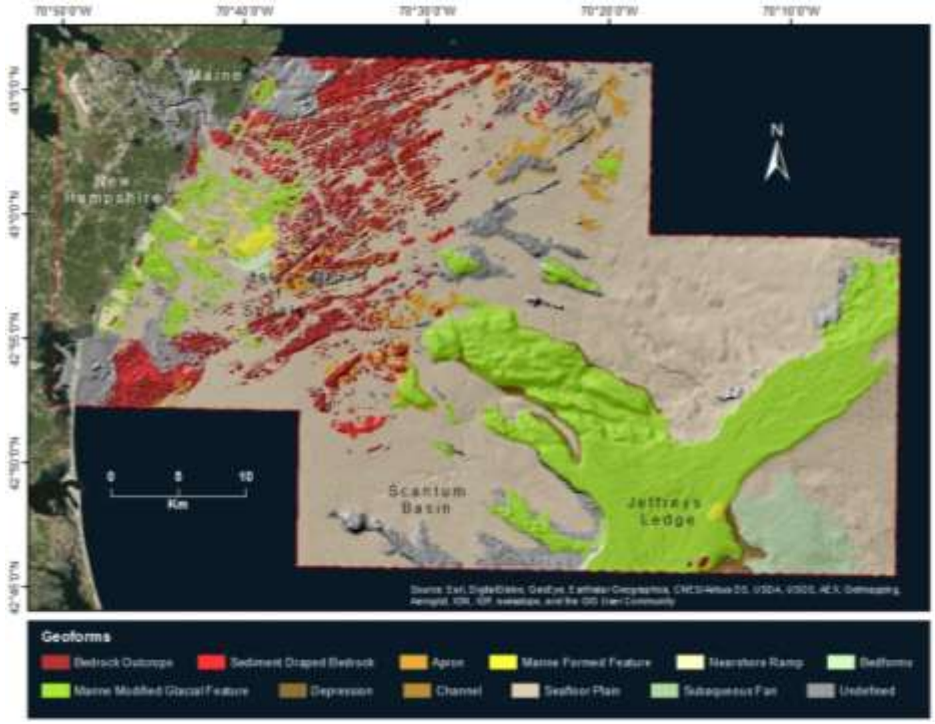


Figure 21-1: Major geoforms or physiographic features of the New Hampshire and vicinity continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS).

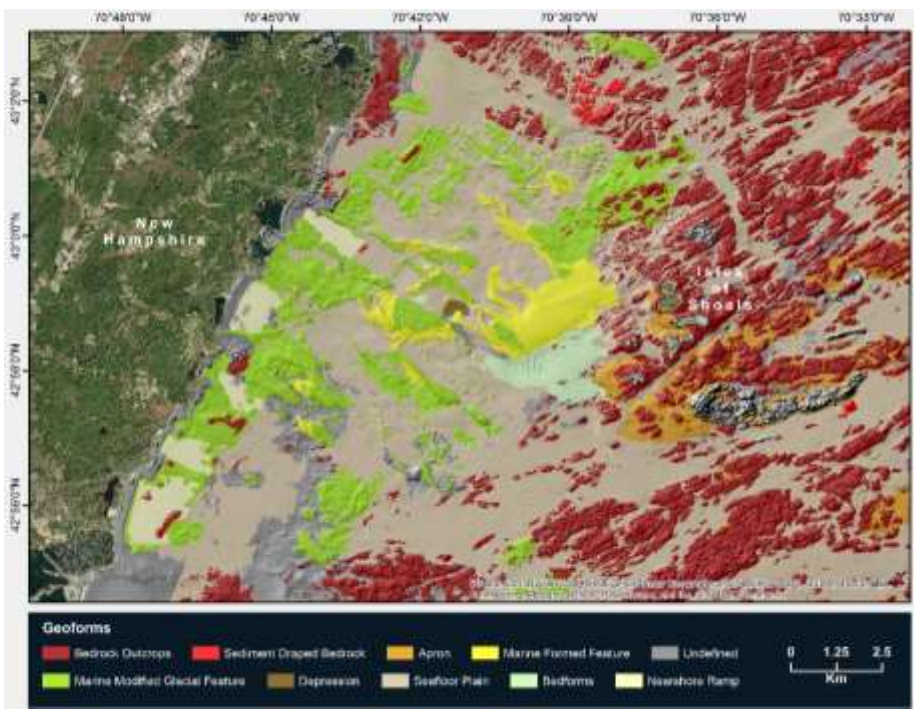


Figure 21-2: Major geoforms or physiographic features of the inner New Hampshire continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS). The map is an enlargement of Figure 21-1 nearshore region.

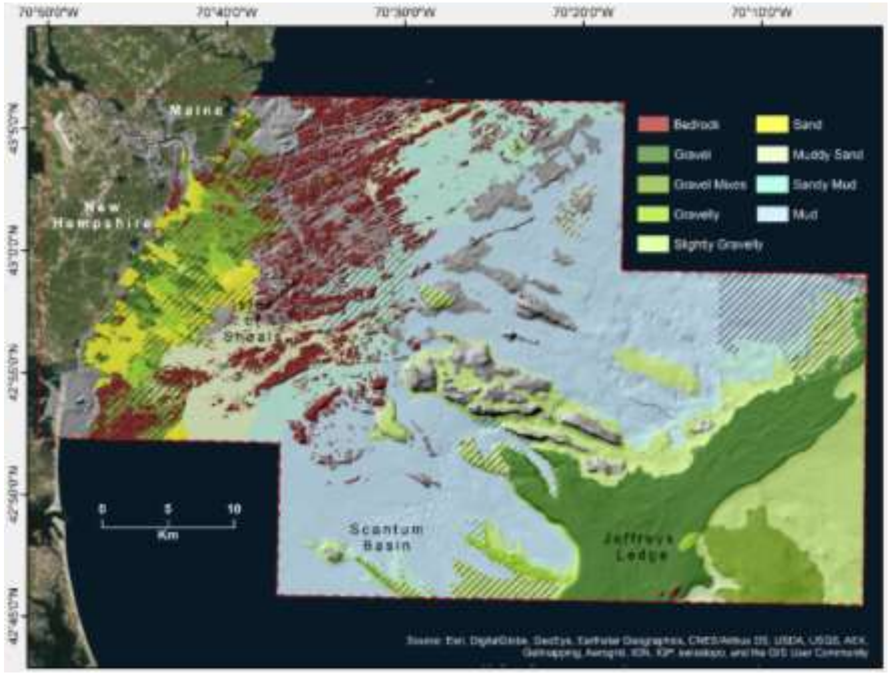


Figure 21-3: Surficial sediment map of the New Hampshire and vicinity continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS) Geologic Substrate Groups.

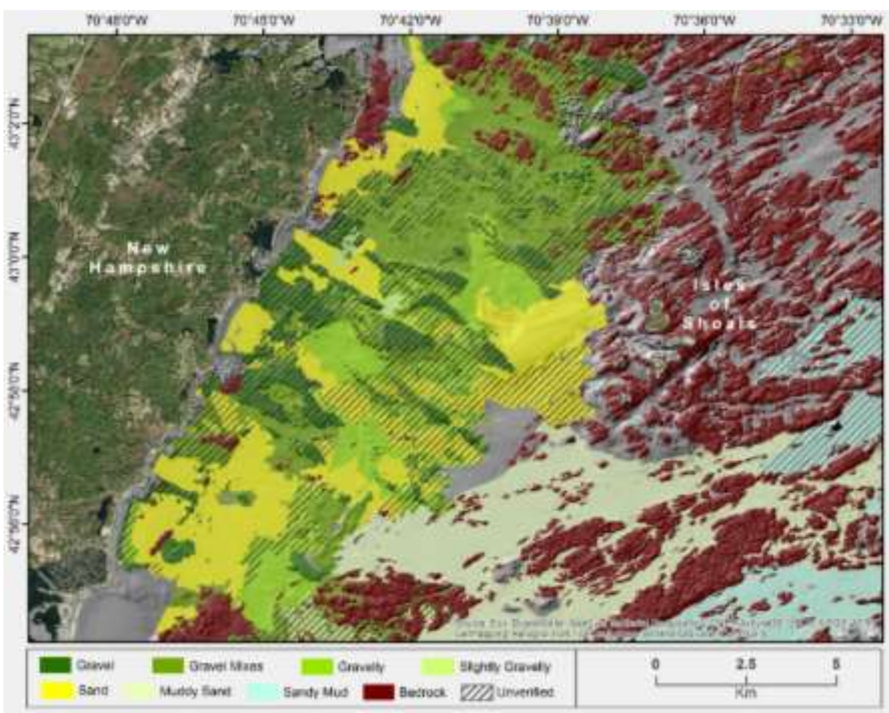


Figure 21-4: Surficial sediment map of the New Hampshire continental shelf. Mapping criteria based on the Coastal and Marine Ecological Classification Standards (CMECS) Geologic Substrate Groups. The map presented here is an enlargement of Figure 21-2 nearshore regions.

Project: **Assessment of Offshore Sand and Gravel Resources on the New Hampshire Shelf**
JHC Particpants: Larry Ward and Zachary McAvoy
(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 21-5 and 21-6). 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.

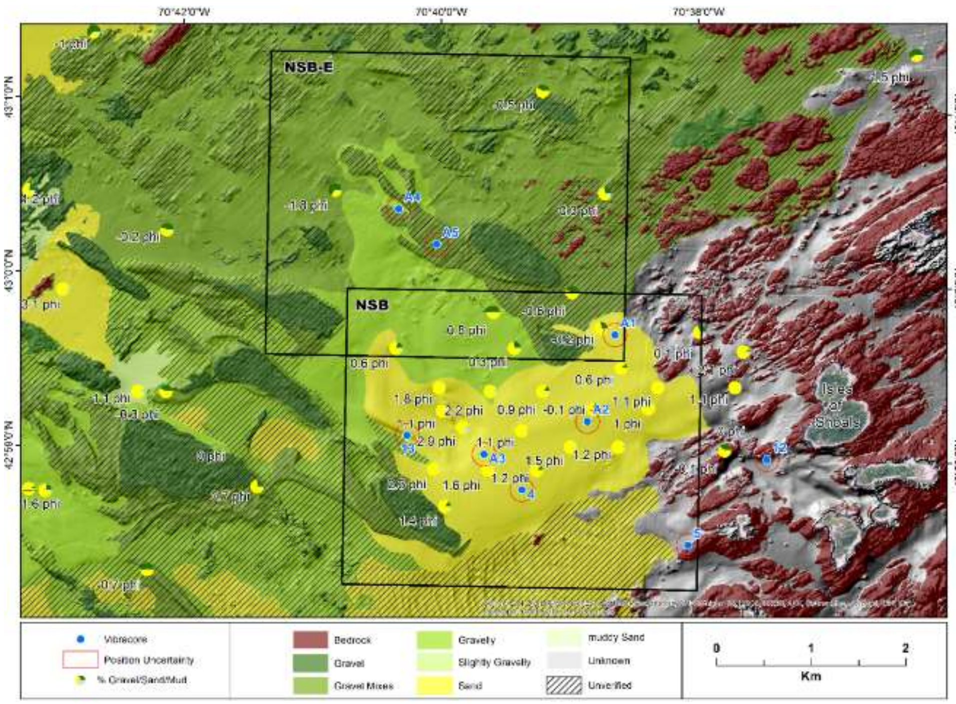


Figure 21-5: Surficial sediment map of the northern sand body (lower box) and adjacent marine modified glacial deposits and associated shoals (upper box).

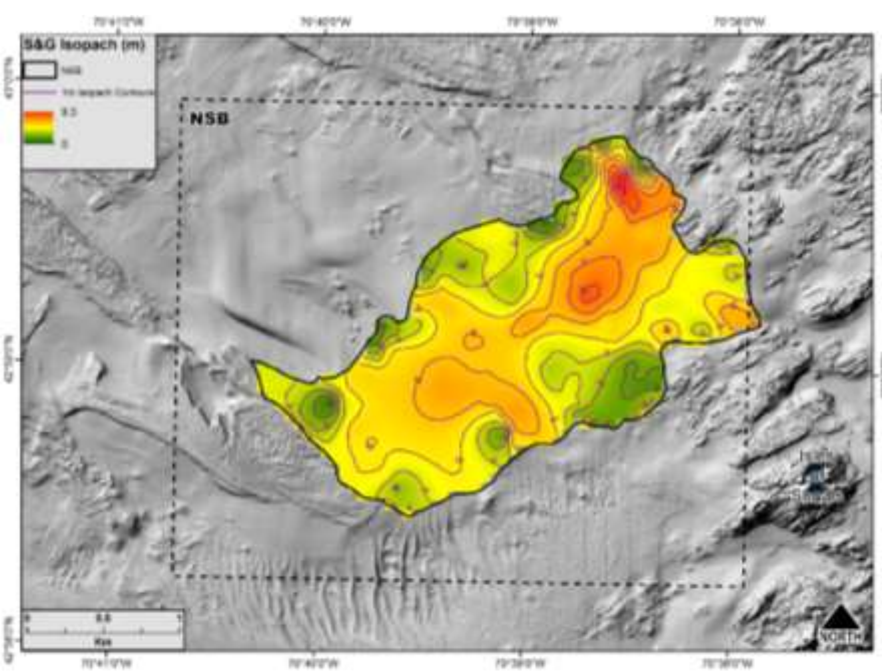


Figure 21-6: Potemtial sand and gravel thickness (isopachs) for the northen sand body.

Project: **Shoreline Characterization and Coastal Resiliency**
JHC Particpants: Larry Ward, Kaitlyn McPherran
(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 21-7). 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.

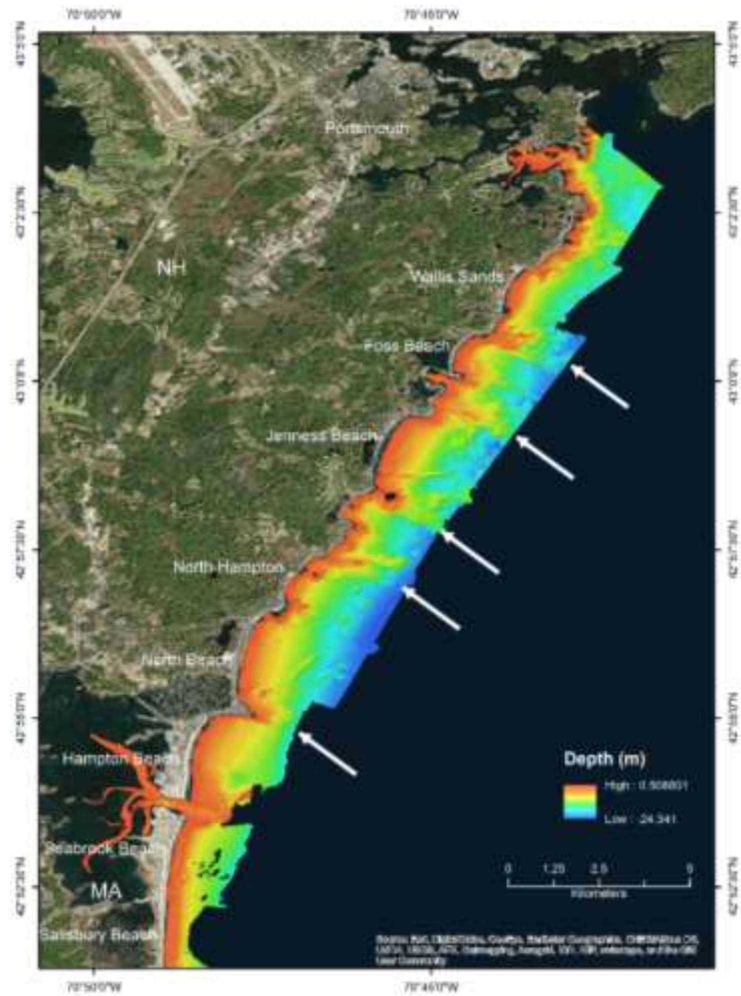


Figure 21-7: Nearshore bathymetry of the coast of New Hampshire based on a 2010 lidar survey by USACE JALBTCX. Arrows point to obstructions separating New Hampshire beaches and likely interrupting longshore sediment movement.

Sub-Theme: SONAR

TASK 22: ***GeoCoder/ARA:*** *Renew efforts in the future development of ARA characterization algorithms, updating the code so that it uses stand-alone modern C++ libraries for mosaicking and seafloor characterization and allowing it to handle "theme" based characterization and incorporate of data from different sensors through the integration of backscatter processing libraries with HUDDL.* ***Giuseppe Masetti***

Project: **Oceano – GeoCoder/ARA**
JHC/CCOM Participants: Giuseppe Masetti, Brian Calder, Tony Lyons, Larry Mayer
External Participants: Tor Inge Birkenes Lønmo (Konsgberg Maritime AS)

The *Oceano* code suite aims to provide, through a modular collection of software libraries and tools, a consistent and physically-based data processing workflow for acoustic backscatter collected using underwater acoustic systems such as side scan sonar (SSS) and multibeam echo-sounders (MBES). *Oceano* currently supports several major data formats (.all - Kongsberg Maritime, .gsf - Generic Sensor Format, .xtf – Extended Triton Format, etc.) using a generalized and modular approach to the problem of reading raw data.

Once data is successfully imported, *Oceano* provides tools and functionalities to radiometrically and geometrically correct the raw backscatter data. Outputs from *Oceano* include the creation of backscatter mosaics, estimation of seafloor properties, and the detection of the presence of objects on the seafloor. The creation of such products also takes advantage of the bathymetric information when available. This works builds on earlier work at the Center (particularly Geocoder, which has been transferred to several of our industrial partners), and attempts to extend its capabilities and incorporate recent improvements in our understanding of backscatter.

A working prototype of the software has been developed. It is internally used at the Center to process legacy data formats that are not currently supported by existing commercial software. Given the number of existing data formats and new progress in bathymetric acoustic systems, the *Oceano* suite requires continuous upgrades, but use of HUDDL, a Center-developed technology that provides a mechanism to create a description of a data format that is then converted into drivers for several programming languages, should simplify the process. Ongoing collaboration with Tor Inge Birkenes Lønmo (a visiting scholar from Kongsberg Maritime AS) should specifically improve support for the Kongsberg EM 2040, a very popular shallow-water MBES. Possible improvements in the seafloor characterization (e.g., using data collected at multiple frequency) are also being explored through collaboration with Tony Lyons.

Modern sonar systems provide high resolution measurements of acoustic backscatter that were unthinkable just a few decades ago, but many aspects of data acquisition can impact these measurements, reducing the quality of the output mosaic. A new tool (*StormFix*, Figure 22-1) has been developed from the *Oceano* project to address these issues. The tool takes advantage of the recently-added validation and writing features of HUDDL to detect and reduce artifacts in backscatter mosaics.

For seafloor characterization, weather related artifacts can increase the risk of erroneous boundary identification between acoustic facies. Although such risk can never be totally removed it can be decreased by modeling the expected types of artifacts and attempting to identify them in the early phases of data processing. For example, the identification of ping-oriented artifacts is facilitated by working at a survey line level and the presence of overlapping areas between survey lines (when available) can be used to improve confidence in the resulting characterization. The *StormFix* tool identifies the presence of this type of artifact (e.g., bubble wash-down) and then attempts to reduce the loss of information in impacted areas.

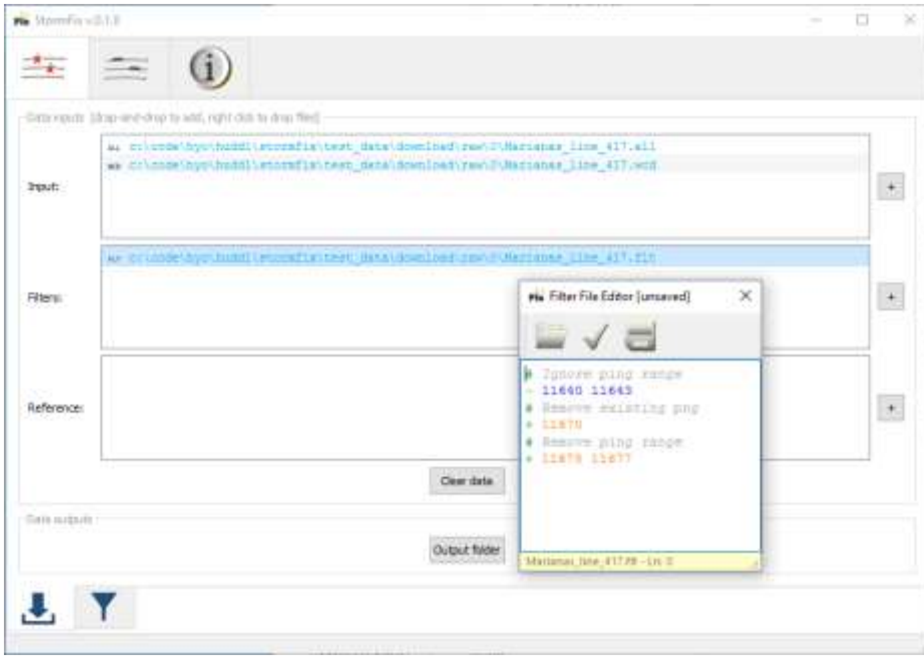


Figure 22-1 – A screenshot of the StormFix application, currently in its incubation phase, showing the dialog to help the user create a data filter to be applied in the following reduction step.

TASK 23: ***Single-beam Characterization:*** *Continue efforts to use single-beam sounders to study the relationships between acoustic backscatter and load-bearing strength, mud fraction (i.e., grain size distribution), and water content (bulk density), with a focus on relating these properties to sediment transport, geohazards, and ecosystem dynamics (including nutrient fluxes and environmental health).* ***Tom Lippmann***

This project has not yet started under this grant

TASK 24: ***Multi-frequency seafloor backscatter****: Undertake controlled experiments designed to understand the physical mechanism for seafloor backscatter at high frequencies (>100 kHz) commonly used on the shelf for mapping habitat, managing resources, etc. Explore the higher order statistics of backscatter (e.g., scintillation index) as potential aids to interpreting habitat, and to look at temporal changes in backscatter for a variety of substrates over a wide range of time scales. This effort includes the need for the collection of broadband, calibrated seafloor backscatter along with "ground-truth" measurements using stereo camera imagery, bottom grabs, and box cores (to examine potential contributors to volume reverberation).* ***John Hughes Clarke and Tom Weber***

Project: **Multi-Spectral Backscatter**
JHC/CCOM Participants: John Hughes Clarke, Anand Hiroji
NOAA Collaborators: Glen Rice and Sam Greenaway, HSTP
Other Collaborators: Mel Broadus and Rebecca Martinolich, U.S. Naval Oceanographic Office, Fabio Sacchetti and Aodhan Fitzgerald, Marine Institute, Galway, Ireland , Kjell Nilsen and Berit Horvei, Kongsberg Maritime, Norway.

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.

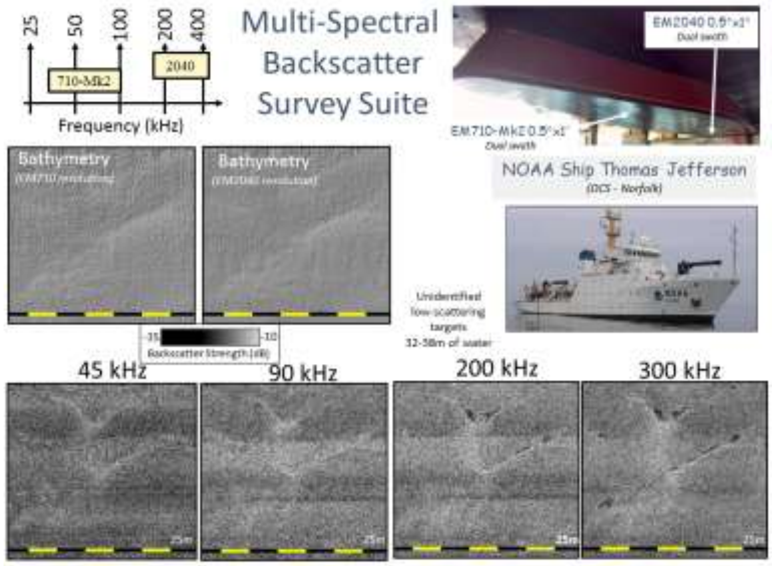


Figure 24-1: Using two passes (90 and 300 kHz, and 40 and 200 kHz) over the same seafloor, four frequency views of the same seafloor are presented. Data from NOAA Ship Thomas Jefferson, October 2016.

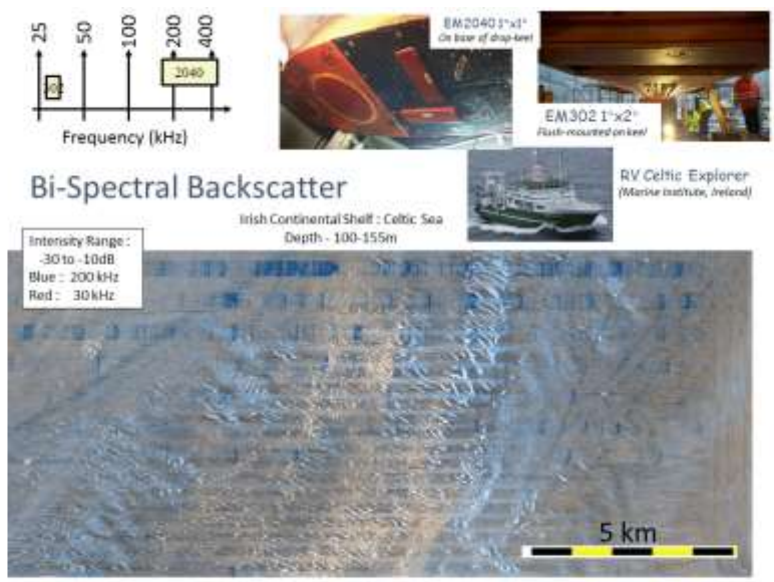


Figure 24-2: RV Celtic Explorer – operational bi-spectral survey results from the Irish Continental Shelf, September 2016

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 24-1 and 24-2).

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 extracted 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 24-3 and 24-4). 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.

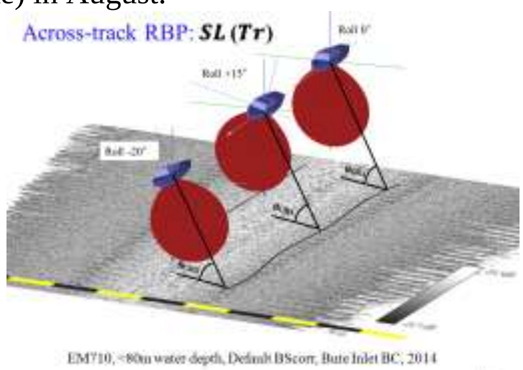


*Figure 24-3: Showing the influence of roll modulation on the overprint of the **across**-track sonar-relative beam pattern on uncorrected seafloor backscatter data.*

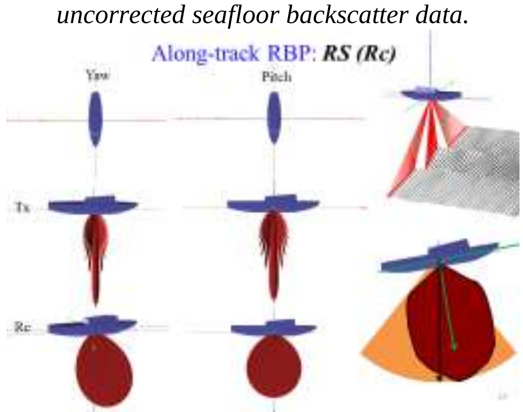


*Figure 24-4: showing the effect of pitch or yaw perturbations on the **along**-track receiver beam pattern*

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.

Sub-Theme: LIDAR AND IMAGERY

TASK 25: ***LIDAR Waveform Extraction****: Extract features of LIDAR waveforms that can be associated with particular seafloor or habitat, as well as assess morphological and spectral characteristics of imagery data to better define habitat (with initial focus on eelgrass and macroalgae. Develop procedures to extract appropriate data for input into NOAA's environmental sensitivity index (ESI), expand the types of habitats being evaluated and use data fusion methods to combine acoustic, LIDAR, and optical data sets into a coherent picture of seafloor type. Understand the fundamental controls and limits on the performance of the sensors we utilize using the LIDAR simulator as well as experiments to better understand the impact of the diffuse attenuation coefficient and the bottom reflectance on the returned imagery.* ***Shachak Pe'eri***

Project: Evaluating the Utility of EAARL-B Lidar Waveforms for Characterizing Benthic Habitats

JHC/CCOM Participants: Jenn Dijkstra, Kristen Mello
NOAA Participants: NOAA/NOS/IOCM; Tim Battista, Bryan Costa
Other: Christopher Parrish and Nick Wilson, Oregon State University

Over the last four decades, global coral-reef and seagrass systems have been lost, and the rate of decline for coral reef systems is estimated to be 1-2% per year. Anthropogenic pressures such as ocean warming, habitat loss, decreased water quality, increased sedimentation, and ocean acidification will exacerbate the estimated yearly loss. These essential fish habitats house a number of commercially-important juvenile and adult fish, and shellfish, species. Coral reefs, in particular, have exceptionally high biodiversity that rival terrestrial rainforests in their support of a wide variety of species from all trophic levels. Their physical structure and the spatial arrangement of species and community assemblages on the seafloor create various levels of habitat structure that are critical for the maintenance of diversity, and can dictate the identity and size of associated species. Consequently, delineating and characterizing their community structure is critical for coastal restoration efforts for improved coastal resiliency and for the management of critical marine habitat.

In order to explore the relationship between LIDAR waveform metrics and characteristic features (e.g., patchiness, percent cover, coral height) of coral habitats that goes beyond habitat delineation, LIDAR waveform analysis and ground-truthing studies were conducted. The goal is to assess the usability of LIDAR reflectance for mapping essential fish habitats in tropical ecosystems, which would extend the capabilities of LIDAR for ecological characterization of essential fish habitats. Chris Parrish and Nick Wilson utilized the knowledge and experience gained in the Super Storm Sandy project (e.g., computing waveform features for the EAARL-B using the Airborne Lidar Processing System (ALPS) software), to extract waveform standard deviation, peak amplitude, and numerical integral (Area Under the Curve;

AUC) around the island of Flat Cays, ~2.5 km Southwest of St. Thomas (U.S. Virgin Islands), using data collected by NOAA. The area around Flat Cays is surrounded by variable depth coral reef with one of the best stands of threatened elkhorn and staghorn (*Acropora* spp.) coral. Dijkstra and Mello, in collaboration with Battista and Costa, ground-truthed LIDAR derived waveform metric data around the island of Flat Cays, St. Thomas USVI between September 3 and 9, 2016. Ground-truth was carried-out using SCUBA at shallow sites[2] and a towed depressor wing (Battista and Costa) mounted with green lasers, one HD Seaviewer camera (for real-time video), two GoPro Hero4 cameras at deeper sites, and a Sensus Ultra pressure and temperature data logger set to record at one second intervals. Nine shallow-water sites around Flat Cays were selected for ground-truth using SCUBA (Figure 25-1). These sites were selected based on depth (<15 m) and to sample the full range of habitats and LIDAR waveform metrics (habitat type (bedrock, pavement, coral reef, sand with scattered coral and rock, sand; lidar waveform features). At each site (nine total), underwater video of a 10x10 m area were collected in a "lawnmower" pattern using a GoPro Hero3+. Screen grabs from these videos were integrated using Rzhanov's software (see description of the mosaicing process in report on Grant NA10NOS4000073) to create seamless 100m^2 mosaics of the seafloor (Figure 25-2). Heights of 20 species and seafloor depth were collected at each site within the 100m^2 mosaiked area. Depth data was collected by holding Sensus Ultra data logger and tracing the seafloor along 7-10 transects within the mosaiked area. These depth data will be converted to continuous measurements of rugosity, and analysis of the remaining dataset is on-going.

Figure 25-1: Mello using a GoProHero3+ to collect underwater video of the seafloor that will later be "stitched" together and form a seascape.

[2] Funding for fieldwork provided by NOAA grant NA10NOS4000073.

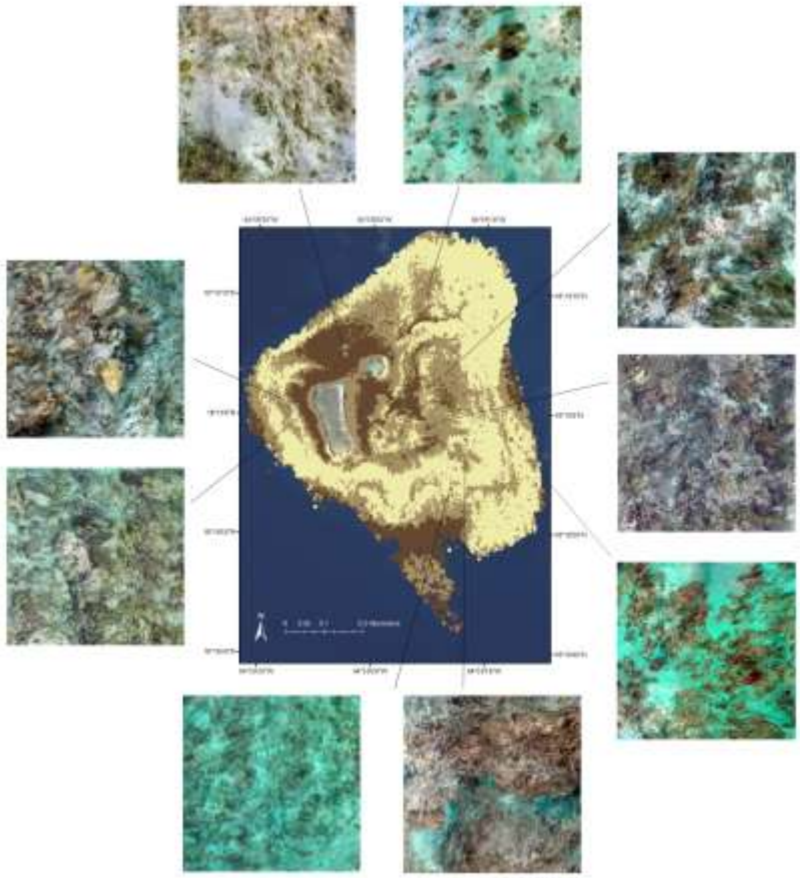


Figure 25-2: EAARL-B Lidar reflectance around the island of Flat Cays in the U.S. Virgin Islands. Images are 100m^2 mosaics (collected by SCUBA divers) of shallow water (5 to 15m) seafloor coral assemblages.

Sub-Theme: CRITICAL MARINE HABITAT

TASK 26: ***Object-based Image Analysis:*** *Use a combination of data sets (e.g., sonar backscatter, LIDAR reflectance, images) to explore the use of Object-Base Image Analysis (OBIA) for the detection and characterization of critical marine habitats. Combine MBES data (bathymetry, water column backscatter, seafloor backscatter mosaics, seafloor roughness) collected at multiple high frequencies (200, 300, and 400 kHz) with video data (ground truth) to detect and delineate benthic habitats and explore the use of a 2-D imaging sonar or 3-D multibeam scanning sonar to determine the identity and abundance of fish and mobile shellfish species.* ***Jen Dijkstra***

Project: **Evaluating the use of a high-frequency sonar to detect crustaceans in turbid environments**

JHC/CCOM Participants: Jenn Dijkstra, Kristen Mello, Brandon O'Brien

NOAA Collaborators: Chris Taylor, National Centers for Coastal and Ocean Science (Beaufort, NC)

Other Collaborators: Win Watson (UNH)

The overall goal of this study is to understand the use of Essential Fish Habitats (EFH; e.g., eelgrasses, oyster reefs) by crustaceans such as lobster and crab species in the Great Bay Estuary. Currently, there is concern that the introduction of introduced crabs into these habitats may be detrimental to these economically important EFHs.

The project team is considering the use of a DIDSON 300M (Dual-Frequency Identification Sonar, SoundMetrics Corp.). The DIDSON 300M is a high-resolution sonar system that operates at a frequency of 1.1 or 1.8MHz and produces video-like images. It ensonifies an area ranging from 1 to 30 m from the transducer. The sonar system is particularly useful in turbid environments because traditional video and dive surveys can be problematic. It has been used successfully to examine the behavior, sizes and abundance of various fish species. The novelty in this study is its use to discern hard-shelled crustaceans. If we are successful in developing and demonstrating this approach to survey crustaceans in turbid environments such as the Great Bay Estuary, this approach will likely be a widely useful technology.

Project: **Evaluating the use of Use Water-Column Data to Identify and Characterize Benthic Habitats**

JHC/CCOM Participants: Jenn Dijkstra, Semme Dijkstra, Ashley Norton, Kristen Mello

In August 2015, under grant NA10NOS4000073, Semme Dijkstra, Ashley Norton and Jenn Dijkstra collected water column data at Nubble Light House in York, ME using a Teledyne MB1 operating at a frequency of 200kHz. Ground-truth data were collected by a team of divers led by J. Dijkstra in September, 2015. These data consisted of taking underwater photographs of ~80, 1m^2 quadrats of a number of benthic habitats. GPS coordinates were obtained for each image at the water's surface using a non-survey-grade, but ruggedized and waterproof, receiver in the Nikon COOLPIX AW110. Within each quadrat, divers recorded 2-5 measurements of seaweed canopy. A second ground-truth dataset was collected using a GoPro Hero3+. The video was mosaicked into 100m^2 sections with the purpose of comparing 1m^2 and 100m^2 ground-truth data with the water column data.

In the current reporting period, Norton and Semme Dijkstra created a map of rise times from the MB1 water column data at nadir. On a flat seafloor, the rise time of the bottom echo represents the canopy height of seaweeds. Once depth and slope corrections are applied to the MB1 data, the rise times on rugged or sloped areas are expected to represent the height of seaweed assemblages. These results have been combined with the bathymetry and point sampling (Figure 26-1). Figure 26-2 relates the ground-truthed heights of seaweeds within a 1m^2 quadrat to the closest rise time of the nadir beam that is within 1 m of the nadir beam point. This correlation, while not statistically significant, is intriguing, as the depth and slope corrections must still be applied to the MB1 data. Few ground-truth data are included in the correlation due to the distance of the point from the nadir beam as displayed on the map. This number will increase with knowledge of the size of the nadir beam footprint and the number of beams included in the MB1 analysis. Other factors that introduce error to this correlation are diver *in-situ* positioning, geomorphology of the seafloor, and the positioning of the MB1 system.

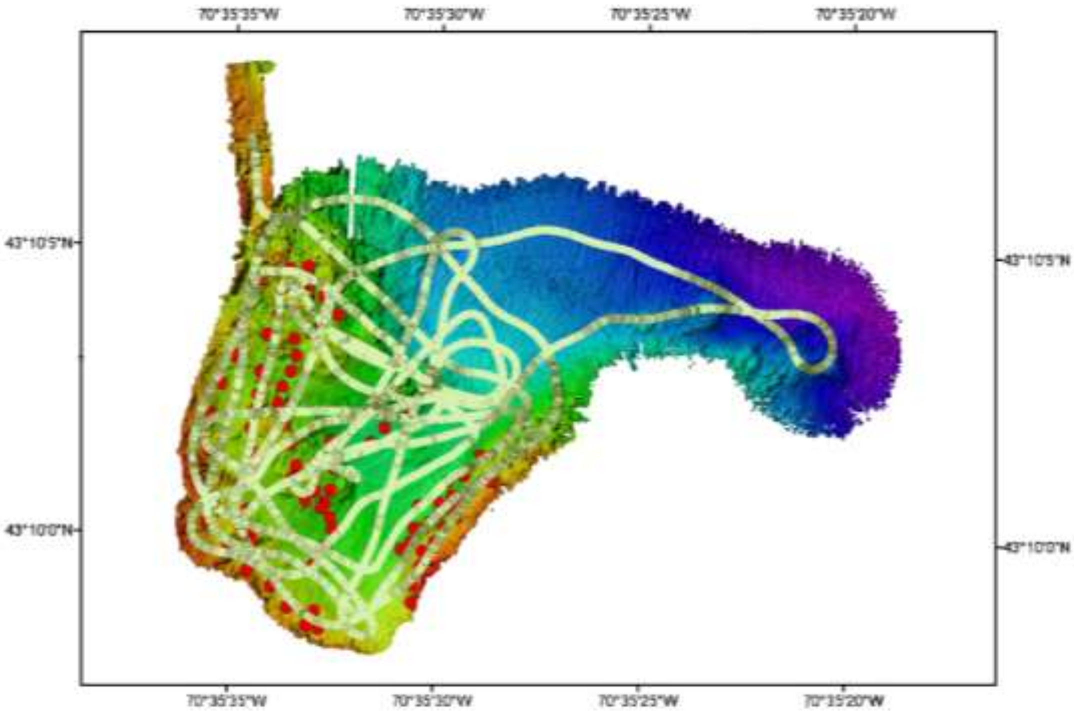


Figure 26-1: Bathymetry overlaid by echo rise times (continuous shades of green) and quadrat samples of benthic assemblages (red dots). Lighter shades of green indicate the smallest echo rise times while darker shades of green indicate the highest echo rise times.

