Applied Research Laboratory
University of Hawaiʻi

Global Maritime Forum
2021 Final Report

"Fathoming the Future: Examining Evolutionary Variables
in a Multidimensional Maritime Domain"

September 21-23, 2021
Honolulu, Hawaiʻi

National Maritime Intelligence-Integration Office
Applied Research Laboratory at the University of Hawaiʻi

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The forum adhered to a variation of the Chatham House Rule. Beyond the opinions expressed in the keynote presentations and by the invited panelists, no attributions are included in this report. The opinions expressed in this publication are those of the keynote speakers and panelists. They do not reflect the opinions or views of the United States (US) National Maritime Intelligence-Integration Office (NMIO) or its members.

The NMIO supports the Director of National Intelligence and the National Security Council Staff by coordinating and integrating the US Intelligence Community's perspective on maritime issues. The NMIO leverages its deep and varied expertise to solve problems and build collaboration among the Global Maritime Community of Interest by breaking down barriers to intelligence integration and information sharing.

Executive Summary

The National Maritime Intelligence-Integration Office (NMIO) partnered with the Applied Research Laboratory at the University of Hawai'i (ARL at UH) to support, develop, host, facilitate, and assess the 8th Global Maritime Forum. Global Maritime Forums are designed to bring together the government, academic, research and development, intelligence and industry maritime-related leaders to continue building the Global Maritime Community of Interest (GMCOI) and Maritime Science & Technology Community of Interest. Together, participants identify roadmaps and make policy recommendations to enhance maritime security and counter threats. The objectives of the Global Maritime Forums are to:

• **Encourage public-private-academic-international partnerships to explore ways to expand capabilities and capacity**
• **Tap into a broad and deep international talent pool with no restrictions on participation**
• **Identify actionable results and ideas that have the potential to become future projects**
• **Understand emerging technologies through science and technology outreach; glean lessons learned from previous scientific breakthroughs, research, and development efforts**

The 8th Global Maritime Forum was held September 21-23, 2021. Due to the COVID-19 pandemic, the forum was conducted virtually to ensure the safety of all participants and adhere to health directives issued by the State of Hawai'i. Participants joined the virtual forum from Canada, Ecuador, France, Japan, Indonesia, Italy, the United Kingdom and the United States.

The overarching theme of the 8th Global Maritime Forum was "Fathoming the Future: Examining Evolutionary Variables in a Multidimensional Maritime Domain" with emphasis on three topics: seafloor infrastructure and technology, climate influences on the undersea domain, and autonomous influences on the undersea domain. The forum included two keynote presentations, three panel discussions, two days of working group meetings and virtual demonstrations of three technologies under development at ARL at UH.

Participants of the 8th Global Maritime Forum were asked to identify changes that they felt needed to occur by 2040 to best protect the undersea domain and to design a competition to stimulate solutions to the identified challenges. A snapshot of challenges and recommendations are as follows:

SEAFLOOR INFRASTRUCTURE AND TECHNOLOGY

Challenges identified: data sharing, protecting the environment, international cooperation, and expanding the use of uncrewed vehicles.

Recommendations: design competitions using uncrewed systems, foster international competitions to promote strategic cooperation, increase public interest by creating an "undersea discovery" race.

CLIMATE INFLUENCES ON THE UNDERSEA DOMAIN

Challenges identified: global monitoring and modeling, resource protection and national security, and education and citizen involvement.

Recommendations: leverage social media to engage youth, develop competitions using augmented and virtual reality simulations to promote knowledge and understanding, develop policies in concert with conducting competitions.

AUTONOMOUS INFLUENCES ON THE UNDERSEA DOMAIN

Challenges identified: data collection, data sharing and data analysis.
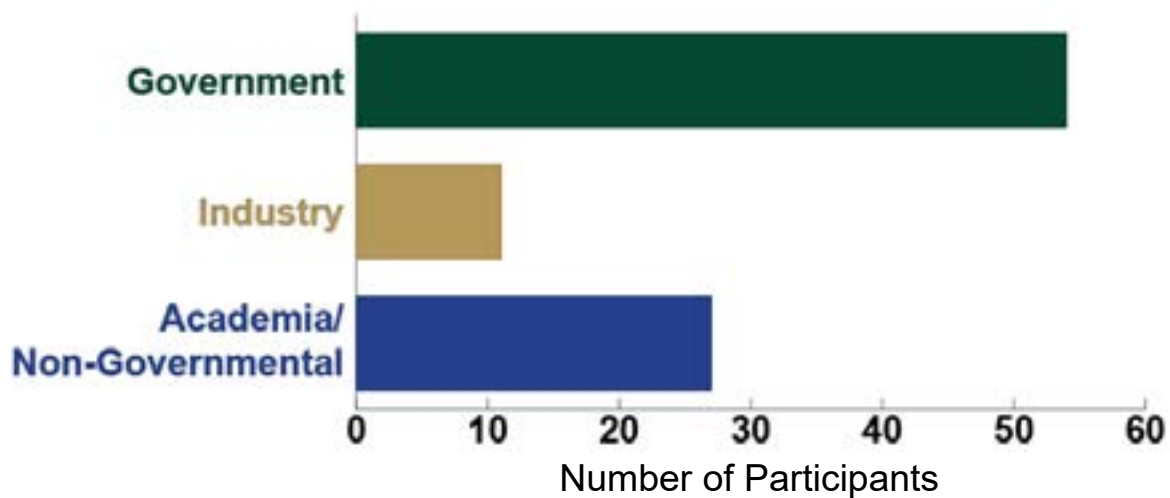
Recommendations: develop competitions that integrate systems, sensors, artificial intelligence and machine learning to monitor characteristics (e.g., vessel traffic, fisheries health, coastal change), collaborate with law enforcement in conducting exercises.

Global Maritime Forum Participant Demographics

COUNTRIES
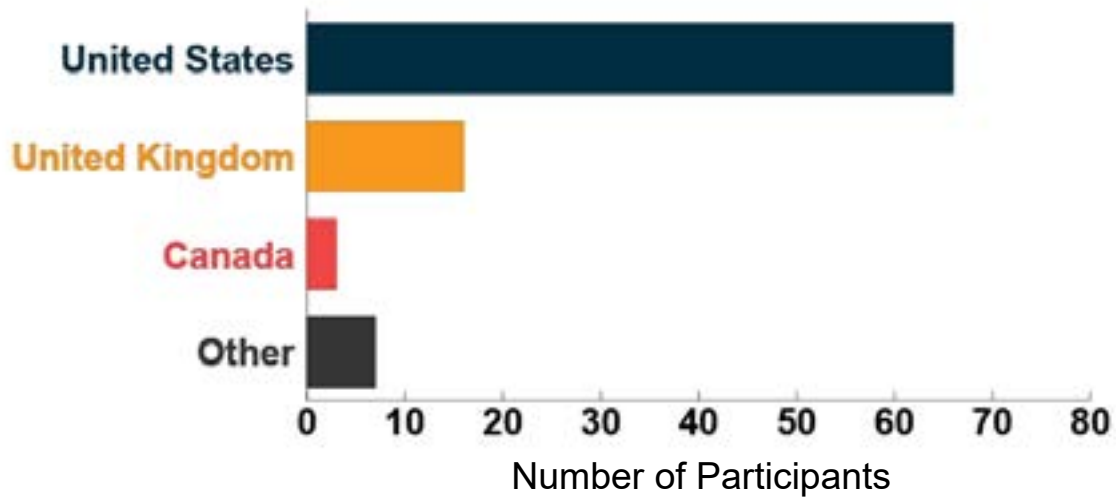
Number of Participants

SECTORS

Number of Participants

Global Maritime Forum

FOREWORD

Organized and executed by NMIO, the Global Maritime Forum (GMF) is a three-day workshop designed to stimulate discussion and action on solutions to complex issues of technology and its effects on national maritime policy.

The GMF directly supports the NMIO S&T mission and strategic guidance as set forth by the Office of the Director of National Intelligence (ODNI) to engage academia, think tanks, the private sector, and foreign governments for a common understanding of the implications of emerging technologies in the maritime domain. It represents one of NMIO's more ambitious outreach efforts in which leading United States (US) and international experts collaborate on presentations and panel discussions to explore and share technical information and formulate actionable recommendations for senior government officials.

Each year the Director of NMIO chairs the GMF in conjunction with local partners and/or sponsors. In previous years, NMIO S&T partnered and co-sponsored the GMF with the Italian Navy and Centro Alti Studi per la Difesa, the National Aeronautics and Space Administration (NASA) Ames Research Center, the Applied Physics Laboratory at the University of Washington and the University of Liverpool. This year the GMF was co-hosted by the ARL at UH and addressed seafloor infrastructure and technology in addition to autonomous and climatological influences on the subsea domain. The GMF 2021 theme was "Fathoming the Future: Examining Evolutionary Variables in a Multidimensional Maritime Domain."

APPLIED RESEARCH LABORATORY AT THE UNIVERSITY OF HAWAI'I

Established in 2008, ARL at UH is one of five Navy-sponsored University-Affiliated Research Centers (UARC). The ARL at UH serves as a center of excellence for critical Navy and national defense needs, conducting research, development, testing and evaluation (RDT&E) to address challenging and emerging problems. The ARL at UH efforts focus on Ocean Environmental Effects, Astronomical Research, Advanced Electro-Optical Systems, Detectors, Arrays and Instrumentation, Environmental Sensor Research and Remote Sensing, New Renewable Energy, and Mission-Related and Public-Services-Oriented Research and Development (R&D).

GLOBAL MARITIME FORUM 2021 PARTNERSHIP

The GMF 2021 partners included keynote speakers, panel moderators and panelists, session facilitators and note takers, organizers and administrators, and the all-important forum participants. This report captures GMF 2021 virtual session interactions from diverse settings including laboratories, private offices, vessels, remote workplaces, and conference rooms, all of which were repurposed as studios. We applaud the community's ingenuity in coming together!

PROGRAM COMMITTEE

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Executive Biographies

REAR ADMIRAL CURT COPLEY, US NAVY

Rear Admiral (RADM) Curt Copley is the Director of the National Maritime Intelligence-Integration Office and Commander of the Office of Naval Intelligence (ONI). Prior to joining NMIO, RADM Copley served as the Deputy Director of Operations at the National Security Agency (NSA). He has completed operational tours and shore assignments across the globe in Iraq, Afghanistan, Japan, Italy, Spain, Germany, and the United Kingdom.

MEKISHA MARSHALL, NMIO

Ms. Mekisha Marshall is the Chief S&T Advisor and S&T Department Head at NMIO. In this capacity, she advises the Director of NMIO on the implications of current and emerging technologies that have the ability to produce new threat vectors in the maritime domain. She engages and collaborates with various sectors within the government, academia, think tanks, and the private sector to understand the implications of emerging technologies that have the ability to produce new threats or challenges in the maritime environment; or conversely, those that offer new opportunities to improve maritime security.

MARGO EDWARDS, ARL AT UH

Dr. Margo Edwards is the Director of ARL at UH and a Senior Research Scientist in the Hawai'i Institute of Geophysics and Planetology at the University of Hawai'i at Mānoa (UHM). She received her doctoral degree in marine geology and geophysics from Lamont-Doherty Earth Observatory of Columbia University. Edwards specializes in remote sensing of the seafloor using optical and acoustic systems. She leads ARL at UH in its mission to imagine and develop agile, innovative and cost-effective solutions to problems impacting Maritime Domain Awareness (MDA) stakeholders and the planet.

Opening Remarks

Ms. Mekisha Marshall kicked off the GMF 2021 by welcoming the attendees and staff. Mindful of the COVID-19 pandemic, this was the first-ever all-virtual GMF to ensure the safety of participants and adhere to health directives issued by the State of Hawai'i. Ms. Marshall pointed out that, while a virtual platform was not an ideal approach to foster collaboration of old friends and initiate introductions to new colleagues, the objectives of NMIO – to enhance information sharing, integrate emerging technologies and find solutions for upcoming challenges – were fully achievable for the GMF 2021 by leveraging recent advances in teleconferencing.

Dr. Margo Edwards shared her excitement to meet kindred spirits interested in MDA among the GMF community and to have the opportunity to virtually demonstrate how ARL at UH tests new technology in the field. Dr. Edwards shared the mission of ARL at UH and how it fits into the context of co-hosting the GMF 2021. The ARL at UH, as one of the five Navy UARCs, focuses on six core competency areas: ocean research, astronomy, sensor development, remote sensing, renewable energy, and public-service-oriented R&D.

The ARL at UH has the distinct advantage of being able to "kick the tires" of technology in the wide variety of ecosystems, wind, wave and tidal conditions, and geological settings in the Hawaiian Islands.

Rear Admiral Curt Copley outlined the mission of NMIO: to apply solutions to MDA, looking out for new technologies that present threats and opportunities. He highlighted two topics that will drive the next decade: climate change and illegal, unreported and unregulated (IUU) fishing. Of particular interest to RADM Copley were issues concerning data management; he encouraged attendees to discuss topics regarding common data sharing standards and common data analytics that come to the same conclusions. Excited about a new era of strategic competition in the maritime domain, RADM Copley posed overarching questions for forum participants to think about over the course of the GMF 2021: "What is the data we need? What are the problems we are trying to solve? What questions do we need to ask?"

Global Maritime Forum Participants on Zoom

Keynote: Admiral, USGC (ret.) Paul F. Zukunft

Admiral (ret.) Paul F. Zukunft served as the 25th Commandant of the US Coast Guard (USCG) from 2014-2018, forging alliances among partner nations in Central and South America to combat transnational criminal organizations trafficking illicit drugs; establishing an Arctic Coast Guard Forum comprised of the eight Arctic Council nations to address issues in the Arctic domain; revitalizing diversity across the work force; sharing best practices across the military, federal and commercial maritime sectors to advance cybersecurity; and facilitating more than $4.6 trillion in US maritime commerce on an annual basis. Admiral (ADM) Zukunft's 41 years of active-duty service and eight commands, including command of three Coast Guard cutters, spanned the globe. Under his leadership the USCG emerged as the gold standard for promoting maritime safety and security.

KEYNOTE SUMMARY

Admiral Zukunft's keynote address to the GMF 2021 focused on the evolution of MDA. He presented a progression of the advances in maritime communications, beginning with Morse code used on the RMS Titanic; then describing the use of weather balloons, Loran A, B and C; and ultimately the Global Positioning System (GPS). Admiral Zukunft described how technical challenges facing maritime security professionals have evolved from detecting cartel "go-fast" boats to semi-submersible vessels that are harder to detect. Admiral Zukunft speculated that bad actors are in the process of shifting to the use of uncrewed systems, in parallel with the maritime security professionals who work to counter their illegal activities. He highlighted the importance of satellite signals for communication, helping with distress signals, precision navigation, and precision timing. The challenge, he explained, is dealing with those who choose to "go dark" and stay undetected by evading the Automatic Identification System (AIS), which is used to monitor vessel activity at sea. He described regions of "darkness" when it comes to MDA; for example, in the warming Arctic where nascent sensor arrays are not yet sufficient to detect illicit activities at a time when Russia enjoys Arctic hegemony.

Admiral Zukunft touched on the topics of environmental stewardship and climate change. Recounting his experience with the Deepwater Horizon oil spill, he discussed the importance of partnerships to leverage technology and funding to solve critical issues. On the topic of climate change, ADM Zukunft explained that opportunities and challenges are often intertwined in the maritime domain, citing examples including how ships will transit through the Arctic as sea ice retreats, the migration of fish to colder waters, the exploitation of the seabed for harvesting minerals and oil, and the impacts of sea level rise.

Admiral Zukunft concluded his keynote address with a discussion of the "wave of the future," focusing specifically on uncrewed vessels. While the use of uncrewed vessels will ultimately significantly expand MDA, their use raises a series of new "what-ifs" regarding the rules and regulations that maritime policies are only beginning to address.

Answering questions from the attendees, ADM Zukunft detailed how far the USCG's trust and confidence measures have evolved, with many nations allowing the USCG to intervene in illicit activities with up to "deadly force." Asked about data sharing, ADM Zukunft opined that an important characteristic of government data platforms is not so much "owning" the data, as the data being accessible, adhering to a high level of data integrity, and promoting information sharing between trusted domestic and international data users. Advocating the importance for human interactions, ADM Zukunft asserted that technology cannot replace all elements of port security and emphasized diplomatic approaches for sharing information. Admiral Zukunft ended the question-and-answer session by underscoring the importance of being proactive instead of reactive regarding possible disruptions in the maritime domain.

> Advocating the importance for human interactions, ADM Zukunft asserted that technology cannot replace all elements of port security and emphasized diplomatic approaches for sharing information.

Image Credit: US Coast Guard

Semi-submersibles, which conduct illicit activities, may soon by replaced by uncrewed vessels

Seafloor Infrastructure and Technology

Panel Moderator

Dr. Kathryn (Kate) Moran is a Professor in the Faculty of Earth and Ocean Sciences at the University of Victoria and President and Chief Executive Officer of Ocean Networks Canada. Her previous positions include Professor of Oceanography and Ocean Engineering and Associate Dean of Research and Administration at the University of Rhode Island and Assistant Director of the White House Office of Science and Technology Policy, where she focused on Arctic, polar, ocean, and climate policy issues and the Deepwater Horizon oil spill. Dr. Moran has testified before Congress on climate change and is active in public outreach on topics related to the Arctic, ocean drilling, and climate change.

Panelists

Dr. Bruce Howe is a Professor in the Department of Ocean and Resources Engineering at the UHM. He develops ocean observing infrastructure for the provision of power, communications, and positioning throughout the ocean volume, with an emphasis on cabled and acoustic systems. As Chair of the international Joint Task Force (JTF) Science Monitoring And Reliable Telecommunications (SMART) Cable initiative, Dr. Howe leads the effort to incorporate sensors into commercial trans-ocean submarine telecommunication cable systems to form a planetary-scale observing system for climate, ocean circulation and sea-level monitoring, and tsunami and earthquake warning.

Dr. Larry Mayer is a Professor and the Director of the Center for Coastal and Ocean Mapping at the University of New Hampshire. He chairs the National Academies of Science's US Committee for the Decade of Ocean Science and serves on the US State Department's Extended Continental Shelf Task Force, the US Navy's Science Ice Exercise Advisory Committee, and as Vice Chair of the Board of the Ocean Exploration Trust. Dr. Mayer has participated in more than 95 cruises including 14 mapping expeditions in the ice-covered regions of the high Arctic. His current research deals with sonar imaging and remote characterization of the seafloor as well as advanced applications of three-dimensional visualization to ocean mapping problems and applications of mapping to United Nations Convention on the Law of the Sea (UNCLOS) issues.

Mr. Guy Noll leads the national mapping products department of the Geographic Information System (GIS) company, Esri, with maritime, aviation, and topography production tools and automation of workflows and data quality extensions to the Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS). Prior to joining Esri, Mr. Noll worked for more than 24 years in the National Oceanic and Atmospheric Administration (NOAA), retiring with the rank of Captain in the Commissioned Officer Corps. His primary interest is in implementations by partners and users of ArcGIS components that include maritime patterns such as disconnected editing, real-time observation and edge analysis with geofenced triggers and alerts, autonomous navigation support, and water column visualization.

The first panel of the GMF 2021, moderated by Dr. Kate Moran, focused on undersea infrastructure and technology. Panelists included Dr. Larry Mayer, Dr. Bruce Howe, and Mr. Guy Noll.