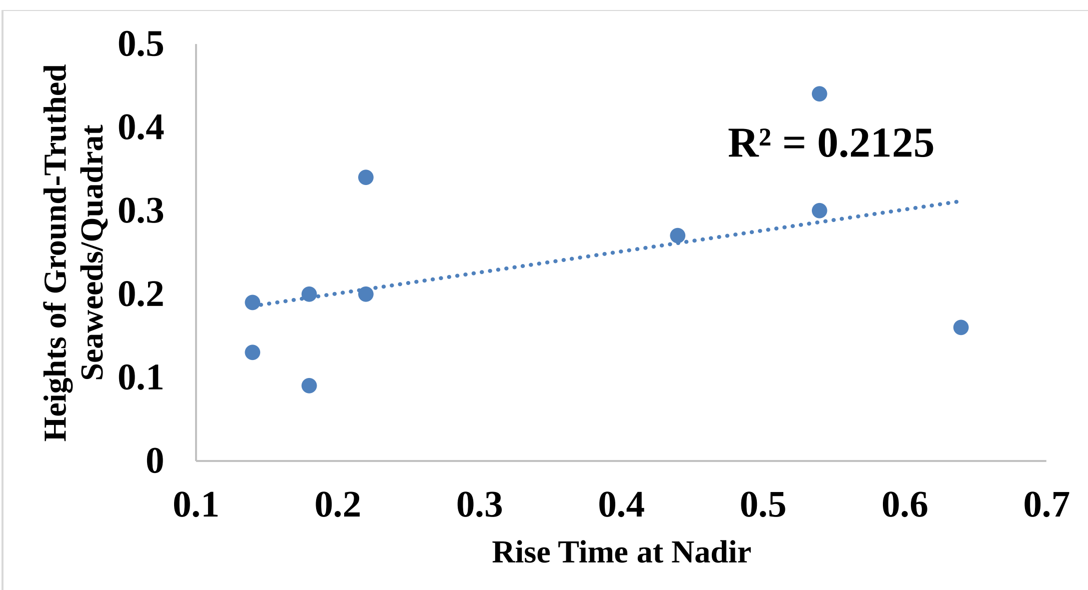


Figure 26-2: Relates the heights of seaweeds within a 1m^2 quadrat to the closest nadir beam within 1 m (see text for further detail).

Under Grant NA10NOS4000073, S. Dijkstra, Norton and J. Dijkstra collected water column data at several sites with different seaweed species composition using a Teledyne MB1 operating at a frequency of 200 kHz. This was done to gain a better of understanding of the relationship between acoustic water-column data and the composition of the seaweed assemblage. Ground-truth data were collected by a team of divers using a GoPro Hero3+ underwater video camera led by J. Dijkstra and K. Mello between July 18 and August 12. Ground-truth data consisted of collecting underwater video of a 100m^2 area (Figure 26-3). Based on our previous experience correlating ground-truth data with water-column data, we decided a larger ground-truth footprint of the seafloor would give us greater correlative abilities. We are currently using a combination of software developed by Rzhanov, and commercially available software to create a mosaic that will be used to ground-truth sonar data

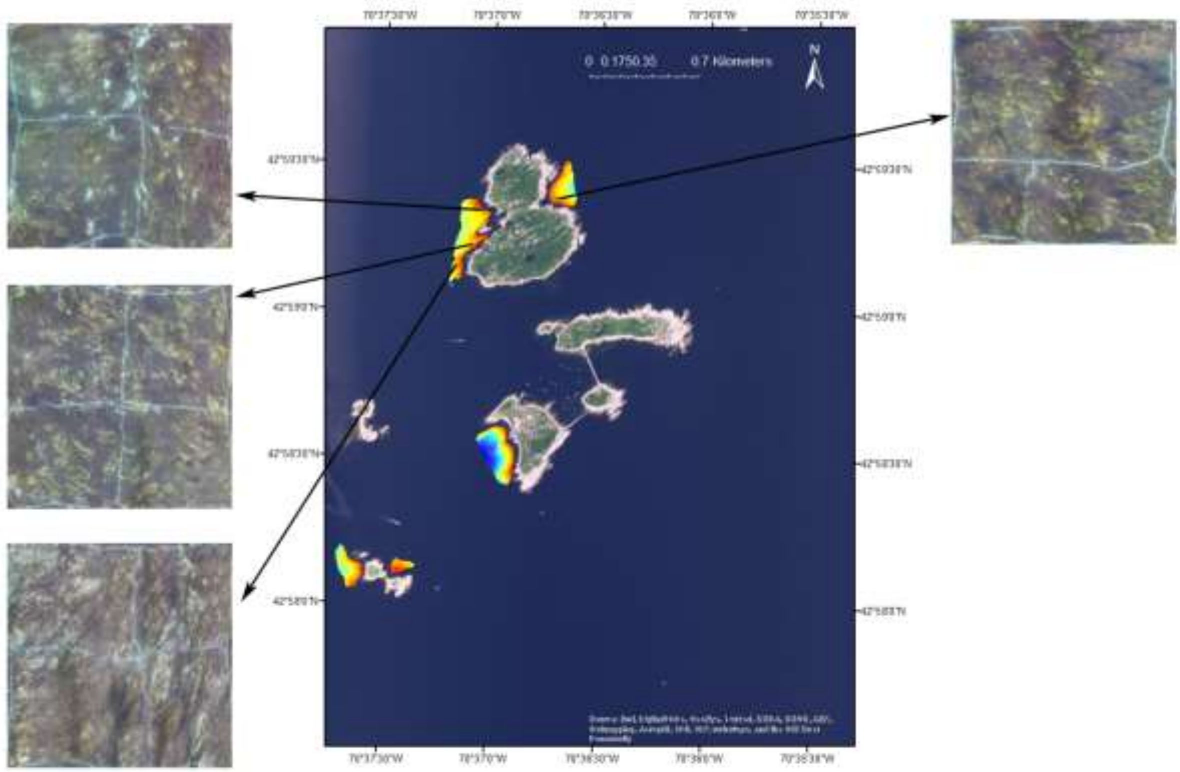


Figure 26-3: Bathymetry and underwater seascapes (100m^2) of four of nine sites where underwater video and water-column data were collected.

Project: **Mapping the 3D Structure of Seaweed Assemblages**
JHC/CCOM Participants: Jenn Dijkstra, Colin Ware, Drew Stevens, Brandon O'Brien and Kristen Mello

Along with the 2D methods developed to characterize seaweed habitats the project team are developing new techniques for defining the 3D structure of seaweed species. These methods promise to provide a bridge between mapped areas of seaweed and the habitat they afford for associated species.

The 3D structure of two common seaweed species in the Gulf of Maine has been determined. The team collected and photographed a third seaweed species for the assessment of 3D structure. The team also collected, identified, counted and measured invertebrates from 4 common seaweed species (>7,000). Results of this study indicate that algal species with many fine branches host smaller individuals than algal species with large blades or have small flat branches. These data will be used to test the relationship between interstitial volume and invertebrate size. These data will also be used explore the relationship between seaweed composition collected at the level of seascapes (100m^2 – see old grant and section 2B of the new grant for details on the creation of seaweed seascapes) and size distribution of organisms.

Integrating biological, 3D visualization and models, underwater video and acoustic mapping of seaweed habitats (Figure 26-4).

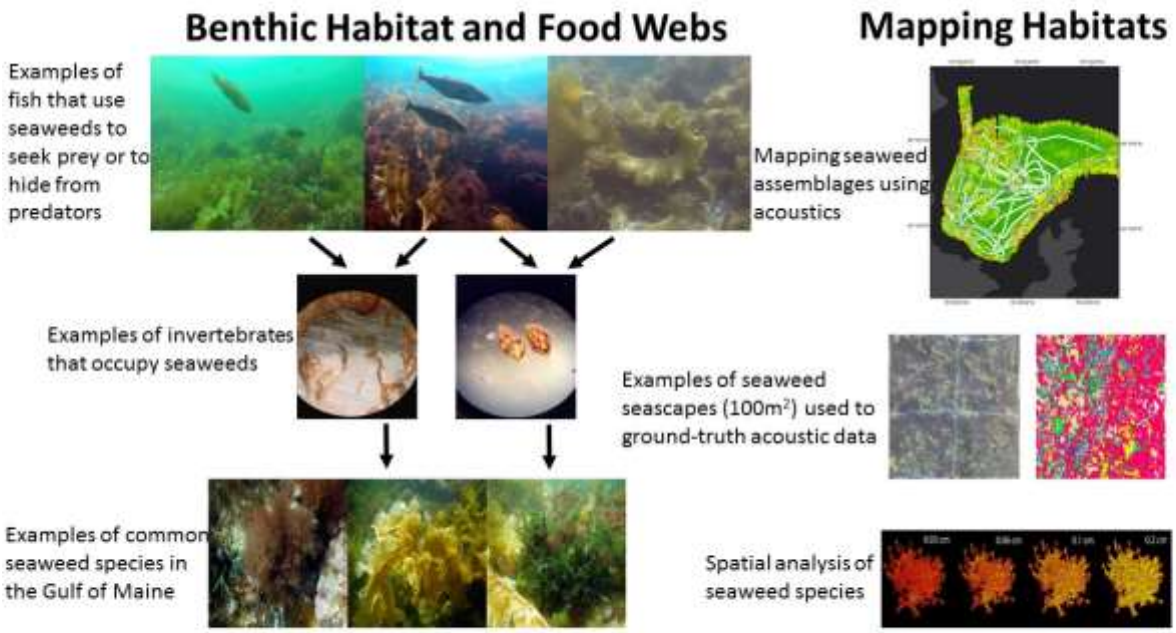


Figure 26-4: The project team integrates in-situ sampling techniques with 3D visualization, models and remote-sensing (underwater video and acoustics) to understand the effect of changing seaweed assemblages on ecosystem processes. In-situ sampling is used to identify features of seaweed assemblages that can be mapped using acoustics and to validate the 3D spatial analysis. By integrating these data, it is the goal of the team to be able to ultimately identify and characterize seaweed assemblages using only remote-sensing techniques with minimal ground-truth. Project team members: Dijkstra (J), Ware, Dijkstra (S), Rzhanov, Norton, Mello and O'Brien.

TASK 27: ***Video Mosaics and Segmentation Techniques:*** *Generate geo-referenced and optically corrected imagery mosaics from video transects of the seafloor and use image analysis techniques to detect and segment the imagery into regions of common species assemblages using the homogeneity of color tone within a region.* ***Yuri Rzhanov***

This project has not yet started under this grant

TASK 28: *Margin-wide Habitat Analysis:* *Large-scale, continental-margin-wide habitat mapping effort that involves the regional data sets we have collected in support of the establishment of the limits of the extended continental shelf under Article 76 of the Law of the Sea Treaty.* ***Jen Dijkstra, Larry Mayer, and David Mosher***

Project: **Margin-Wide Habitat Analysis**
JHC/CCOM Participants: Kristen Mello, Jenn Dijkstra, Larry Mayer, Dave Mosher
NOAA Participants: Mashkoor Malik, Derek Sowers, and Elizabeth Lobecker

As a first step towards mapping and characterizing deep-sea benthic habitats, Kristen Mello and Jenn Dijkstra have focused on the Atlantic Continental Margin. The ultimate goal of the project is two-fold. First, these data will provide valuable information on the densities of species assemblages, including essential fish habitats such as corals, along a latitudinal gradient and among different seafloor features (canyons, seamounts, and seeps). Second, these data will be correlated to substrate type and integrated with multibeam backscatter products that will explore the use of acoustic backscatter for seafloor and habitat characterization.

In the current reporting period, Mello and Dijkstra have collaborated with NOAAs Ocean Exploration and Research (OER) group (Mashkoor Malik, Derek Sowers, and Elizabeth Lobecker) to coordinate our efforts for ROV video analysis. The OER team has developed a ROV data analyzer tool that Mello has modified in order to increase the number of species or groups of species as well as substrate type that can be added to the event log. Through our collaborative efforts, we are now able to collate CTD data with ROV sediment and species analysis along each ROV transect. We have used this tool to analyze sediment and species distribution from 10 sites including canyons, seamounts, seeps, and USGS hazardous areas (Figure 28-1). The classification scheme, as much as possible, is following the Coastal and Marine Classification System (CMECS) developed by NOAA.

We continue to use Matlab code written by Semme Dijkstra to divide the ROV tracks into 50 m longitudinal sections. J. Dijkstra and Mello chose this length to facilitate comparison of species assemblages and substrate type with the archive backscatter data collected in the region, as the minimum mapping unit of the backscatter data in the region is between 25 and 50 meters. A fifty centimeter swath of the ROV video is analyzed along the 50m sections. Along with plotting distribution patterns of organisms and sediments along a ROV track, we are using these data to investigate differences and/or similarities, heterogeneity, and diversity in community assemblages along and among ROV tracks (Figures 28-2 and 28-3). We will also use these data to explore relationships between abiotic factors such as oxygen concentration, depth, sediment, temperature, etc.

We have also recently installed computer-aided software engineering (CASE) tools for ArcGIS 10.3. This is a tool that allows us to create and organize a personalized geodatabase to store and easily analyze very large datasets. Using this tool, we will be able to combine sonar data, CTD, and our ROV data, and perform complex spatial analysis that we can use to predict critical coral ecosystems and species rich habitats.

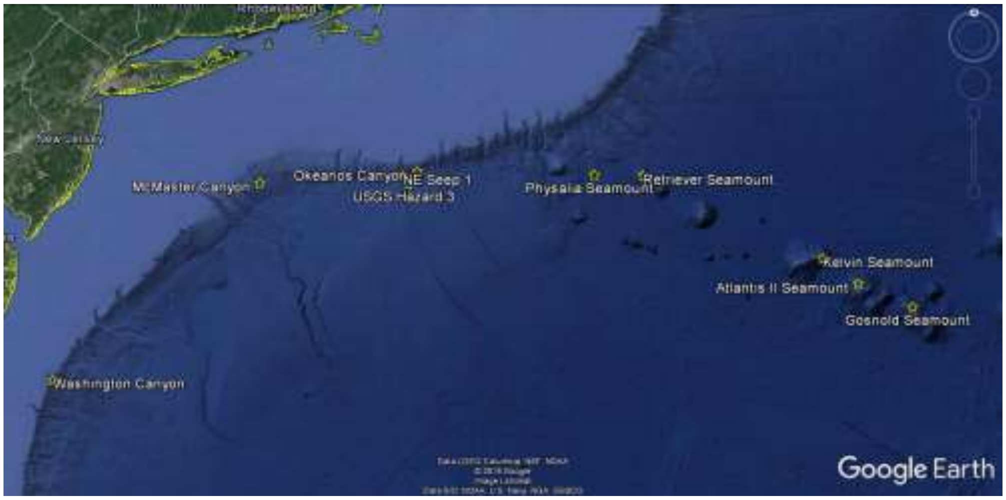


Figure 28-1: Map of deep sea sites used for analysis.

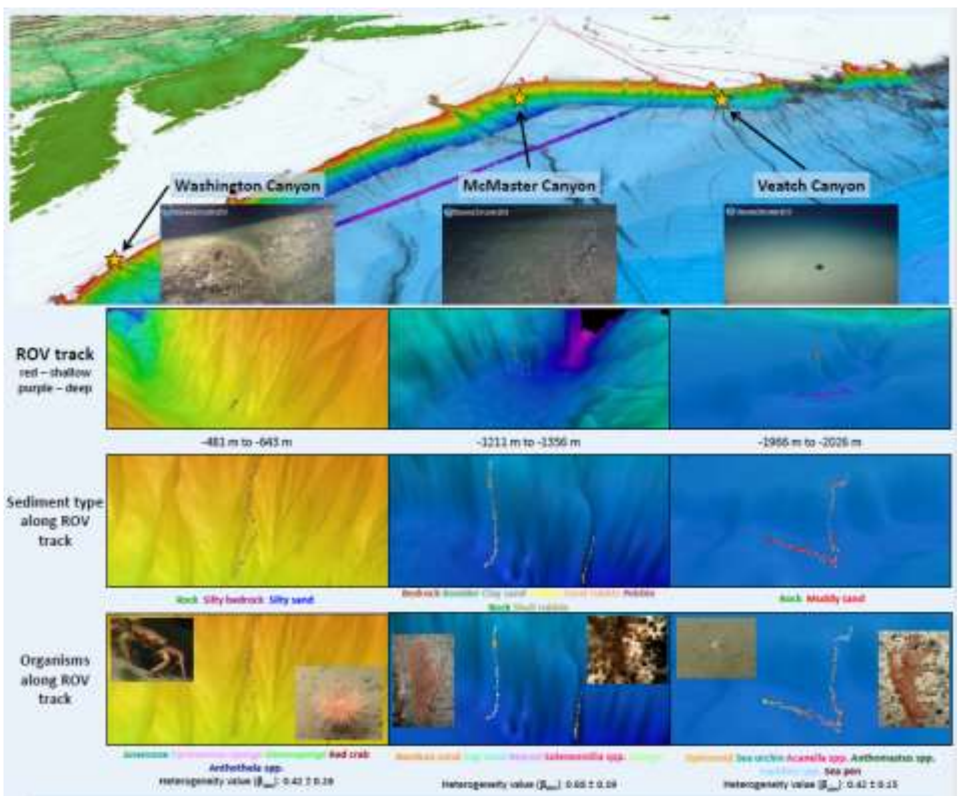


Figure 28-2: Plotted organismal and sediment distributions along three analyzed canyon ROV tracks along the Atlantic Continental Margin.

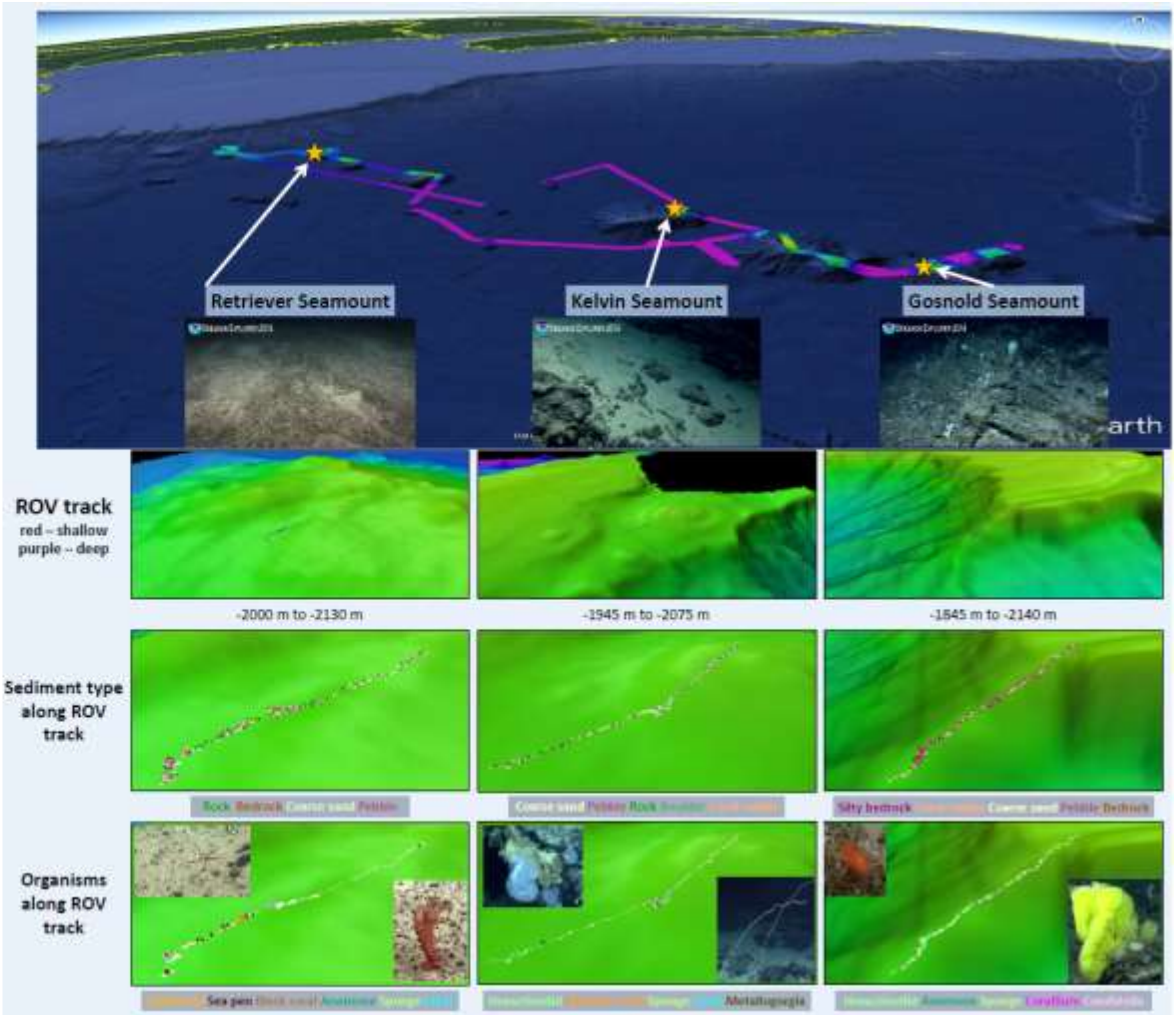


Figure 28-3: Plotted organismal and sediment distributions along three analyzed seamount ROV tracks along the Atlantic Continental Margin.

Sub-Theme: Coastal Resilience and Change Detection

Task 29: ***Shoreline Change:*** *Develop techniques to use ALB data to constrain satellite-derived bathymetry shorelines. Work with NOAA's Navigation Services Division to explore the viability of using relatively inexpensive commercial-off-the-shelf (COTS) 2-D laser scanners, integrated with GPS, motion sensors, and cameras, to produce fully geo-referenced ranges and intensities of shoreline features.* ***Shachak Pe'eri***

Project: **Performance Analysis of Industrial Laser Scanner**

JHC/CCOM participants: John Kidd, Shachak Pe'eri, Firat Eren and Paul Lavoie

NOAA Participants: Andy Armstrong (OCS, JHC), Sam Greenway and Eric Younkin, Holly Jablonski and Michael Davidson (OCS)

Survey launches of the OMAO hydrographic fleet and Navigation Response Vessels often encounter natural and man-made non-contiguous shoreline features such as piers, jetties and exposed shoal features that need to be validated. The Center, working in collaboration with Hypack has been exploring the use of an industrial laser scanners for mapping surface features for this purpose. Research efforts have focused on the integration of the system on a survey vessel and analysis of system performance. The system performance parameters being assessed include extinction range, range uncertainties, data density, and internal reference frame validation. Additionally, a new method for boresight calibration will be attempted. Center personnel have been working in concert with OCS/CSDL to introduce the system and make it a standard shoreline survey tool aboard NOAA field units. It is currently in use on the NOAA Ship *Fairweather* but plans are in place to introduce it on the NOAA Ship *Rainer,* NOAA Ship *Thomas Jefferson, and* NOAA Ship *Ferdinand R. Hassler* this winter.

After careful consideration, the Velodyne VLP-16 laser scanner was selected as the best candidate because of 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, with a wavelength of 903nm, provide the ability to map targets above the water surface up to 100 m and as well as providing images of the water surface.

The reported 2.00° 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°, 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 29-1). 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° around a particular laser beam to resolve the peak intensity (Figure 29-2). 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 29-3). Results show an average net offset of all beams with respect to the reference frames of -0.014° with a standard deviation of 0.053°. 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.

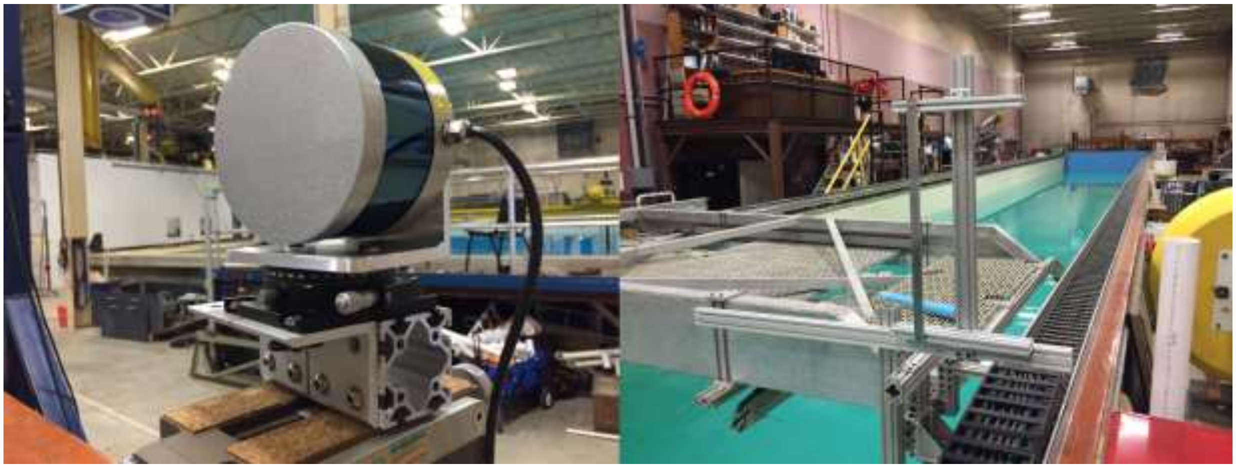


Figure 29-1: Left: Laser scanner mounted vertically centered over the ultra-high precision rotating compass. Right: Narrow vertical aluminum target.

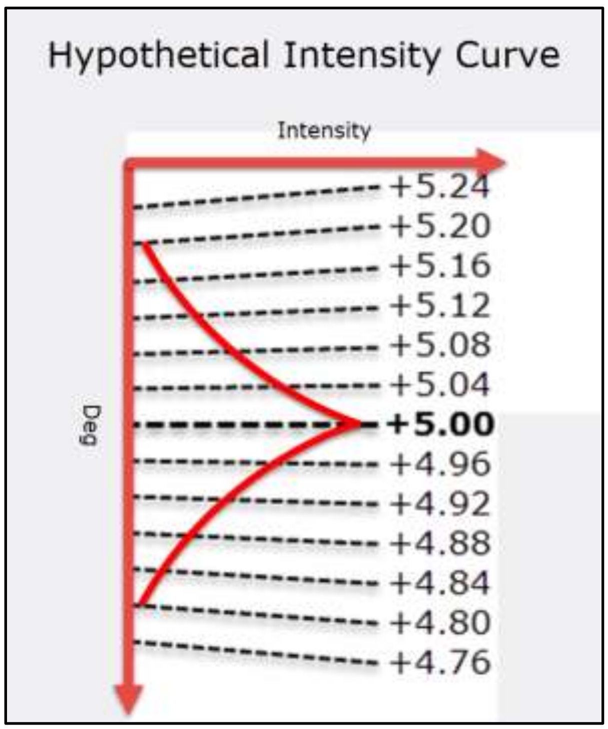


Figure 29-2: Hypothetical intensity returns, centered around the +5° beam, caused by rotating the scanner by incriments of 0.04° through a window of ±0.24° centered around the assumed location of the lasser beam.

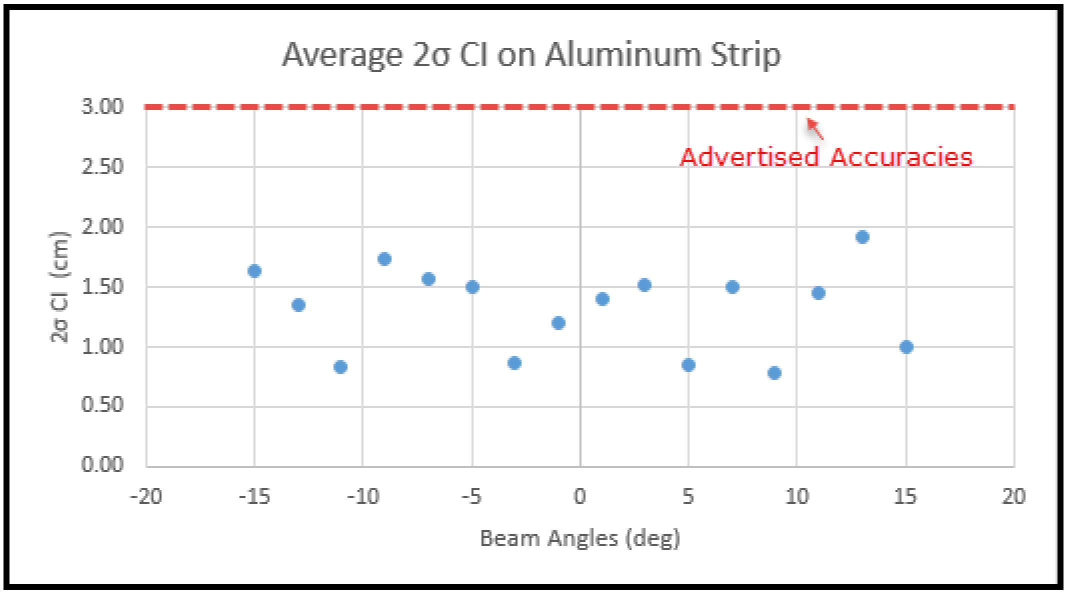


Figure 29-3: Performance of each laser beam on aluminum strip target outperformed manufactures specifications.

In July 2016, a 3-day cruise aboard the R/V *Gulf Surveyor* was conducted within Portsmouth Harbor to collect a field performance dataset in an effort to empirically assess the scanner's range, data density with respect to relative to various mounting orientations and scanner rotation rates, and the ability to detect overhead cables crossing the channel.

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 45^{o} pitch angle forward. Results, shown in Figure 29-4, show a decrease in data density as range increases with an inverse square relationship. Results also show that at a given range, the various scanner configurations (rotation rates and mounting angles) have minor effect on data density. The largest contributor of these random variations is most likely vessel motion (changes in speed and yaw).

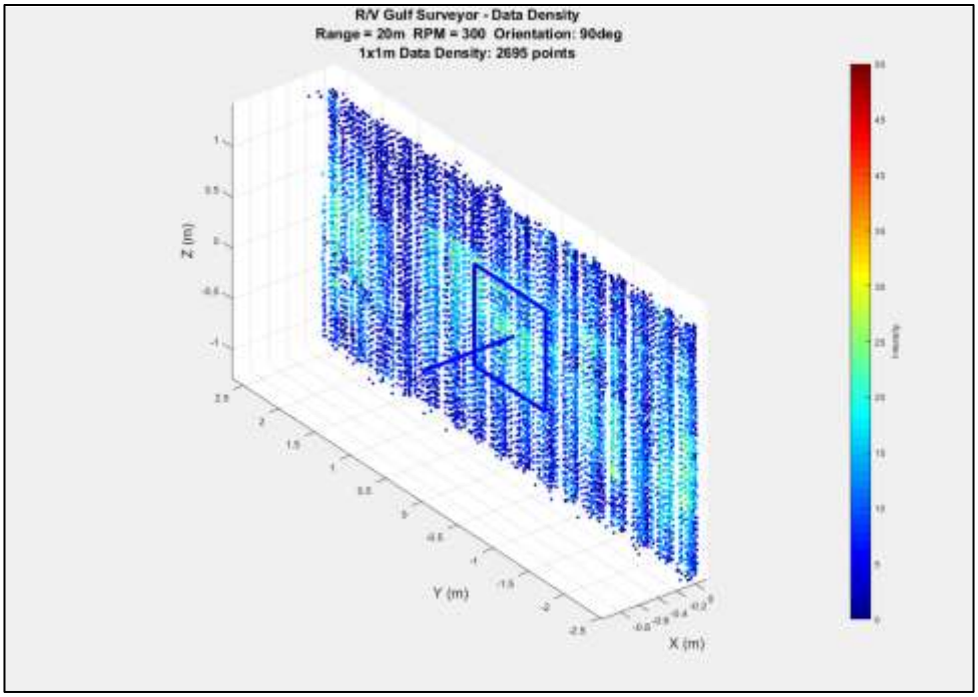


Figure 29-4: Data on UNH pier-face viewed from an oblique angle from one pass at 20m range with the unit scanning vertically at 300RPM. Blue box- 1x1m box used to determine data density. Blue line- normal vector of best-fit plane used to rotate data to align with Y-Z axis.

The ability of the system to depict bridges (Figure 29-5) and overhead cables crossing the channel (Figure 29-6) 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.

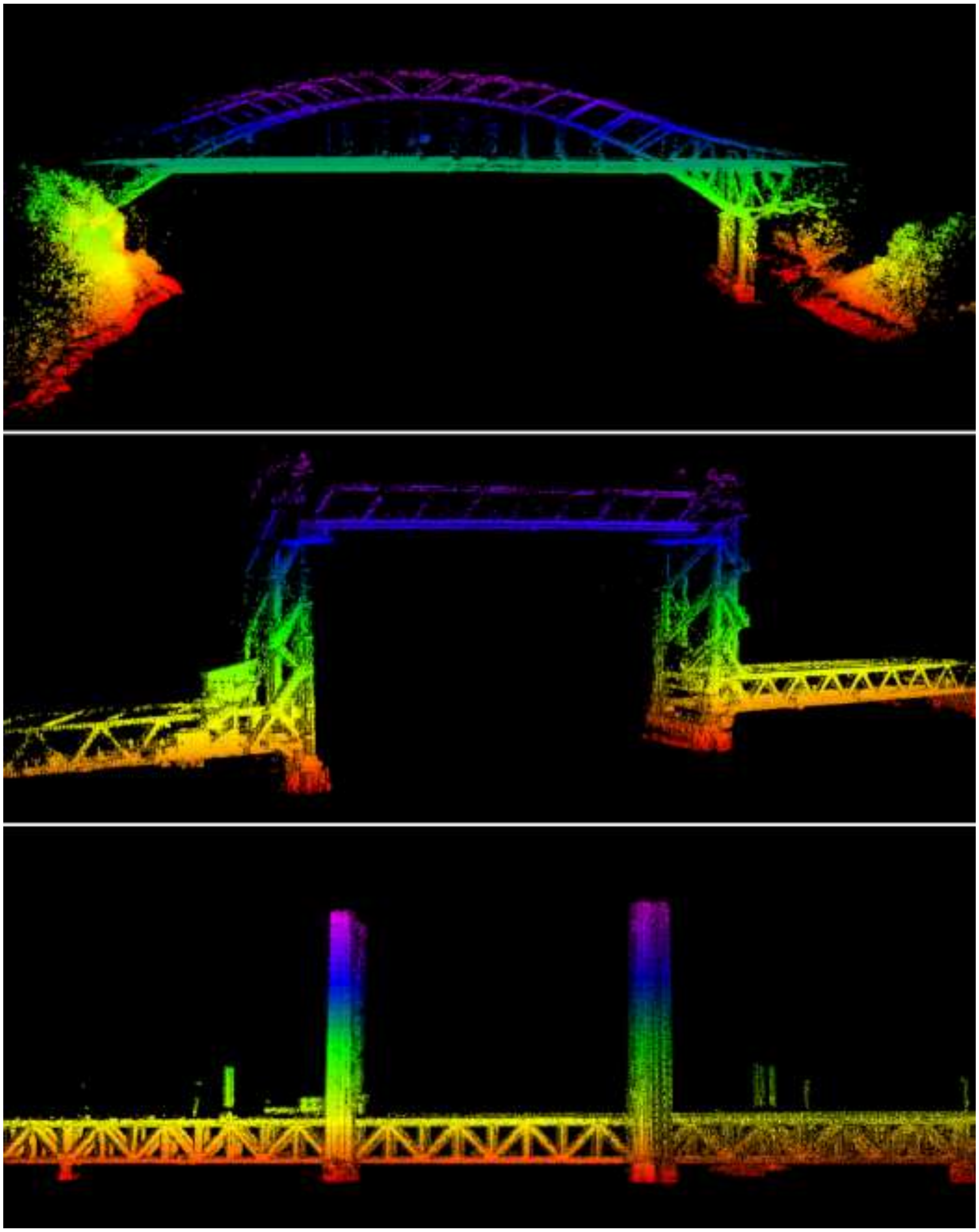


Figure 29-5: Laser scanner data of three bridges within Portsmouth Harbor. Top: I-95 Bridge. Middle: Memorial Bridge. Bottom: Sarah Mildred Long Bridge.

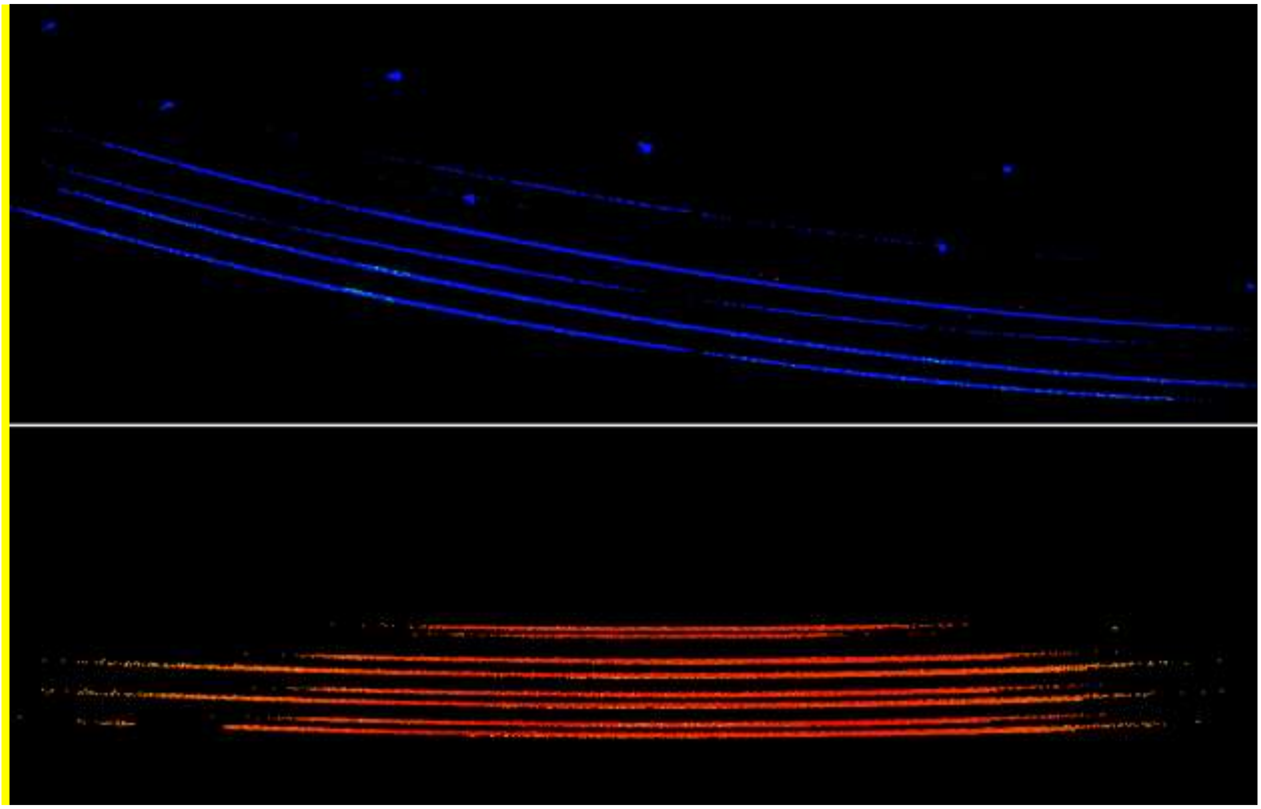


Figure 29-6: Laser scanner data on two sets of overhead power cables within Portsmouth Harbor. Top: 165ft high cables crossing the main channel north of the I-95 Bridge. Bottom: 65ft high cables crossing Back Channel.