Dr. Larry Mayer opened the panel with a discussion of seafloor mapping technology. Beginning with a chronology of seafloor mapping systems, he described technological innovations from lead lines to broadband sonar systems. Dr. Mayer emphasized how rapidly this field is changing, citing recently developed capabilities that have expanded from detecting where the seafloor is to classifying what the seafloor is. To continue this evolution, the Nippon Foundation and the General Bathymetric Chart of the Oceans (GEBCO) launched the Seabed 2030 Project to map Earth's entire seafloor by the year 2030. Dr. Mayer explained that the cost of mapping Earth's seafloor is comparable to the cost of mapping the planet Mars, and he advocated that, "we owe it to our own planet" to map Earth. Dr. Mayer outlined several approaches to achieve the goal of mapping Earth's entire seabed: (1) ensure that ships equipped with sonars are constantly mapping; (2) deploy autonomous surface platforms equipped with mapping systems; and (3) develop autonomous sparse arrays.

Dr. Bruce Howe spoke about essential ocean infrastructure. He underscored the importance of providing power for seafloor infrastructure, which presents a challenge because there is no appreciable energy source in remote, deep ocean settings. Dr. Howe recommended leveraging shared infrastructure by combining the essential components of power and telecommunication. He outlined the SMART subsea cable project already underway, which is designed to integrate existing underwater cables with embedded sensors. Dr. Howe proposed the integration of branch units into nodes along these cables to support technologies such as autonomous underwater vehicle (AUV) docking stations. The SMART cable systems are intended to also support position, navigation, and timing for AUVs using acoustic systems that will also enable acoustic tomography measurements of the deep ocean. Dr. Howe emphasized the theme of using submarine telecommunications structures for mutual benefit.
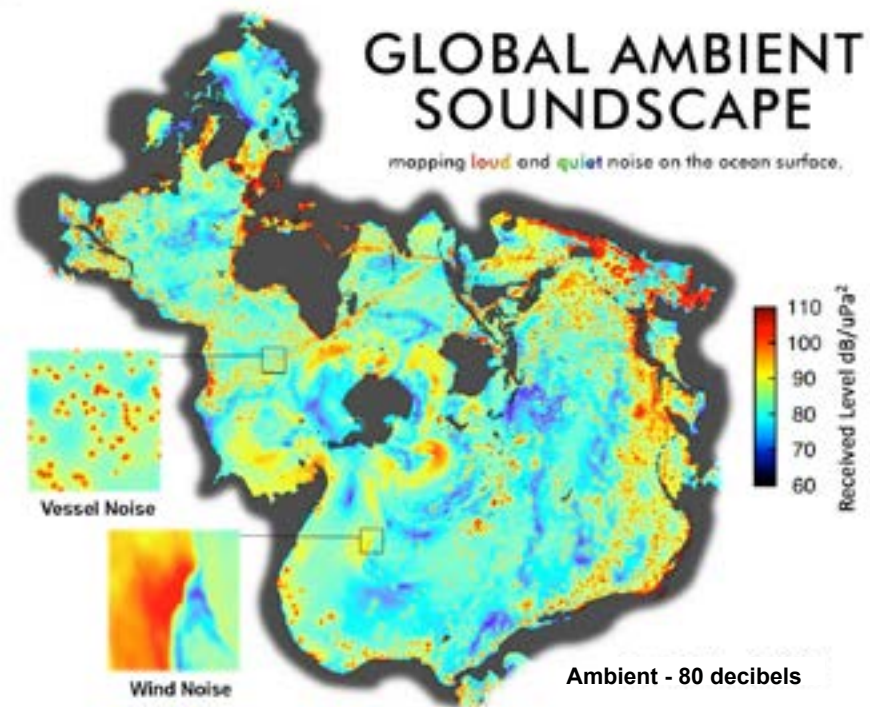
Measured ambient sound strength in the global ocean
Figure credit: After Heaney et al., 2021.
Data: Spire Global Applied Ocean Sciences

Seafloor Infrastructure and Technology

Dr. Kate Moran expanded on the discussion of undersea cables, presenting an overview of Ocean Networks Canada (ONC), a network of cabled observatories off the west coast of North America that openly provides data access. Initiated on Canada's west coast, ONC has expanded to Canada's east coast and into the Arctic, putting ocean observing in the hands of indigenous and local communities that live in these high-latitude environments. The ONC develops products for ocean health, safety, and climate solutions, with sensors that can detect earthquakes, oil spills, and underwater noise. She concluded with some of the climate solutions ONC is focusing on, including Solid Carbon, a negative emissions technology designed to capture carbon dioxide from the atmosphere, pump it into the seafloor, and transform it into stone.

Mr. Guy Noll was the final presenter for this panel, describing the use of digital twin models in maritime navigation. He discussed GIS applications already underway, such as anti-collision and vessel pattern analysis using AIS data. He described novel efforts, such as training models to simulate the capabilities of the human eye to create digital assistance that could help reduce vessel collisions. Mr. Noll emphasized the importance of transitioning from product-based thinking to service-based thinking to ensure the use of real-time, up-to-date information. Using a combination of open-source and commercial tools currently available, the digital twin model can capture, visualize, analyze, and share data.

After their presentations, the four panelists addressed questions from the audience. When asked about the effects of sonar and other technologies on marine mammals, the panelists confirmed that they are paying attention to this research area and acknowledged a broad spectrum of results and opinions. Responding to a question regarding the role of citizen scientists, Dr. Mayer mentioned inexpensive tools being developed to enable crowdsourcing for seafloor data, for example by collecting bathymetry data from commercial or recreational fishing vessels. Mr. Noll reminded the audience that remote sensing from satellites and Light Detection and Ranging (LIDAR) systems has provided excellent data in many shallow coastal areas. On the topic of community engagement, Dr. Moran described "Youth Science Ambassadors," an initiative that provides one-on-one training with, and community college courses for, indigenous youth. Rear Admiral Copley asked about data standards; the panel responded by describing the oceanographic community's commitment to data quality assurance, discussing the challenges of handling data derived from different system manufacturers and processing streams. Considering progress to date, the panelists were confident that data quality will continue to improve and are optimistic about the future of undersea sensing, urging the GMF 2021 participants to create sustainable systems, "unleash our imagination" and "keep at it!"

The Youth Science Ambassador Program is an innovative initiative of ONC. The program connects youth from local communities with world-leading ocean science from ONC's observatories and the place-based Indigenous knowledge of the ocean that exists within their region.

Oceannetworks.ca/learning/get-involved/
youth-science-ambassador

Keynote: Dr. Chip Fletcher

Dr. Charles (Chip) Fletcher is the Interim Dean and a Professor of Earth Sciences in the School of Ocean and Earth Sciences and Technology at the UHM. He is also Chairperson of the Honolulu Climate Change Commission, and author of three textbooks on physical geology, climate change, and geologic hazards in Hawaiʻi. Dr. Fletcher and his students have published over 120 peer-reviewed articles on Pleistocene and Holocene reef history, beach processes, and the impacts of sea level rise.

KEYNOTE SUMMARY

In his keynote address, Dr. Fletcher connected changes in the global climate to fundamental aspects of human life and offered solutions for combatting climate change. Dr. Fletcher described key climate change indicators including: a plot of average yearly temperatures showing the acceleration of global warming over the past six years; similarly increasing trends in carbon dioxide (CO_2) levels collected from Hawaiʻi's Mauna Loa Observatory; and data documenting Arctic warming at twice the rate of the global average.

Dr. Fletcher discussed several ensuing effects related to climate change that have implications for Earth's oceans and MDA: 23% of CO_2 released into the atmosphere is absorbed by the ocean, leading to ocean acidification, which impacts many marine species. The accumulation of freshwater in the North Atlantic Ocean has caused global ocean circulation to slow down. Glaciers and ice sheets are melting, causing sea level rise. The ocean absorbs heat from the air, causing thermal expansion of water that accounts for roughly half of sea level rise. Groundwater depletion in some shore-based settings can exacerbate sea level rise. In combination, changing climate conditions and the accompanying sea level rise are expected to cause devastating flooding for coastal communities such as Honolulu. In addition to these impacts in the maritime domain, Dr. Fletcher described a multitude of climate change consequences for people in terrestrial settings, from food and water shortage to disease spread. He listed sobering predictions based on current data trends: that by 2050 an additional 300 million people will be malnourished and 216 million people will be displaced; by 2070, 19% of Earth's land will be too hot for human existence. He pointed to climate change, overconsumption and population growth as the causes of the COVID-19 pandemic. Dr. Fletcher emphasized that disease, environmental damage, climate change, and inequality often create feedback loops that amplify each other, worsening conditions over time.

Dr. Fletcher offered a wide range of solutions to mitigate the climate crisis. To meet the desired limit of no more than 1.5° Celsius (C) warming set in the Paris Climate Agreement[1], he proposed using industrial-scale CO_2-capturing techniques to transition to negative emissions. Dr. Fletcher described the use of CO_2 as a fuel source as a promising trend, along with the increased production of renewable energy. Additional suggestions to protect Earth's oceans and mitigate the impact of climate change on the maritime and terrestrial domains included: build a zero emissions electric grid; decommission existing fossil fuel infrastructure before the end of its lifetime; invest

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1 The "Paris Agreement," which is also referred to as the Paris Accords or the Paris Climate Accords, is an international treaty on climate change, adopted in 2015. It covers climate change mitigation, adaptation, and finance.

in emissions-free transportation and zero emissions industry and buildings; revolutionize agriculture practices; reduce consumer consumption; and enact transformational societal change. Dr. Fletcher concluded his presentation with a quote from his opinion piece in *The Hill*, saying, "It's not enough to cut emissions, we need economic development that does not destroy nature."