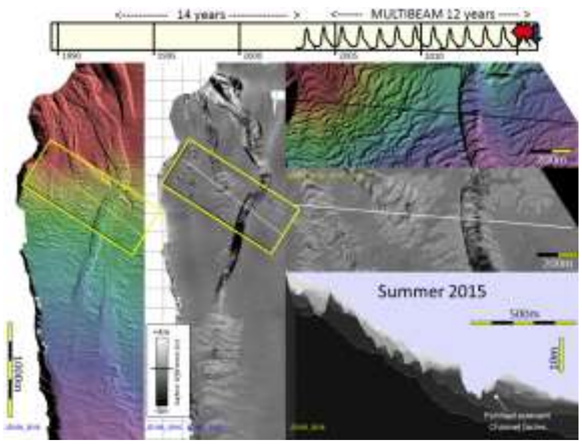
TASK 30: ***Seabed Change Detection*****:** *Continue our efforts to understand the limits to which we can detect changes through understanding of the theoretical limits of both bathymetric and backscatter resolution as determined by sensor characteristics, system integration, and appropriate calibrations and compensations. We will also look at the mobility (or transport) of both inshore and offshore sediments in an effort to better understand the need for re-surveying in different areas.* ***John Hughes Clarke, Tom Lippmann***

Project: **Seabed Change Detection**
JHC/CCOM Participants: John Hughes Clarke
NOAA Collaborators: Sam Greenaway (NOAA HSTP)
Other Collaborators: Gwynn Lintern and Cooper Stacey (Geological Survey of Canada).
Peter Talling and Matthieu Cartigny (National Oceanography Centre, UK)
Ian Church (Ocean Mapping Group, UNB)

As every mariner knows, seabed morphology can change, especially in areas of strong currents and unconsolidated sediment such as river mouths and shallow tidal seas. NOAA has both the charting and environmental survey mandate to monitor rapidly changing areas in the U.S. coastal zone and inner continental shelf.

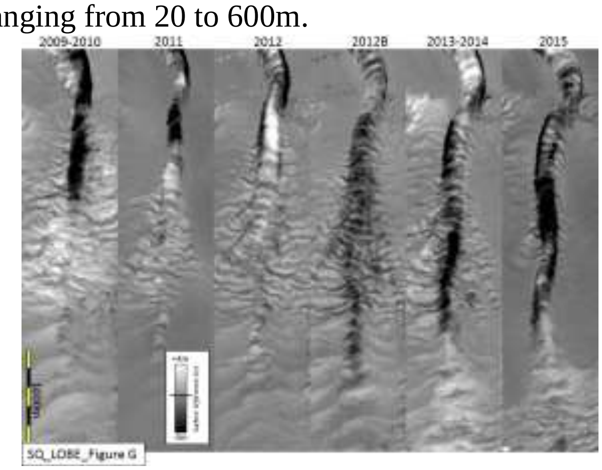
To identify seabed change before it becomes significant at chart scale (i.e., changes that occur over weeks or months rather than year time scales), requires an ability to maintain the total propagated uncertainty in the bathymetric measurements below the typical scale of change (~0.1m). This is the survey challenge that this project addresses.

This research program works both directly with NOAA as well as partnering with other organizations interested in monitoring decimeter-scale seabed changes due to river discharge, delta front landslides and turbidity current processes. A multi-year resurvey program has been conducted for the past 12 years in the fjords of British Columbia, Canada. Using external funding to support ship-time, these projects have been used to assess the limits of detection of real seabed change. By differencing surveys, one reveals both the real seabed change (if any), and the systematic biases in each survey due to imperfect integration (Figures 30-1and 30-2).



Change Figure 30-1: 2015-2016 seafloor changes, Squamish prodelta (depth ranges 20-200m). Showing the entrenchment of the channel, and the net growth of the associated stratigraphy.

In 2016, new spring and autumn surveys were undertaken at these test sites, with CCGS Vector, by the Canadian Hydrographic Service (funded by GSC and NOC). The data were processed at CCOM and compared to the previous year's surveys. The focus of research here has been to assess the limits of change detection in depths ranging from 20 to 600m.



Change Figure 30-2: Zoom view of the annual seabed change (depths: 100-150m) detected over the past 6 years. Note increasing entrenchment of the delta lobe channel.

Also in 2016, as part of the NOAA Ship Thomas Jefferson multi-spectral seafloor characterization experiments, a new dataset was collected over pre-existing NOAA bathymetry and backscatter (Hassler, 2011) in an area under consideration for offshore wind farms (in Virginia state waters). In this case, the primary change noted over the five-year period was major reorganization of the surficial backscatter character. From a habitat perspective, however, backscatter changes are just as important as bathymetric changes.

TASK 31*:* *Detecting Change in Benthic Habitat and Locating Potential Restoration Sites:* *Investigate the use of topographic-bathymetric lidar systems and acoustic systems to determine storm induced changes in seagrass, mixed Submerged Aquatic Vegetation, and sand using spatial metrics such as patch size, patch density, and percent cover of benthic habitats from data collected by the EAARL-B topo-bathymetric lidar and aerial images.* ***Jenn Dijkstra and Super Storm Sandy Team***

Project: **Thirty Plus Years of Change in Seaweed Assemblages in the Gulf of Maine**

JHC/CCOM Participants: Jenn Dijkstra, Kristen Mello, and Colin Ware

Other Participants: Larry Harris, University of New Hampshire, Christopher Wells, University of Washington

In connection with our work using multibeam backscatter and video mosaics to identify and characterize benthic habitats in the Gulf of Maine (see Task 26), we have used archive underwater imagery coupled with *in-situ* sampling of seaweed species to investigate temporal shifts in critical seaweed assemblages on habitat structure and food webs. The project team has documented temporal changes in seaweed assemblages by analyzing almost 40 years of photographs of seaweed assemblages. Concurrently, methods were developed to investigate temporal shifts in 2D habitat structure and biodiversity of associated mesoinvertebrates (funding for this portion stemmed from the Shoals Marine Laboratory). Results of the study indicate that the composition of Gulf of Maine subtidal seaweed assemblages has undergone a phase shift over the past four decades from a kelp-dominated assemblage to a red filamentous seaweed assemblage that is predominantly composed of introduced red filamentous algae. The 2D complexity of the assemblage has increased over time, while canopy height has declined due to the large number of short (>0.3m in height) introduced species.

As height of seaweed species is a key determinant for distinguishing among species assemblages, this is a characteristic that S. Dijkstra, Norton, and J. Dijkstra will use to distinguish among seaweed assemblages using acoustically collected water-column data (see Evaluating the Use of Water Column Data to Identify and Characterize Benthic Habitats under Task 26).

TASK 32*:*Marine/Coastal Decision Support Tools: *Development of approaches to creating interactive decision support tools that can integrate multiple data sources (e.g., bathymetry, sediment texture, zoning, habitat mapping, ship-traffic) with advanced visual analysis tools (e.g., probes and lenses).* ***Tom Butkiewicz and Vis Lab***

This project has not yet started under this grant

TASK 33*: Temporal Stability of Seafloor:* *to address the problem of temporal stability of the seafloor we will combine our remote sensing expertise and ability to remotely map seafloor change with our studies of seafloor stability and its relationship to forcing conditions to attempt to derive indices of temporal seafloor stability that can then be input into navigational risk models and used to inform NOAA and others of the needed frequency of repeat surveys in certain regions.* ***Lab-wide effort***

Project: **Seafloor Stability**
JHC/CCOM Participants: Tom Lippmann, Kate von Krusenstiern, Jon Hunt

This work began in the summer of 2016 as part of the Master's Thesis research of Kate von Krusenstiern under supervision of Tom Lippmann. The goals of the research are to assess the quality of bathymetric data in shallow navigable waterways, and to determine the "likelihood" that a nautical chart value in an energetic shallow water region with unconsolidated sediment is valid a certain length of time after the data has been collected. This work will build on efficient acoustic survey methods in shallow water using personal watercraft and small boats. The bathymetric data will be used to establish the Coupled Ocean Atmospheric Wave and Sediment Transport (COAWST) model. Verification of the modeling system will be done with *in situ* observations of flows and from observed bathymetric evolution. Forward model runs with decimated and modified bathymetry will be done to evaluate sensitivity of sediment transport, coastal erosion, flooding, and inundation to bathymetric accuracies and resolution.

In the current reporting period, we have made significant progress. Von Krusenstiern has created a composite topographic bathymetry from the Hampton-Seabrook region that includes water depths on the continental shelf up to 30m and topographic elevations up to 8m above mean sea level (Figure 33-1). The data sources include JHC/CCOM, NOAA, and USGS bathymetric surveys conducted on the inner shelf, USACE LIDAR surveys (primarily 2011) for the inner, harbor, and nearshore topography, as well as compilations from the USGS coastal relief model for elevations up to 8m above mean sea level. These bathymetric data were used to create a 10m by 10m and 30m by 30m rectilinear grids for the Hampton-Seabrook study area, extending from several kilometers off shore to the entire inland marshes inundated at the highest spring tides.

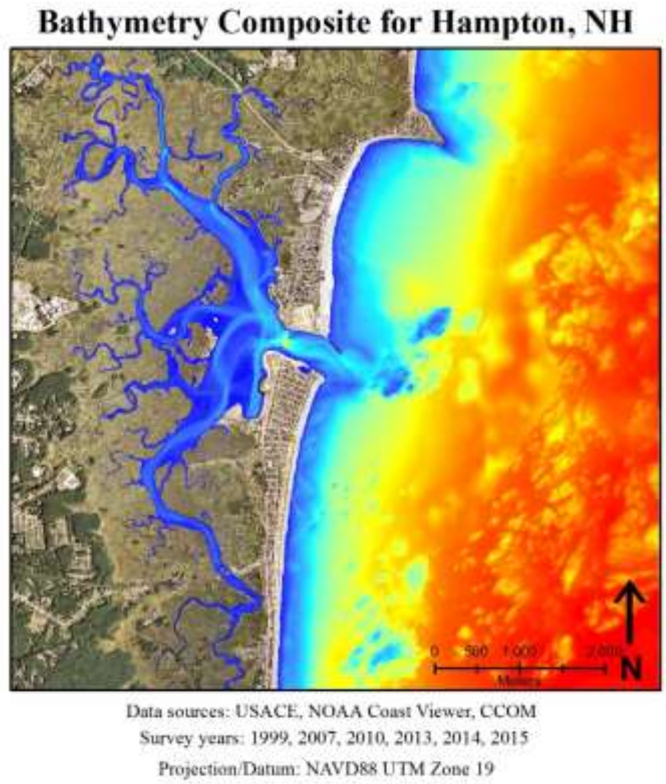


Figure 33-1: The bathymetry (elevations below mean sea level) compiled for the Hampton/Seabrook inlet, harbor, and estuary. Depths extend to 30 m.

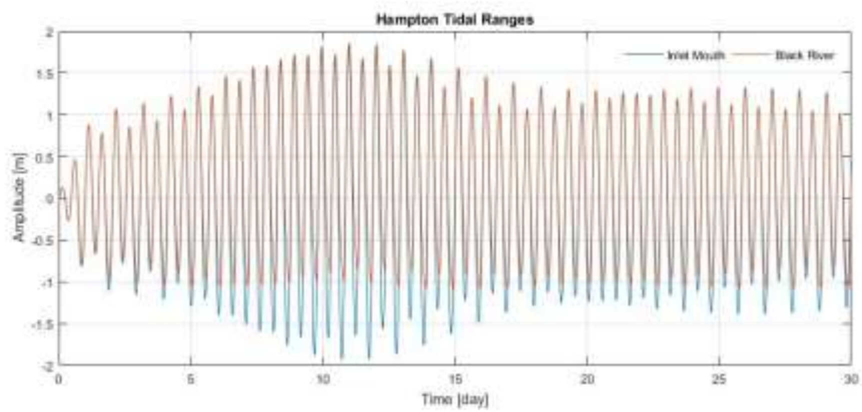


Figure 33-2. Example 30 day time series of sea surface elevation from sites near the inlet mouth and in the back bay.

Figure 33-3. Locations of the time series of sea surface elevation shown in Figure 30-4

The hydrodynamic model used in COAWST (the Regional Ocean Modeling System, or ROMS) was tested for numerical stability using both grids and analytical tides for 30-day model runs. These model runs were conducted for 2D depth-averaged conditions (single layers) and for 3D vertically-varying conditions with eight terrain-following (sigma) coordinates. Example time series of sea surface elevation from two locations within the model grid are shown in Figure 33-2. Figure 33-3 shows where these data were obtained within the grid. These data (and others) show strong changes to the M2 tides and harmonics. Dissipation estimates for the tides range about 10% for the north and central regions, and up to 80% for the southern part of the estuary. These data are qualitatively consistent with local understanding of the tides, and will be quantitatively evaluated this coming year with *in situ* observations to be obtained with bottom mounted ADCPs. The spatial variability of depth-averaged currents for an "average" tide during flooding and ebbing conditions during the 10m grid run with eight sigma layers are shown in Figures 33-4 and 33-5. These data are also qualitatively consistent with general behavior of currents in the inlet and harbor, and will be quantitatively verified with existing and new observations over the coming year.

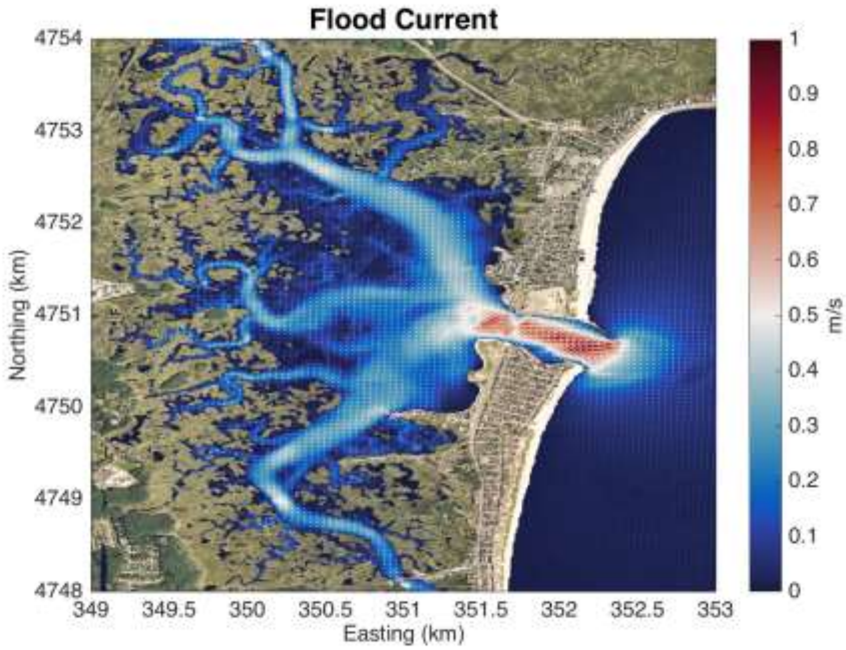


Figure 33-4. Example spatial map of depth averaged flood currents during an "average" tidal cycle from the 3D model run with eight sigma layers. Background color contours are current magnitude (in m/s). Vectors show the magnitude and direction of the flow. Spatial locations are decimated by a factor of 16 for display purposes.

Verified hydrodynamic flow model fields can be used to estimate bottom shear stresses if general sediment characteristics are known, including porosities, bottom roughness (for 3D runs), bottom drag coefficients (for 2D runs), and median grain diameters and densities. To test the stability of the model, preliminary sediment transport runs were conducted for the 10m, 3D (eight layer) model with estimated bottom boundary and sediment characteristics. Figure 33-6 shows the bathymetric evolution of the bathymetry for a 24-hour period. We intend to run these sediment transport models for extended periods of time for both 3D and 2D cases. The 2D runs are significantly faster and allow for multiyear evolution to be examined.

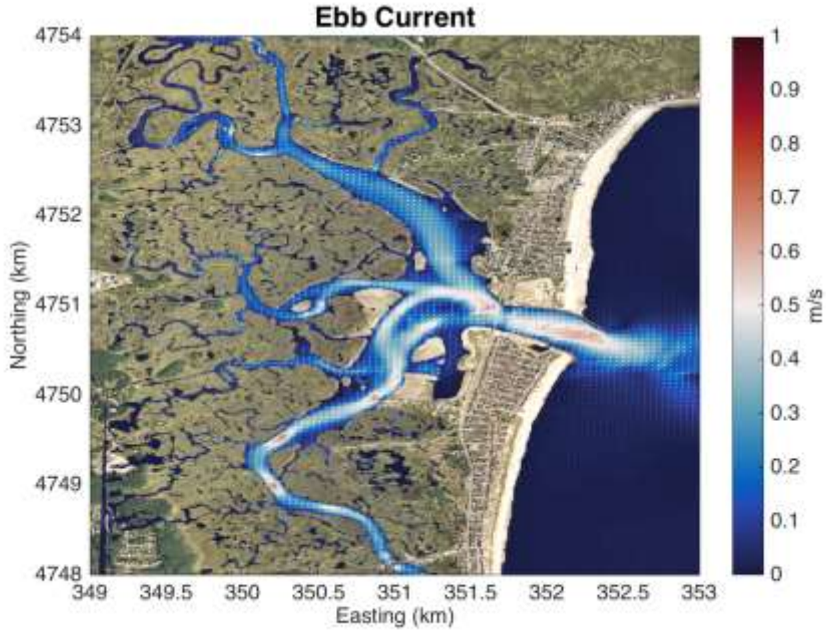


Figure 33-5. Example spatial map of depth averaged ebb currents during an "average" tidal cycle from the 3D model run with eight sigma layers. Background color contours are current magnitude (in m/s). Vectors show the magnitude and direction of the flow. Spatial locations are decimated by a factor of 16 for display purposes

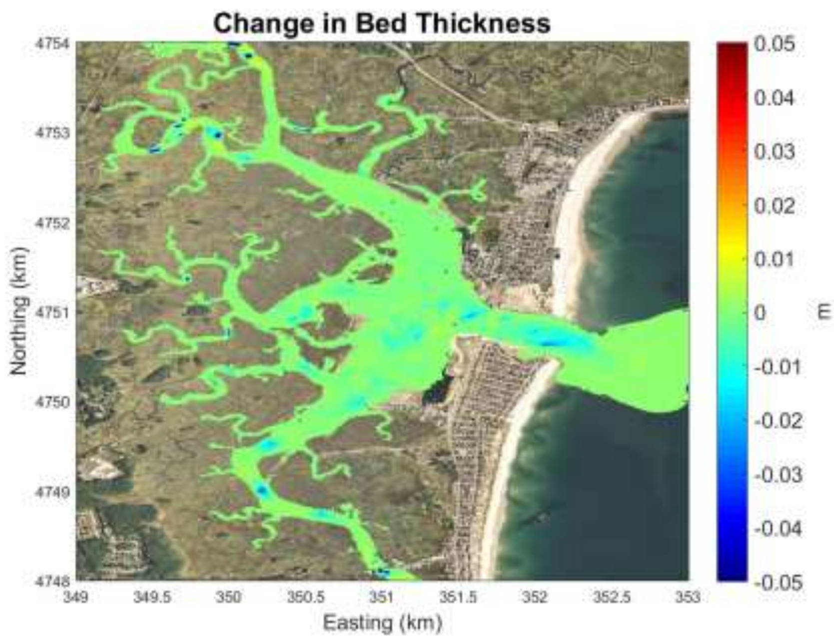


Figure 33-6. Example spatial map showing the bathymetric (bed) change for a single 24-hour 3D model run with three sediment size classes and the "standard" sediment transport parameters for the COAWST model.

In order to test the sediment transport evolution we re-surveyed Hampton/Seabrook Inlet and Harbor this past winter (under NOAA Grant NA10NOS4000073). The new bathymetry is shown in Figure 33-7. These data will be used to compare with the 2011 Lidar surveys for bathymetric change evaluation. Model runs will be conducted for the five year period between surveys (in 2D form) to predict the evolution of the inlet and compare with observations for model verification.

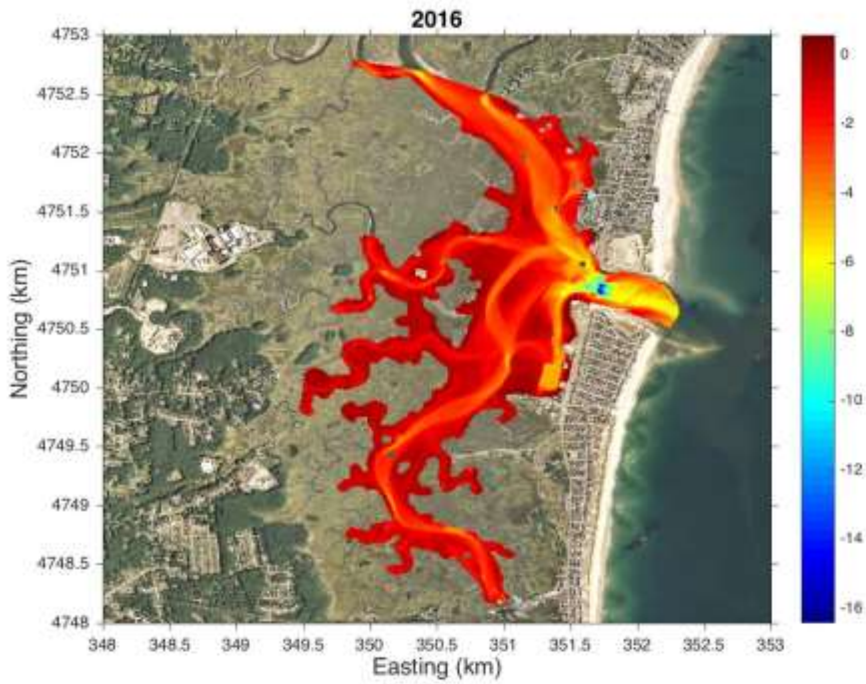


Figure 33-7. Hampton/Seabrook bathymetry re-surveyed by the Center in 2016 using the 200 kHz single-beam echosounder onboard the Coastal Bathymetry Survey System (CBASS). About 200 approximately east-west oriented transect lines with 20m spacing were surveyed over a three month period.

RESEARCH REQUIREMENT 1.D: THIRD PARTY AND NON-TRADITIONAL DATA

FFO Requirement 1.D: "*Development of improved tools and processes for assessment and efficient application to nautical charts and other hydrographic and ocean and coastal mapping products of data from both authoritative and non-traditional sources.*"

THEME: 1.D.1 THIRD PARTY DATA

TASK 34: ***Assessment of Quality of Third Party Data:*** *Investigate methods for combining multiple repeated, or pseudo-repeated, measurements, as well as decision rules for what constitutes "sufficient" evidence to determine that the third-party data indicates that there are issues with existing hydrographic database or chart, and thus that action is required. Finally, we will also attempt to determine what sort of action is required (i.e., resurvey, update chart, etc.).* ***Brian Calder***

This project has not yet started under this grant

THEME: 1.D.2 NON-TRADITIONAL DATA SOURCES

Sub-Theme: AIRBORNE LIDAR BATHYMETTRY (ALB)

TASK 35: ***Airborne Lidar Bathymetry:*** *Continue our efforts to better understand other ALB data sets (e.g., USGS coastal mapping program or other surveys of opportunity). Additionally, working with NOAA, future operating procedures and workflows will be developed to help update near-shore areas of the NOAA charts based on file format (LAS 1.2 or LAS 1.4) and class type.* ***Shachak Pe'eri***

This project has not yet started under this grant

Sub-Theme: AIRBORNE LIDAR BATHYMETTRY (ALB)

TASK 36: ***Satellite-Derived Bathymetry:*** *Continue our efforts to understand the limits and possibilities of deriving bathymetry from satellite-borne optical sensors. Future efforts will focus on developing improved and simplified uncertainty models for easy application with particular attention on developing enhanced techniques to derive bathymetry in regions with turbid waters (e.g., the Arctic). Thus the focus of our efforts will be on multi-temporal processing to identify and monitor dynamic areas and explore how SDB can be used to better define surveying and charting priorities.* ***Shachak Pe'eri***

Project: **Multi-image Satellite Derived Bathymetry Processing**
JHC/CCOM Participants: Shachak Pe'eri, Lee Alexander, Tom Lippmann and Yuri Rzhanov
NOAA Participants: Anthony Klemm (OCS), Shachak Pe'eri (MCD)
Other Participants: Christopher Parrish (Oregon State University)

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 36-1). Given the estimated ellipsoidal boundaries, it was possible to identify dynamic and stable areas as well as shifting trends of shoal features.

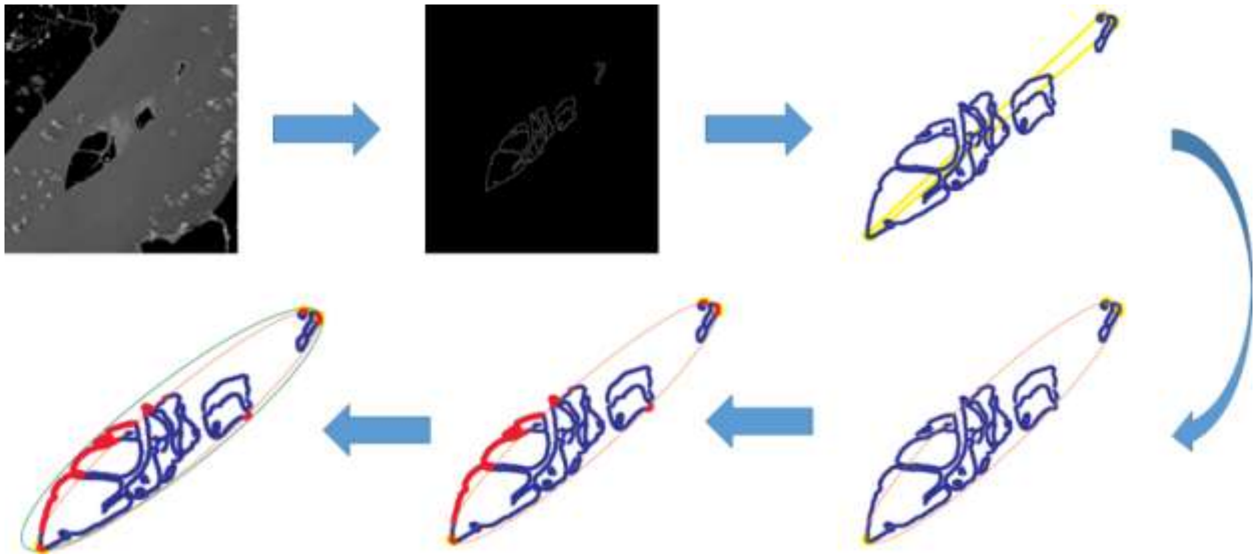


Figure 36-1: Processing workflow, applied to the Amazon River, showing the process from band ratio until a final envelope ellipse.

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 36-2). Based on these ellipses, it is possible to predict near future feature dynamics. Figure 36-3 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.

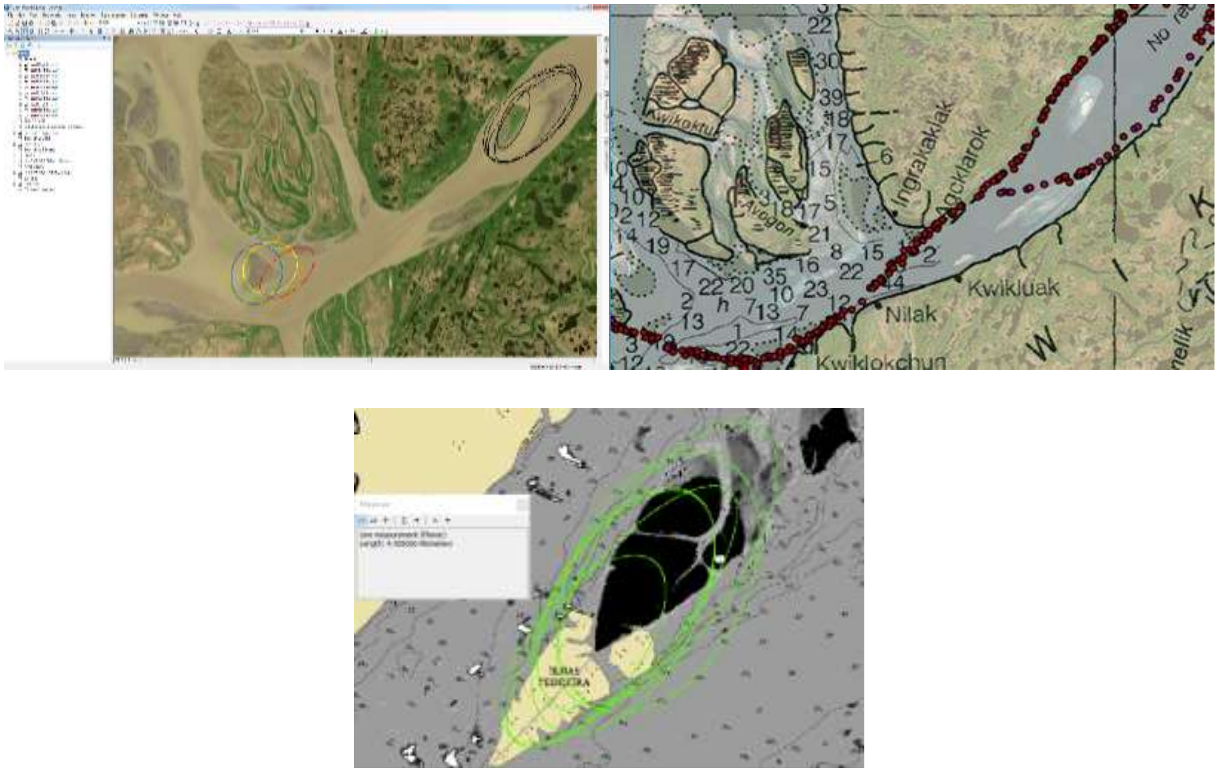


Figure 36-2: (Upper left image) Shoal features identified from satellite imagery between 2005 and 2015 in the Yukon River. (Upper right image) AIS tracks of vessel traffic (2013) on the NOAA chart confirming the location of the shoals by navigating around them. (Lower image) Movement of shoal features from 1986 to 2008 in the Amazon River.

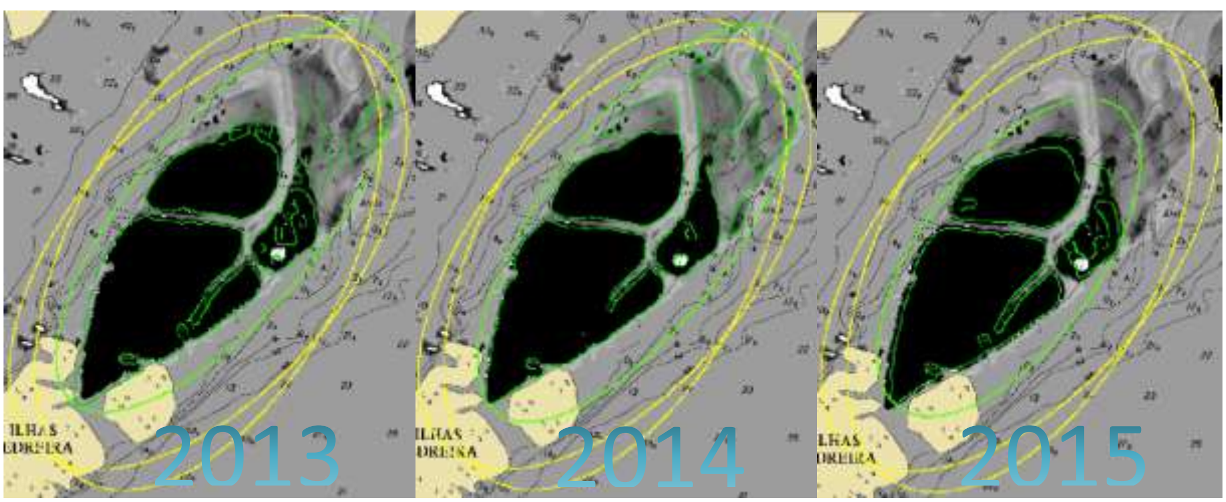


Figure 36-3: Shoal feature predicted boundaries (yellow ellipses) using satellite imagery from 1982 to 2008, in the Amazon River, compared against observed data (green ellipses), for the years 2013, 2014 and 2015.

Project: **Multi-area non-linear SDB Estimation and Bottom Identification**
JHC/CCOM Participants: Shachak Pe'eri, Richard Friere
NOAA Participants: Anthony Klemm (OCS), Shachak Pe'eri (MCD)
Other Participants: Christopher Parrish (Oregon State University)

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.

PROGRAMMATIC PRIORITY 2: TRANSFORM CHARTING AND NAVIGATION

RESEARCH REQUIREMENT 2.A: CHART ADEQUACY AND COMPUTER-ASSISTED CARTOGRAPHY

FFO Requirement 2.A: "*Development of improved methods for managing hydrographic data and transforming hydrographic data and data in enterprise GIS databases to electronic navigational charts and other operational navigation products. New approaches for the application of GIS and spatial data technology to hydrographic, ocean, and coastal mapping, and nautical charting processes and products.*"

TASK 37: ***Managing Hydrographic Data and Automated Cartography:*** *Investigate algorithms for the appropriate interpolation of data from sparse sources for use in populating a single-source database product, and to combine these products in a consistent and objective manner so as to provide, on demand, the best available data for the area, with associated uncertainty. Investigate methods for rasterization of vector product charts that better reflect the "style" of the current printed chart and develop methods to tackle the generalization problem for nautical cartography using both gridded bathymetric source and vector products for other chart components, with the ultimate goal of providing a vector product that can be rasterized at any given scale and still reflect the "style" of current charts.* ***Brian Calder and New Hire***

Project: **Nautical Chart Production Systems**
JHC/CCOM Participants: Brian Calder, Erin Nagel, Paul Johnson, Jordan Chadwick
NOAA Collaborators: John Nyberg (NOAA MCD), Mike Brown (NOAA MCD)

In order to ensure that the research and development done at the Center in support of the "Transform Charting and Navigation" programmatic priority is tested on a system compatible with NOAA processes and workflows, Brian Calder, Erin Nagel, Paul Johnson, and Jordan Chadwick have set up a charting production system based on ESRI's Nautical Solution for ArcGIS, and have transferred to the Center a full copy of the databases associated with NOAA's Nautical Charting System Mk. 2 (NCS2), which drives this production system. This allows for testing of algorithms in NOAA's native environment, and on complex and large datasets, which would otherwise be very difficult to do. The database transfer is intended to be a one-time process (i.e., it will not be continuously updated from NOAA's Marine Charts Division), and Chadwick and Johnson have put in place additional IT safeguards to ensure that the database is not accessible from outside of the Center, and that any products generated are not available for distribution. This ensures data security, and provides assurances that no experimental "products" might escape to potentially cause confusing elsewhere.

Based on this database, Nagel and Calder were able to participate in a project with NOAA's Marine Chart Division to understand the use of measurement units within the NCS2 database. In the current configuration, the database contains objects that have depth information represented in a number of different measurement units so as to ease comparison with legacy products (for example, charts with depths in fathoms, or fathoms and fractions). As part of a process refinement effort, MCD is currently entertaining a modification that would retool the database to avoid this practice, instead converting all data to a single measurement unit on ingestion into the database. In addition to participating in the technical panel convened to review this suggestion, availability of a copy of the NCS2 database allowed Nagel to prototype a version of the database with all depths expressed in a single measurement unit. This allowed for testing of the basic concept, including development of standard practices, and demonstrated that it was a relatively simple matter to reconfigure the database, but still provide the custom labelling of depth data required to allow for comparison against legacy products. This custom database was then supplied to NOAA for further testing.

TASK 38: ***Chart Adequacy and Re-survey Priorities:*** *Investigate methods to formally assess the adequacy of a chart based on many factors, weighting the strength of each so as to determine a metric that can be normalized over many charts or chart areas, so that it can be used to rank areas in order of resurvey need. In addition, there is a requirement to determine the value of a survey in any given area, defined as the benefit to the adequacy of the chart that is derived from conducting a survey (i.e., if we resurvey an area, how much better does the chart become?) and we therefore propose to investigate methods to assess survey benefit as an economic driver in the resurvey priority decision. Linked together, these two methods may provide a schema to rationalize the setting of resurvey priorities beyond the "Critical Area." These efforts are clearly linked to our seafloor change analyses and risk model efforts (Task 30 and Task 41).* ***Brian Calder, New Hire, and Giuseppe Masetti***

Project: **Survey Management and Chart Adequacy**
JHC/CCOM Participants: Brian Calder, Giuseppe Masetti, Pamela Lezaeta

Quantitative measures of the resurvey priority for individual areas have become a common request from a number of hydrographic agencies, the current process being both subjective and time consuming. One method by which this may be addressed is to assess the relative risk entailed by a transit over any given area of interest by a surface ship, and in a previous reporting period Calder developed a scheme that used an extensively data-driven under-keel clearance model to assess risks in the area of NOAA Chart 12222 (Chesapeake Bay, Hampton Roads, and Port of Norfolk, VA) to do so. The resulting model took into account environmental effects, knowledge of the bathymetry from archival sources, and the ship traffic in the area (derived from AIS observations) to derive the risk estimates, and demonstrated that it could be used to prioritize areas for survey effort. Further information on development of this model is given under Task 41, following.

Theoretical extensions of the basic model toolkit have continued in the current reporting period by extending use of the model into survey management. That is, given an area to be surveyed, analysis of the risks – and more specifically the potential for risk reduction – can be used to determine likely areas to survey first, which types of tools to use for the survey of any particular sub-area, and how to tell when the survey effort has done enough and should be considered complete.

The first of these tasks is similar to the resurvey priority problem: given the best estimate of risk, where is there potential to reduce that risk through further survey effort? Since this is done *a priori*, the new bathymetry is not known, but an estimate of potential risk reduction can be achieved by assuming that the best case of a new survey would find all previously unknown objects, and reduce the bathymetric uncertainty to current magnitudes. The resulting prediction of potential risk reduction shows (Figure 38-1) that there are some areas with higher potential reduction in risk, but also that there are some areas where there is high risk, and no potential to remove it through further survey. That is, even if an ideal survey were to be conducted with the best available tools, it is unlikely that the situation would improve in some areas.

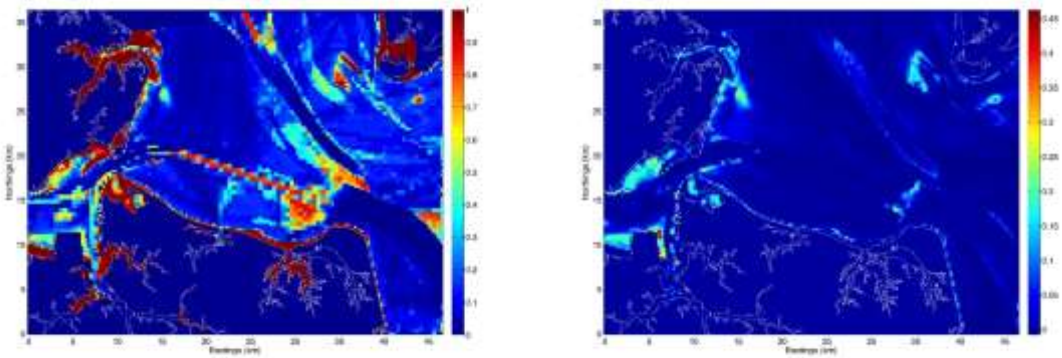


Figure 38-1: Estimated a priori surface risk for Chart 12222 (left) and potential improvement in risk (right) from an ideal survey. Areas of high risk reduction might be surveyed first in order to improve efficiency, or hedge against problems/weather later in the survey effort. Note that many areas of high risk show no likelihood of reduction with extra survey effort, indicating that they are simply inherently risky places to go.