During the question-and-answer session, audience members asked Dr. Fletcher to describe how he predicts the Earth will change in the near future. He assured them that the places where they live will still exist, but they will be under duress from the natural and geopolitical pressures, especially near maritime, state and country borders. Referencing the earlier projection that 19% of the earth will become uninhabitable by 2070, Dr. Fletcher predicted that 20% of the earth could eventually become unable to support agriculture. Dr. Fletcher was asked what individuals and corporations can do to mitigate the worst impacts of climate change, and he offered several suggestions: individuals can shift towards a plant-based diet; governments can increase taxes on the beef industry; those working in the maritime domain can follow the example of shore-based transportation organizations and shift away from the use of fossil fuels; governments can make nuclear energy and other pivotal technology part of the discussion about alternative sources of energy; and consumers can hold corporations accountable for their behavior and encourage investment in environmentally supportive trends.

> "It's not enough to cut emissions, we need economic development that does not destroy nature."
>
> - Dr. Fletcher, *The Hill*

Figure Credit: Dr. Chip Fletcher

21st century sea level rise of ~1.5 meters is predicted to submerge most of Waikiki, Hawai'i

Climatological Influences on the Undersea Domain

Panel Moderator

Dr. Robin Bell is a Research Professor at the Lamont-Doherty Earth Observatory at Columbia University and past President of the American Geophysical Union. Dr. Bell's research examines Earth's large ice sheets holistically, with the goal of understanding how ice sheets work and how they will change in the future. She has published over 100 peer-reviewed articles and more than 30 other publications concerning the challenges presented by climate change in the polar regions. Dr. Bell also works to enable coastal communities around the globe to develop scientifically informed strategies to respond to changing sea levels.

Panelists

Dr. Christian V. Braneon is a climate scientist and civil engineer who co-leads urban research at the Climate Impacts Group of the NASA Goddard Institute for Space Studies (GISS), serves as a visiting professor at Barnard College, and co-leads the Environmental Justice and Climate Just Cities Network at the Earth Institute of Columbia University. His primary research, conducted as part of the NASA-Microsoft partnership, has developed applications of remote sensing data that enhance resilience to urban heat stress. Dr. Braneon is currently a co-investigator on a research project that will produce new data products, providing new information and insights on the role of coastal marshes in the global carbon and nutrient cycles.

Dr. Brian Glazer is a professor in the Department of Oceanography in the School of Ocean and Earth Science and Technology at the UHM. He serves on the National Science Foundation's Ocean Observing Initiative Facilities Board as well as the Deep Submergence Science Steering Committee. Dr. Glazer's research involves building and using autonomous samplers, chemical analyzers, and assets from the National Deep Submergence Facility. Currently, Dr. Glazer's scientific laboratory focuses on the interface between chemistry and biology within coastal Hawai'i. He has spent the past three years developing affordable sensors, instruments, and a web-based data platform to enable hyper-local ocean observations.

Climatological Influences on the Undersea Domain

The second panel of the GMF 2021, moderated by Dr. Robin Bell, discussed how climate change is affecting the undersea domain from the tropics to the poles at spatial scales ranging from the local fishpond to entire continents. Panelists included Dr. Christian Braneon and Dr. Brian Glazer.

Dr. Christian Braneon opened the panel, discussing the influence of climate change on coral bleaching in the Mesoamerican reef region. Reflecting Dr. Fletcher's discussion of the global increase in temperature, Dr. Braneon predicted a 1.5-2° C increase in sea surface temperature (SST) by mid-century in the Mesoamerican reef region and a 2-4° C increase by end of century. Such an increase in SST can lead to more Degree Heating Weeks (DHW), which increases the severity of coral bleaching events. Sharing predictions from a few global climate models, Dr. Braneon showed that even using the lowest model projections, the DHW is expected to increase above the threshold for moderate coral bleaching events by the end of this century. These increases in temperature will negatively impact the Mesoamerican reef region, including maritime industries such as tourism and fishing.

Dr. Brian Glazer described his efforts to democratize access to ocean observing technologies, recounting his journey from scientist interested in sensing the ocean to his current projects helping communities use low-cost sensors to monitor climate impacts on their local maritime environment. Dr. Glazer has worked extensively in 400-year-old Hawaiian fishponds, developing low-cost telemetry systems to transmit real-time data collected nearshore to an open-access website. He noted that adding telemetry to existing research-grade sensors and loggers is now "routine" and can yield data with unprecedented spatial and temporal resolution. The next step, Dr. Glazer explained, is to develop inexpensive, rigorous sensors to measure some of the most common oceanographic parameters such as tides, air and water temperature, atmospheric and water pressure, salinity, and dissolved oxygen. Using low-cost sensors, Dr. Glazer initiated a program called SMART (Strategic Monitoring and Resilience Training) Ala Wai, designed to get UH students involved in sampling and observing Honolulu's Ala Wai watershed, which includes the famous Waikiki Beach. Dr. Glazer thinks that involving the community in environmental monitoring can increase coastal oceanographic measurements, benefit local and indigenous understanding of environmental change, and increase the amount of information available to support maritime stakeholders.


Expensive sensors, inexpensive telemetry for hyper-local environmental monitoring
Image Credit: Brian Glazer, UHM

Dr. Robin Bell shifted the panel's focus from the tropics to the changing ice, coastlines, and oceans in the polar regions of the planet. She used multiple metrics to describe how ice sheets are rapidly changing: "rivers of ice" draining into the ocean at speeds that are twice as fast as previously measured; ice sheets stretching and thinning; and ice sheets losing mass each year. Dr. Bell explained that because of geological processes such as isostatic rebound, sea level rise does not occur uniformly around the Earth. For example, in Greenland, where rapid melting is decreasing the weight of ice sheets pressing down on the terrain, the land is rising slowly and sea level is falling. Dr. Bell recommended that along with advancements in projects such as carbon sequestration and renewable energy, it is critical to provide global access to data derived from ocean observing networks for MDA.

During the question-and-answer session, the panelists reinforced a common theme in all three presentations, discussing effective ways to engage stakeholders in their research. Dr. Braneon underscored the benefits of engaging diverse communities, ranging from maritime professionals to local residents, at the outset of the project. In the case of citizen science, this will require developing and disseminating quality assurance practices, but the gains that accrue from engaging a broad swath of society in behavioral change are long-lasting and very valuable. Dr. Glazer emphasized the point that getting technology into the hands of young people not only fosters their interest in science, but also enhances personal involvement in the public trust. All the panelists agreed that when behavioral change is an outcome of a research project, the global citizenry is better able to promote, develop and safely

and effectively implement new technologies. When asked about carbon sequestration, the panel agreed that sequestration technologies and storage solutions are still in the early stages of development, but they predicted that the desire to store carbon in subsea geologic formations will take on a sense of urgency as the negative impacts of climate change increase. The panel discussed increasing conflicts over water rights due to the changing economic imperatives and economic and geopolitical competition for coastal, offshore and ocean resources. Asked for their thoughts on guiding corporate behavior, the panel urged enforcement of compliance measures driven by, coordinated with, and monitored by scientific agencies to improve alignment between industry and governmental objectives.
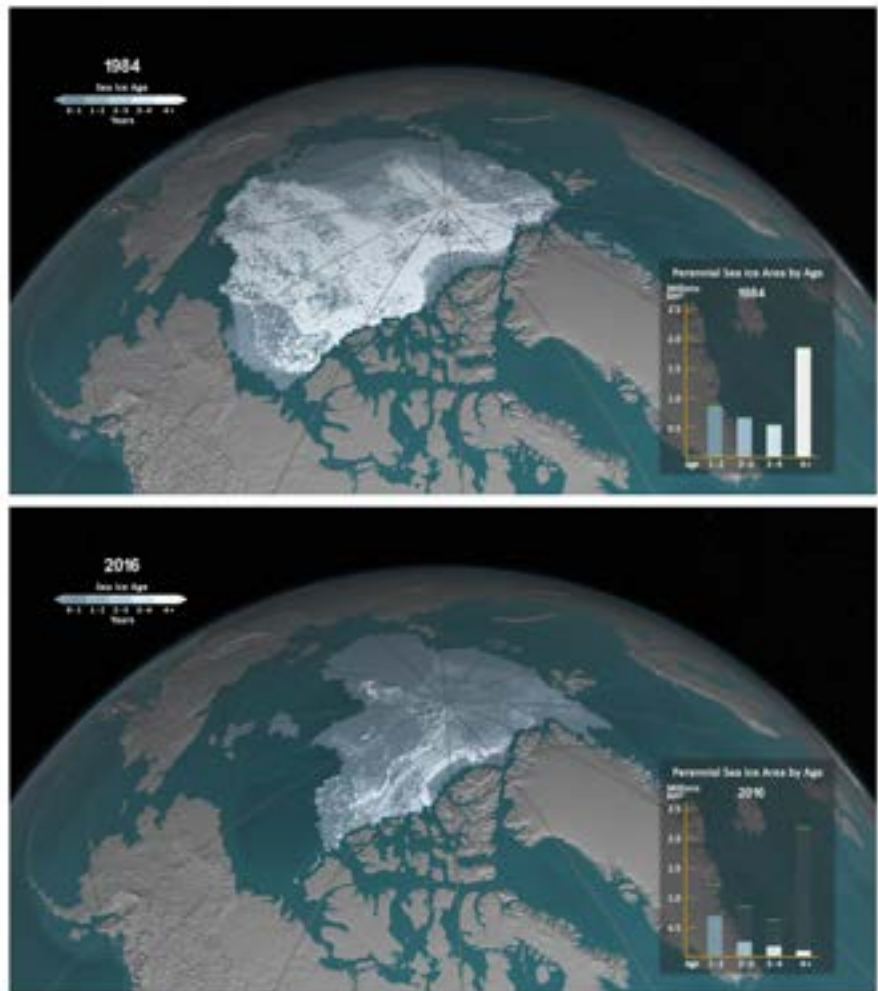
Extent of the Arctic ice canopy compared between 1984 and 2016
Figure Credit:National Climate Assessment Vol. 1

Autonomous Influences on the Undersea Domain

Panel Moderator

Dr. Brian Bingham is a Professor in the Mechanical and Aerospace Engineering Department and Director of the Consortium for Robotics Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School (NPS). Dr. Bingham received his doctoral degree in mechanical engineering from the Massachusetts Institute of Technology in 2003. Dr. Bingham served as a member of the founding faculty at the Franklin W. Olin College of Engineering from 2005-2009 and was on the faculty of the UHM from 2009-2015. His research involves developing innovative tools for exploring, understanding, and protecting the marine environment. This work includes projects on underwater navigation, autonomous vehicles, and sensor integration.

Panelists

Dr. Ayodeji (Deji) Coker serves as the Office of Naval Research (ONR) Portfolio Manager for Autonomy. In this role, he leads ONR's corporate strategy in autonomy, manages the corresponding investment portfolio, and focuses on best practices to transition, operationalize, and field autonomous uncrewed systems to the Department of Defense (DOD). Dr. Coker also serves as a Science Director for Artificial Intelligence, Autonomy, and Unmanned Systems at the Office of Naval Research Global (ONRG) London office, bringing domain expertise in complex adaptive systems, distributed and collaborative autonomy, and command-and-control battlespace awareness.

Dr. Andrew Nuss is a program manager in the Tactical Technology Office at Defense Advanced Research Projects Agency (DARPA). His portfolio includes uncrewed maritime systems, undersea influence, underground influence, and cross-domain teaming. Prior to joining DARPA, Dr. Nuss held positions in the Office of the Secretary of Defense's Strategic Capabilities Office where he led the development and transition of uncrewed surface vessels and long-range surface-to-surface munitions. Dr. Nuss has held positions at NAVSEA and in the Naval Surface Warfare Center Carderock Division focused on the survivability of surface ships and submarines.

Dr. Ballard Smith is currently the Innovation Area Lead for National Security Next and Outcome Lead for Undersea Command, Control and Communications at the MITRE Corporation. In these roles, he oversees a large portfolio of internal research and development projects and helps to set priorities for undersea related work. Previously, Dr. Smith was posted at the MITRE location in Honolulu where he served as a technical advisor for the US Indo-Pacific Command and helped shepherd new undersea technologies in support of joint operations, focusing on the improvement and standardization of undersea acoustic communications.

The final panel of the GMF 2021, moderated by Dr. Brian Bingham, focused on the impacts of autonomy on the undersea domain. Panelists included Dr. Deji Coker, Dr. Andrew Nuss, and Dr. Ballard Smith.

Dr. Deji Coker opened the final panel with a presentation about Intelligent Autonomous Systems (IAS). He outlined key elements for the future of autonomous systems, including affordability, scalability, and risk tolerance. Dr. Coker highlighted IAS strategy objectives, such as providing the investment management framework for funding, workforce development, and infrastructure. He described important measures of effectiveness for autonomous warfighting technologies, including their effect on target, capacity, operational tempo, survivability, and operational readiness. To Dr. Coker, policy and ethics are critical to the IAS strategy, and he stressed the importance of investment in ethical systems that have effective communications and can be trusted to behave properly. He closed with a list of IAS-enabled advantages that he seeks: smaller, more numerous, and distributed capabilities; intelligent machines that can adapt in unstructured environments; and the ability to make sense of overwhelming amounts of data.

Dr. Andrew Nuss presented examples of projects that DARPA has supported to advance the DOD's activities in the undersea domain. He cited DARPA's Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) program, an effort to evaluate whether an autonomous surface vehicle could follow collision regulations. The success of ACTUV demonstrated that vessels can operate effectively without humans. Dr. Nuss emphasized the importance of balancing the virtual world with the real world as both provide important context for testing new technologies. He talked about how the private push in the space domain has made it easier and cheaper for the DOD to make advancements with space technology and recommended finding a way to replicate this public-private partnership in the maritime domain. DARPA works to assist private companies with unique ideas and solutions to adjust their goals to meet DOD objectives. He described a DARPA initiative, the Embedded Entrepreneur Initiative, to help small companies build a solid foundation and avoid the proverbial "valley of death" in building innovation.

Dr. Ballard Smith discussed challenges in developing autonomous systems and described some innovations from the MITRE Corporation. He stressed the "why factor" – in the case of autonomous systems, determining where autonomy is useful, which is not everywhere. Dr. Smith cited oil companies' R&D as an example of using autonomy successfully. He advocated for finding similar missions within DOD where autonomous approaches can be implemented. Dr. Smith outlined key challenges in implementing autonomous systems: communications – integrating new technologies that can overcome undersea low bandwidth constraints; planning and monitoring – watching monitoring systems and integrating them into the broader system; launch and recovery – getting systems in place, making sure they stay there, and getting them back; developmental support – reducing barriers to entry to autonomous systems; and regulatory constraints – getting permission to use these systems. He highlighted autonomous innovations that have been successful: "marsupial-ism" – putting small uncrewed systems onboard larger systems; modular systems approach – making software updates easier by dividing large entities into smaller modules; and integration with larger systems – using autonomy where possible and with clear objectives. Dr. Smith closed with a discussion of machine learning (ML) systems, emphasizing the importance of testing these systems for performance under myriad of diverse circumstances.

Autonomous Influences on the Undersea Domain

Dr. Brian Bingham rounded out the autonomous influences panel, giving an overview of the CRUSER program that he directs at NPS. He recommended using CRUSER and programs like it to test new ideas related to operationally focused S&T problems. Dr. Bingham urged the MDA community to stay abreast of technology innovations resulting from industry investment in R&D. He encouraged broader use of uncrewed systems to facilitate richer environmental sampling, while acknowledging that technological development is only one aspect of effectively using autonomous systems. He advocated for creating or revising maritime policy, laws, and ethics in partnership with the development and refinement of autonomous systems. Looking to the future, Dr. Bingham drew attention to two reports by the US Navy, the Science and Technology Strategy for Intelligent Autonomous Systems and the complementary Unmanned Campaign Framework, as informative resources for moving forward with autonomous technology.

Dr. Bingham began the question-and-answer session with a question for each of the panelists: how can those working in autonomy develop systems that satisfy the objectives of the science community and the DOD? Dr. Coker emphasized the mutual advantage of the two groups working together and recommended following a model similar to that of Elon Musk and SpaceX with NASA. This collaboration facilitates high-risk, rapid testing and improvement of space technology. Dr. Nuss pointed out that space-based data is an existing product that is well-positioned to become more useful and more profitable for MDA. He highlighted the importance of forming partnerships with non-governmental organizations and other countries for solving complex issues in the maritime domain. Dr. Smith agreed with the other panelists, noting that environmental monitoring and mapping, anomaly detection, and secure transportation are key areas where public and private interests align.

The panel then turned to audience questions, beginning with a discussion of how the role of humans in operations will change over the next 10 years. Dr. Coker explained the importance of manned-unmanned teaming, especially the necessity of performing as teammates. Dr. Nuss described the cyclic nature of hardware and software improvements within autonomous systems and suggested true autonomy may be limited, at least in the short term, by considerations including cost. Dr. Bingham supported the human-in-the-loop concept, agreeing that full autonomy is not the goal; rather, the objective is to continue increasing the performance of the autonomous systems. Dr. Smith advocated setting a specific goal of "one operator controlling several systems" as opposed to "several operators controlling one system" to take the best advantage of autonomous innovations in the near term. The panelists then shifted their discussion to consider expanded autonomous operations in the Arctic to monitor climate change impacts. They agreed that communication will be a critical step in advancing autonomy and MDA in the polar regions. Dr. Coker raised the topic of artificial intelligence (AI) in relation to data collection, explaining the need for AI systems to know which data should be validated, analyzed and archived to allow AIs to make similar decisions to humans. The discussion ended with each panelist underscoring key take-away messages for the participants: read the Science and Technology Strategy for Intelligent Autonomous Systems and the Unmanned Campaign Framework; advocate for improved data- and information-sharing capabilities throughout the GMF community; focus on the "why factor" before developing autonomous solutions; and enhance education and workforce development.

Moku o Loʻe

TECHNOLOGY DEMONSTRATIONS

Moku o Loʻe, colloquially referred to as "Coconut Island," is the site of UH's Hawaiʻi Institute of Marine Biology (HIMB), the only research laboratory built directly on a coral reef in the US. Located towards the southern end of Kāneʻohe Bay on the eastern side of the island of Oʻahu, HIMB has a decades-long history of R&D in the waters surrounding Moku o Loʻe to monitor and study ocean processes. Prior to COVID-19 pandemic restrictions mandated by the State of Hawaiʻi, the intent of the GMF 2021 was to invite forum participants to visit Moku o Loʻe in person so they could witness demonstrations of uncrewed technologies under development by ARL at UH. When the GMF 2021 shifted to a virtual format, the demonstrations were filmed and presented after the panel discussing Autonomous Influences on the Undersea Domain.

HAWAIʻI AS A TEST RANGE

Dr. Margo Edwards set the context for the virtual technology demonstrations of the GMF 2021 with an overview of the benefits of conducting testing and evaluation in Hawaiʻi. Hawaiʻi is an ideal site to serve as a test range because of its mild climate, which allows operations to be conducted most days of the year. In terms of studying the undersea environment or assessing the performance of sensors and systems in these environs, most Hawaiian islands provide access to ocean depths from 0 to 4000 meters within kilometers of shore. Hawaiian waters exhibit visibility that ranges from opaque to crystal clear circulating over a variety of geological substrates including basaltic lava, coral reefs, and muddy and sandy sediments. Hawaiʻi resides near the center of the Pacific Ocean, a convenient gathering place for the myriad nations of the Pacific Rim, and serves as the home base of the US Indo-Pacific Command and USCG District 14. Additionally, Hawaiʻi is a central hub for a diverse collection of governmental agencies and private industries intricately involved in maritime activities.