Selecting which tool to use for the survey (e.g., VBES, VBES and sidescan, MBES, LIDAR, SDB, etc.) can be couched in terms of the expected effects of the survey. For example, if a particular tool is expected to find all objects of greater than 1m height off the seafloor with probability of detection of 0.95, the expected effect will be to limit the potential rate of unobserved objects, and to limit their height distributions (Figure 38-2). Different probabilities of detection and residual height estimates can then be simulated (Figure 38-3) to determine the optimal tool for any given area. The results generally agree with intuition about different survey methodologies (full object detection and full coverage surveys are generally preferred, for example). An interesting observation, however, is that in this area while there are some areas that clearly benefit from full-coverage surveys with object detection, there are many others where there is no significant advantage in selecting a tool with full coverage capabilities, since there is no potential reduction in risk in the area with any methodology – the extra resources and cost involved are therefore mostly wasted.

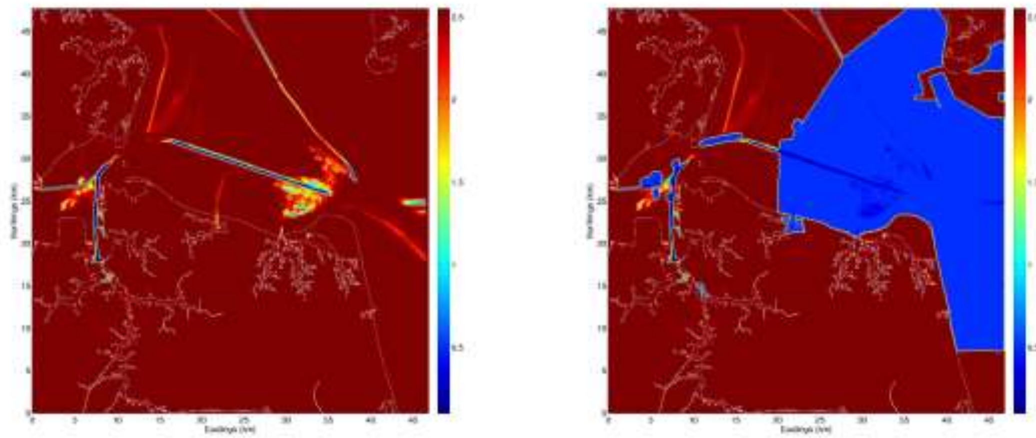


Figure 38-2: Estimate of the mean height of potentially unobserved anthropogenic objects before (left) and after (right) a potential new survey operation. The initial reductions (left) are due to AIS ship draft observations (in this case for 2013), which effectively act as wire drags; the predicted reduction post-survey (right) is based on hypothetical survey specifications that require detection of objects 1m above the sea floor.

During the survey, the question of survey completeness is a common concern. There is little advantage in attempting to determine the height (or presence) of small obstructions in deep areas with shallow shipping, for example. In practice, however, it can be difficult to justify these types of decisions, and the natural inclination of a surveyor might be to survey all areas equally, "just to be sure." As the survey data is being collected, however, analysis of the reduction in predicted risk that has been achieved, along with the potential for further reduction, can be used to assess when further survey is inappropriate. In practice, these arguments would be applied piecewise as new data arrives, but the overall effect can be demonstrated (Figure 38-4) by taking an entire survey area into account. These results clearly demonstrate the improvement inherent in increased probability of detection for survey tools, showing for example that with P(D) = 0.99 (Figure 38-4(b)) there is little left to gain from any further survey, and that the survey should be considered complete, while with P(D) = 0.05 (Figure 38-4(d)) there are still gains to be had in certain areas, although a tool with higher probability of detection would likely be required to realize them. An alternative assessment would be to choose a minimum "acceptable" risk, and stop surveying when this has been achieved.

Again, however, it is clear from these results that there are many places within the area of interest where even after only a simpler survey with low probability of detection (Figure 38-4(d)), there is no residual risk reduction to be achieved. This suggests that the appropriate protocol for surveying in this area may be to survey first with a simpler method (e.g., VBES and sidescan), and then to survey with a more capable tool (e.g., a MBES) only the areas where potential for residual risk reduction is demonstrated. Such a methodology might have potential for reduction in survey effort, leading to shorter, cheaper, surveys.

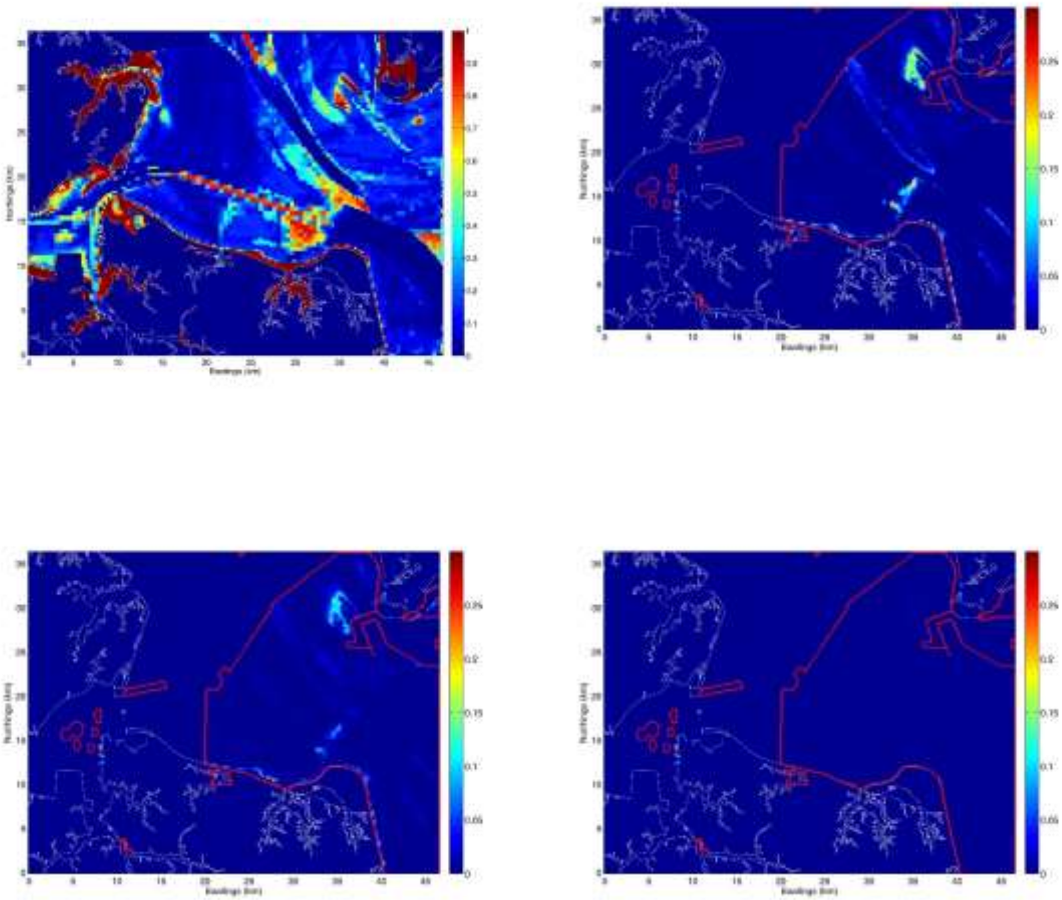


Figure 38-3: Predicted benefit (a priori) of different survey tools, measured relative to a tool with zero probability of object detection; red lines indicate the limits of survey. Top left: estimate of risk; top right: residual objects limited to 1.0m, probability of detection 0.99; bottom left: residual objects limited to 1.0m, probability of detection 0.05; bottom right: no residual object height limit, probability of detection 0.05. Full coverage (bottom left, top right) are clearly beneficial, with higher probability of detection (top right) an extra benefit. However, there are some areas where all of the tools show no significant potential for knowledge improvement, suggesting that the cheapest tool should be used to minimize survey cost.

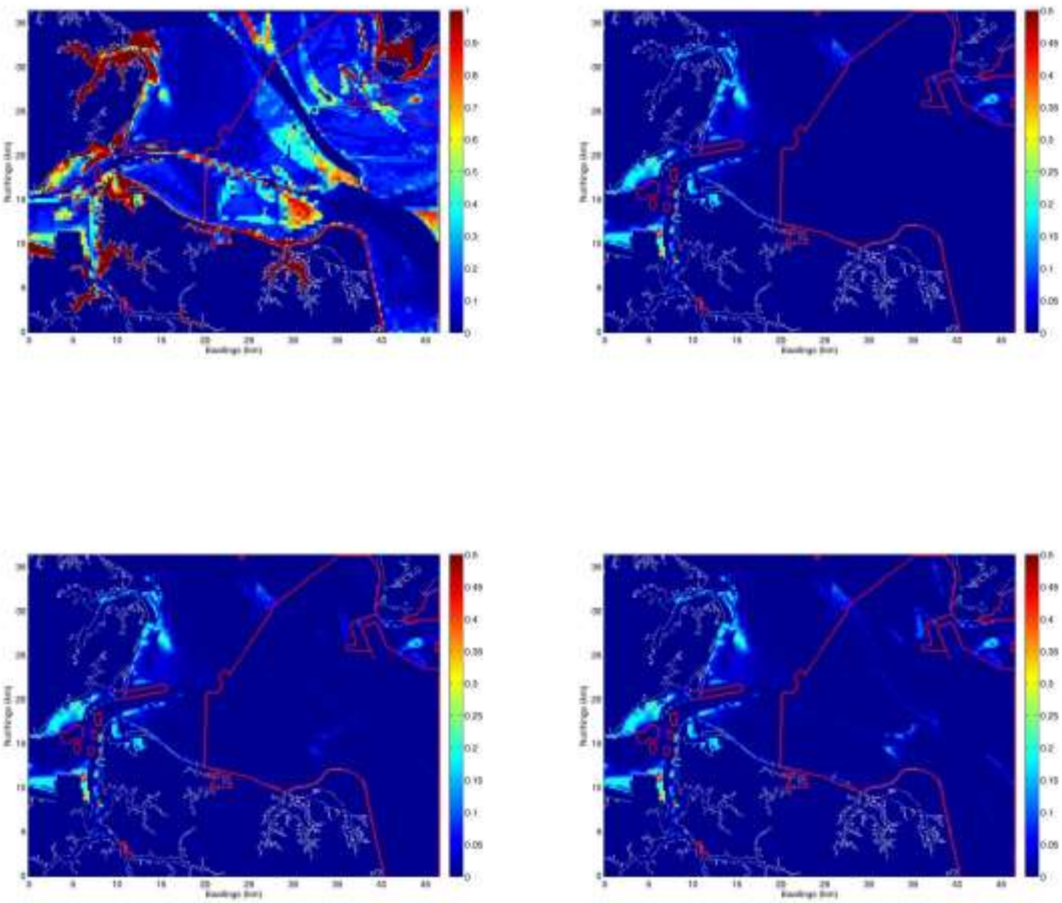


Figure 38-4: Available residual risk reduction for different survey tools; red lines indicate the limits of survey. Top left: estimated a posteriori risk; top right: available risk reduction for probability of detection 0.99; bottom left: probability of detection 0.50; bottom right: probability of detection 0.05. With P(D) = 0.99, there is clearly little additional advantage to survey, while with P(D) = 0.05 there is clearly residual improvement from methods with better object detection capabilities. Note, however, that even with P(D) = 0.05, there are areas where there is no significant residual reduction to be had, suggesting that fast but approximate methods might be a better first choice for survey.

In fact, even object detection might not be as required, as might be expected for the first pass of survey effort. Comparison of the residual risk reduction available after survey with an instrument that does not constrain the height of unobserved objects (e.g., simple VBES survey) with those where there is low probability of detection, but height reduction (e.g., VBES with sidescan) shows (Figure 38-5) that the gain may not be significant enough to warrant the effort. Different areas will vary, but this suggests that simpler approximate first pass "exploratory" survey that highlights where further effort is appropriate might be a viable methodology for more efficient survey, rather than assuming *a priori* that the natural choice, since a full coverage object detection tool is available, is to use it everywhere.

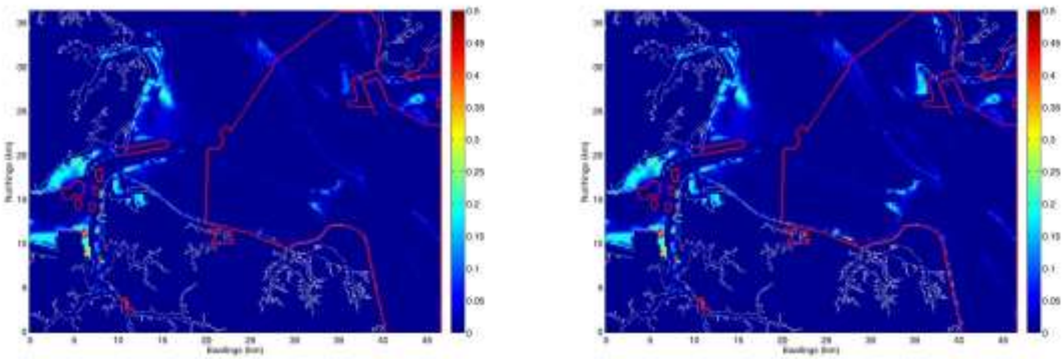


Figure 38-5: Comparison of residual risk improvement available with (left) and without (right) residual object height constraint for a system with probability of detection 0.05 and object height constraint of 1.0m. There are obvious benefits to being able to constrain the potential height of any objects that are not detected, but there are many areas where there is no benefit. Consequently, it is possible that an approximate survey method (e.g., simple VBES) might be sufficient to highlight areas where further effort is required, leading to more efficient survey.

Project: **SeaDOG**
JHC/CCOM Participants: Giuseppe Masetti, Brian Calder

The Continuous Depth Output Generator (SeaDOG) is an algorithm that has been developed to mimic the interpretation of an expert navigator called upon to plan a journey using nautical charts and other documentation. The concept is that the interpolation among bathymetric features is not linear, but has a variable skewness based on several factors (e.g., the purpose of the journey, the quality of the available information, or the age of the survey data). In order to parametrize such a scenario, SeaDOG provides a family of depth interpolators created using a B-spline approach (Figure 38-7).

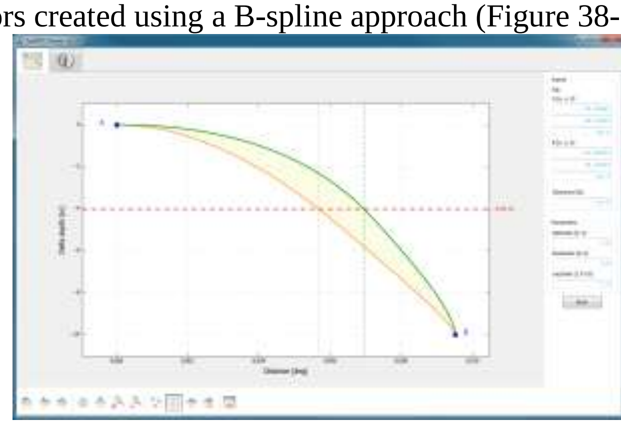


Figure 38-7: For each pair of input point features, two distinct interpolation curves are created based on an optimistic and a pessimistic evaluation of the source of information. The intersection of the 'fuzzy' area between the two curves and the required clearance (minimum keel depth) provides an estimation of the uncertainty in the safety depth contour.

The primary output of such an algorithm is to support the estimation of a ternary decision layer ("go", "maybe go", and "no-go") (Figure 38-8). In the case of multiple sources of information, different techniques are being explored to fuse the resulting ternary spatial distributions (e.g., using a Bayesian categorical distribution estimation technique). Description of techniques for Bayesian fusion are reported in the progress report for grant NA10NOS4000073.

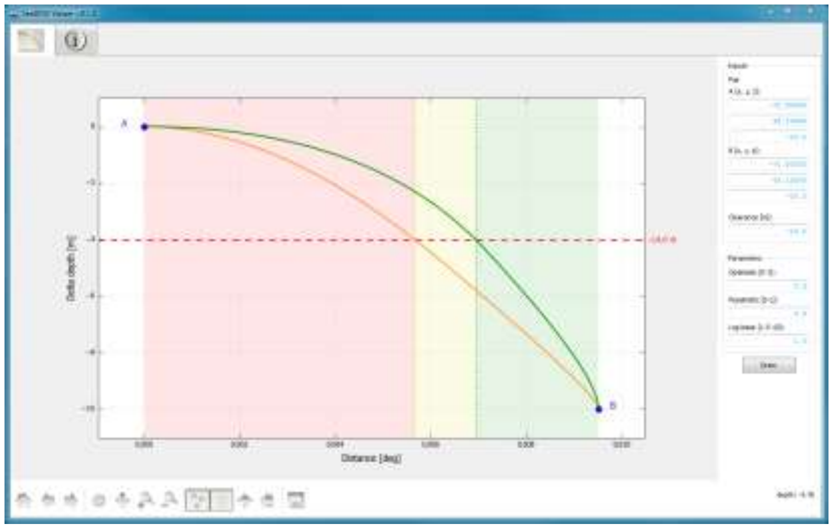


Figure 38-9: An example of estimation of the ternary distribution layers along a pair of point features and given a required clearance depth: the "no-go" region in red, the "maybe go" region in yellow, and the "go" region in green.

TASK 39: ***Hydrographic Data Manipulation Interfaces:*** *Investigate interfaces, interaction methods, and visualization techniques for the inspection, analysis, and remediation of hydrographic data problems, with particular emphasis on novel interaction methods and computer-assisted depiction of problem areas. Specifically investigate visualization techniques for point-wise hydrographic data, and variable-resolution gridded data, with particular emphasis on clear depiction of the data within hydrographic constraints as well as gesture-based interaction, stereo imaging, and multi-touch capable displays.* ***Brian Calder, John Hughes Clarke, Tom Butkiewicz, and Colin Ware***

Project: **Immersive 3D Data Cleaning**
JHC/CCOM Participants: Tom Butkiewicz, Andrew Stevens, Colin Ware

As part of the ongoing effort to explore new interfaces for hydrographic data manipulation, Tom Butkiewicz and graduate student Andrew Stevens are creating an immersive 3D, wide-area tracked, sonar data cleaning tool. This builds upon previous experimentation that has shown natural hand-based interaction and interaction with other six degree-of-freedom (6DOF) devices to be fast and intuitive for positioning and interaction within 3D environments. The stereoscopic display assists in depth perception, and the ability to freely move about provides for frequent motion parallax cues and negates the need to manually reposition virtual camera viewpoints repeatedly.

The system relies on an HTC Vive virtual reality (VR) system, which consists of a head mounted display (HMD), two hand-held six degree-of-freedom (6DOF) controllers, and a laser-based wide-area tracking system which accurately and rapidly calculates the positions of all of these components in a 5m x 5m tracked space.

Basic data cleaning is now functional. The system loads raw sonar point clouds, and displays them color-coded by uncertainty values. The user can move around to look at the data from different angles, or can use the left controller to "grab" the data and move it with their hand, e.g. bring a small feature close to their face to examine it. The right-hand controller is used as an editing tool. It has a spherical volume cursor attached to its end. Swiping a thumb right/left on the controller's trackpad makes the cursor bigger and smaller, while swiping up and down moves the cursor closer to, or further away from, the controller (Figure 39-1). This is useful for editing distant points without moving yourself or the data.

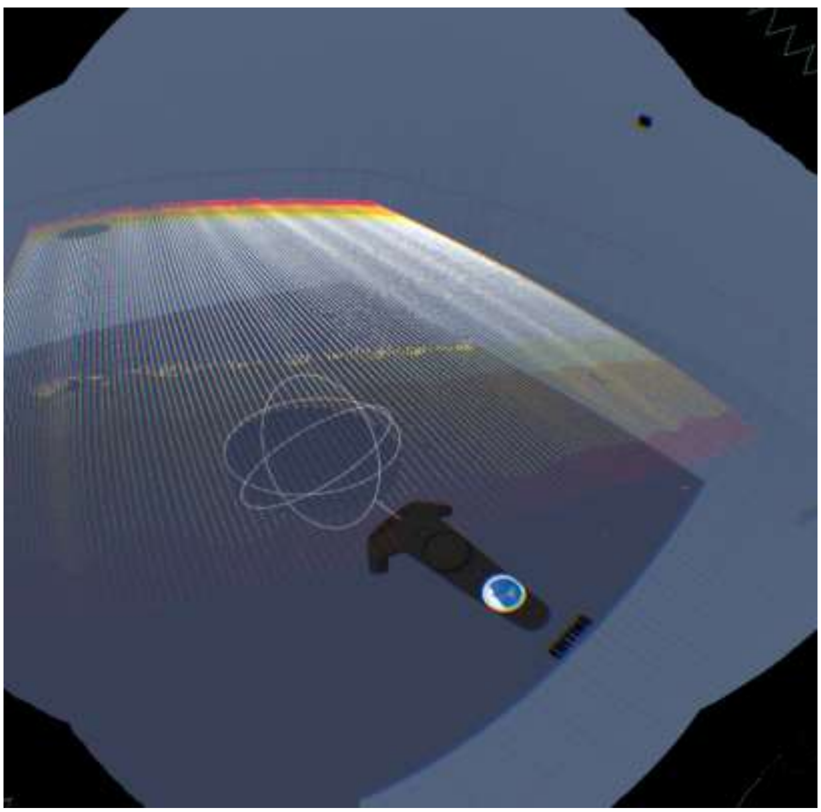


Figure 39-1: Data editing tool controlled by the hand held interaction device. The spherical cursor is used to mark points to be ignored.

RESEARCH REQUIREMENT 2.B: COMPREHENSIVE CHARTS AND DECISION AIDS

FFO Requirement 2.B: "*Development of innovative approaches and concepts for electronic navigation charts and for other tools and techniques supporting marine navigation situational awareness, such as prototypes that are real-time and predictive, are comprehensive of all navigation information (e.g., charts, bathymetry, models, currents, wind, vessel traffic, etc.), and support the decision process (e.g., under-keel clearance management)."*

THEME: 2.B.1: INFORMATION SUPPORTING SITUATIONAL AWARENESS

TASK 40: ***Currents, Waves and Weather:*** *Improve navigation planning systems by the development of methods showing forecast ocean currents, sea state, and surface winds, and specifically to demonstrate methods for high quality portrayal of ocean and near-shore currents, sea state and weather information on electronic chart displays; investigate animated portrayals of the same variables; and investigate the use of multi-slice profile views to show current speed, salinity and temperature distributions. We propose to design, build, and evaluate prototype displays based on sound perceptual principles. We will work with NOAA and appropriate IHO committees (e.g. Tides, Water-levels and Currents Working Group – TWCWG) to evaluate these products and help establish standards for the portrayal of this information.* ***Colin Ware, Briana Sullivan, and Vis Lab***

Project: **S-111 (Surface Current) Product Specification**

JHC Participants: Briana Sullivan, Roland Arsenault, Colin Ware
NOAA Collaborators: Carl Kammerer (NOAA CO-OPS), Kurt Hess (NOAA OCS)
Other Collaborators: Ed Weaver (NGA Contractor) and WR Systems

Briana Sullivan attended the TWCWG (Tides Water-levels and Currents Working Group) meeting in April, following up on the status of the portrayal section of the S-111 product specification. During the meeting Sullivan conducted breakout sessions with the SCWG (Surface Current Working Group) where there was strong interest in the surface current representation proposed by Sullivan (Figure 40-1).

Figure 40-1 – The dynamic SVG arrow.

Project: **Flow Pattern Identification Study: Animated vs Static Portrayal**
JHC Participants: Colin Ware and Daniel Bolan
Other Collaborators: David Rogers, Jim Ahrens (Los Alamos Natl. Lab), Rikki Miller (UNH**)**

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 40-2 and 40-3) 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 40-2) and one of the animated methods was also the best in an advection path tracing task (Figures 40-3 and 40-4).

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.

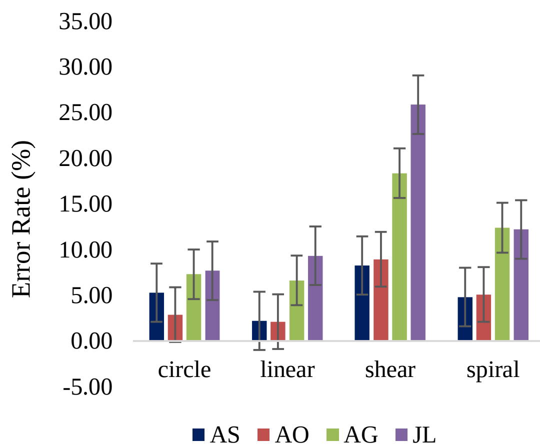
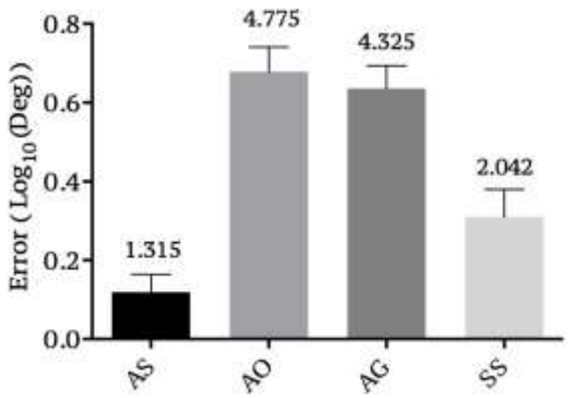


Figure 40-2: Results. Mean error rates for Experiment 1, comparing different methods for visualization of vector flow. AS: Animated streamlets. AO: Animated orthogonal particles. AG: Arrow Grid. JL: Equally spaced streamlines using the Jobard and Lefer algorithm.



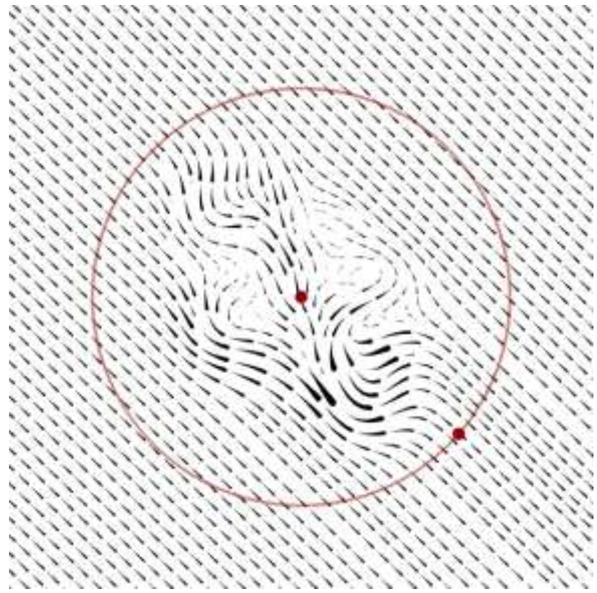


Figure 40-3: Mean log errors for Experiment 2, showing lower error rate for Animated Streamlines) Anti-log values are provided above each bar. AO: Animated orthogonal particles. AG: Arrow Grid. JL: Equally spaced streamlines using the Jobard and Lefer algorithm.

Figure 40-4: 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.

TASK 41: ***Under-keel Clearance, Real-time and Predictive Decision Aids****: Develop methods to assess the input parameterization for real-time under-keel own-ship models, and then to apply these models to form real-time interactive decision-support tools, with off-line planning modes, allowing the user to choose the most appropriate method for the task in hand. Specifically, investigate and develop methods for the assessment of geological and anthropogenic variability in a survey area, with the aim of providing calibration constants for risk-based under-keel clearance models. Investigate methods for establishing the own-ship calibration constants as well as methods for adapting real-time and predictive environmental models for use in the appropriate segments of the risk-based under-keel clearance model. In visualizing the results of this model, we will investigate methods for portraying the uncertainties and risk associated with this information in a fashion most meaningful to the mariner.* ***Brian Calder and Vis Lab***

Project: **Risk Models for Precise Navigation**
JHC/CCOM Participants: Brian Calder, Giuseppe Masetti, Pamela Lezaeta

Understanding the uncertainty associated with hydrographic data, and how to best communicate this to the end user (e.g., of a chart), is a current area of interest within the international hydrographic community. Accepting that it would be extremely challenging to assess the bathymetric uncertainty associated with any given area – and in any case, not particularly useful or informative for the user – in a previous reporting period, Brian Calder developed a probabilistic risk model for under-keel clearance that can be used to assess the generalized risk of a ship of particular type undertaking a given trajectory over bathymetry that might be only partially defined. Marked spatial point process models are used to estimate the potential effects of objects not explicitly defined in the bathymetry, allowing a general statement of risk to be developed at any given point in an area of interest, or along arbitrary trajectories. The overall model takes into account environmental effects, ship traffic estimates derived from AIS observations, and the characteristics of the ship in question to generate an estimate of the risk of each transit that can be accumulated or summarized in a number of ways to provide predictive statistics and maps that assist in communication of uncertainty; the derived statistics may also be used in other fields, such as resurvey priority prediction and survey management (see Task 38 for further details). The model essentially acts as a toolbox on which other predictive models can be built.

In the current reporting period, the technical development of this model has continued, with Calder adding the ability to run in a multi-threaded environment for performance, and to use both memory-mapping and lazy (copy on write) evaluation for the spatial point process models in order to minimize required compute resources. These modifications dramatically improve the efficiency of the code (the code is essentially CPU-bound, and therefore can readily extend to higher numbers of processors), and minimize the memory required for use of large models (reducing from several gigabytes to a few tens of megabytes). Calder and Masetti also collaborated in porting the code to the Windows platform, and Calder added the facility to sample bathymetry at different resolutions as a stop-gap towards variable resolution data availability. The ability to write output in BAG format was also added, making the outputs more readily distributable and readable. Calder and Jordan Chadwick also commenced a collaboration to convert the multi-threaded single-processor parallel code into a fully distributed parallel algorithm utilizing JHC/CCOM's compute cluster. In an effort to support investigations by Colin Ware into visualization of risk, Calder also added the facility to apply vertical offsets to the ship heights in order to run different loading scenarios, and extended the code-base to allow for filtering of the ship generation engine, which allows the user to focus on specific classes of ships (or even particular ships) in order to investigate particular behavior scenarios.

A common problem with all models of this type is that they are heavily dependent on the quality of the calibration of the source data models used to drive them. Most of the source models used here are observation based and need no further calibration, but the model of potentially unobserved objects (i.e., the objects or bathymetric variations not recorded in the archive data for various reasons) is open to some debate. In particular, there are open questions as to how to predict the object rate, what the distribution of object heights should be, and the spatial characteristics of the object locations. Calder and Lezaeta have therefore begun work on a sub-project to address the calibration of this model, taking into account the known geology of the area along with statistical evidence of object that might be gathered from limited modern data in the area.

THEME: 2.B.2: CHARTS AND DECISION AIDS

TASK 42: ***Ocean Flow Model Distribution and Accessibility:*** *Continue working with the TWCWG to develop S100 specifications for how to disseminate, visualize, and make use of ocean flow data from observation and simulation to end-users. This includes feature-aware compression of immense data sets into smaller and thus more easily transmittable snippets, 2-D visualization methods that integrate into existing charting environments, and analysis tools to increase the usefulness of this data for users.* ***Briana Sullivan***

This project has not yet started under this grant

TASK 43: ***Chart Update Mashup (ChUM) - Modernization of Data Set Maintenance:*** *Continue and enhance the Chart Update Mashup effort by integrating other supplemental data with the chart including Coast Pilot data. Continue Digital 3-D Coast Pilot prototype efforts with a focus on using the database from Coast Pilot Branch at OCS and displaying the structured results in a web-based prototype using Google Maps.* ***Briana Sullivan***

Project: **Coast Pilot Database**
JHC Participants: Briana Sullivan
NOAA Collaborators: Tom Loeper - OCS

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. 43-1). Further examples of the prototype are presented in Figures 43-2 through 43-4.

Figure 43-1: Coast Pilot added menu to jump to chapters after seeing Sullivan's prototype (Figure 8-2).

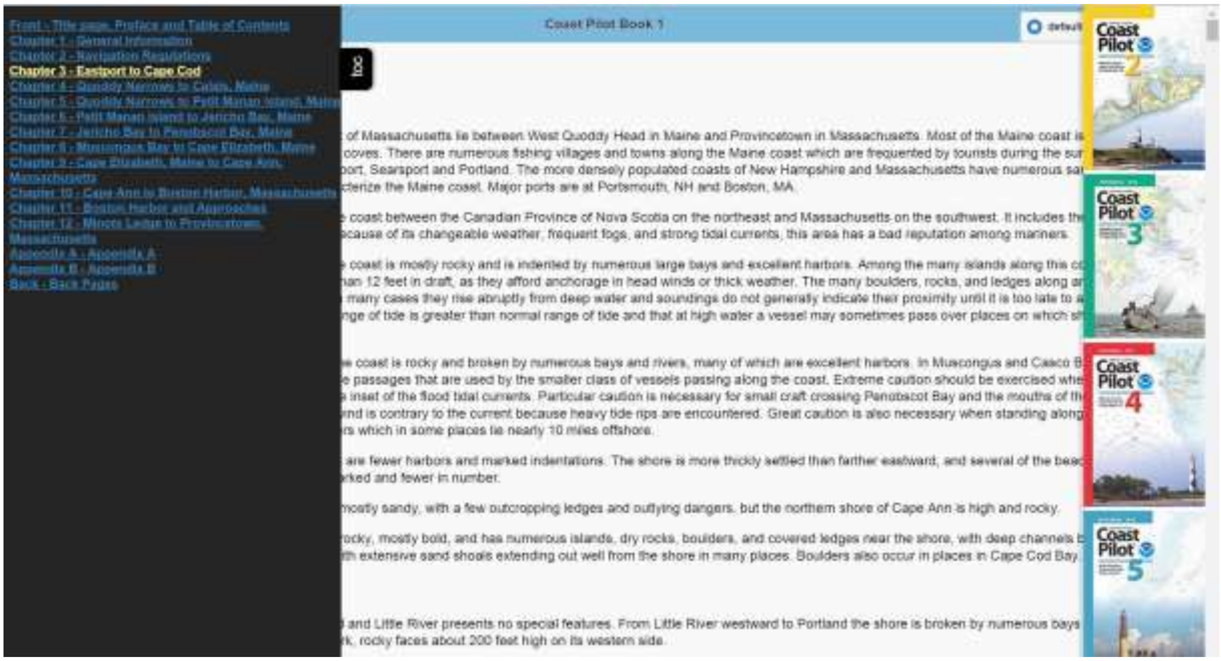


Figure 43-2: Sullivan's 2015 prototype example using jQuery – a more efficient way to navigate within the text-based layout.

Sullivan's work this year has included the "low hanging fruit", i.e., showing how the data can first be filtered by Book (Figure 43-5), then by Chapter and Feature (Figure 43-6), and eventually by Category.

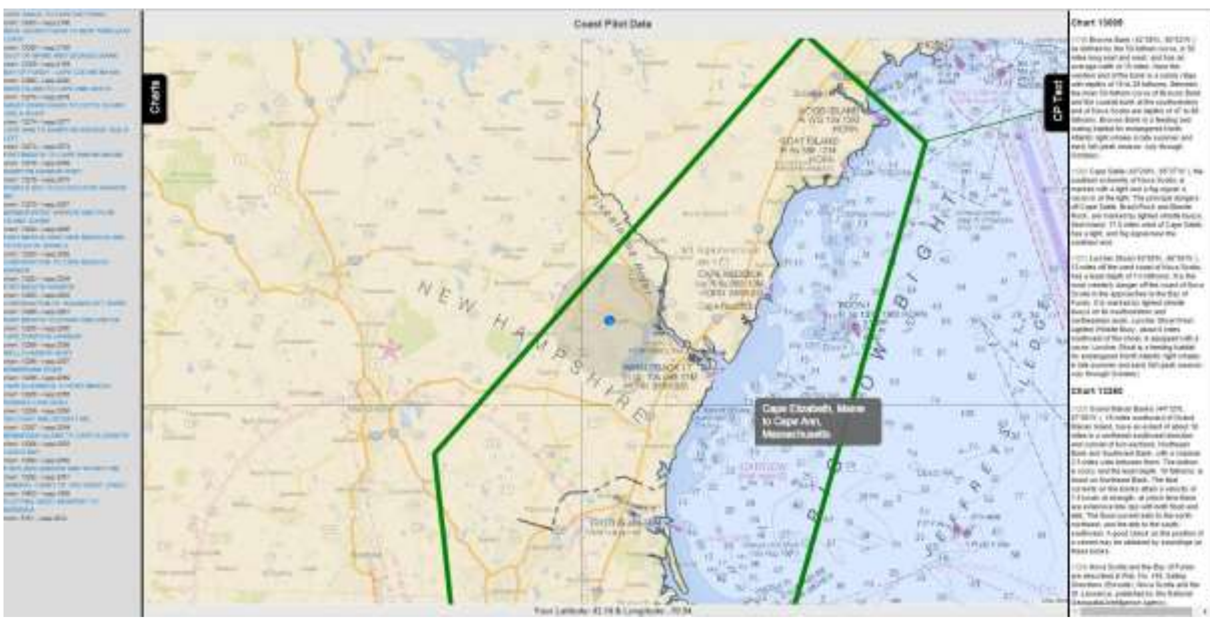


Figure 43-3: iCPilot 2015 Prototype - showing only charts (only tab on the left) within viewport and associated Coast Pilot data.

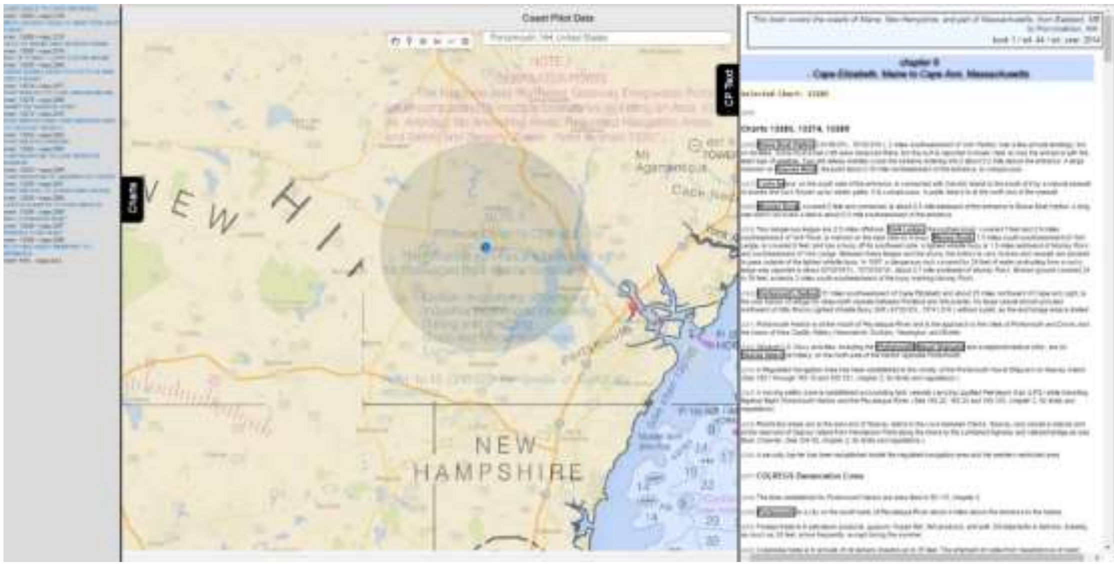


Figure 43-4: iCPilot 2016 Prototype updates: charts tab - showing only first 20 charts within viewport and the associated formatted Coast Pilot data, with the features highlighted.