Members of NMIO observe live demonstration at the Moku o Loʻe and HIMB facilities
Figure Credit:HIMB

Automatic Identification System Heads Up Display

Mr. Baseem Missaghi
ARL at UH Mobile Applications Developer

Testing AISHUD functionality near Honolulu Harbor   *Image Credit: ARL at UH*

The ARL at UH was contracted by the US Navy Submarine Force Pacific to develop the AISHUD (Automatic Identification System Heads Up Display) to help improve MDA. The goal of this project was to provide submarine watchstanders with fused information to improve decision making in heavy surface traffic environments. Specifically, the AISHUD provides watchstanders and control room personnel with the ability to correlate visual information with a vessel's AIS data using a portable device such as an iPhone. The AISHUD is a user-friendly application implemented on low-cost, commercial-off-the-shelf (COTS) hardware that shows the position and heading of nearby vessels using three-dimensional augmented reality visualization. This enhanced data acquisition supports operations in denied, intermittent and low-bandwidth communications environments.

Mini-Sonobuoys

Mr. Josh Levy
ARL at UH Uncrewed Aerial Vehicle Analyst

The NMIO contracted ARL at UH to develop robust communications nodes that can be dropped into water from an altitude of 10 meters using an Uncrewed Aerial Vehicle (UAV) and, post-drop, communicate with a subsurface acoustics node. This task leveraged ongoing ARL at UH R&D to fabricate ruggedized, low-cost, rapidly deployable networks of environmental sensors for characterizing littoral environments. The ARL at UH designed and developed electronics and hardware, customized existing open-source software, and integrated

Mini-Sonobuoy at the ocean surface after deployment
Image Credit: ARL at UH

COTS technology to create a prototype payload that survived the impact of multiple 10-meter drops into the ocean and successfully communicated data to a subsurface node using acoustic protocols. The ARL at UH then modified the UAVs payload system to carry and individually deploy two sonobuoys during one flight. The overarching objective of this project is to support rapid characterization of an environment in the wake of natural or man-made disasters without exposing humans to potentially dangerous conditions. Next steps involve manufacturing additional payloads, integrating capabilities such as GPS and acoustic to radio frequency communications to improve MDA, and enabling near-real-time data viewing for improved situational awareness.

Transport and drop of Mini-Sonobuoys   *Image Credit: ARL at UH*

Uncrewed Surface Vehicle Demonstration

Dr. Brennan Yamamoto
ARL at UH Robotics Engineer

Unexploded ordnance and discarded military munitions, collectively referred to as munitions and explosives of concern (MEC), affect virtually every coast in the continental US, the Hawaiian Islands, Guam, other US territories and inland waterways. DOD and private industry have made significant investment to develop technologies to detect MEC and assess the effects of MEC constituents on the environment; however, the diversity of MEC types, disposal methods, detection and assessment technologies, in addition to variable environmental settings, have made it difficult to systematically compare the effectiveness of various technologies. The ARL at UH is working to develop a test range complex, essentially a suite of technology demonstration sites, for evaluating and comparing the efficacy of MEC tools. An important objective of this project is to integrate uncrewed systems, including UAVs and uncrewed surface vehicles (USVs), into the deployment and recovery of the test range.

Over the past year, ARL at UH tested and integrated a real-time kinematic (RTK) GPS system with two USVs, one built by UH students and one COTS USV. Each USV was equipped with a very high-resolution side-scan sonar for rapid seafloor mapping in water depths less than 15 meters. Autonomous driving capability was incorporated in the command-and-control system for the COTS USV, as was a mechanism for deploying empty cylinders of approximately the same diameter and weight as munitions to serve as surrogate targets. Using a linear actuator, the deployment mechanism was able to drop multiple targets upon command from a ship- or shore-based remote-control operator. The ARL at UH used a COTS LIDAR system, mounted underneath a hybrid gas-electric UAV, to produce sub-meter-scale maps of bathymetry and topography around Moku o Loʻe. This past summer, ARL at UH successfully demonstrated the ability to deploy a dozen munitions-like targets and characterize the environment in which the targets were dropped primarily using uncrewed systems over a period of approximately eight hours.

Uncrewed surface vehicles (foreground) and orange floats marking deployed objects   *Image Credit: ARL at UH*

Working Group Collaborations

RATIONALE AND OBJECTIVES

A primary objective of national investment in MDA is to assure freedom of navigation across the world's oceans. A condition of MDA is ensuring security of national and common oceanic domains under global law. High performance in many technical disciplines is needed to inform and contribute to progressively more effective MDA. Considering the constructive categories of seafloor infrastructure and technology, and climatological and autonomous influences on the undersea domain, how can improvements lead to more effective MDA? A central tenet of the GMF 2021 was that informed advocacy by the Global Maritime Community of Interest (GMCOI) will enable progressively higher levels of MDA and decision advantage by applying evolving technical capabilities to the forum's three panel topics. To that end, the GMF 2021 established a number of working groups to identify challenges and produce recommendations for the development and application of maritime technologies related to the three panel topics. The GMF 2021 participants were assigned to one of the following working groups: seafloor infrastructure and technology, climatological influences, and autonomous influences. On the first day of the forum, each working group met virtually for about an hour to answer the question, *"What changes do you feel need to occur by 2040 in order to best protect the subsea domain?"*

After the climatological influences panel had concluded its discussion on the second day of the forum, the GMF 2021 attendees and facilitators gathered virtually in the same working groups and discussed a second topic. Considering the keynote presentations, the panel discussions and the conversations during the previous day's working group sessions, working group participants were asked to answer the question: *"How would you craft a competition to stimulate the general public to create solutions to the identified problems?"*

The GMF 2021 working groups were encouraged to explore and share technical information, strategize and brainstorm to formulate practical, actionable recommendations for the GMCOI. When describing potential solutions based on the success of other efforts, participants were asked to give attribution. While the virtual nature of the forum did not allow the same type of sidebar discussions that might take place at an in-person event, several of the GMF 2021 attendees remarked that meeting virtually invited them 'into the offices and living rooms' of internationally recognized leaders for intimate discussions on topics of mutual importance. The following are summarized outcomes of the working group discussions.

Benefits of a Virtual Meeting

Admiral, USCG (ret.) Paul Zukunft during his keynote presentation

> "I felt like I was having a one-on-one conversation with a former Commandant of the US Coast Guard"
>
> *- GMF participant*

Seafloor Infrastructure and Technology Working Groups

The Seafloor Infrastructure and Technology working groups discussed several topics that they would like to see addressed by 2040 for the benefit of the GMCOI: data sharing, environmental concerns, international cooperation, and expanded use of uncrewed vehicles.

DATA SHARING

Seafloor Infrastructure and Technology working groups highlighted the benefits of establishing maritime agreements between all stakeholders (government, industry, private organizations), including intergovernmental agreements. Participants particularly emphasized the objective of strengthening partnerships between government, industry, and academia, specifying the collection, sharing, and access of data as key components of collaboration. They noted the importance of protecting data integrity, documenting the chain of custody for data, and developing robust and cost-effective analytics (including AI and ML). Participants echoed the panelists' suggestion to foster community involvement in monitoring and measuring the environment, which could substantially expand the breadth of observations possible assuming that data quality assurance objectives could be established, disseminated and met.

ENVIRONMENTAL CONCERNS

In their discussion of expanding undersea infrastructure, participants of these working groups were wary of potential negative environmental impacts. As an example, they cited the effects of very low frequency sonar on marine mammals. They stressed the need to develop and evaluate approaches in the context of environmental impacts. They recognized that coastal regimes are under continuous threat from sea level rise and storm damage and advocated for innovative solutions to these threats. They highlighted focusing on decarbonization of the ocean and atmosphere. Regarding the use of subsea telecommunication cables to detect earthquakes, participants discussed how to maximize the benefit of this infrastructure to provide effective international warnings and mitigate impacts. They discussed potential man-made and natural factors that could damage subsea cables and best practices for detecting and repairing damage.

INTERNATIONAL COOPERATION

International cooperation was identified as a critical component of successfully building undersea infrastructure. Working group participants discussed the UNCLOS, which established a legal framework within which all activities in the oceans and seas must be carried out. The UNCLOS provides the international legal basis for the use and conservation of the ocean environment and its natural resources, but it has not yet been ratified by all nations, including the US. The working group discussed the International Seabed Authority, which governs mineral-related activities on the seafloor, and suggested it as a paradigm for governing telecommunication cables and global acoustic networks. The participants underscored the desire to develop international agreements that emphasize strategic cooperation over strategic competition, fostering adaptable laws to protect and manage the international undersea domain, and developing a governing body to oversee international policy. Participants noted that there would be security concerns associated with seafloor mapping and undersea cables and echoed the desire to involve the international intelligence community to ensure data integrity and protection.
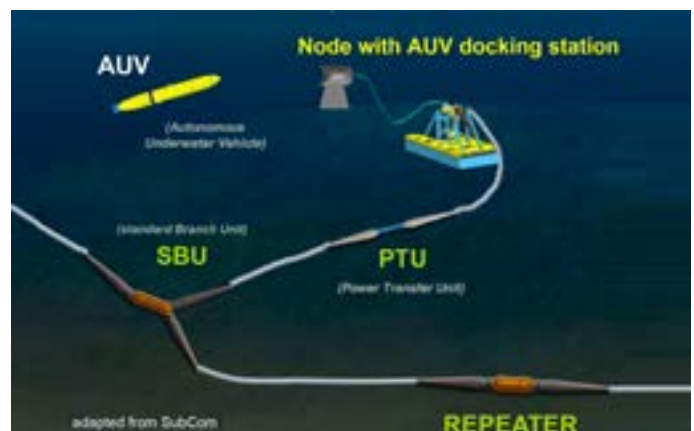
The international intelligence community can help ensure data integrity and protection for seafloor mapping and undersea cables

Figure Credit: Bruce Howe, UHM

UNCREWED VEHICLES

Participants recognized the advantages of providing more security in the ocean and in ports, and they discussed the important role of uncrewed vehicles in monitoring both above and below the ocean surface. Current methods of detecting and assessing threats such as drug trafficking and sea-disposed munitions are insufficient compared to the global extent of these threats. Uncrewed semi-submersible, low-profile surface, or underwater vehicles have the ability to detect anomalous behavior, identify potential targets, and signal human operators for intervention when abnormal activity is detected. Uncrewed vehicles have many other potentially beneficial capabilities such as measuring hull integrity for ships or detecting illegal fishing activity. Working group participants advocated for increasing autonomous operations of uncrewed vessels as a long-term objective for creating maps of the global ocean. They also recommended developing policies for engagement and operation of unscrewed vehicles as a critical early step prior to the broad deployment of these vehicles.

WORKING GROUPS RECOMMENDATIONS

INCREASING PUBLIC INTEREST

The Seafloor Infrastructure and Technology working group conversations underscored the desire to increase public interest and engagement with the ocean. The space industry was endorsed as a model to inspire the general public's interest in the undersea domain. Efforts to create an undersea "race," similar to what is presently occurring with commercial entities launching citizens into space were discussed. At the other end of the spectrum, inspiring young people to engage with the ocean through community science – from afterschool programs to augmented and virtual reality games to social media – could create more interest in the ocean and build the future maritime workforce. Engaging private industry partners as well as academia and government are crucial to creating strong educational programs that can be distributed as early as elementary school. Improved visualization tools, hands-on education, and general awareness of the oceans and its role in daily life are key to generating increased public interest.

INCREASING PUBLIC INVOLVEMENT

Fostering citizen science to expand public engagement was a popular idea among the Seafloor Infrastructure and Technology working groups. Referencing Dr. Brian Glazer's outreach program, participants stressed that smart phones are already providing sensing power for those interested in using it. This type of low-cost infrastructure near the coast is feasible, but how can smart phones be used to access deeper, more remote parts of the ocean? Working group participants saw value in regionally and locally equipping people with technology, but they recognized the challenges associated with incentivizing the public to get involved. An example might be compensating fishermen for collecting seafloor mapping data while they are fishing. For private boats, a competition to collect high quality oceanographic data within established time and budget constraints could further increase public engagement – multiple non-profit foundations (e.g., the Schmidt Ocean Institute) already sponsor oceanographic research.

ADDITIONAL RECOMMENDATIONS

The Seafloor Infrastructure and Technology working group participants agreed on several key components for a competition. They suggested designing a competition where "everyone is a winner" in some form. This could be achieved by distributing winnings amongst the participants, framing the prize as a benefit to the public good, and/or combining contributions from all participants to meet the end goal. Participants agreed that common standards should be used (i.e., no proprietary software) and that this could be incentivized by including it as a ranking criterion. They also recommend making the competition international to promote strategic competition. Participants acknowledged that both revolutionary ideas (completely new concepts) as well as evolutionary ideas (modifications to existing concepts) should be rewarded.

Mapping Competition

A specific idea presented during the Seafloor Infrastructure and Technology working group discussion was to create a mapping competition using autonomous systems to map the seafloor and increase security in port environments. The general public could assist in real-time data curation by "controlling" uncrewed vessels undertaking the mapping. The concept discussed was similar to the augmented reality Pokémon Go mobile game developed and published by Niantic, Nintendo and the Pokémon Company in 2016, but in this example finding seafloor life or an interesting object could yield a reward in the game. Participants highlighted two challenges for mapping: the sensor(s) and the uncrewed vehicle. To lower costs, the working group participants suggested emulating UAV racing leagues, which use less expensive equipment (e.g., airframes fabricated via three-dimensional printing) due to the significant potential for damage that results from flying objects through obstacle courses at high speed. The final aspect of the competition deemed necessary by working group participants was developing a plan for storage and access of the mapping data. Many countries have repositories managed by government agencies such as NOAA that provide open access to data, but coastal databases are typically controlled by their respective countries; hence, data sharing agreements between collaborating nations will need to be arranged.

Multibeam data collected across the Pacific by an uncrewed system transiting from San Francisco to Hawai'i
Figure credit: Larry Mayer, University of New Hampshire

Climatological Influences on the Undersea Domain Working Groups

The Climatological Influences on the Undersea Domain working groups discussed these major themes: global monitoring and modeling, resource protection and national security, and education and citizen involvement.

GLOBAL CLIMATE MONITORING AND MODELING

The Climatological Influences on the Undersea Domain working groups recognized the need for a sustainable global observing system. Participants thought it important to better understand the deep ocean and the Arctic through increased data collection efforts to inform effective climate change response plans. One suggestion was to develop observing systems using low-cost electronics and sensors in coastal and littoral environments to document climate stress factors. For large-scale transboundary ocean measurement systems like SMART cables, participants noted that international partnerships and agreements are crucial for successful implementation and operation. The participants discussed installing sensors on commercial vessels to significantly increase the amount of data used to monitor climate impacts. Working group participants agreed that sharing the harvesting and analysis of the data as broadly as possible was necessary to foster public support to address climate change. The participants recognized that sharing data comes with challenges, including security of information and data products plus the responsibility of controlling who has access to it. They advocated for using data analytics, including AI and ML, to recognize patterns and implicit signs of climate stress. In concert with increasing data volumes, quality and security, the group recommended expanding the resolution of climate models to improve climate science. Working group participants emphasized that climate science is a national security issue and studying the threats posed by climate disruptions will benefit the entire maritime community.

RESOURCE PROTECTION AND NATIONAL SECURITY

Climate change is and will continue to impact resources and present national security concerns. The Climatological Influences on the Undersea Domain working groups highlighted the impact of climate change on fisheries, focusing on how ocean acidification will impact migration patterns of fish, which in turn will affect food security for nations reliant on fishing. Participants recommended concentrating on policy and behavioral changes that they expect to have more of an impact than new technology; for example, when it comes to protecting living resources and the surrounding ecosystems. Creating agreements between nations was a recommended means to protect fisheries and potentially increase food security. The working group participants also discussed the exploration and exploitation of the Arctic. Participants agreed it would be beneficial to better characterize the Arctic and develop infrastructure to monitor, protect, and maintain sovereignty in the region. To assess future threats posed by climate change, participants advocated using the New Zealand Department of Defence as a model for setting up a defense enterprise at the intersection of defense and security.

EDUCATION AND COMMUNITY INVOLVEMENT

The Climatological Influences on the Undersea Domain working group participants highlighted the importance of investment in the future workforce for addressing climate change. Participants recommended advocacy for training and education be clearly expressed to national leadership as a tool to lessen the impacts of climate change and innovate mitigation strategies. This requires engaging the future workforce early in their development, fostering basic skills in science, technology, engineering and math, and creating project-based learning and training in specialized areas such as cable station management or fisheries science. The threats of climate change present a good target for applying and developing data science; for example, through integration of basic environmental research with topics more familiar to the intelligence community: cybersecurity, information assurance, and data analytics using AI and ML. Participants were keen to involve local and indigenous communities in community-based science, balancing the adoption of new technology with the ingestion of traditional knowledge to improve understanding. Ultimately, providing local communities with opportunities to integrate both new and time-honored approaches for monitoring their environment will help citizens better manage their own resources.

WORKING GROUPS RECOMMENDATIONS

ENGAGING YOUTH

How to engage the future generation of scientists, engineers, and policymakers was a topic discussed during the second day of the Climatological Influences on the Undersea Domain working groups. Participants acknowledged that social media provides a variety of perspectives and priorities, which comes with advantages and disadvantages, but it has the potential to motivate and organize people to create innovative solutions for climate challenges. Working group participants suggested that developing an augmented or virtual reality simulation could be a good way to get youth interested in climate issues. They advocated building a game to accommodate a variety of age groups, allowing players to choose different roles in the game (e.g., scientist, manufacturer, policymaker, shipping agent) to gain multiple perspectives of climate initiatives. The game could start with local issues and then expand to the global repercussions of climate change. Throughout the course of the game, new information could be infused into the scenario, perhaps from actual seafloor sensors or uncrewed vehicles, to allow role players to consider policy changes or potential impacts on the ecosystem. This could ultimately help train future decision makers for how to approach development of climate change mitigation plans for optimal global environmental and economic health.

ADDITIONAL RECOMMENDATIONS

The Climatological Influences on the Undersea Domain working group participants considered other aspects of designing competitions to tackle MDA challenges such as climate change and IUU fishing. Some participants offered the idea of an alternative prize to cash, such as an opportunity to join a sea-going research expedition. Several participants suggested starting with a small, simple, local problem; for example, tackling plastic management. A suggested plastic-management competition was designing plastic-free commercial items with awards given to the competitor who used the least amount of plastic. The anti-smoking movement was cited as an effective past example that could be replicated for IUU fishing, for example by creating a competition to label seafood to identify its source. On a global level, participants worried about competitions that adapt to the needs and capabilities of specific communities, acknowledging that communities often come up with solutions that work for specific cases but not are not generally effective. Participants recognized that policy needs to be developed and implemented to yield lasting change and urged that policy makers be given an important role when designing these competitions.