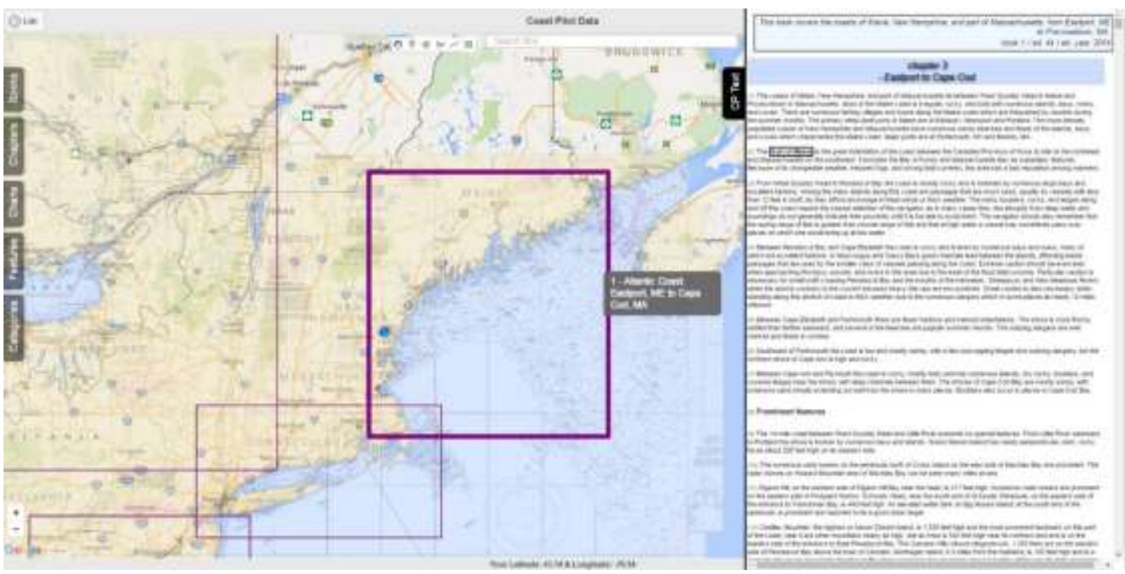


Figure 43-5: iCPilot 2016 Prototype updates: books tab - working tabs (on the left) for Books (book outlines also showing), Chapters, Charts showing only associated Coast Pilot data for each of those geo-referenced areas.

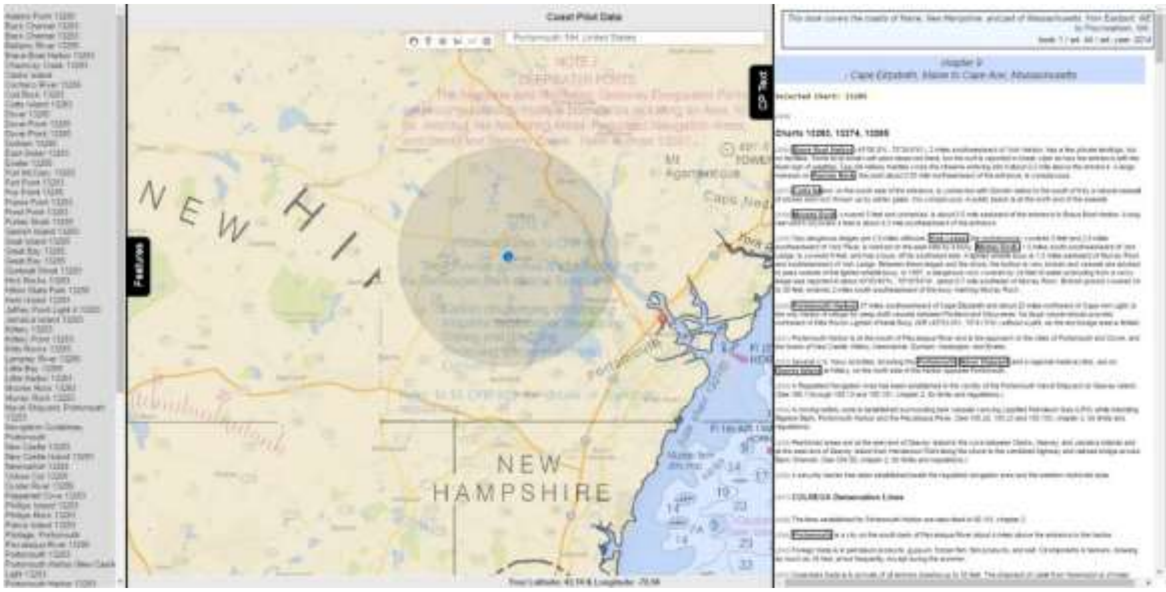


Figure 43-6: iCPilot 2016 Prototype updates: features tab – when the Coast Pilot text is updated (in the CPText tab on the right) the associated features are listed in the Features tab (on the left).

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 43-7). 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.

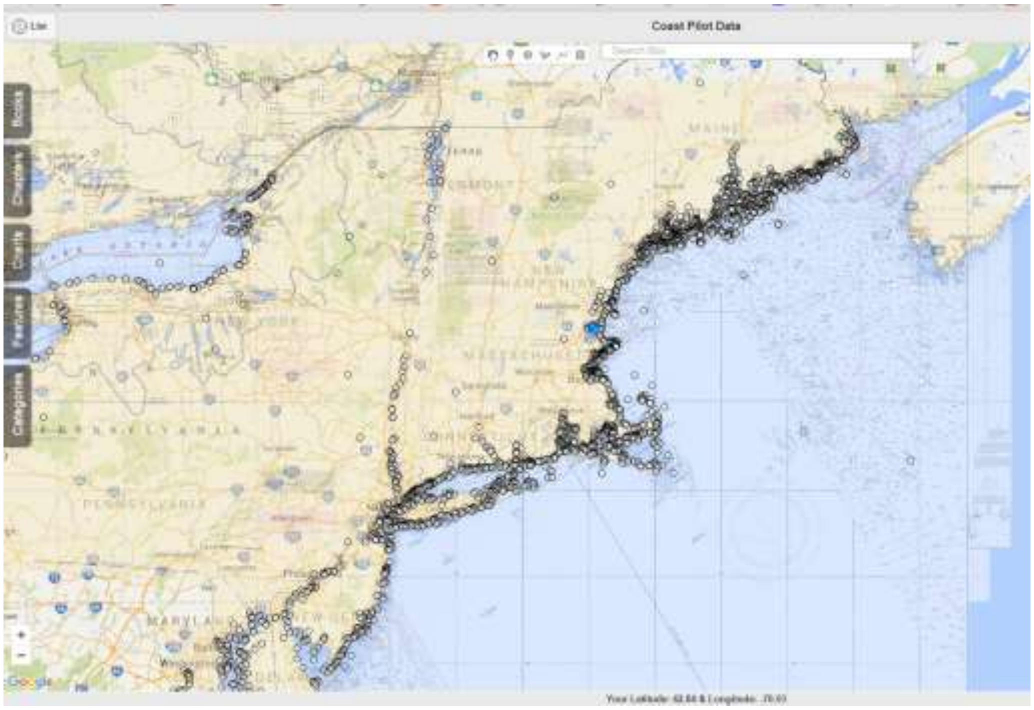


Figure 43-7: Circles representing the chart features that have associated Coast Pilot text

Hovering over a circle will change its color and display the feature's name (Figure 43-8).

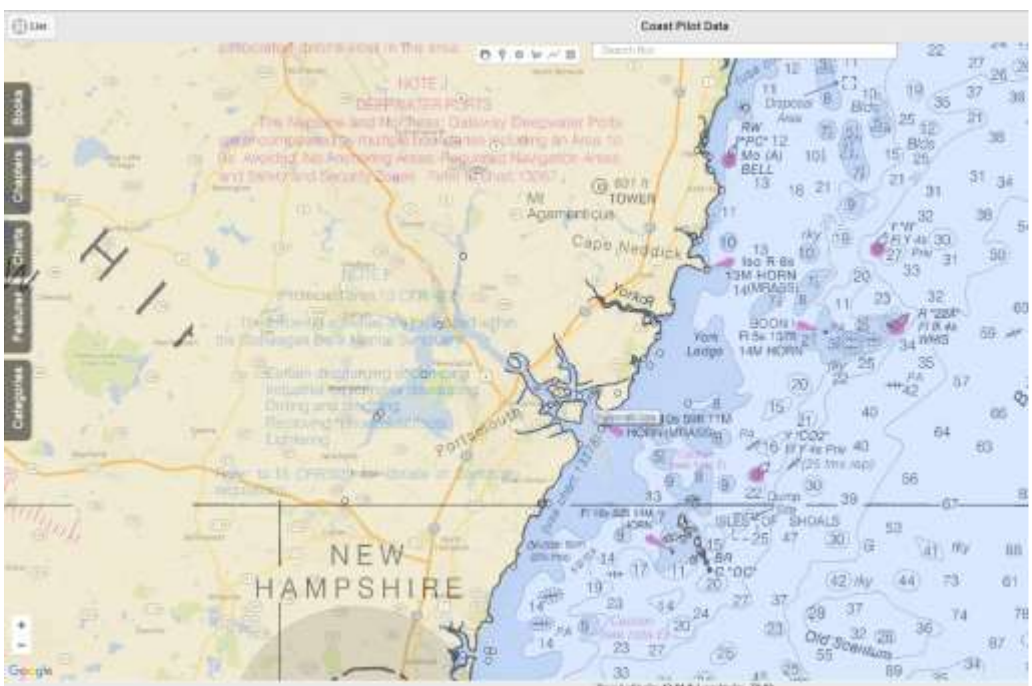


Figure 43-8: Demonstration of hovering over a geo-reference CP-feature

Clicking on the feature will display the associated Coast Pilot text for that feature. (Figure 43-9).

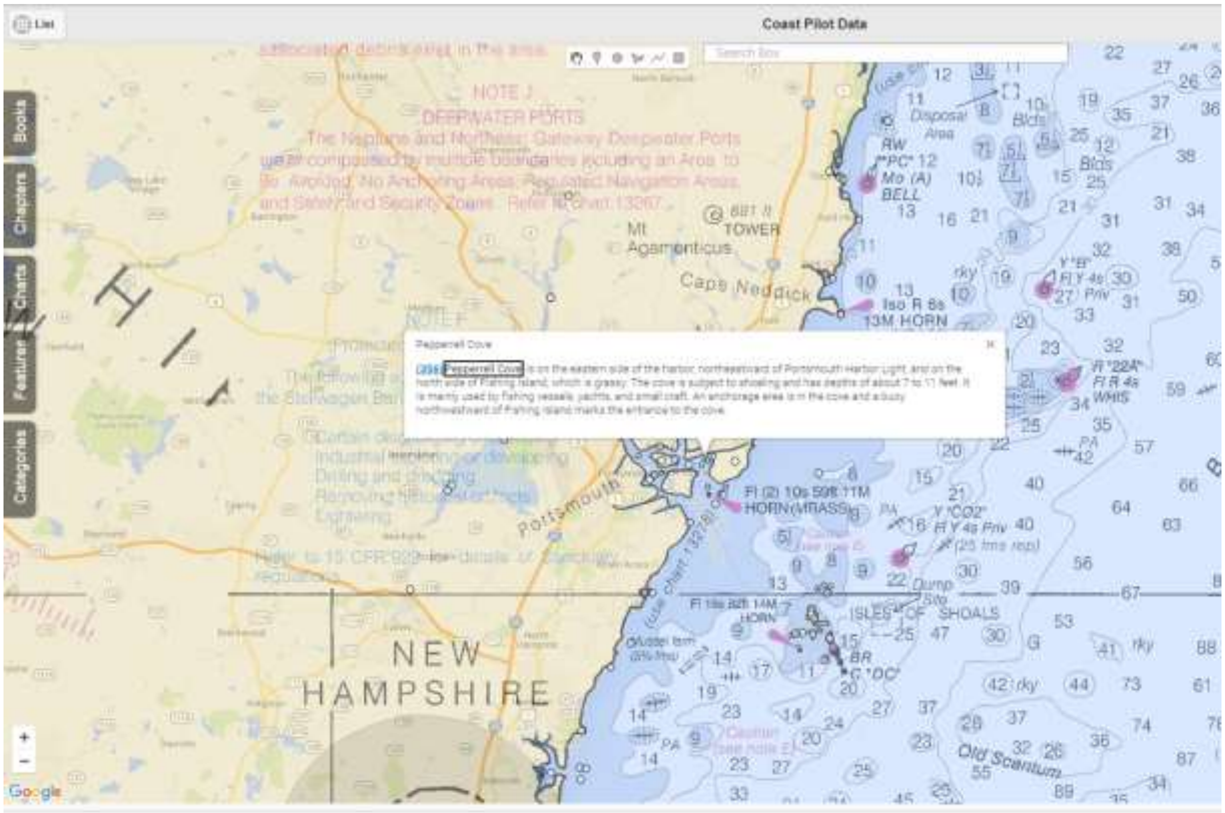


Figure 43-9: Demonstration of click on feature to produce Coast Pilot text

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.

Project: **ChUM – Chart Update MashUp**
JHC Participants: Briana Sullivan
NOAA Collaborators: Tom Loeper - OCS

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 43-10).

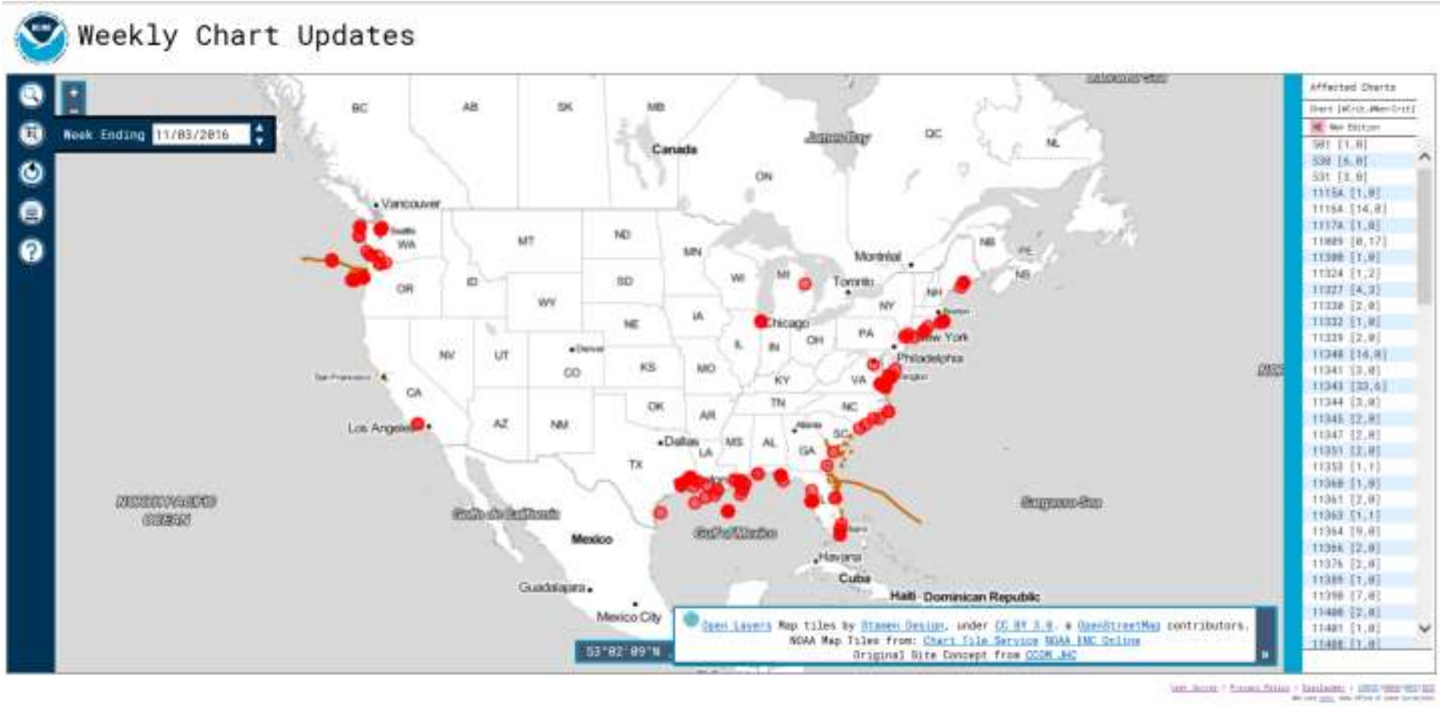


Figure 43-10: OCS Weekly Chart Updates based on the ChuM prototype

Project: **Nautical Information Provision Working Group (NIPWG)**
JHC Participants: Briana Sullivan
NOAA Collaborators: Tom Loeper OCS
Other Collaborators: Jens Schroeder-Fuerstenberg – NIPWG Chair

The March IHO NIPWG meeting resulted in various efforts that align with Sullivan's focus on supplemental information to the nautical chart. The NIPWG is tasked to create a product specification related to the various publications made to supplement the nautical chart including:

S-122 Marine Protected areas product specification

S-125 Marine Services product specification

S-126 Physical Environment product specification

Sullivan's experience for the past few years working with S-111 has put her in a position to give input on the S-122 product specification (the product specification that is most developed). The chair of NIPWG asked Sullivan to participate in reviewing the latest draft of S-122 and give comments as appropriate. This allowed her to contribute to entering model objects and attributes into the Feature Catalogue Dictionary in the new IHO Registry. In this capacity, Sullivan helped to lead the way on to how to use the new registry as well as give valuable feedback on how to improve the registry. She is now in a better position to explain to the other member states how they can also contribute so the work can be better distributed.

Sullivan has also contributed to the S-125 sub-working group. The working group is tasked to come up with the initial data structure for the Marine Services that should be included within the specification. Sullivan's work with the Notice to Mariners (see Sullivan's project: ChUM – Notice to Mariners) overlaps with the tasks of the working group so it will be accomplishing two of her goals with one effort. She worked closely with the Finish representative to S-125 after March, establishing a dialogue on the data structure and needs of S-125.

The S-126 work also overlaps with the work Sullivan is doing with the Coast Pilot data (see Sullivan's project: iCPilot – the interactive Coast Pilot). Her intention is to use the Coast Pilot data as a test case for how things could be done. Implementing the data structure and testing it early in the process will help to guide the working group in what things are important, how things should be laid out, and what the end result could look like.

During the S-126 meeting Sullivan had the opportunity to canvas the various Hydrographic Organization's (HOs) representatives to find out how they intended to implement the standards. The resounding response was "I have no idea!" Sullivan proposed a visualization workshop to show proof-of-concepts for how to visualize the hydrographic, but also to have a forum where HOs as well as industry could come together and discuss ideas for how they would like to see data integrated into their various systems. Sullivan also suggested that the HOs would have a place to share how they are currently generating their publications to get ideas and contacts for collaboration for how to transition to the S-1xx standards. Sullivan agreed to host this important workshop at UNH in May 2017.

TASK 44: ***Augmented Reality in Electronic Charting and Navigation****: Research on how to utilize augmented reality devices in support of enhanced navigation. Expand and modify to provide a range of scenarios (collision avoidance, harbor entry, etc.) using our virtual ship simulator.* ***Tom Butkiewicz and Vis Lab***

Project: **Augmented Reality for Marine Navigation**
JHC/CCOM Participants: Tom Butkiewicz, Andrew Stevens, Colin Ware

Augmented Reality (AR), which is the superimposition of digital content directly over a user's real world view, is an emerging technology that may have great potential for aiding safe marine navigation. The first mass-produced AR device, Microsoft's HoloLens, is now available. Butkiewicz evaluated the HoloLens and found it unsatisfactory for marine navigation use due to a variety of shortcomings. Firstly, the HoloLens is not bright enough for viewing outdoors in sunlight. Its inside-looking-out tracking system is also unsuited for a marine environment, as it is designed to work in an interior room, not a windowed bridge looking out onto open water. Finally, the field-of-view is poor, only approximately 40 degrees. This would make it impossible to provide satisfactory situational awareness, as the user would only get information in the very center of the field of view and would miss anything in the near periphery.

To explore the potential of future, more capable AR devices, Butkiewicz has been developing an AR simulator. This virtual reality (VR) system will allow simulation of a wide range of possible AR devices, without the need for the actual AR technology or solving complicated registration challenges. For example, we can experiment with providing the AR overlays at a range of different field-of-view angles, which should provide insight into the capabilities necessary for AR hardware to provide good situational awareness in marine navigational tasks.

Butkiewicz has set up an HTC Vive VR system in the data visualization research lab. The system uses a laser-based wide-area tracking system to track users and hand-held interaction devices within a 5m x 5m space. This is sufficient to provide for a one-to-one re-creation of the R/V *Gulf Surveyor's* (RVGS) bridge area, allowing users to walk around the RVGS's bridge as they would in real life, for example moving from window to window, and even leaning one's head out the side doors to look aft.

Butkiewicz has evaluated two candidate software engines for creation of the simulation, the Unreal Engine and the Unity Engine. Experimentation with the Unreal Engine showed it was very capable for rendering of terrain and bathymetry data, and was extensible enough to support a custom shader that generated real-time, color-coded, tide-aware draft depth alerts (Figure 44-1). While the Unreal Engine was excellent for many aspects of the project, it was missing a key feature that would be needed for our purposes – it did not have the ability to separate entities into multiple rendering layers which can be seen or not seen by the multiple cameras needed to simulate an AR interface. This feature is available in the competing Unity Engine, which was therefore selected for future development.

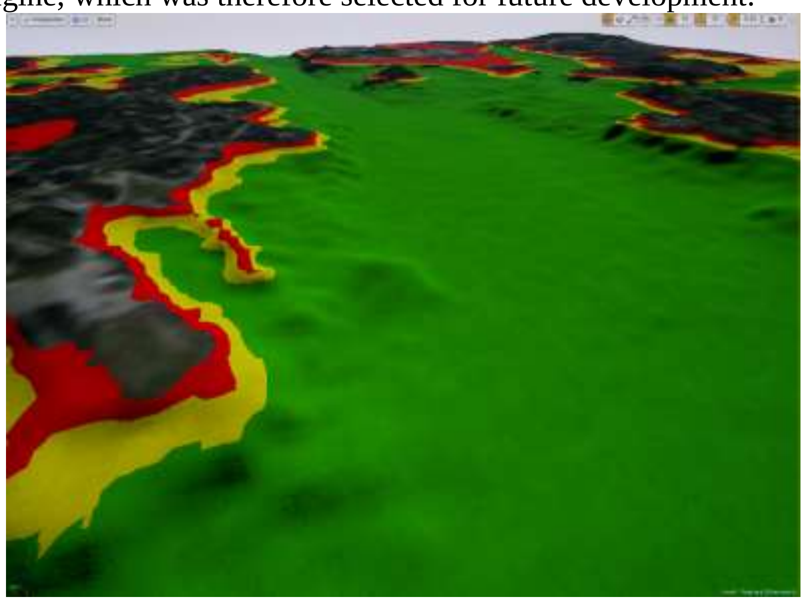


Figure 44-1: Screenshot from the Unreal Engine based simulator, showing bathymetry data around the UNH Pier in Newcastle, NH. Bathymetry is color coded in real time to provide tide-aware warnings for water depths within range of vessel draft. (Green is safe, yellow is warning/risky, red is too shallow.)

Butkiewicz is currently developing the AR simulator using the Unity Engine. While Unity was not designed to support georeferenced terrain, its built-in terrain engine is flexible enough to ingest some real-world geospatial data. Butkiewicz is developing custom code to better support common georeferenced/geospatial data types, and has documented a standard process that allows for common geospatial formats to be converted into compatible formats and imported into the Unity Engine. Once in a compatible format, Unity's terrain engine takes care of the usually difficult tasks such as managing level of detail, and produces a very fast visualization of the data (Figure 44-2).

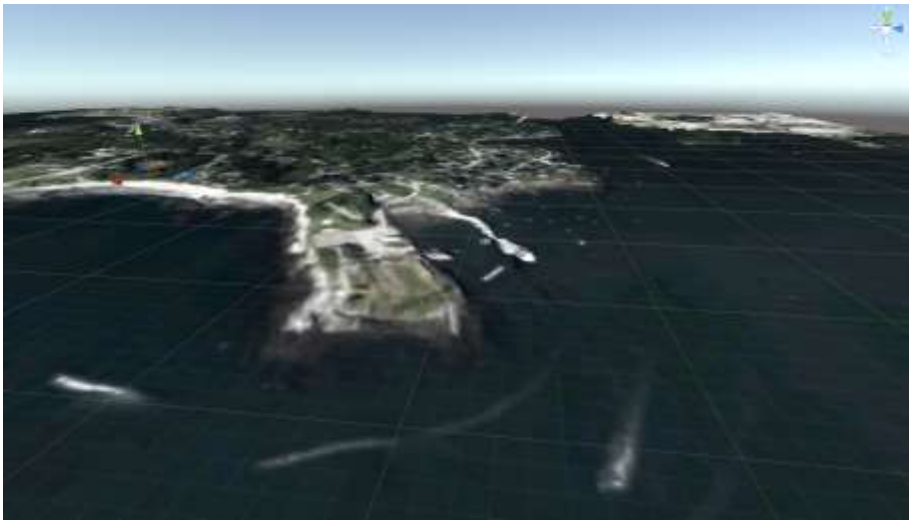


Figure 44-2: Screenshot from Unity engine editor of a terrain model of Newcastle, NH / Portsmouth harbor. Data is ~1m resolution derived from DEMs and bathymetry maps, textured with satellite photos.

An ancillary goal of this project is to create a digital version of the Center's new vessel, the R/V *Gulf Surveyor*, both for possible training purposes and to allow for side-by-side real-world to virtual-world comparison in human factors studies. Butkiewicz experimented with using ground-based LIDAR data previously collected by an outside surveying company to recreate 3D models of the *Gulf Surveyor* (see FACILITIES section of INTRODUCTION), however the data lacked color (having only basic grayscale reflectance) and had many holes (Figures 44-3 and 44-4). Instead, Butkiewicz and graduate student Andrew Stevens combined sections of the LIDAR scans along with hand-modeling to produce a cleaner bridge model, which is currently being textured with photographs of the actual vessel (Figures 44-5 and 44-6). The screens on the virtual bridge will support data/charts being drawn on them in real time to simulate actual navigation tasks.

Figure 44-3: The raw point cloud from the ground based LIDAR scanner.

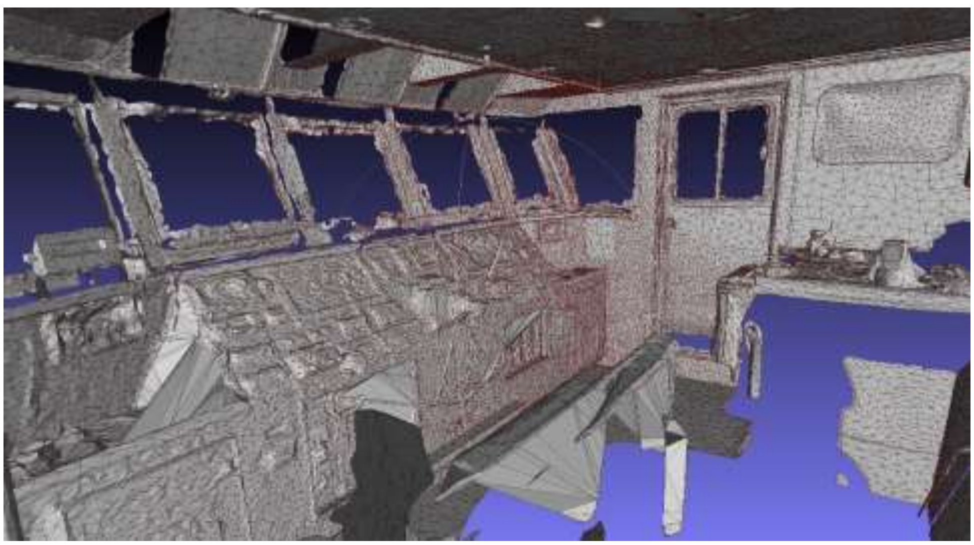


Figure 44-4: Uncleaned and untextured simplified 3D model of Gulf Surveyor's bridge, generated from the point cloud of a ground based LIDAR scanner.

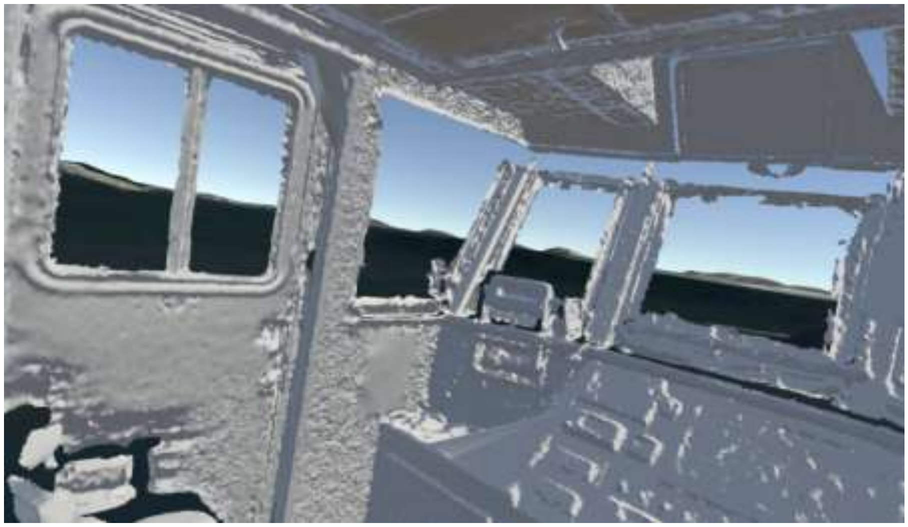


Figure 44-5: Testing screenshot from within simulator, showing view from inside virtual Gulf Surveyor bridge (model is uncleaned and untextured) looking out at Portsmouth Harbor towards Kittery, ME.

Figure 44-6: Screenshot from within simulator, showing view from inside virtual Gulf Surveyor bridge, with photo-textured instrument panel, looking towards UNH's Newcastle Pier.

The terrain models used in the simulation were generated using 1m DTMs and bathymetry data, and were textured by draping satellite photos. This provides a decent base, and makes good coastlines / ridgelines at a distance. However, it looks blurry when near the shore, and lacks important details like navigational landmarks. To address this, and provide more realistic shorelines, Butkiewicz has been experimenting with 3D coastline capture using Structure-from-Motion (SfM).

Butkiewicz has successfully demonstrated the creation of high-resolution 3D, photo-textured coastline models using only standard digital photographs as input. In collaboration with Shachak Pe'eri and John Kidd, a DSLR camera was included alongside a LIDAR sensor on a short LIDAR data collection cruise around the UNH pier. The camera took a photo off the side of the RVGS towards shore every 1 second, resulting in a data set of approximately 400 photos.

These photos were processed using the Structure-from-Motion algorithms in Agisoft's PhotoScan. The photos are first examined to find matching visual features that allow images to be registered with each other, and the location and orientation of the camera is then determined for each photo. The details in the paired images are then projected out into a colored point cloud. This point cloud can then be triangulated into an irregular 3D mesh or a height-mapped 2.5D surface. High resolution textures are generated that, when applied to the mesh, provide excellent detail.

As seen in the following images (Figure 44-7 through 44-14) the resulting mesh is very high-resolution, although the accuracy is yet to be determined. This could be done by registering the point cloud with the simultaneously collected LIDAR data. The accuracy is sufficient for use in our simulation, where the models are primarily used for visual purposes. Even though they are mostly just facades of the objects (pier, buildings, trees), they appear complete in the simulation because the user is always in a boat on the water, a viewing angle that matches the collection angles.

Figure 44-7: A sample photo (of Fort Constitution and the New Castle Coast Guard station) taken from the DSLR camera that took a photo every second.

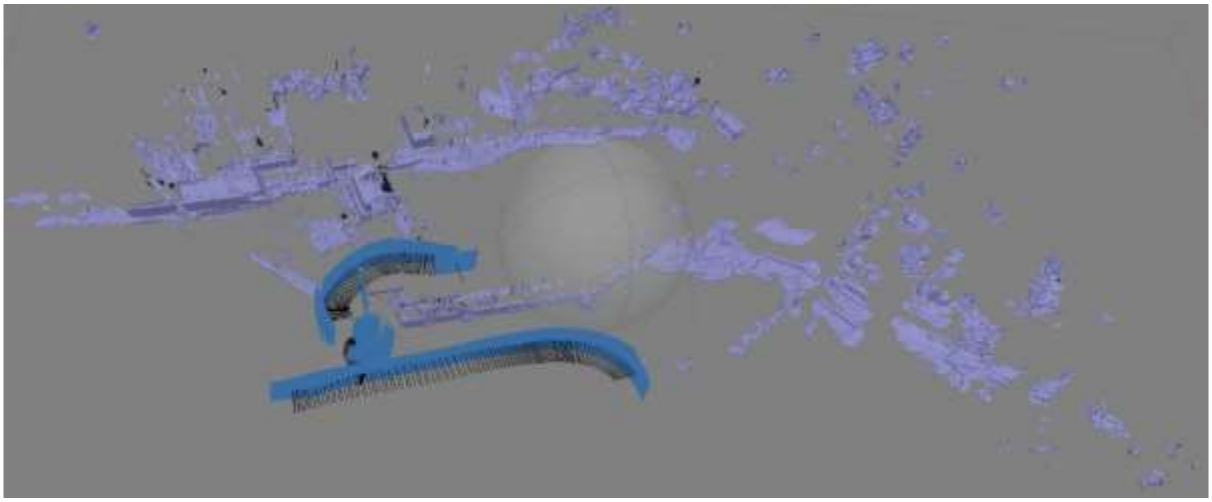


Figure 44-8: The calculated camera locations and resulting full-resolution triangular mesh for the 394 image dataset.

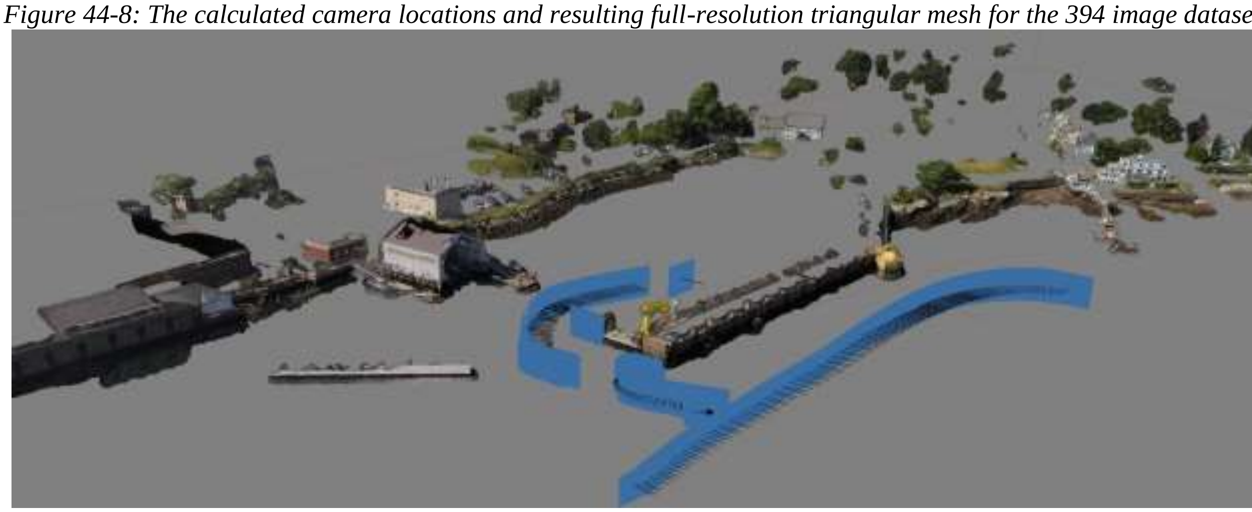


Figure 44-9: The resulting mesh with photo textures applied.

Figure 44-10: Color point cloud of Fort Constitution waterline.

Figure 44-11: Color point cloud of the waterline/shoreline at Fort Constitution and New Castle Coast Guard station.

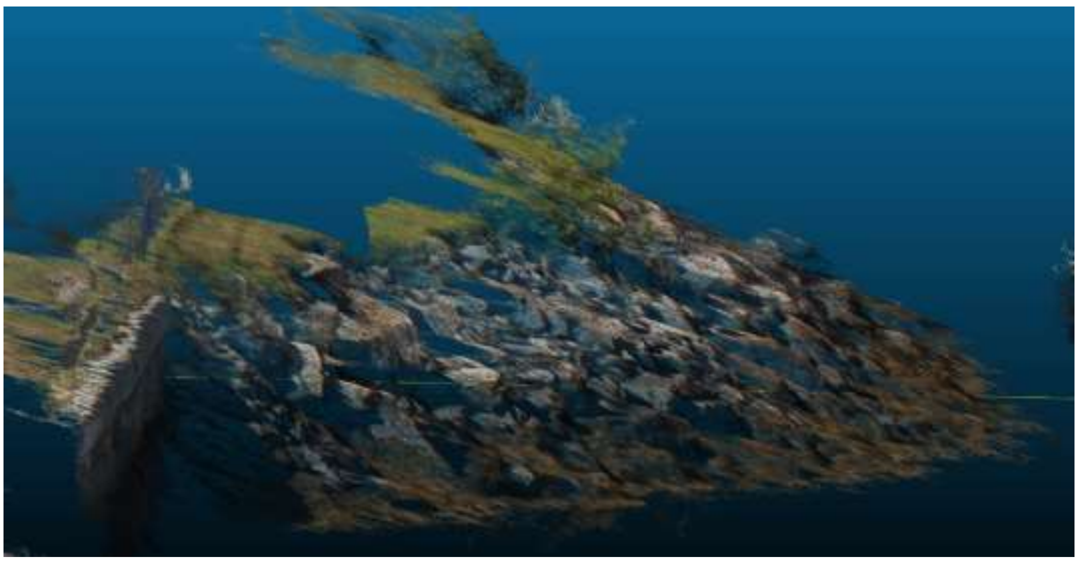


Figure 44-12: Detailed side view of the color point cloud shown in the previous figure, showing the 3D detail of the point cloud capturing the rocks / rip-rap.

Figure 44-13: Panoramic screenshot from inside the AR simulator showing the models generated through the SfM process using this 394 photo dataset.

The simulation now has a functional ocean model, complete with physics (buoyancy, etc.), that allows the sea state to be changed from calm to stormy. The weather (fog) and time of day can also be changed dynamically, such that we can lower visibility to almost nothing if desired to show how AR could aid navigation in zero-visibility scenarios. Lighthouses and buoys are currently being added based on the NOAA charts, with their lights' colors and blink patterns replicated.

Figure 44-14: Different visibility conditions in the AR simulator, with Portsmouth harbor lighthouse in the background behind Fort. Constitution.

RESEARCH REQUIREMENT 2.C: VISUALIZATION AND RESOURCE MANAGEMENT

FFO Requirement 2.C: *"Improvement in the visualization, presentation, and display of hydrographic and ocean and coastal mapping data, including 4-dimensional high resolution visualization, real-time display of mapping data, and mapping and charting products for marine navigation as well as coastal and ocean resource management and coastal resilience."*

THEME: 2.C.1: GENERAL ENHANCEMENT OF VISUALIZATION

TASK 45: ***Tools for Visualizing Complex Ocean Data****: Continue our work producing novel 2-D, 3-D, and 4-D visualization solutions that address the unique needs of coastal and ocean applications. This work will focus on: developing novel visualization and interaction techniques; conducting human factors studies to understand the perceptual issues critical to creating successful visualizations, and; improving existing marine data visualization applications based on these findings.* ***Colin Ware and Vis Lab***

Project: **BAG Visualization Tool**
JHC/CCOM Participants: Roland Arsenault, Brian Calder, Giuseppe Masetti

A tool, bagViewer, was developed by Roland Arsenault to interactively display Bathymetric Attributed Grid (BAG) files. A primary goal of bagViewer is to allow the exploration of BAG's variable resolution extensions developed by Brian Calder.

A BAG is displayed as an interactive 3D surface with top down lighting and color-coding-by-depth provided from a selectable color map. Navigation is inspired by the center of workspace concepts as seen in GeoZui4D and Fledermaus. Moving around on the surface is accomplished by clicking the middle mouse button or wheel while rotating around the center of the scene is enabled when the left mouse button is depressed. The mouse wheel is used for zooming into the scene and the right mouse button allows vertical exaggeration to be controlled.

The bagViewer software is targeted towards multiple platforms with modern graphics GPUs. Cross platform capability is achieved using the C++ programing language augmented with the Qt cross platform GIU framework and the OpenGL graphics API. The build process is controlled by CMake which can target multiple platforms and development environments. Development is being done by Arsenault on a Linux machine while Giuseppe Masetti provides testing on Windows with Visual Studio and Calder does the same on MacOS with XCode. Reading of BAG files is through the Open Navigation Surface's BAG library.

Modern OpenGL (version 3.2, core profile) is being used to navigate large, multi-gigabyte BAG files interactively. Data transfer between the CPU and GPU, which may become an I/O bottleneck, is minimized by storing elevation and normals (used for lighting) as texture maps in GPU memory. Shaders are used to lookup depths from the elevation texture and to adjust the vertices of a predefined unit grid tile to a given elevation. This approach saves on memory by only saving a height per vertex, and calculating the x and y components based on tile position. This tiling is also used to perform view frustum culling to speed up rendering. Standard tiles have been designed to allow multiple level of detail (LOD) based on dyadic simplifications of the tile to achieve interactive rendering speeds.

The current state of bagViewer is that BAG files of various sizes may be loaded and displayed while being navigated in an interactive fashion. The variable resolution extensions have been added in the current reporting period. Load times for larger BAGs may be significant, which is a limitation of the BAG file format: in some cases, large areas of null values still have to be read into memory to determine that they are null. (The Open Navigation Surface Working Group have, as a target for the next release of the library, a solution for this problem.) Figures 45-1 and 45-2 show BAG data from ECS cruise KM1520. In order to make the software more available, bagViewer is now included as an optional part of the standard release of the BAG library, supported by the Open Navigation Surface Working Group.

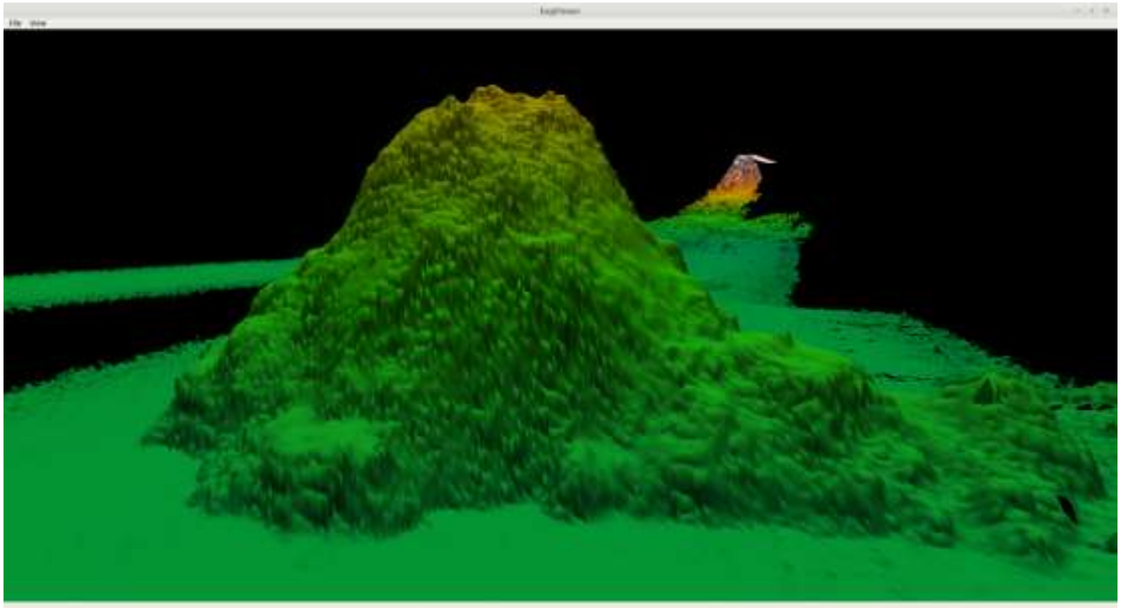


Figure 45-1: Patch test area for the KM1520 cruise seen in bagViewer.

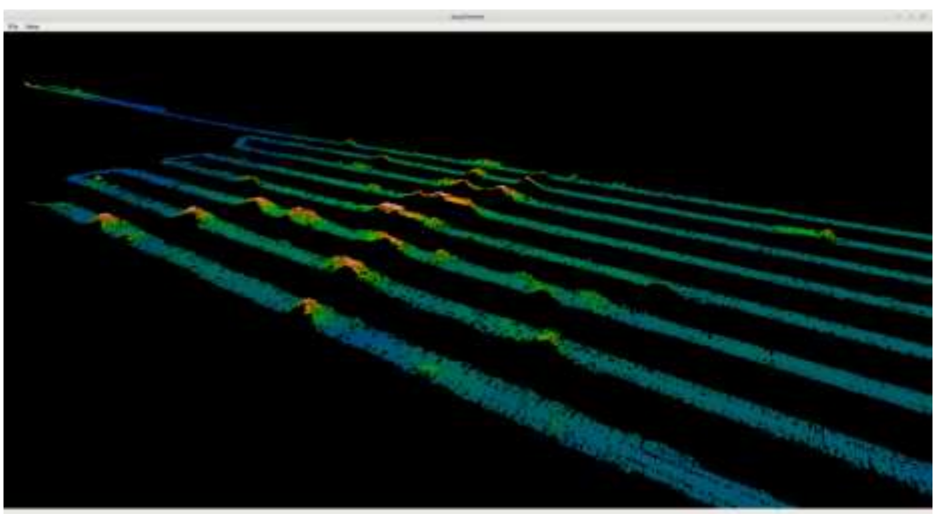


Figure 45-2: Large (13GB) BAG file generated from in-progress KM1520 cruise. Despite the large size, the scene may be navigated interactively with bagViewer.

Project: **Hairy Slices**
JHC Participants: Colin Ware, Drew Stevens, Tom Butkiewicz

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 45-3, 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.

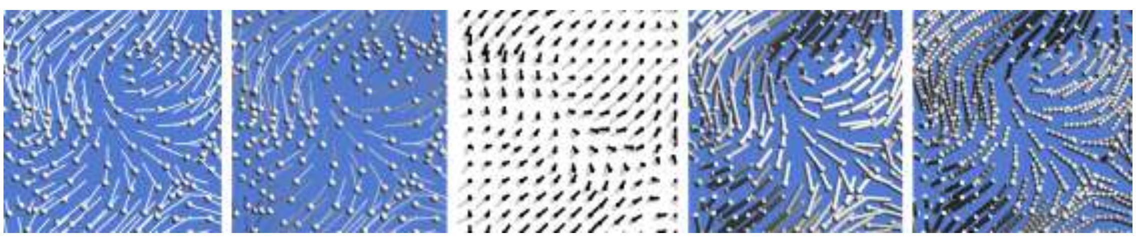


Figure 45-3: Hairy Slices though a vector field portrayed in five different ways.

TASK 46: ***New Interaction Techniques****: Study and develop new interaction techniques and user interfaces that go beyond the usual "mouse and keyboard" paradigm, and explore how these can be applied within ocean mapping and related domains. This includes natural interfaces such as multi-touch displays and gesture-based interfaces.* ***Tom Butkiewicz and Vis Lab***

This project has not yet started under this grant

PROGRAMMATIC PRIORITY 3: EXPLORE AND MAP THE CONTINENTAL SHELF

RESEARCH REQUIREMENT 3.A – EXTENDED CONTINENTAL SHELF

FFO Requirement 3.A: : *"Advancements in planning, acquisition, understanding, and interpretation of continental shelf, slope, and rise seafloor mapping data, particularly for the purpose of delimiting the U.S. Extended Continental Shelf."*

TASK 47: ***Lead in Planning, Acquiring and Processing ECS Bathymetric Data:*** *Maintain role as lead in the planning, acquisition, and interpretation of ECS bathymetric and backscatter data, applying advances in acoustic system calibration and operational "best practices" developed in support of other Program Priorities to improve the quality of data collected on the continental shelf, slope, and rise, with particular regard for the Center's involvement in ocean exploration campaigns aboard the NOAA Ship Okeanos Explorer (both at sea and via telepresence) and other ECS mapping projects.* ***Jim Gardner, David Mosher, Larry Mayer***

Project: **Planning and Acquiring ECS Data**
JHC/CCOM Participants: Jim Gardner, Larry Mayer, David Mosher, Brian Calder, Giuseppe Masetti
NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), John McDonough (OER)

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 47-1). 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.

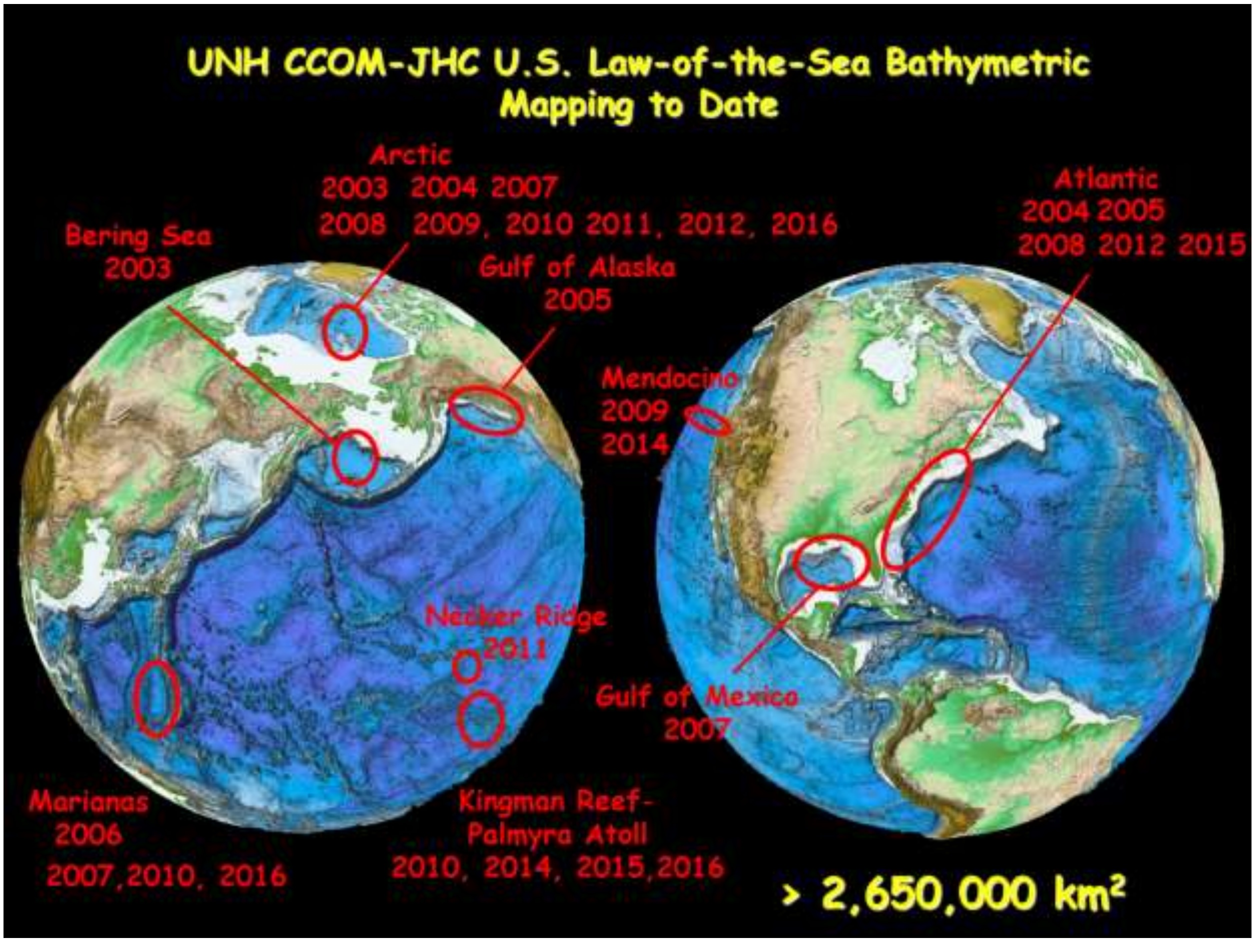


FIGURE 47-1. Summary of Law of the Sea multibeam sonar surveys collected by the Joint Hydrographic Center. To date more than 2.65 million square km of data have been collected.

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 47-2 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.

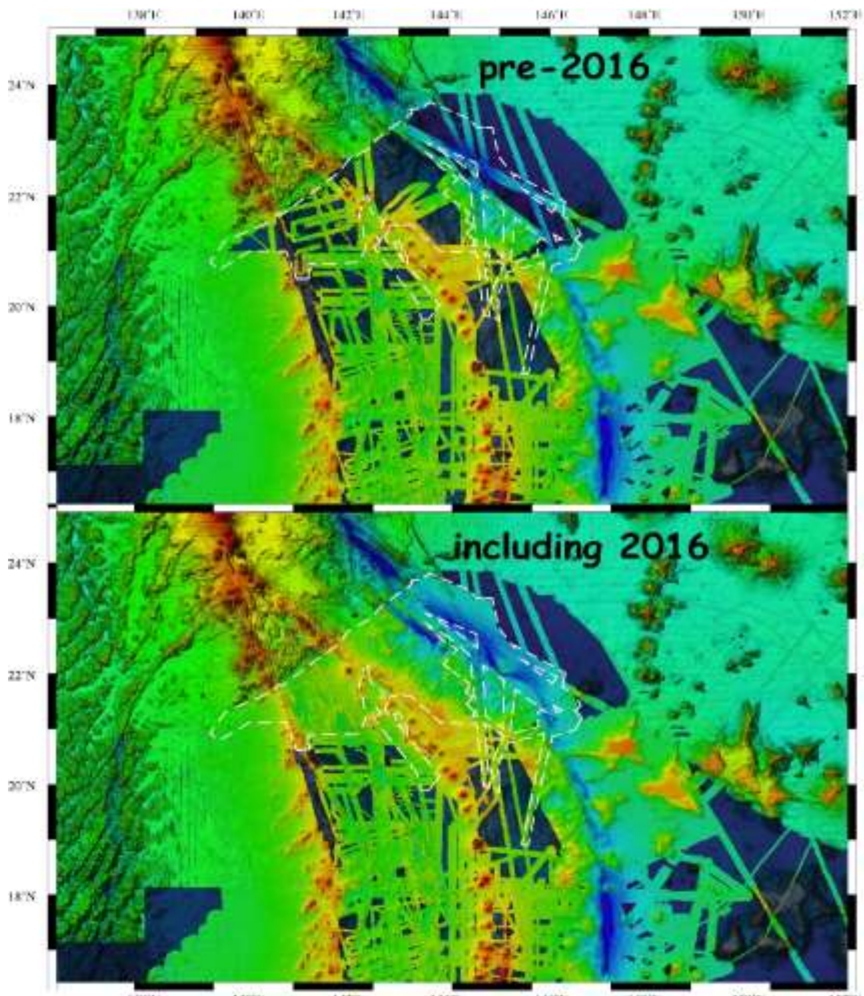


Figure 47-2: Upper panel shows pre-2016 MBES coverage; lower panel shows coverage after the 2016 ECS cruise. White polygon outlines the area mapped in 2016.

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. 47-3), 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. 47-4). 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.

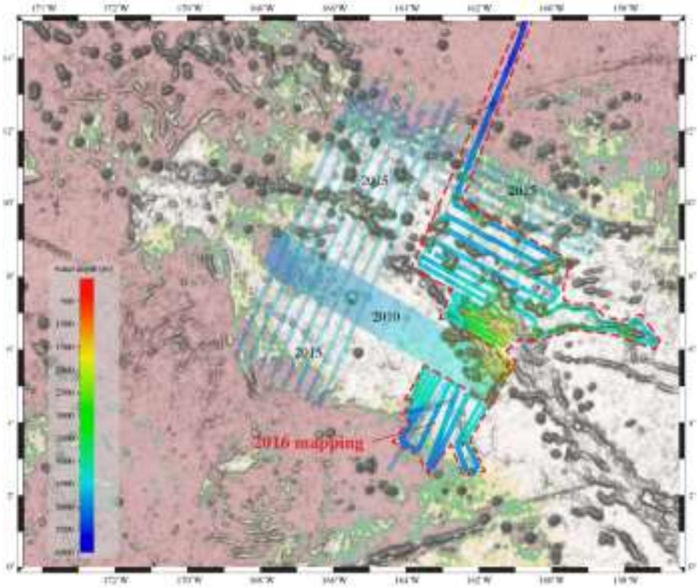


Figure 47-3: JHC/CCOM ECS multibeam bathymetry collected in Kingman Reef-Palmyra Atoll area. Semitransparent multibeam lines collected in 2010 and 2015. Red dashed area outlines data collected in 2016. White area on base map is the Line Islands platform. Base map from Sandwell and Smith v. 18.1.

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, and 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.

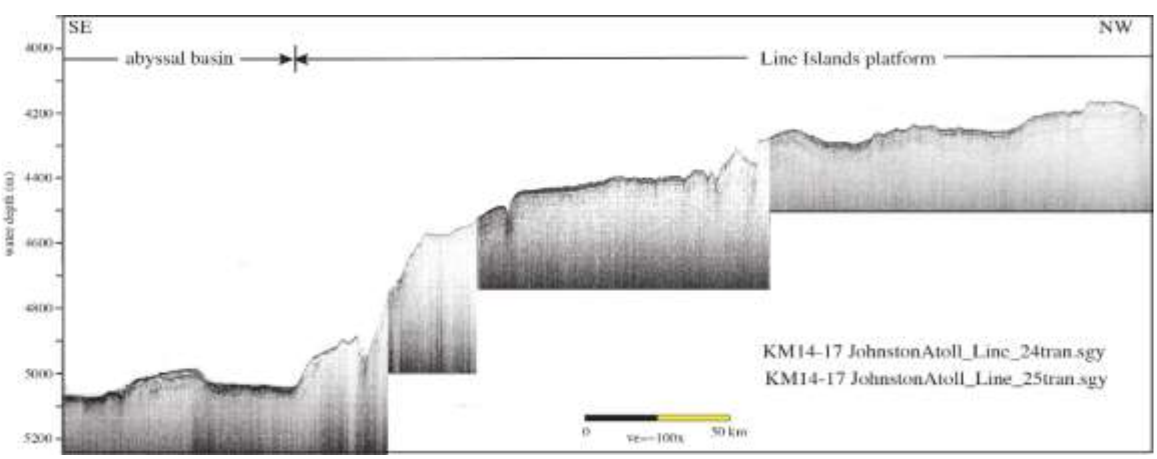


Figure 47-4: Knudsen subbottom profile across the western edge of the Line Islands platform that Kingman Reef and Palmyra Atoll are constructed on.

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 47-5). 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.

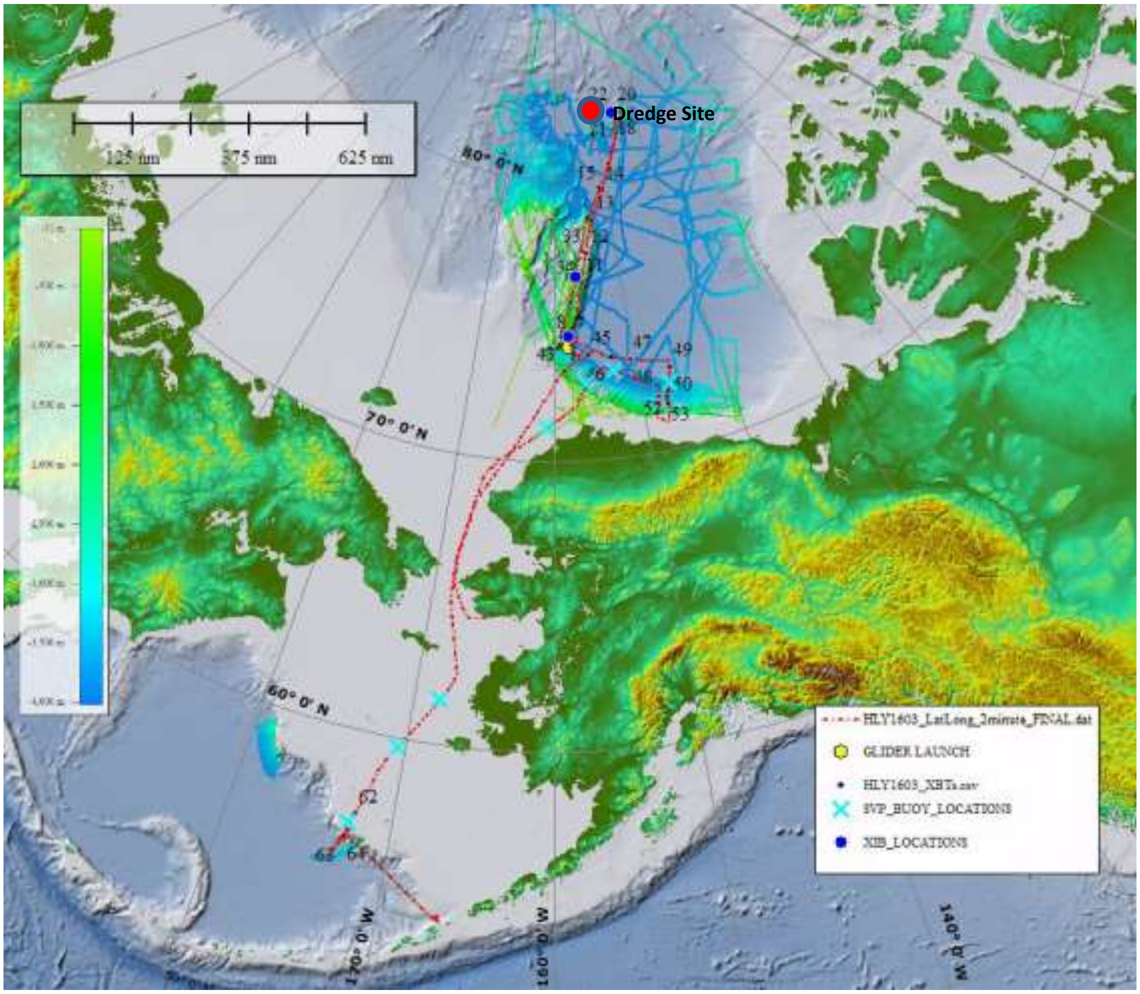


Figure 47-5: Trackline for HEALY 1603, 2016 ECS cruise in the Arctic. Red circle represents location of dredges collected for Canada.

Project: **Generation and Validation of New Law of the Sea Bathymetry and Backscatter Grids and Derivative products.**
JHC/CCOM Participants: Jim Gardner, Paul Johnson, Brian Calder, Giuseppe Masetti, Larry Mayer
NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), Elliot Lim (NCEI), Jennifer Jencks (NCEI)

Over the course of 2016, Jim and Paul 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 47-6, 47-7, and 47-8). 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 true, 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 47-6: Location map showing the final bathymetry over each of the core Law of the Sea sites, except for the Arctic.

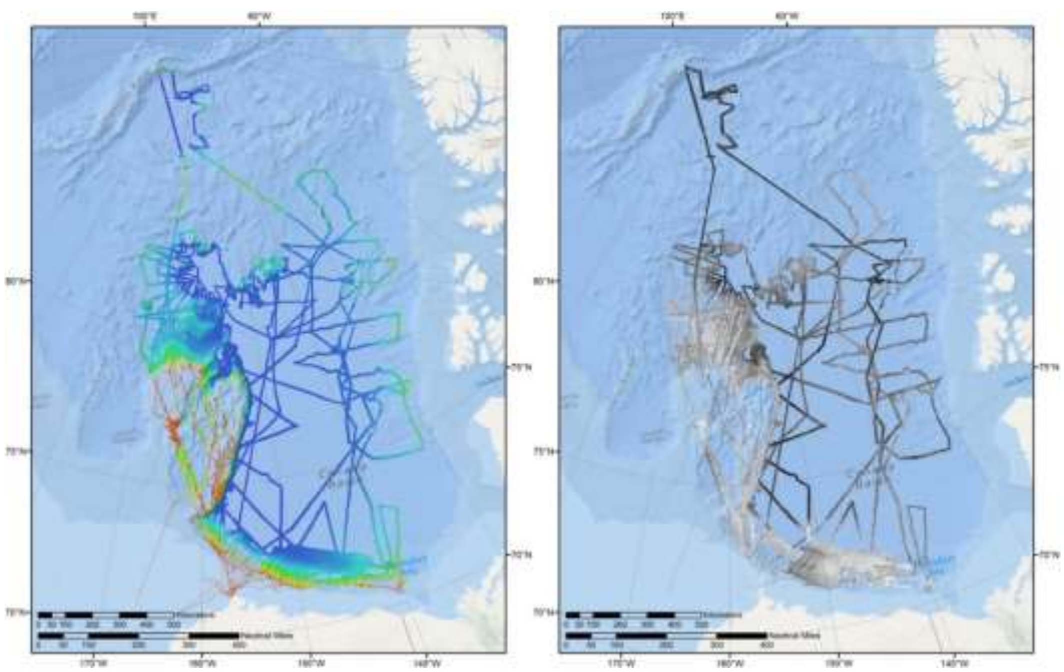


Figure 47-7: Final Arctic bathymetry and backscatter grids as submitted to the Law of the Sea program office.

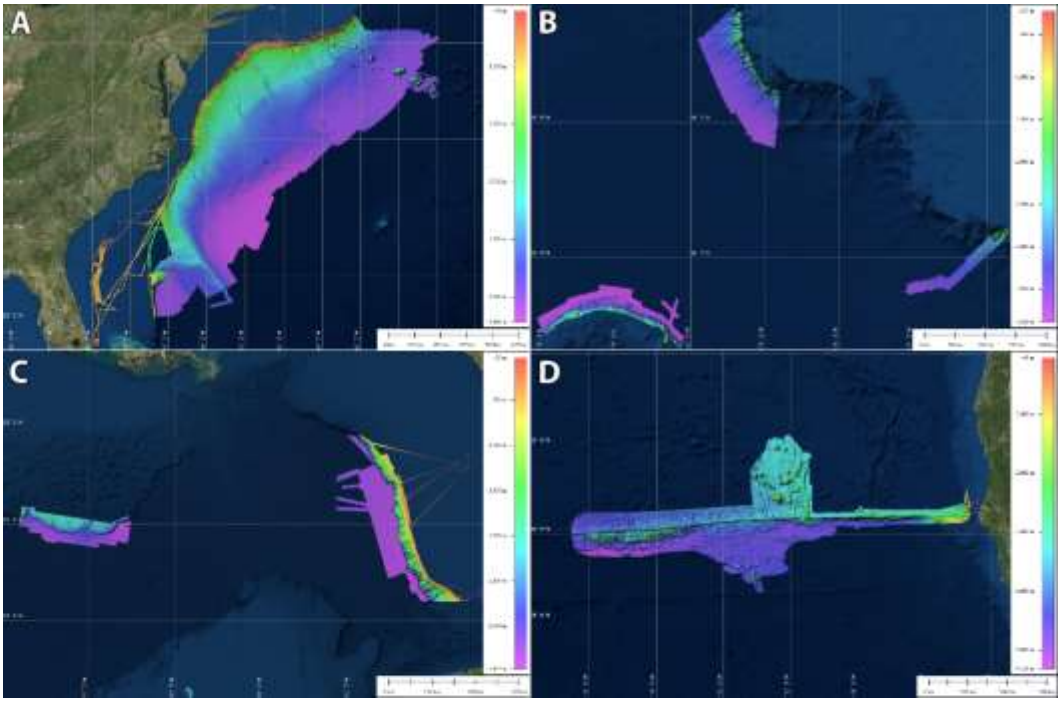


Figure 47-8: Final core area bathymetry grids for the Atlantic Margin (A), the Bering Sea including the Beringian Margin and Bowers Ridge (B), the Gulf of Mexico including the Eastern and Western Gaps (C), and Mendocino Ridge (D).

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 (i.e., Figure 47-7, 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 for the generation 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 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 surveys backscatter. Grids were then fused based on this ranking into a single backscatter grid file (i.e.,Figure 47-7, right).

Following completion of the bathymetry and backscatter gridding, metadata was 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 a 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 assessable 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 47-9; 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.

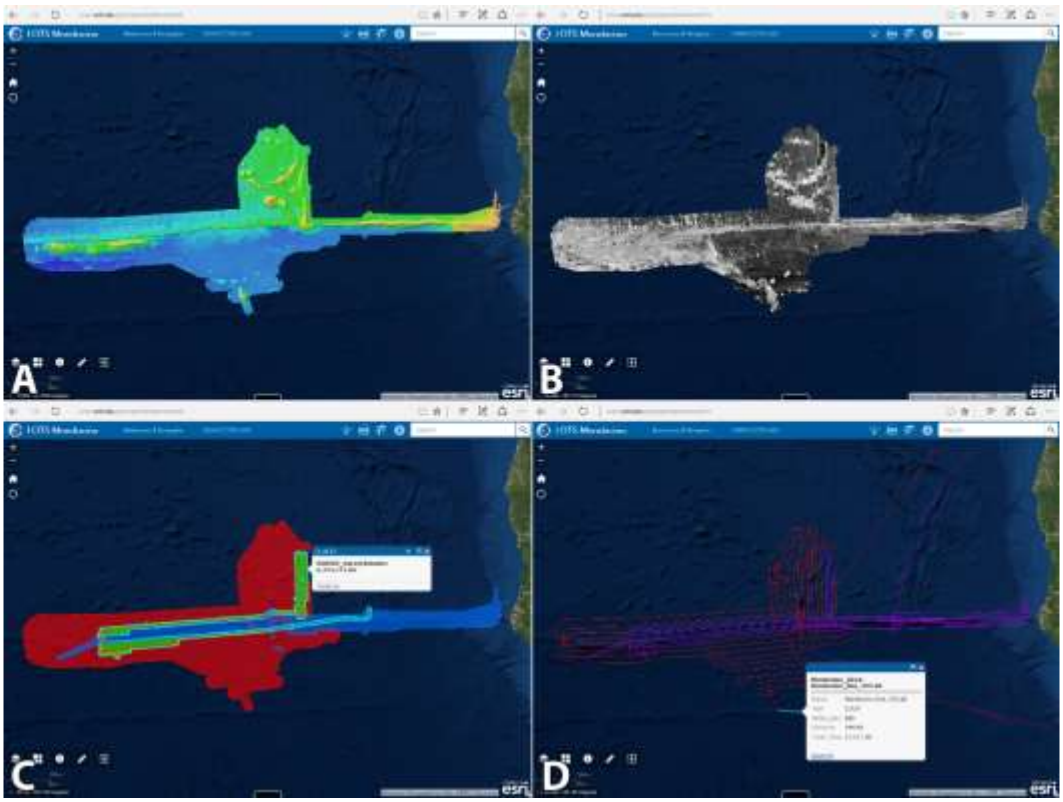


Figure 47-9 Mendocino Ridge bathymetry (A), backscatter (B), survey bounds (C), and navigation (D) dynamic maps available through the Center's website at **http://ccom.unh.edu/gis/maps/Mendocino2016/** .

TASK 48: ***Extended Continental Shelf Task Force:*** *Continue to play an active role in ECS Taskforce activities, as well as working on the analysis and documentation needed to delineate the U.S. Extended Continental Shelf and continue to publish geologic and morphologic interpretations of the mapped regions in peer-reviewed scientific literature.* ***David Mosher, Jim Gardner, Larry Mayer***

Project: **2016 ECS Meetings, Manuscripts and Bathymetry Analyses**

JHC/CCOM Participants: Jim Gardner, Larry Mayer, David Mosher, Paul Johnson, Brian Calder,

NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), Elliot Lim (NCEI), Jennifer Jencks (NCEI)
Other Participants: Brian van Pay (State Dept), Kevin Baumert (State Dept)

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.

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. 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.

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 48-1a and 48-1b 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 and these were applied to each of the 12 areas of ECS interest, and the resulting histograms and statistics have been sent to the Project Office.

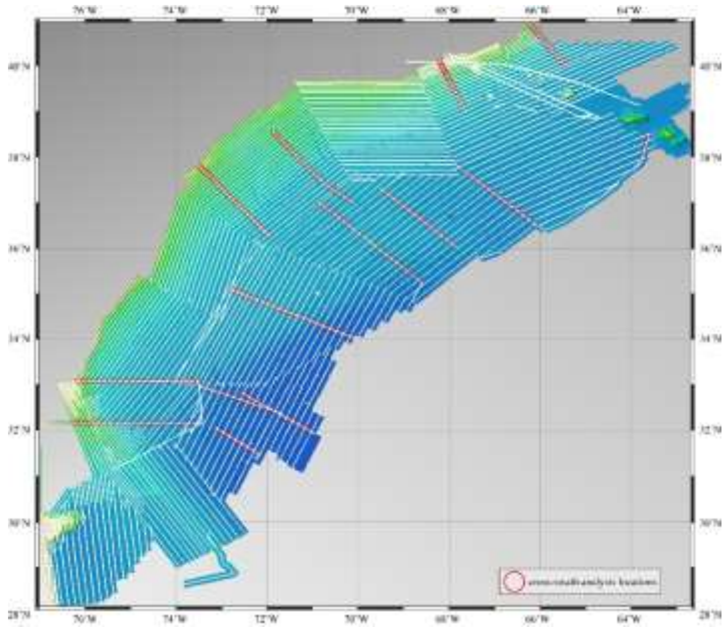


Figure 48-1a: Map of the JHC/CCOM ECS multibeam survey tracklines showing each swath crossing (red circles) where a cross-swath analysis was performed.

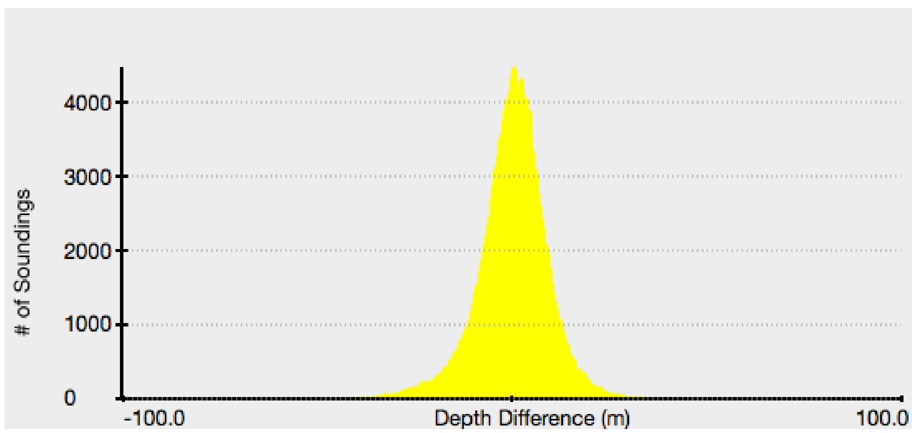


Figure 48-1b: Histogram of sounding-depth differences from cross-line check of Atlantic Line 25 and Dipline 16 (fairly smooth bathymetry). Kongsberg Maritime EM121a.

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.

TASK 49: ***Best Approaches for Legacy Data and Delineation:*** *Develop mechanisms to capture legacy data relevant to and in the appropriate format for ECS purposes, to explore best approaches and technologies to fill data gaps (e.g., strategic use of high-resolution subbottom profiling), to better document the uncertainty of the data collected in a form appropriate for ECS analyses, to develop and optimize approaches for calculating and selecting the needed ECS delineation points and lines, and to establish a geologic context most appropriate for ECS delineation.* ***David Mosher, Jim Gardner, Larry Mayer***

Project: **Surficial Geology Map of Arctic**

JHC/CCOM Participants: David Mosher, Kimberly Baldwin, Jim Gardner, Larry Mayer

NOAA Collaborators: Andy Armstrong (OCS), Margot Bohan (OER), Elliot Lim (NCEI), Jennifer Jencks (NCEI)

Other Participants: Jason Chaytor (USGS), Deborah Hutchinson (USGS)

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 49-1) to reduce complexity that often occurs while icebreaking, also known as speed correction (Figure 49-2); 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.

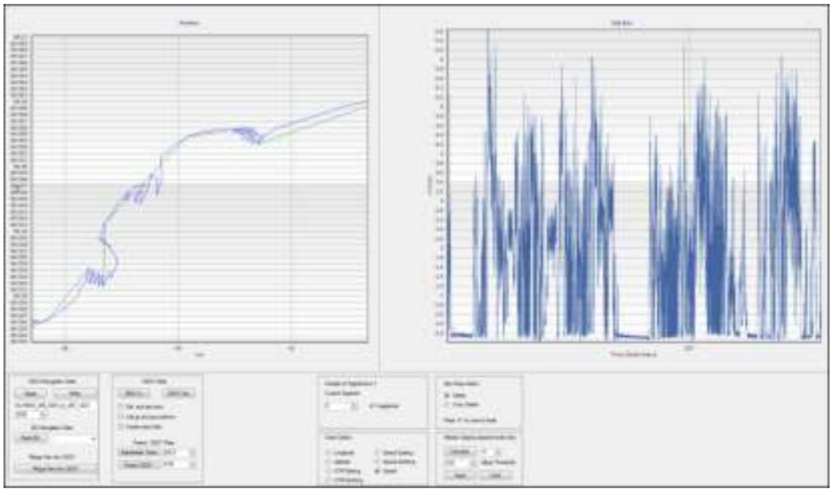


Figure 49-1: Screenshot of the NRCAN program NavClean. The left side of the program shows a plot of the subbottom tracklines (in blue). The green line is the defined interpolated track that data will be subsampled to in order to reduce the overall complexity caused by icebreaking. The right shows a plot of speed vs. distance.

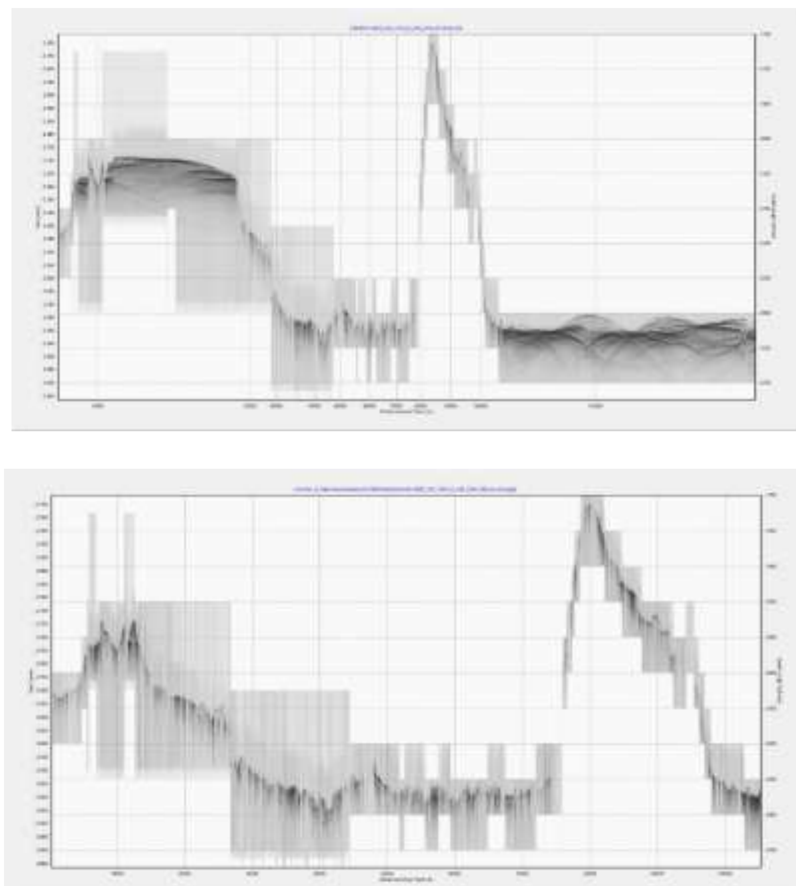


Figure 49-2: Comparison of two subbottom images without speed correction (top) versus with speed correction (bottom). Notice how the speed corrected plot has equidistance spacing.

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 49-3). All existing processed data along with tracklines showing data holdings of other countries were compiled onto one ArcGIS project (Figure 49-4). 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 49-5). 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.

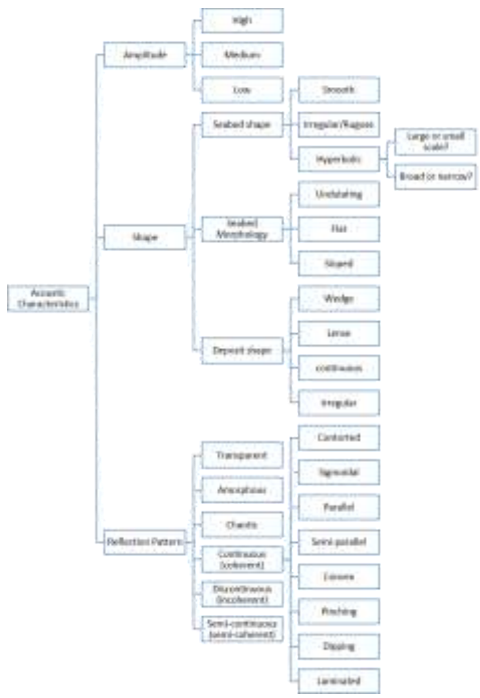


Figure 49-3. Acoustic facies classification schema, developed at the working meeting in Bremerhaven on 23-24 May, 2016.

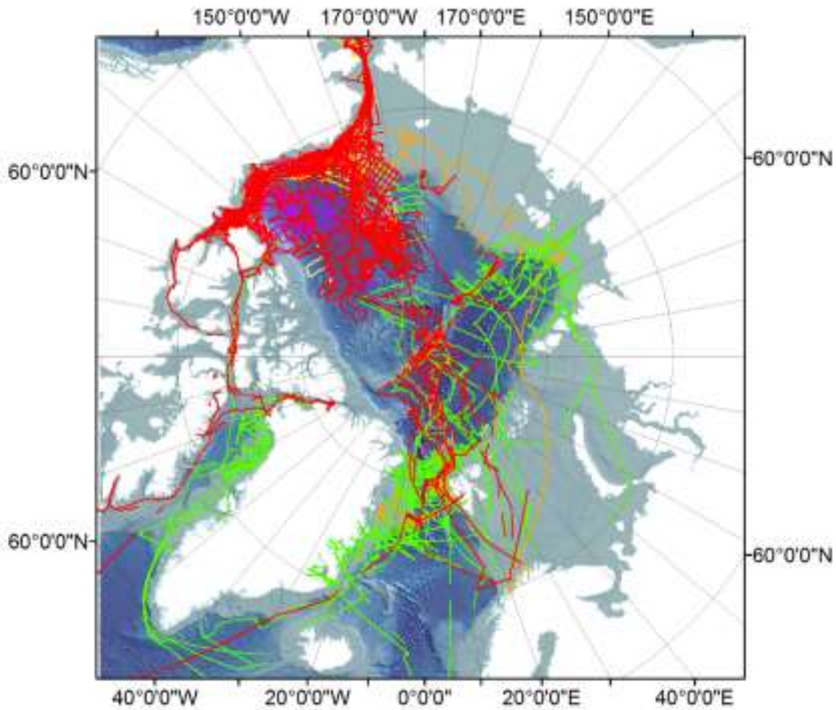


Figure 49-4: Tracklines showing the compilation of existing subbottom data holdings (red) as well as tracklines of subbottom data holdings not currently in the project from other countries (green= Germany; orange= Sweden; purple= Canada; yellow= US). Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

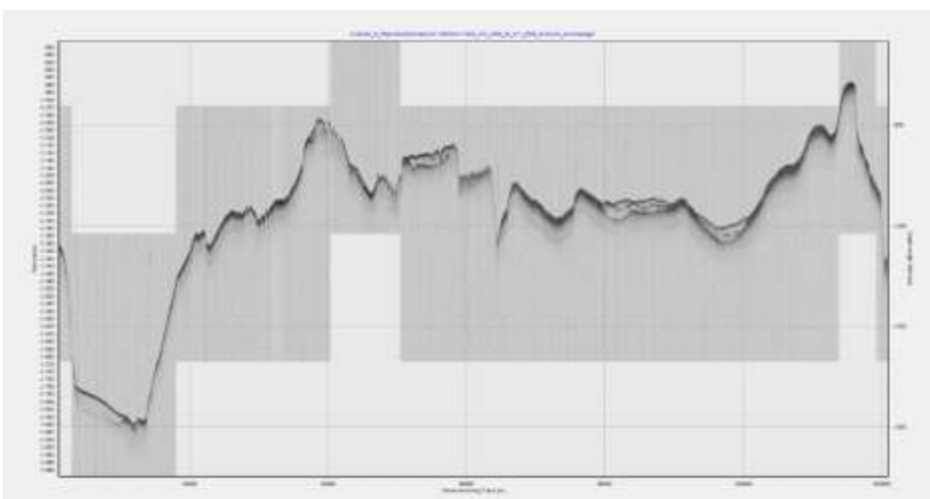


Figure 49-5: An example of processed subbottom data collected on the most recent USCGC Healy ECS Cruise in October, 2016. This line extends across the Northwind Ridge and shows a variety of acoustic facies including 5c, 5e, 6a and 10a, among others (see Figure 49-10 for legend).

The various seismic facies (e.g., Figure 49-6) are currently mapped on an ArcMap project (Figures 49-7, 49-8, 49-9 and 49-10). 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 49-7, 49-8, 49-9 and 49-10), specifically in the Chukchi Borderland (Figure 49-7, 49-10) and Alaskan Margin (Figure 49-8, 49-10). Attempts have been made to map acoustic facies of the entire Arctic region (Figure 49-9, 49-10), 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.

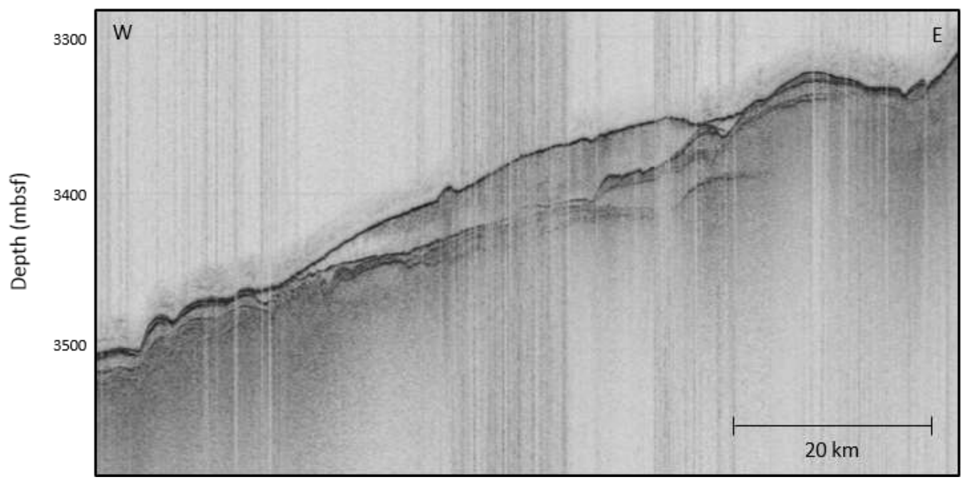


Figure 49-6: One of the acoustic facies (6a) identified in the Arctic subbottom profiler data set (high amplitude, smooth bottom echo with unconformable, stacked, transparent, wedge-shaped deposits). The facies identified will be used to interpret the depositional process and develop a surficial geology map for the Arctic Ocean.

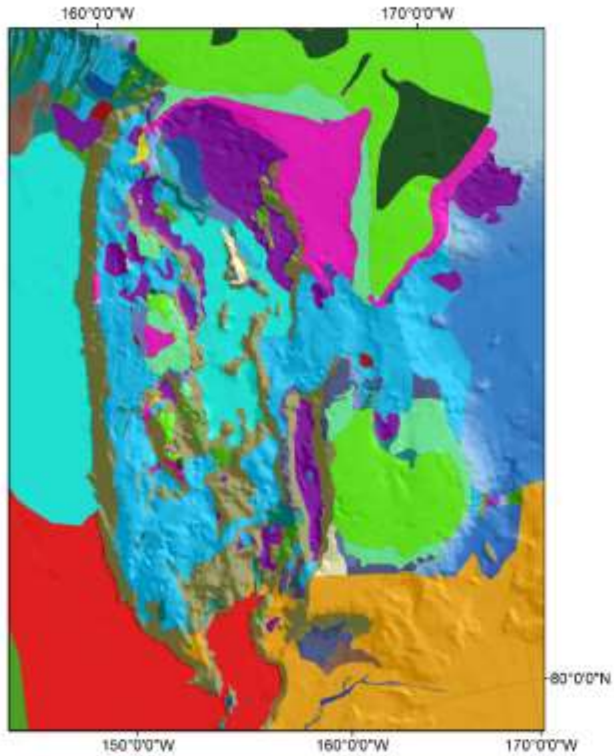


Figure 49-7: Acoustic facies mapped to date of the Chukchi Borderland. See Figure 49-10 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

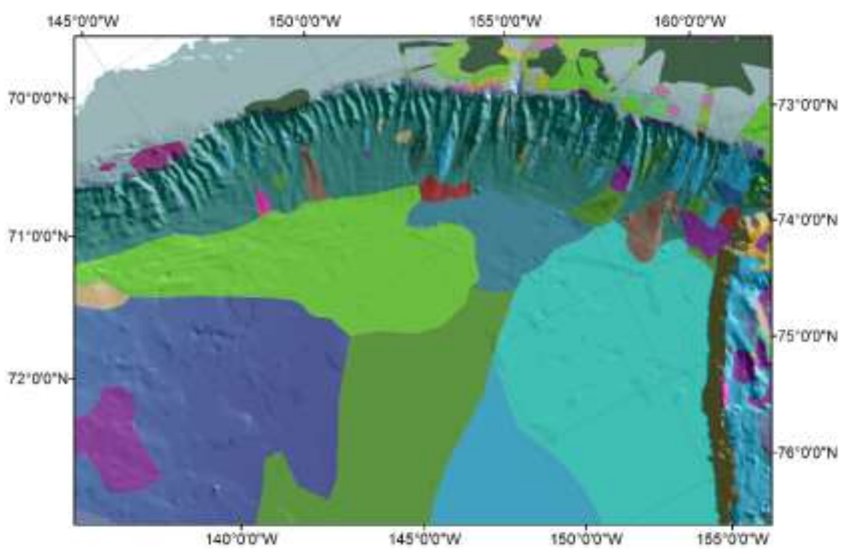


Figure 49-8: Acoustic facies mapped to date of the Alaskan Margin. See Figure 49-10 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

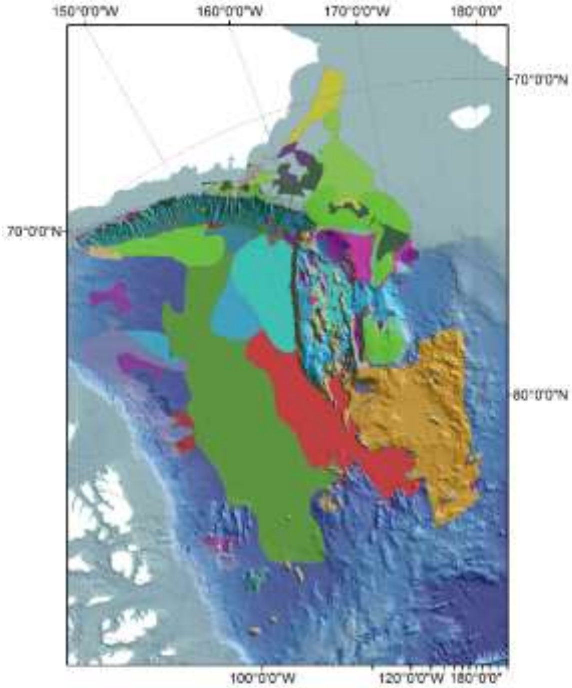


Figure 49-9: Acoustic facies mapped to date of the entire Arctic. See Figure 49-10 for legend. Basemap is IBCAO v. 3 (Jakobsson et al., 2012). Map created with ArcGIS.

Figure 49-10: Acoustic facies legend to date, developed by the acoustic facies classification schema (Figure 49-3). Refer to Figures 49-7, 49-8 and 49-9 for mapped units.

RESEARCH REQUIREMENT 3.B: OCEAN EXPLORATION

FFO Requirement 3.B: *"Development of new technologies and approaches for integrated ocean and coastal mapping, including technology for creating new products for non-traditional applications and uses of ocean and coastal mapping."*

TASK 50: ***ECS Data for Ecosystem Management:*** *Explore the applicability of ECS data for the mapping of regional habitat in support of ecosystem-based management. Attempt to generate marine ecological classification and habitat prediction maps with close attention to Habitats of Particular Concern (HAPCs) such as deep-water corals. The protocols developed for analyzing the Atlantic ECS data will then be available for application to other ECS data sets.* ***Jenn Dijkstra, Larry Mayer David Mosher***

Project: **Use of ECS Data for Ecosystem Management**

JHC/CCOM Participants: Jenn Dijkstra, Larry Mayer, David Mosher, Kirsten Mello

NOAA Collaborators: Derek Sowers (OER), Margot Bohan (OER),

This effort is the focus of the Ph.D. project of Derek Sowers, NOAA OER employee and part-time UNH Ph.D. student. The fundamental concept is to explore the viability of using the margin-wide bathymetric and backscatter data sets collected in support of U.S. ECS efforts for ecosystem management. The initial effort is focused on the Atlantic Margin data set. In 2016, Sowers concentrated on selecting pilot study areas, evaluating existing benthic terrain modeling software tools, gathering and organizing existing datasets, and establishing the data management framework for the research effort. Workflow methods were initially tested on pilot areas within Veatch Canyon (Atlantic canyons site) and the Lindenkohl Canyon deposition fan (abyssal ECS study site). The conceptual framework for the research was presented as a poster at the 2016 University of New Hampshire School of Marine Science and Ocean Engineering Graduate Symposium.

Sowers selected ESRI's ArcGIS Marine Data Model as the basis for managing project data and supporting spatial analysis work. This data model has been widely vetted by marine researchers and managers, and provides templates useful for ensuring appropriate metadata documentation. Sowers compiled a complete list of all input datasets used for the research project, and defined all expected derived output datasets to be managed in the geodatabase. The ArcGIS extension Benthic Terrain Modeler was evaluated for use in helping to generate CMECS Geoform classifications from bathymetry data. This tool is useful because it utilizes customizable classification dictionaries to help with seafloor characterization. Threshold values in the dictionary are based on ecologically meaningful thresholds which in some cases have been defined within the CMECS standard for differentiating various geoforms.

Sowers spent considerable time maximizing coordination with other existing JHC research efforts. This work generally fell into three categories:

1) Processing of multibeam sonar backscatter data for the purpose of characterizing marine substrates. This topic continues to evolve in theory and practice. Software applications for

processing of this data are similarly evolving. Sowers coordinated with Giuseppe Masetti to assess the coding work being undertaken by JHC to improve the stability and robustness of ARA backscatter processing tools and how it could be relevant to evaluation of ECS backscatter data. Coordination was also undertaken with Larry Ward to examine how backscatter data was being analyzed for substrate characterization efforts on the continental shelf of New Hampshire (BOEM funded research conducted by Ward). Insights on backscatter processing from these researchers are being incorporated into the ECS CMECS habitat classification effort. Sowers is using the existing implementation of ARA processing tools in QPS's FMGT software to evaluate potential insights to be gained about deep sea substrates from backscatter.

2) Utilizing the most suitable bathymetric data for the study region. Paul Johnson has recently compiled a bathymetric synthesis grid combining ECS and NOAA Ship *Okeanos Explorer* data of the Atlantic Margin study area that will be used as the basis for deriving CMECS geoforms. This seamless (and heavily quality-controlled) dataset provides an ideal basis for consistent geoform analysis spanning a vast study region.
3) Fine-scale habitat characterization based on annotation of ROV dive video. Jenn Dijkstra and researcher Kristen Mello have been analyzing *Okeanos Explorer* ROV dive videos in the Atlantic Margin canyons and seamounts to map the presence, diversity, and in some case abundance, of benthic biology (see Task 28). This carefully georeferenced biology will then be overlaid in GIS with CMECS geoform and substrate maps to examine correlations between the biota and seafloor substrates for insights into the habitat characteristics of the study region.

Sowers provided a briefing of his doctoral research work to key members of the Northeast Regional Planning Body to gather feedback on how to ensure its usefulness in helping to implement the recently completed (draft) Northeast Ocean Plan. He met with the RPB Co-Chair, web portal administrator, and NOAA lead for CMECS for discussion and feedback. Sowers also provided a presentation of ECS CMECS classification doctoral work to Meredith Westington (Chief Geographer for NOAA Office of Coast Survey) and Margot Bohan of NOAA OER to discuss ways to enhance the long term value of existing ECS datasets to NOAA.

Sowers has also continued his work representing NOAA OER on the federal inter-agency CMECS Implementation Group, where he is working to promote the adoption and application of a standardized "common language" of marine habitats across government agencies and management jurisdictions. In 2016, Sowers worked as part of the *Okeanos Explorer* Annotation Working Group to provide advice on customizing the Ocean Networks Canada annotation software package "SeaScribe" for use on ROV dive videos. Sowers provided specific feedback to the group on integrating the Coastal and Marine Ecological Classification Standard (CMECS) into annotations.

TASK 51: ***Potential of MBES Data to Resolve Oceanographic Features:*** *Explore the possibility of mapping fine-scale structure in the water column with MBES and fisheries sonars. Work with our sonar manufacturer partners to see if certain data acquisition parameters can be optimized for revealing water mass structure and, in particular, evaluate the potential of broadband or multi-frequency data for these sorts of studies.* ***Larry Mayer, Tom Weber, and John Hughes Clarke***

This project has not yet started under this grant

RESEARCH REQUIREMENT 3.C: TELEPRESENCE AND ROVS

FFO Requirement 3.C: *"Improvements in technology for integration of ocean mapping with other deep ocean and littoral zone technologies such as remotely operated vehicles and tele-presence-enhanced exploration missions at sea."*

TASK 52: Immersive Live Views from ROV feeds: *Develop an immersive telepresence system that combines the multiple data streams available from live ROV missions (e.g., video, bathymetry, etc.) with models of the ROV itself into a single 3-D environment. Continue to explore and enhance the use of telepresence to provide shipboard support for mapping systems.* ***Roland Arsenault and Vis Lab***

Project: **Realtime and post-mission 3D interactive display of ROV data**
JHC/CCOM Participants: Roland Arsenault
NOAA Collaborators: Mashkoor Malik, Meme Lobecker (NOAA OER)

A method for displaying real-time and post-mission ROV dives in a web client is being developed by Roland Arsenault. To reach a broad audience, the target platform is a web browser. The goal is to provide an interactive, time-aware, 3D display fusing multiple data streams. The Cesium Javascript library is being investigated because of its WebGL capabilities and its inclusion of a timeline similar to the one developed for GeoiZui4D.

Data from a NOAA Ship *Okeanos Explorer* cruise has been downloaded from NOAA's Ocean Explorer website for testing (EX1504L3). Data from the ship and ROV have been converted to a format that is compatible with Cesium. A markup language, CZML, supporting static and streaming data has been developed by the Cesium developers and was chosen for this test. A Python script was written to write shipboard data into a CZML file.

Initial tests have uncovered limitations with Cesium's default terrain servers, limiting options to an ellipsoid model with no terrain, or a terrain server with only terrestrial topography and no bathymetry. Being Open Source, however, Cesium does support user-provided terrain sources, and supports different schemes for specifying terrain; the quantized mesh approach is being investigated.

Results so far are mixed. A Python script has been written to generate a quantized mesh-based Cesium globe by combining lower resolution SRTM data with bathymetry along with a selected higher resolution grid from NCEI's AutoGrid web-based service. A globe has successfully been created, but it does not yet show the details necessary (Figure 52-1) to make it a useful visualization. To illustrate the difference, Figure 52-2 shows the same high-resolution data in Fledermaus. Work is ongoing to find a way to produce an acceptable web based real time display of ROV operations.

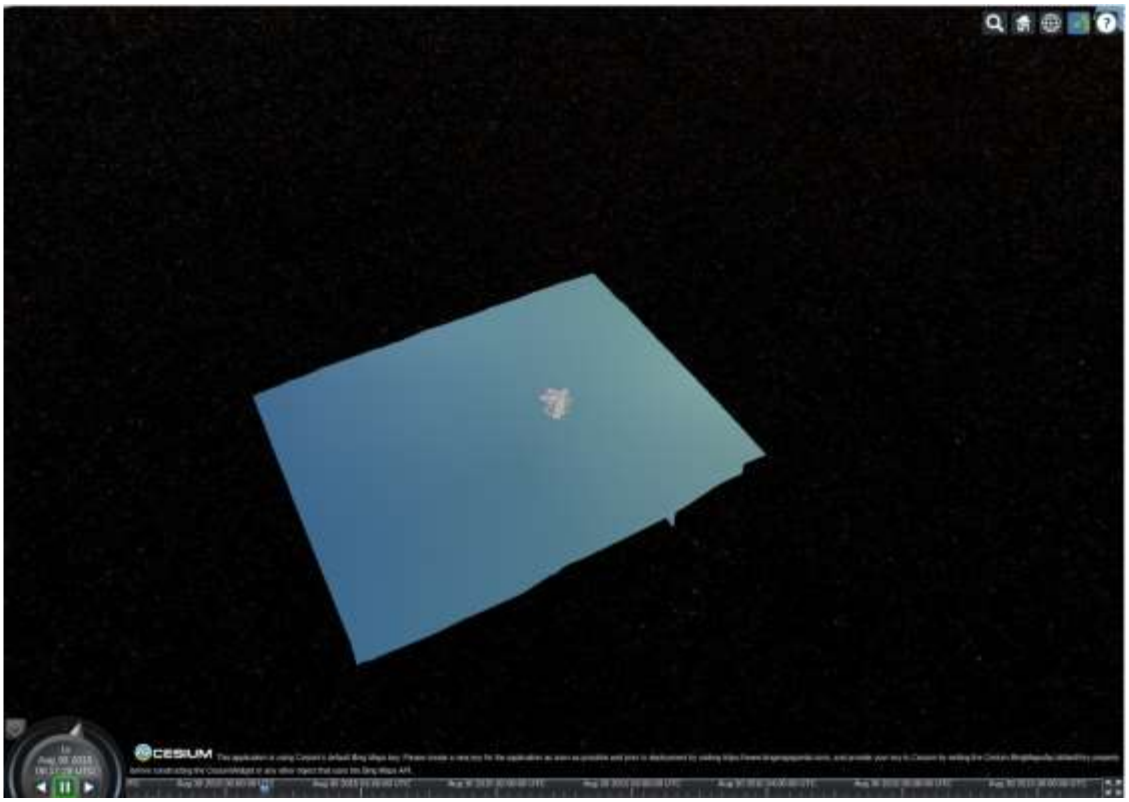


Figure 52-1 High resolution section of bathymetry encoded as a quantized mesh and displayed in Cesium. Bathymetry details do not show up very well.

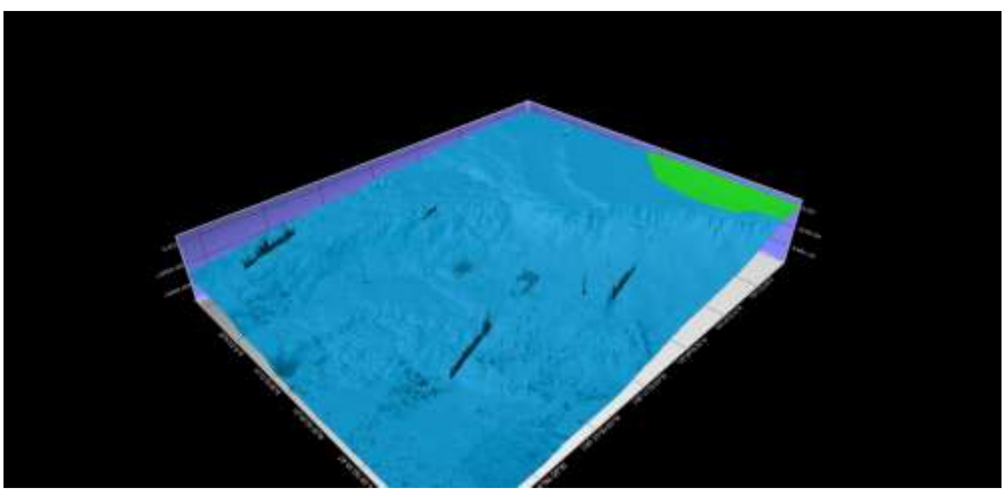


Figure 52-2: High resolution data used for the Cesium globe as seen in Fledermaus.

PROGRAMMATIC PRIORITY 4: HYDROGRAPHIC EXPERTISE

RESEARCH REQUIREMENT 4.A – EDUCATION

FFO Requirement 4.A: *"Development, maintenance, and delivery of advanced curricula and short courses in hydrographic and ocean mapping science and engineering at the graduate education level – leveraging to the maximum extent the proposed research program, and interacting with national and international professional bodies--to bring the latest innovations and standards into the graduate educational experience for both full-time education and continuing professional development."*

TASK 53: Upgrade of Education Program and Update Ocean Mapping curriculum. Modify courses and labs as needed. Develop short courses in collaboration with NOAA and others. **John Hughes Clarke, Semme Dijkstra and Center Faculty**

Project: **Curriculum Upgrades and Development**
JHC/CCOM Participants: John Hughes Clarke, Semme Dijkstra, Brian Calder, and other Faculty
Other Collaborators: Ian Church (USM and now UNB)

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.

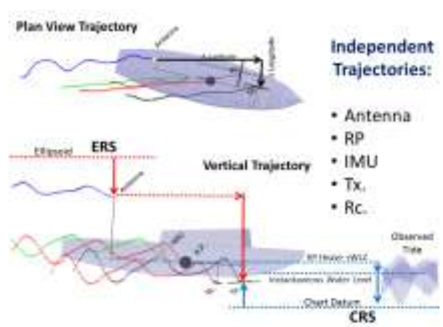


Figure 53-1: Illustration of the dynamic nature of the trajectories of the component sensors in an integrated multibeam system.

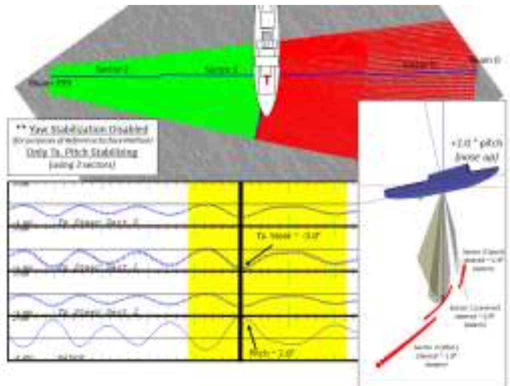


Figure 53-2: Illustration of the additional complications involved in the integration of multi-sector systems.

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.

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 1-18). 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.

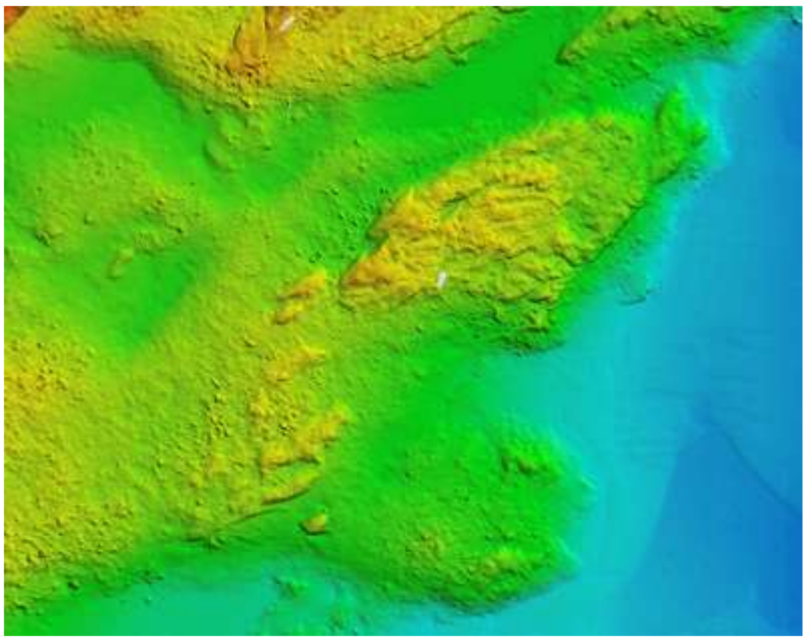


Figure 53-3: Some of the first multibeam data collected with the new research vessel R/V Gulf Surveyor. Note that the data align very well as a result of the IMU placement near the transducer arrays and the accurate survey of vessel offsets (rms < 1mm).

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 1-19).

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.

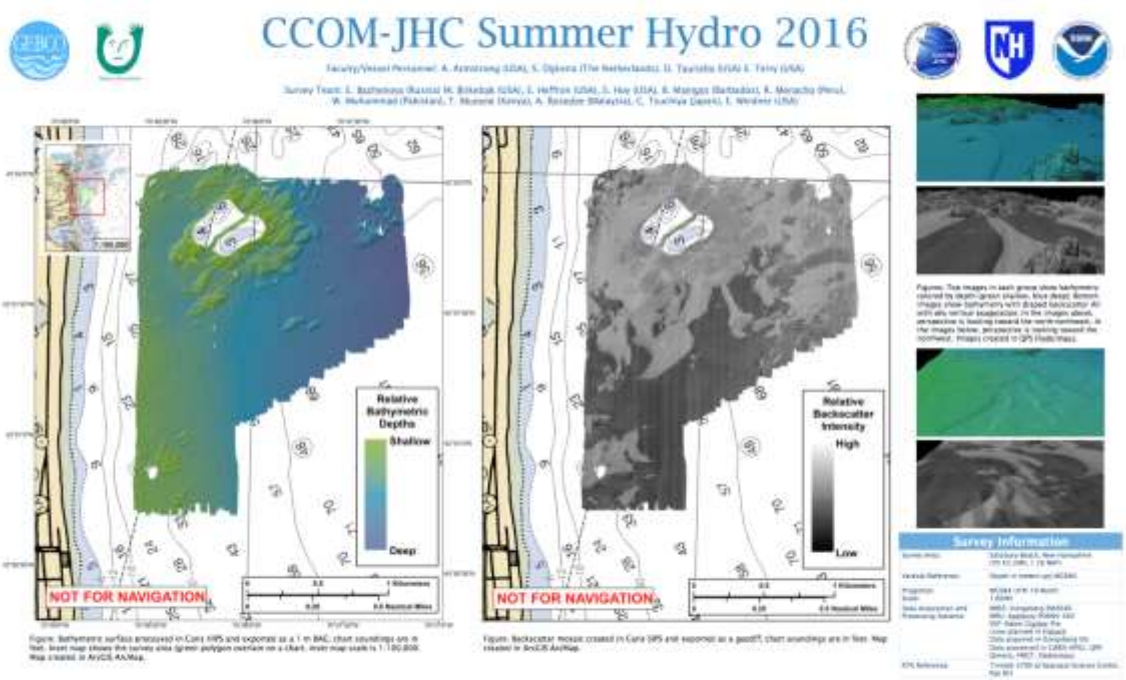


Figure 53-4: Result of Hydro Field Camp survey of Salisbury Beach area.

Project: **GEBCO Training Program**
JHC/CCOM Participants: Rochelle Wigley, Larry Mayer and other JHC Faculty
Other Collaborators: Shin Tani (GEBCO), Robin Falconer (GEBCO), Nippon Foundation

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 53-5).

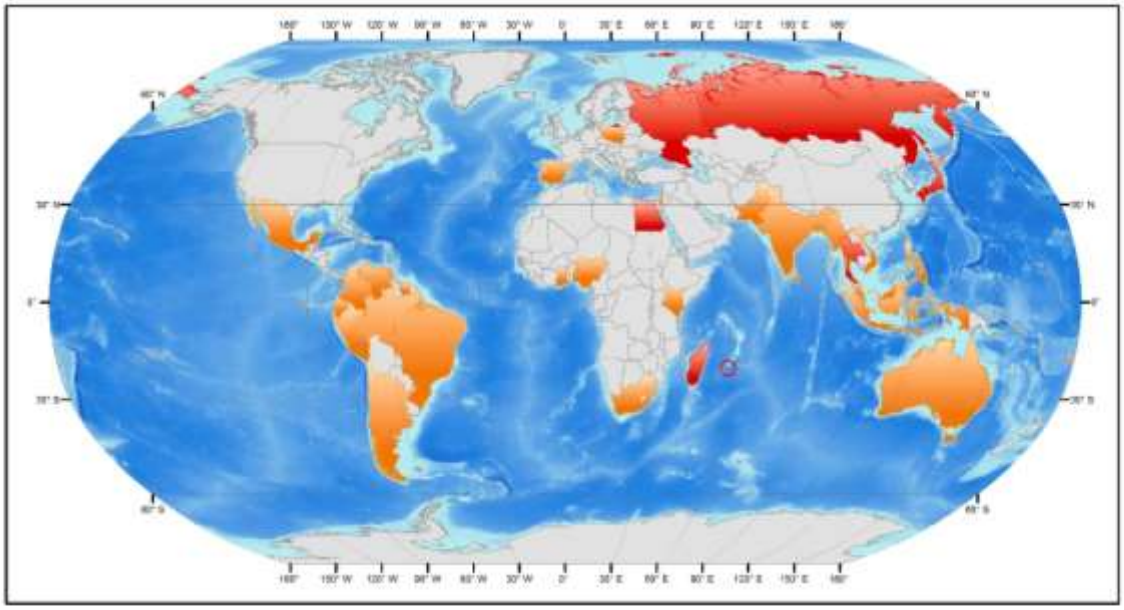


Figure 53-5: The 35 home nations of Nippon Foundation / GEBCO Scholars (Includes Year 1 to 13) with Year 13 in red.

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 153-13 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 53-6).

Figure 53-6: 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 >700 available single surveys, 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 1-15) 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 1-16). 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 53-7: 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 53-8: 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 1-17). 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.

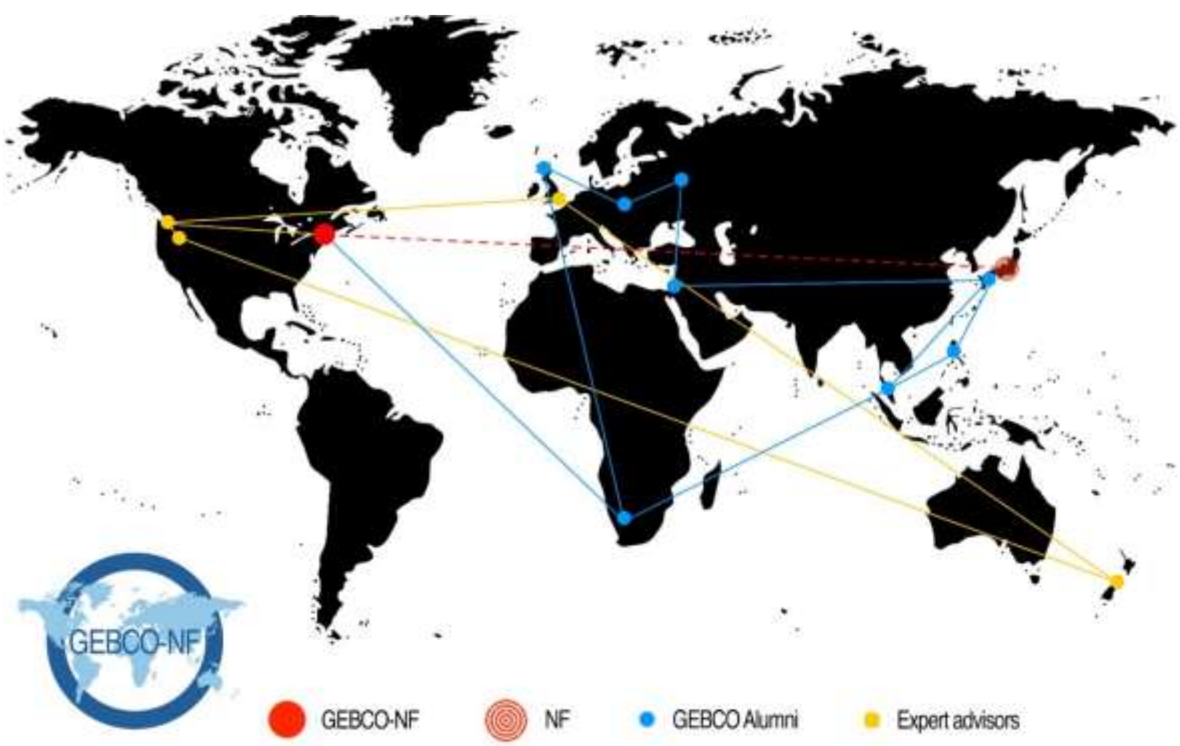


Figure 53-9: GEBCO-Nippon Foundation X-Prize Team

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

Project: **Extended Training**
JHC/CCOM Participants: JHC Faculty
NOAA Participants: Andy Armstrong (JHC/OCS), Rick Brennan (OCS)
Other Collaborators: Many Industrial Partners and other labs

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—see below), host NOAA Hollings Scholars (see below) 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.

SURF Program and Hollings Scholars:

The Summer Undergraduate Research Fellowship (SURF) program was initiated in 2012. The SURF program is designed to create research experiences for undergraduate students who are interested in pursuing graduate work. SURF is aimed primarily at students who are working toward a degree in science, engineering, or math and are completing their junior year. Students accepted into the program spend up to 10 intensive weeks (normally early-June to mid-August) working under the guidance of a faculty member. They conduct research related to acoustics, bathymetric mapping, habitat mapping, LIDAR, marine geology and geophysics, optical imaging, sonar signal processing, or data visualization. Research activities include laboratory experiments, field work, a research cruise, data analysis, model development, or instrument development. The research conducted by the fellows is presented to Center faculty and staff at the end of the summer and summarized in a written report.

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.

RESEARCH REQUIREMENT 4.B – ACOUSTIC PROPAGATION AND MARINE MAMMALS

FFO Requirement 4.B: *"Development, evaluation, and dissemination of improved models and visualizations for describing and delineating the propagation and levels of sound from acoustic devices including echo sounders, and for modeling the exposure of marine animals to propagated echo sounder energy."*

TASK 54: Modeling Radiation Patterns of MBES: *Develop realistic models of the ensonification patterns of the sonar systems that we use for mapping.* **Tom Weber and Xavier Lurton**

Project: **Modeling Radiation Patterns of MBES for NEPA Requirements**
JHC Participants: Tom Weber, Tony Lyons
Other Participants: Xavier Lurton

This is work conducted to satisfy the NEPA requirements for this grant. Tom Weber is currently compiling all of the information about the acoustic systems (particularly below 200 kHz) that will be used for the grant and then using this information to predict the acoustic radiation pattern using a simple model developed by Dezhang Chu for a NOAA fisheries NEPA submission. The main difficulty (or at least the slowest aspect) in this task is determining what the acoustic parameters are for the various commercial systems. These parameters are then used to generate models for the insonified volume (example provided below for the HISAS 1032 using information provided by Tony Lyons and Kongsberg – Figure 54-1). This information is then fed into models of animal density and established acoustic thresholds for marine mammal impact, in order to support calculation of potential takes (see Task 56).

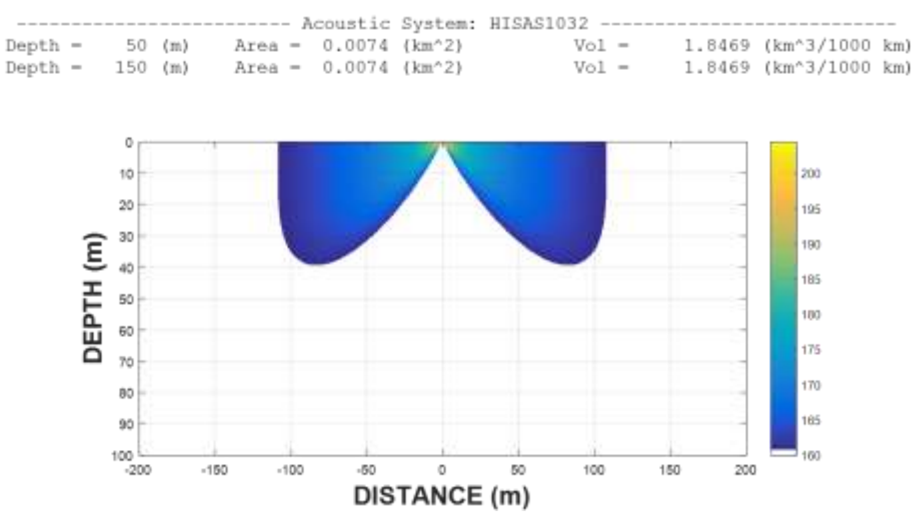


Figure 54-1: Predicted radiation pattern for HISAS 1032 synthetic aperture sonar

TASK 55: Web-based Tools for MBES Propagation: *Use Lurton's models and produce web-based tools for understanding and visualizing sonar ensonification patterns and performance.* ***Roland Arsenault***

This project has not yet started under this grant

TASK 56: Impacts of Sonars on Marine Mammals: *Continue to convene small working groups representing various federal agencies to discuss the common problem of understanding the potential impact of mapping sonars on marine mammals as well as to pursue the possibility of taking a multibeam sonar to a Navy acoustic calibration range.* ***Jennifer Miksis-Olds and Bill Ellis***

Project: **Acoustic Propagation and Marine Mammals**
JHC/CCOM Participants: Jennifer Miksis-Olds, Tom Weber, Bill Ellison, Erin Nagel

The estimation of marine mammal Level B takes, as outlined by the Marine Mammal Protection Act, in response to exposure to high-frequency scientific and mapping sonars was identified as a highest priority in the early stages of this grant. The Center is working in conjunction with NOAA's Office of Coast Survey to model the acoustic sources used, and assess projected marine mammal takes for each JHC project to ensure continued operation in compliance with NEPA.

Assessing the number of marine mammal Level B takes was addressed through a three-component process: operational parameterization, sound source characterization and modeling, and marine mammal density integration. Outputs from each component were combined to determine the estimated number of animal takes in each operational area per year (Figure 56-1). Operational parameterization included defining the operational areas (Figure 56-2), specifying the length and number of transect lines in each operational area/year, and defining the proportional sound source use per transect. Operational parameterization was achieved by querying the primary investigator for each grant project and then combining transects and source use activities in each defined area. Sound source characterization and modeling included source identification and characterization, modeling of sound propagation, and calculation of the ensonified areas exceeding the acoustic criteria of 160 dB re 1 µPa received level for systems operating below 200 kHz. This task was performed by Tom Weber (see Task 54). Estimating marine mammal density in each area involved defining the species in each operational area, estimating the animal density of each species in the area, and applying the animal density values to calculations of volumetric density in each area. This task was completed by Jennifer Miksis-Olds.

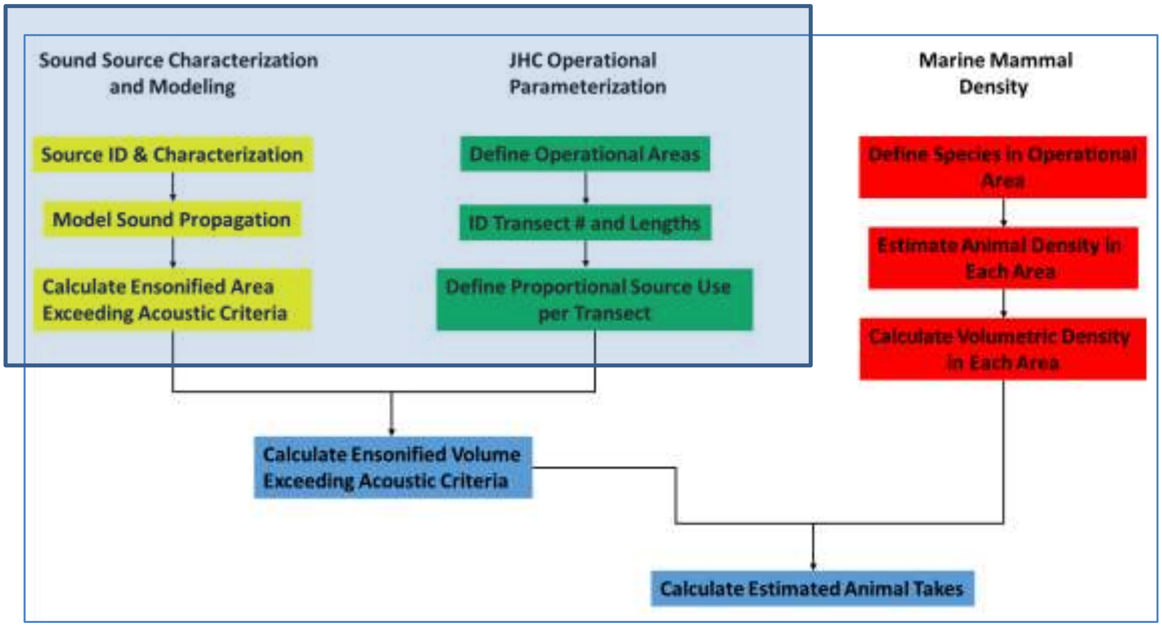


Figure 56-1. Three-component approach for determining the estimated number of marine mammal takes associated with grant funded research projects. Areas highlighted in the blue shaded box were completed under JHC grant NA10NOS4000073. Tasks outside the blue shaded box were completed under this grant, NA15NOS4000200.

Compiling the responses from the operational query of each primary investigator, five operation areas were identified: Gulf of Maine, New England coast out to 24 nautical miles, coastal waters 20 nautical miles off New Castle, NH, coastal waters 50 nautical miles off New Castle, NH, and Coal Oil Point, CA (Figure 56-2).

The habitat-based cetacean density model developed by the Marine Geospatial Ecology Laboratory at Duke University was identified as the most appropriate source of animal density estimates for the U.S. Atlantic coast. Cetacean density data used at Coal Oil Point originated from the Southwest Fisheries Science Center and was accessed through http://cetsound.noaa.gov/cda. Zonal statistics were run in GIS to determine monthly, seasonal, or annual marine mammal density estimate averages, when appropriate, in each operational area for all potentially encountered species at 10km x 10km resolution. Area density estimates were converted to volumetric density estimates by weighting by the maximum depth of the survey transect. Animal density was then computed by multiplying the volumetric density by the source-specific summed line kilometers by the source-specific acoustic area of exposure.

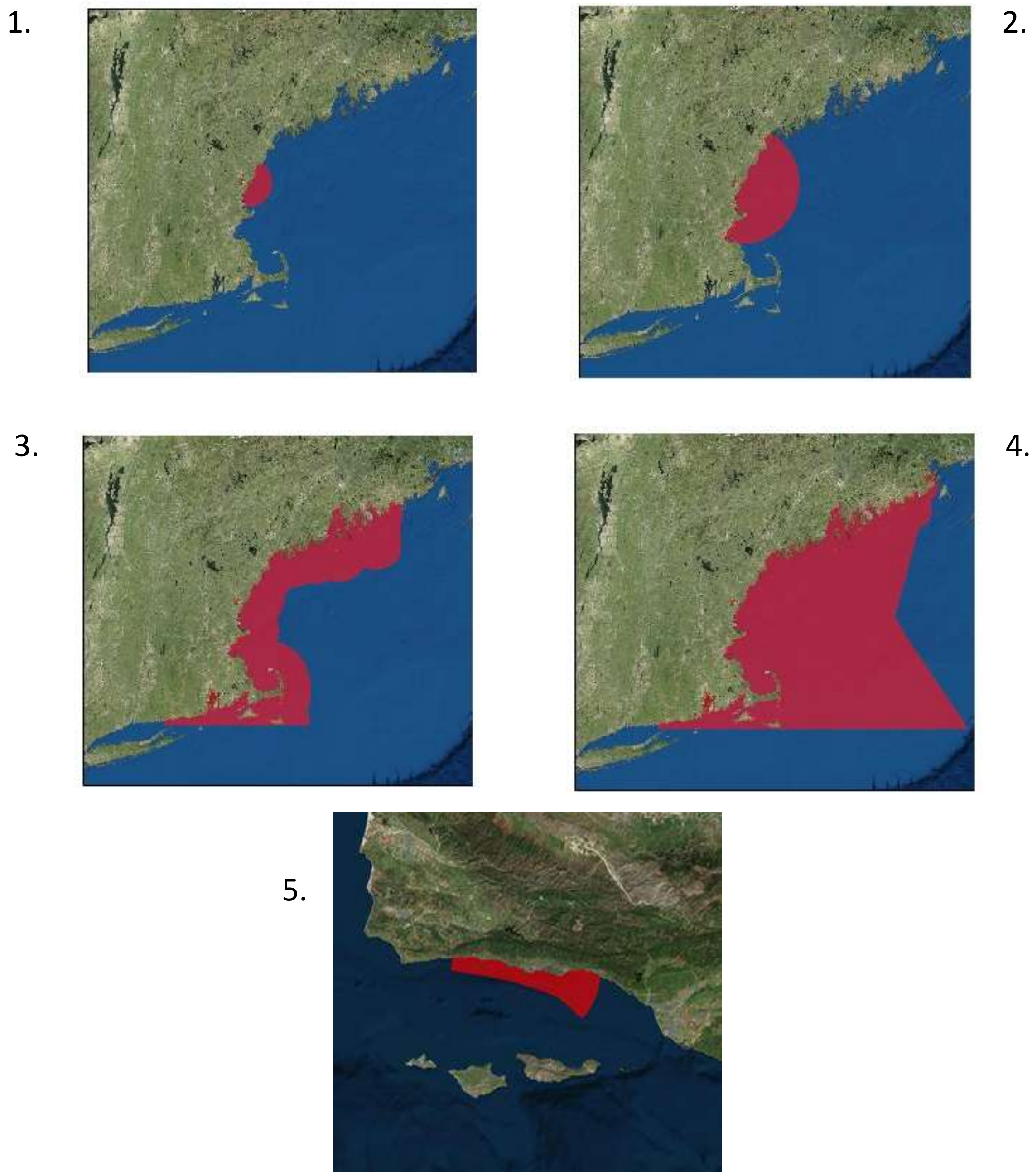


Figure 56-2: Five areas defined by the combined research grant activities. 1. New Castle, NH extending 20 nautical miles from shore. 2. New Castle, NH extending 50 nautical miles from shore. 3. Coastal New England extending 24 nautical miles offshore. 4. Gulf of Maine extending offshore to depths of 200m. 5. Coal Oil Point, CA extending offshore to a depth of 150m.

RESEARCH REQUIREMENT 4.C – PUBLICATIONS AND R2O

FFO Requirement 4.C: *"Effective delivery of research and development results through scientific and technical journals and forums and transition of research and development results to an operational status through direct and indirect mechanisms including partnerships with public and private entities."*

TASK 57: *Continue to* ***Publish, Make Presentations and Promote R2O Transitions:*** ***Lab-wide***

Members of the Center continue to actively publish their results in refereed and other journals, make numerous presentations and transition their research to NOAA and others. A complete list of Center publications, conference and other presentations, reports, and theses can be found in Appendices D and E.

RESEARCH REQUIREMENT 4.D – OUTREACH

FFO Requirement 4.D: *"Public education and outreach to convey the aims and enhance the application of hydrography, nautical charting, and ocean and coastal mapping to safe and efficient marine navigation and coastal resilience."*

TASK 58: ***Expand Outreach and STEM Activities:*** *Expand our activities including participation in the Ocean Exploration Trust's Community-Based STEM Initiative, working with the Marine Advanced Technology Education (MATE) Center (designed to train a marine technology workforce) and developing closer ties with the Shoals Marine Lab.* ***Tara Hicks-Johnson and Colleen Mitchell***

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*
2016-047-29	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 58-1).

Figure 58-1: 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 58-2). 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.

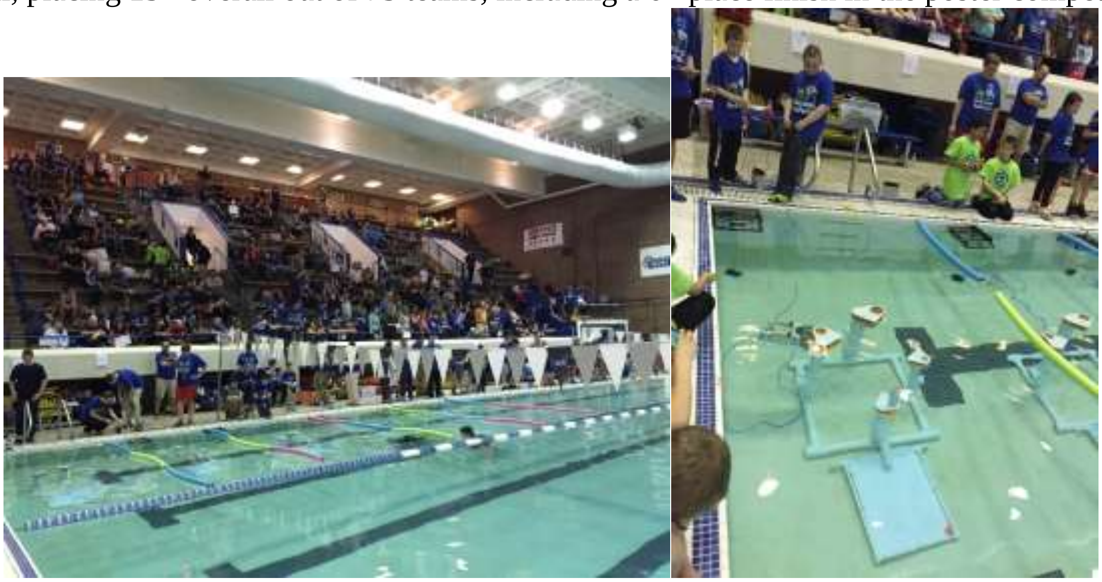


Figure 58-2: Scenes from the 2016 SeaPerch Competition at UNH

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 58-3). 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 58-3: 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 58-4). 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 58-4: 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 (Figure58-5). 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 58-5: 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 58-6). 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 58-6: 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 58-7). 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 58-7: 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 58-8). We also toured the Center and watched highlight videos in the telepresence room.

Figure 58-8: 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 58-9). 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 58-9: 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 58-10) we can surmise that most of these visits are made during the work week.

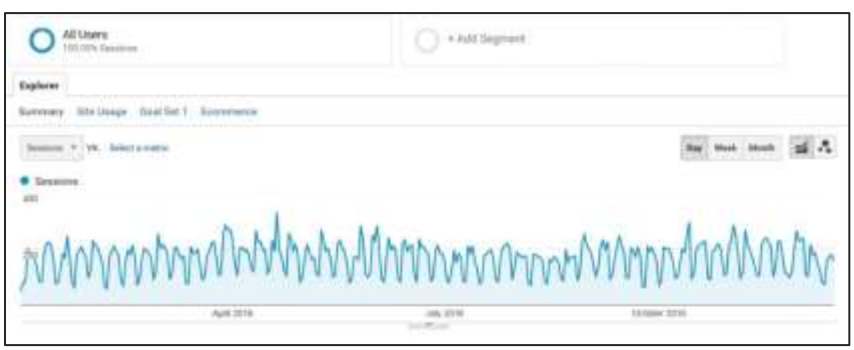


Figure 58-10: Google Analytics graph showing the clear trend of work week visits.

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 58-11).

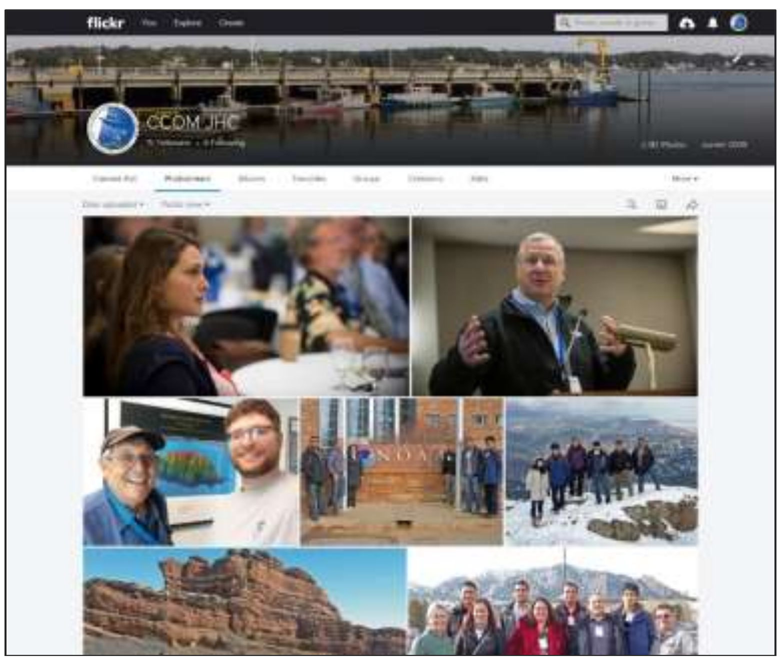


Figure 58-11: The Center's Flickr photostream.

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 58-12).

Figure 58-12: 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 58-13). 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.

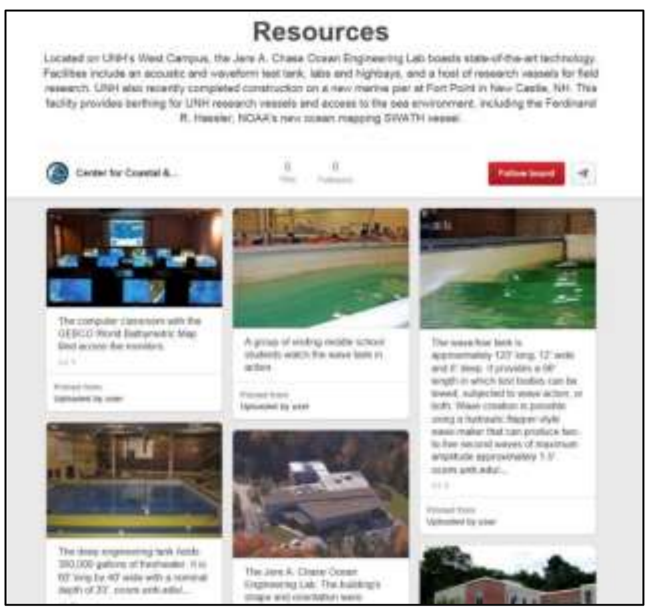


Figure 58-13: The Resources board on the Center's Pinterest page.

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 58-14).

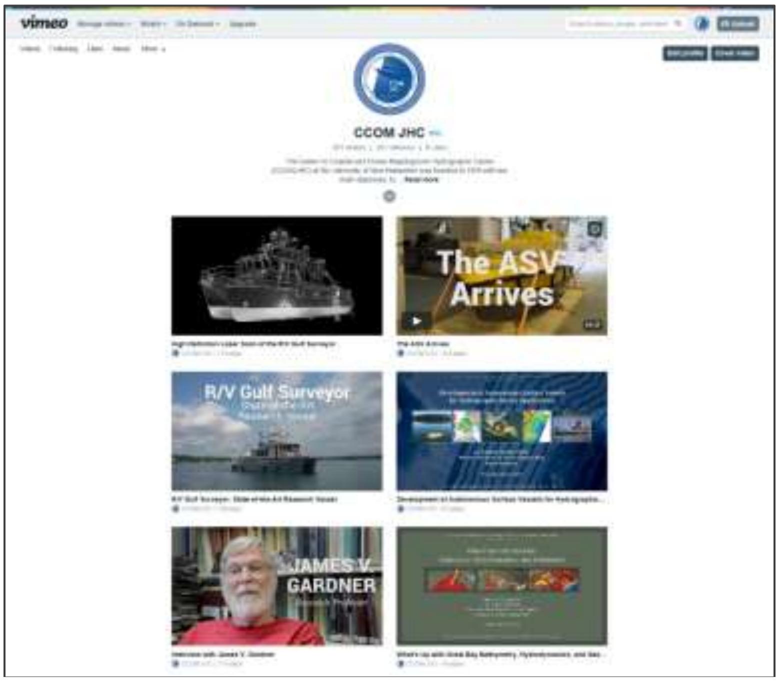


Figure 58-14: A sampling of the videos available in the Center's Vimeo catalog.

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 58-15) 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.

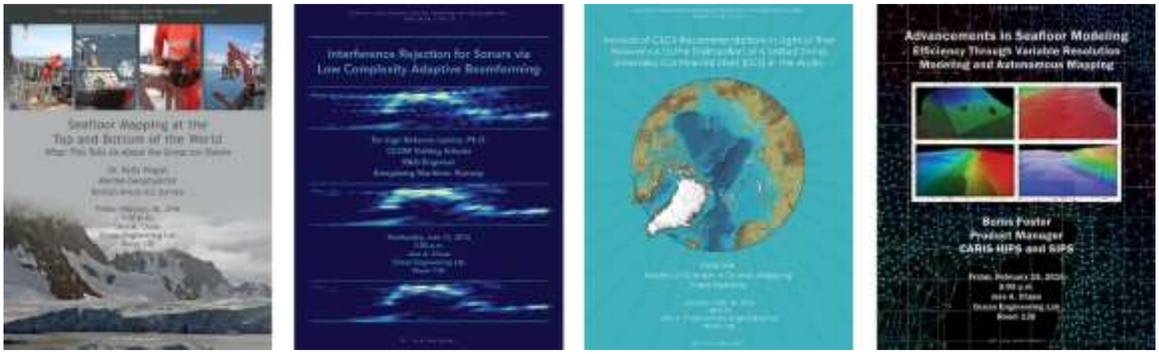


Figure 58-15: A few of the 17 flyers produced for the 2016 seminar series.

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 58-16 and 58-17). 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 58-16. 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 58-17). 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 58-17). The post reached 2,925 people and was liked and shared numerous times.

Figure 58-17. 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 58-18). 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 58-18. 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 (Figure 58-19), and a tour of the new research vessel Gulf Surveyor with Lee Alexander (Figure 58-20). Both are available on the Center's Vimeo site.

Figure 58-19. Interview video with Jim Gardner.

Figure 58-20: 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 58-21 to 58-23).

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 58-21: 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 58-22: Mockup of the final exhibit design, with three touchscreen stations in front of the museums existing piece of a historical shipwreck.

Figure 58-23: 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.

INDUSTRY PARTNERS 2016-2017

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 $8,092,545 for 2016 (see Appendix C).

DATA MANAGEMENT:

TASK 59: ***Data Sharing ISO19115 Metadata:*** *Transition from the FGDC format to the ISO 19115 format.* ***Paul Johnson and Jordan Chadwick***

This project has not yet started under this grant

TASK 60: ***Enhanced Web Services for Data Management:*** *Build upon state-of-the-art web services for the management and distribution of complex data sets.* ***Paul Johnson***

Project: **Enhanced Web Services for Data Management**
JHC Participants: Paul Johnson and IT staff

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 60-1).

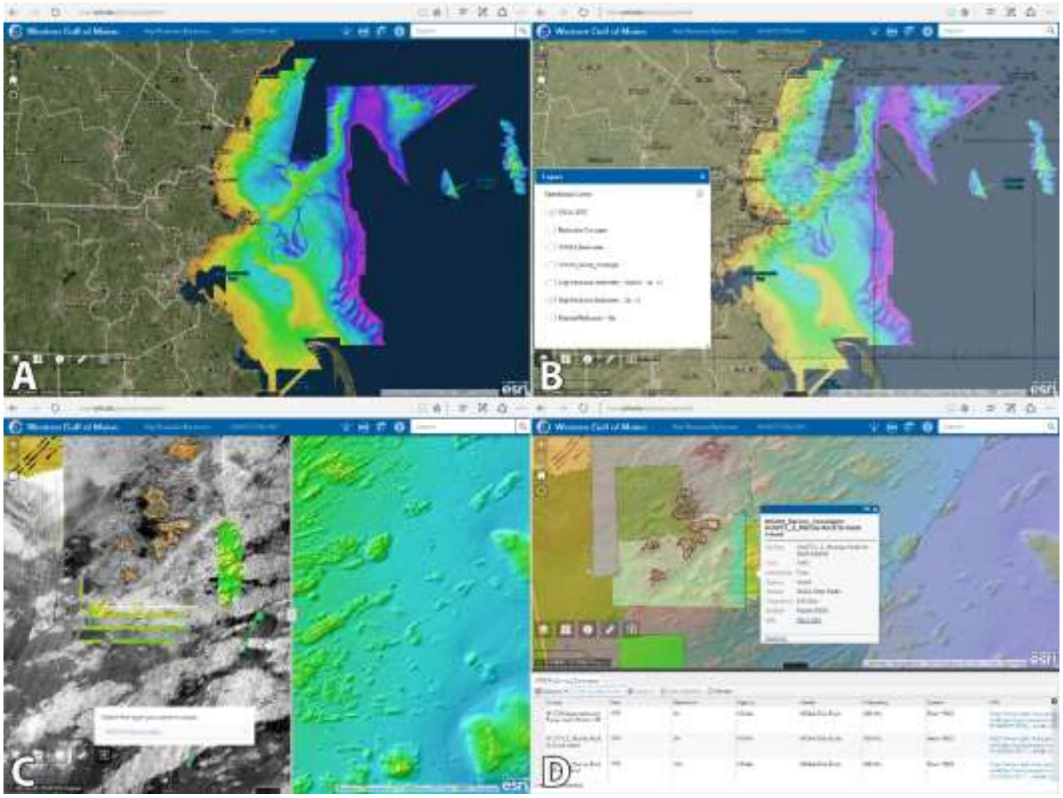


Figure 60-1: Dynamic web maps (http://ccom.unh.edu/gis/maps/wgom2m) served through the Center's website with content provided from the Center's GIS Server and Portal.

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 TASK 47) 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 60-1A), overlaying NOAA raster navigation charts (Figure 60-1B), being able to swipe and overlay datasets (Figure 60-1C), measuring distances and areas, changing underlying basemaps, rendering maps to JPEGs, PDFs, or PNGs, and easily querying information from the served datasets (Figure 60-1D).

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 60-2, works much like a "Google Earth" style viewer.

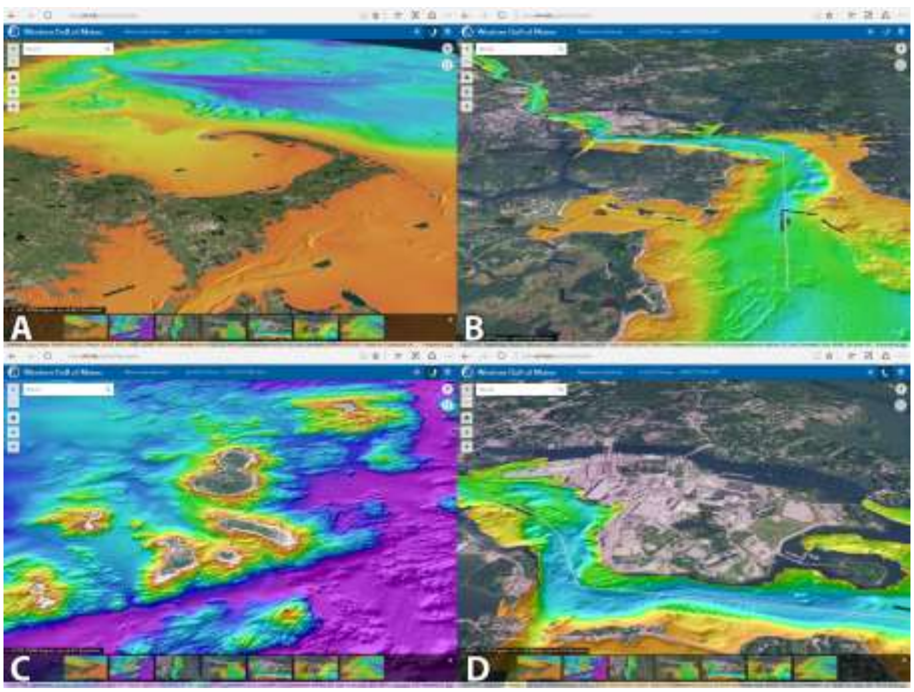


Figure 60-2: Examples of the GIS Portal driven three dimensional geospatial browser. This service can be accessed through **http://ccom.unh.edu/gis/scenes/wgom**.

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 14-18A). 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 60-2A 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 60-2B, 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 60-3).

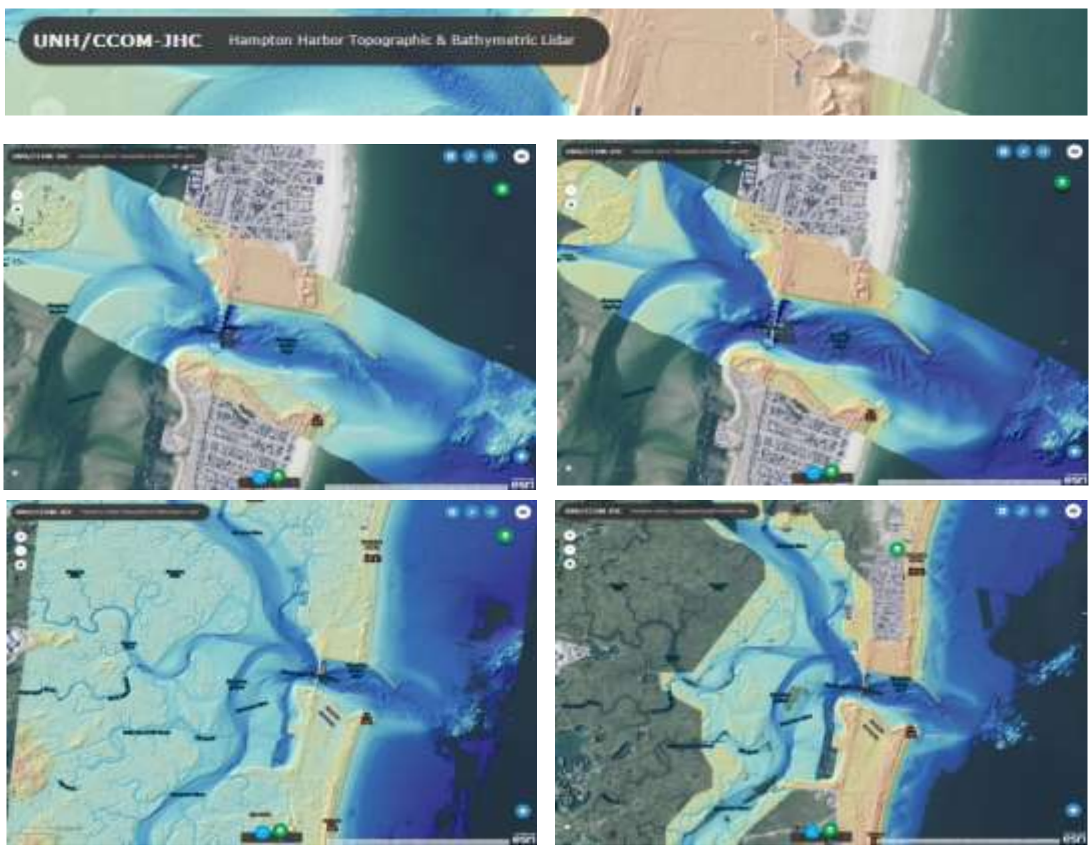
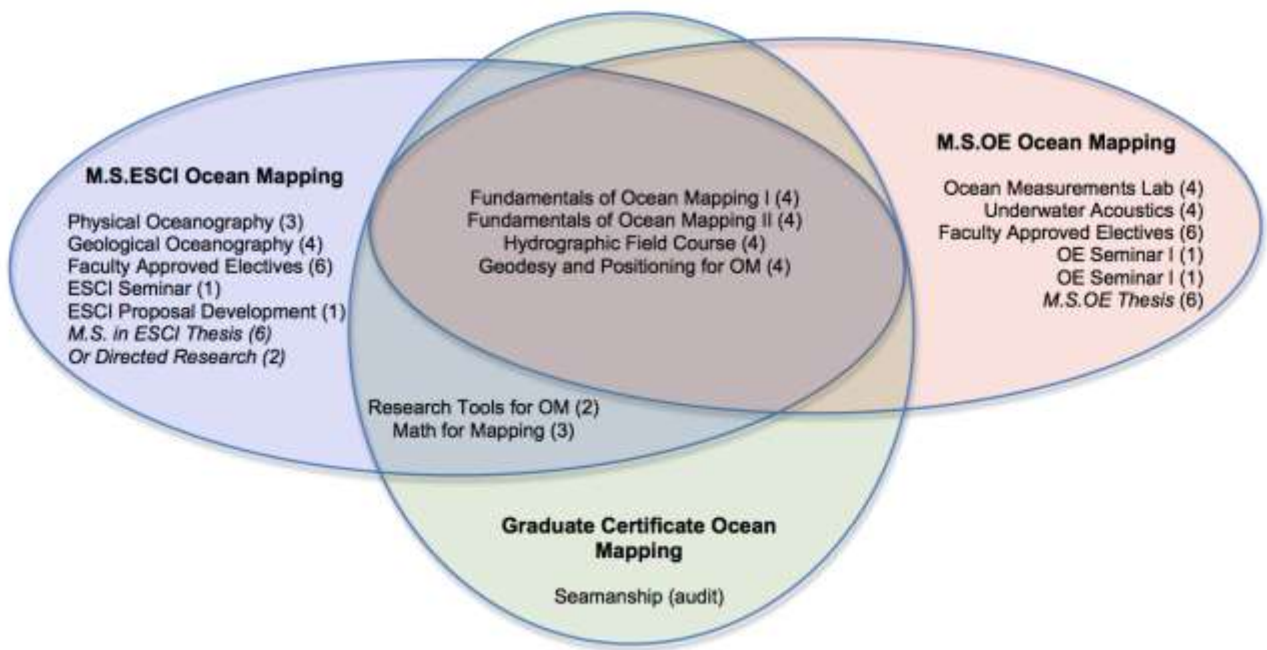


Figure 60-3: Hampton Harbor Topographic and Bathymetric Lidar Digital Elevation Models

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

There are no field programs affiliated with this grant at this time.

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 Tech	-	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

Seminars

Shachak Peeri, Rochelle Wigley, July 11 - 15, 2nd NOAA Chart Adequacy Workshop, GEBCO Year 12 Class, Nguyen Duy Luong (Vietnam), Paulo Pereira Oliveira Matos (Brazil), Danielle van Kuijk (The Netherlands, Mr.Rachot Osiri (Thailand), Marc-André Faucher (Canada) and Cecilia Zuleima Cortina Guzmán (Mexico), Silver Spring, MD, United States

Jenn Dijkstra, September 25 - 27, Sea ice, intensified shipping and Arctic Invasions, Governing Across the Waves: Global Insights for Transboundary Waterways Management in Sensitive and Congested Maritime Spaces, Bowdoin, Maine, United States

Val E. Schmidt, October 4, Autonomous Systems for Marine Science, University of New Hampshire Marine Docents, Portsmouth, NH, United States

Val E. Schmidt, October 21, Autonomous Systems for Marine Science and Hydrographic Mapping, CCOM, Durham, NH, United States

Jenn Dijkstra, October 31, Anthropogenic stressors and coastal ecosystems, Zoology 400, Durham, New Hampshire, United States

Jenn Dijkstra, November 1, Salt Marshes: What are they?, University of New Hampshire, Durham, New Hampshire, United States

Jenn Dijkstra, November 8, Coral Reef Ecology, University of New Hampshire, Durham, New Hampshire, United States

Larry Ward, November 17, Depositional Systems on the Northern MA and NH Inner Continental Shelf: Use of High Resolution Seafloor Mapping to Understand Impacts of Glaciation, Marine Processes and Sea-Level Fluctuations, Department of Earth Sciences, University of New Hampshire, Durham, NH, United States

Technical Presentations

Val E. Schmidt, Cassandra Bongiovanni, Contributed, January 27, Evaluating Outside Source Interferometric Data from USGS: preliminary analysis for chart updates, NOAA Office of Coast Survey (OCS), NOAA Field Procedures Workshop, Seattle, Washington, 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

Val E. Schmidt, Invited, February 18, Autonomous Surface Vehicles, NOAA, 43rd Meeting of the US-Japan Natural Resources Sea Bottom Surveys Panel, San Diego, CA, United States

Cassandra Bongiovanni, Val E. Schmidt, Invited, February 19, Preliminary Results of NOAA's Assessment of PMBS Data Collected by USGS for Chartability, NOAA's National Centers for Coastal and Ocean Science, Long Island Sound Acoustic Subgroup Meeting, Phone Call, United States

Colin Ware, Invited, March 16, Kinematics of Foraging: Humpbacks and Sea Lions, NIWA New Zealand, Wellington, New Zealand

Mashkoor A. Malik, Derek Sowers, Jenn Dijkstra, Contributed, March 17, Coarse and fine scale patterns of community structure of benthic habitats along the US Atlantic Continental Margin. , Benthic Ecology Meeting, Portland, Maine, United States

Larry Ward, Contributed, March 22, Observations of Seasonal Changes and Storm Effects on a Bedrock-Influenced, Paraglacial Coastal System, Geological Society of America, Northeastern Section Annual Meeting, Albany, NY, 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

Elizabeth Weidner, Contributed, April 11, Acoustic and Geomorphological Signatures of Gas Seeps on the East Siberian Margin, SMSOE, SMSOE Graduate Research Conference, 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, Vienna, Austria

Yuri Rzhanov, Firat Eren, Matthew Birkebak, Shachak Peeri, Contributed, April 19, Underwater-Detector Array for Optical Communication and Laser Beam Diagnostics, SPIE, SPIE DCS, Baltimore, Maryland, United States

Larry Mayer, Elizabeth Weidner, Contributed, April 21, Acoustic and Geomorphological Signatures of Gas Seeps on the East Siberian Margin, University of New Hampshire, UNH Graduate Research Conference, Durham, NH, United States

Matthew Birkebak, Firat Eren, John Kidd, 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

Val E. Schmidt, Sam Reed, Invited, May 18, Nautical Chart Awareness for Autonomous Surface Vehicles, Canadian Hydrographic Conference 2016, Halifax, Nova Scotia, Canada

Ramos Ricardo Freire, Lee Alexander, Tom Lippmann, 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

Tom Weber, Kevin Rychert, Alexandra Padilla, Contributed, May 24, Target strength observations of wobbly bubbles, Acoustical Society of America, Target Physics and Scattering, Salt Lake City, Utah, United States

Colin Ware, Keynote, June 17, Visual Thinking about Data: The Cognitive Thread, Interaction and the Visual Query. , Information+ Conference, Vancouver, BC, Canada

Brian Calder, Contributed, June 21, Synoptic Risk Assessment for Ship Passage and Hydrographic Uncertainty Representation, Committee on the Marine Transport System, CMTS 4th Biennial Conference: From Sail to Satellites, Washington, DC, United States

Jenn Dijkstra, Michael Bogonko, Michael White, Erin Nagel, Juliet Kinney, Contributed, July 20, Intensity and Reflectance for Habitat Mapping and Seafloor Characterization using the Super Storm Sandy Lidar Data, JABLTCX, JALBTCX workshop, Silver Spring, MD, United States

Sarah Wolfskehl, Michael Bogonko, Michael White, Juliet Kinney, Contributed, July 21, NOAA Intergrated Ocean and Coastal Mapping: Using Hurricane Sandy Response Data to Help Build a Bridge between Lidar Bathymetry and the Chart, Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), JALBTCX workshop, Silver Spring, MD, United States

Sam Reed, Invited, September 21, Providing Nautical Chart Awareness to Autonomous Surface Vessel Operations, IEEE MTS, IEEE Oceans, Monterey, CA, United States, On September 21, I gave a technical presentation at the IEEE Ocean's Conference in Monterey, CA

Larry Ward, Contributed, October 28, 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, United States

Michael Bogonko, Michael White, Juliet Kinney, Sarah Wolfskehl, Michael Bogonko, Invited, November 3, GIS Application to Marine Debris Assessment and Categorization After Superstorm Sandy, ESRI, ESRI Ocean Forum, Redlands, CA, United States

Larry Mayer, Elizabeth Weidner, Invited, December 15, Quantification of Methane Gas Flux and Bubble Fate on the Eastern Siberian Arctic Shelf Utilizing Calibrated Split-beam Echosounder Data, American Geophysical Union, AGU Fall Meeting, San Francisco, CA, United States