ALTERNATIVES TO COMPETITIONS

Some participants of the Climatological Influences on the Undersea Domain working groups were opposed to competitions and suggested alternative ways to address climate-related issues. They recommended investing in ocean infrastructure by developing free drifting ocean sensors, lowering the cost of deep ocean instrumentation, improving the reliability of connectors, developing and expanding use of AUVs, and advancing the capabilities and versatility of undersea cable systems. Their position was that challenges on the scale of global climate change involve large, complex solutions that are not well addressed through competition but rather through cooperation. If the goal is to diversify technology, they encouraged addressing specific, smaller, and tangible problems such as lowering the cost of equipment, supplies and communications. As an alternative to engaging the broader community, they suggested focusing on identifying students who want to solve climate-related problems and connecting them to enthusiastic and talented mentors. These working group participants cited the example of hackathons as an effective approach for finding motivated students in cybersecurity. Some participants proposed smaller, localized competitions that focus on rewarding students as an alternative to larger, expensive competitions that do not always yield the desired outcome.

Autonomous Influences on the Undersea Domain Working Groups

The Autonomous Influences on the Undersea Domain working groups focused on data collection, data sharing and data analysis.

DATA COLLECTION

Most participants of the Autonomous Influences on the Undersea Domain working groups agreed that autonomous systems are well-suited for collecting information of general benefit, including geological, topographic, oceanographic and other environmental data. They noted that having better maps and information for the undersea domain will enhance many aspects of MDA such as resource management, shipping, security and safety. Participants recommended that autonomous systems be designed using a model-based engineering approach to rapidly expand the rate of data acquisition and improve data resolution. With this quantity and quality of data, fields from global ocean forecasting to local resource management would advance substantively.

DATA SHARING & ANALYSIS

Participants of these working groups highlighted the need for sharing data resources to collectively deal with global issues. There was some debate among the working groups about whether to invest in effectively integrating and analyzing data that already exist or investing in increased and improved data collection efforts. Participants recognized the challenges with integrating large, disparate datasets, but they agreed the effort would improve the quality of a comprehensive database that already exists and would therefore be cost-effective. Integrating data would require standardizing data formats and developing approaches to measure and assure data quality but would ultimately provide a more holistic picture of the ocean. Making a distinction between proprietary and non-proprietary data with different access levels could serve as an incentive for data contributions from non-traditional sources such a citizen scientists. Participants felt that data collected by autonomous methods will be very important for refining models, and with enough data, models could use AI and ML to enhance accuracy and resolution.

OTHER TOPICS

Some of the Autonomous Influences on the Undersea Domain working group participants recommended implementation of autonomous technologies for specific applications, such as the detection of IUU fishing and other nefarious activities or monitoring environmental change over longer time periods. Though R&D involving autonomous vehicles shows promising advances, participants stressed the importance of addressing the realities of the chemical and mechanical wear that the ocean inflicts. Similarly, sensors that will be placed on autonomous platforms need to be ruggedized to better handle ocean conditions. Participants recommended collectively creating a mission set for autonomous vehicles to advertise the unique capabilities of new systems. They inquired about the likely consumers of autonomous data and urged developing testing and evaluation criteria for autonomous systems that would increase user trust in their data collection and surveillance capabilities.

WORKING GROUPS RECOMMENDATIONS

COASTAL MONITORING

The Autonomous Influences on the Undersea Domain working group participants recommended a competition that focuses on fisheries and coastal monitoring for autonomous systems. They suggested developing an exercise to allow surface vehicles to monitor vessel traffic in the maritime domain. The competition could focus on the development of a ruggedized, low-cost platform capable of recognizing and identifying targets using AI and ML. Such a competition would enhance AI and ML capabilities to detect and identify vehicles, or aid in the prevention of IUU fishing and drug trafficking, especially in remote areas. Participants echoed the concerns voiced by keynote speaker ADM Zukunft, who predicted the transition of semi-submersibles to uncrewed vehicles, and they proposed developing a system that could adapt its location in the water column to monitor evolving threats. Coordinating these efforts with the USCG or local law enforcement would be critical to operational success.

CLIMATE CONSIDERATIONS

Participants in these working groups discussed the role of autonomous systems in the context of a changing global climate. They emphasized that most autonomous vehicles reduce emissions that result from using fossil-fuel-powered ships. Autonomous vehicles using fossil fuels have a smaller carbon footprint than large ships, and those using alternative energy sources are more environmentally friendly. In situations where greater endurance is required, autonomous systems can act as force multipliers that are cost effective and less environmentally impactful. Many autonomous vehicles are easy to deploy and recover, and while their endurance does not match that of fossil-fuel-powered platforms, they are well-suited to provide localized remote sensing, especially in shallow environments. Participants of the Autonomous Influences on the Undersea Domain working groups also suggested integrating AI and ML into autonomous systems to model potential future conditions and generate plans for all operators including military and commercial organizations.
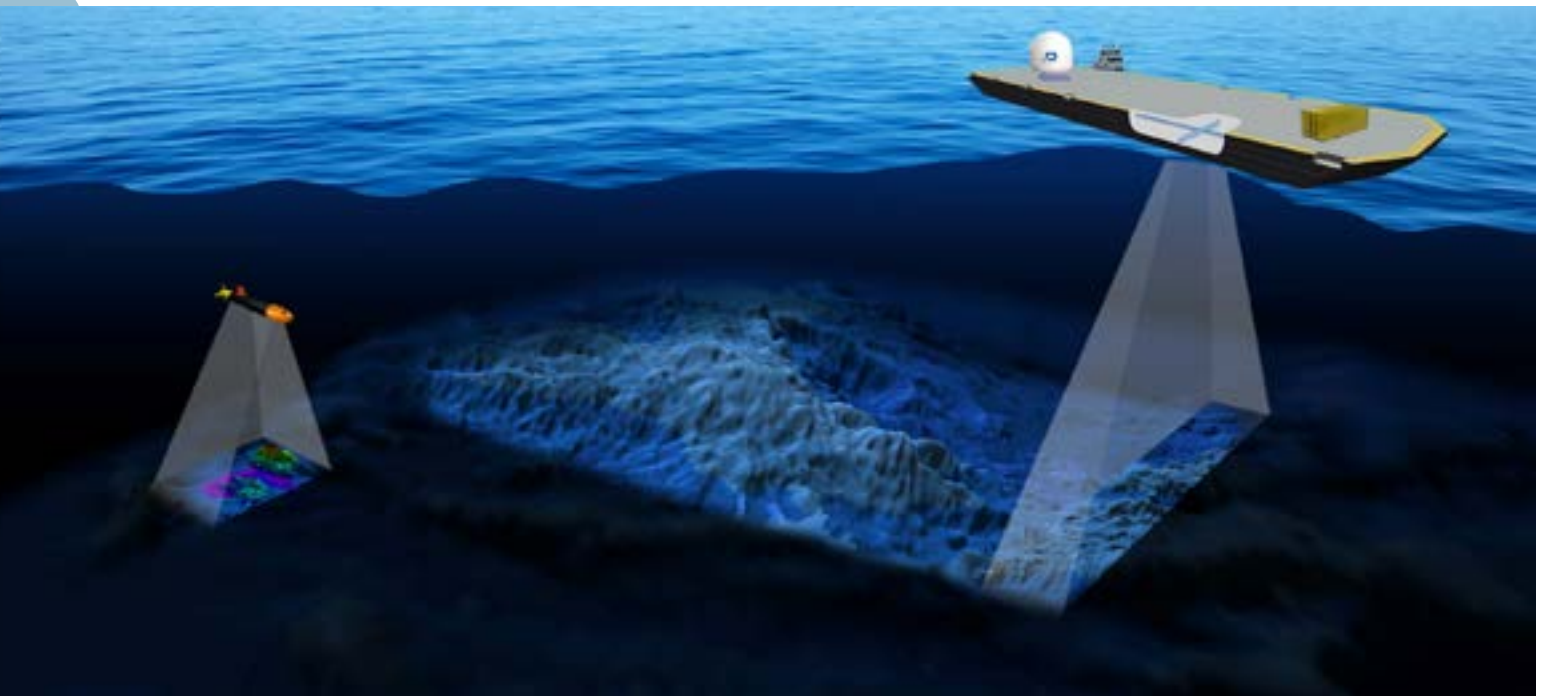
USVs have the potential to significantly expand the amount of data collected
Image credit:Larry Mayer, Martin Jakobsson and Inez Jakobsson

CONCLUSION

The GMF 2021 confirmed the proverb that "necessity is the mother of invention." Occurring in the midst of a global pandemic, the 8th Global Maritime Forum demonstrated new capabilities via advances in telecommunications and affirmed the resilience and dedication of the GMCOI, which assembled across 11 time zones to further its continuing discussion of mutually important topics to advance MDA.

The GMF 2021 theme, "Fathoming the Future: Examining Evolutionary Variables in a Multidimensional Maritime Domain" served as the starting point for broad-ranging conversations about how technology, data, security, commerce, public engagement and public policy contribute to the GMCOI.

Looking to the future, the GMF 2021 participants identified high-level challenges such as protecting resources, fostering international cooperation, safely and securely sharing data, and expanding education and citizen involvement. The GMF 2021 participants recognized and emphasized myriad opportunities to address these challenges, among them using uncrewed vehicles and autonomous systems for enhanced data collection, artificial intelligence and machine learning to bolster global monitoring and modeling, and social media to promote learning and understanding. The challenges and recommendations highlighted during the Working Group collaborations presented in this report include diverse and practical solutions that could be implemented to advance the objectives of the GMCOI.

Image credit:Josh Levy

Table of Acronyms

ACTUV	Anti-Submarine Warfare Continuous Trail Unmanned Vessel
ADM	Admiral
AI	Artificial Intelligence
AIS	Automatic Identification System
AISHUD	Automatic Identification System Heads Up Display
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
ARL at UH	Applied Research Laboratory at the University of Hawaiʻi
AUV	Autonomous Underwater Vehicle
C	Celsius
CO2	Carbon Dioxide
COTS	Commercial-Off-The-Shelf
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
DARPA	Defense Advanced Research Projects Agency
DHW	Degree Heating Weeks
DOD	Department of Defense
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information System
GISS	Goddard Institute for Space Studies
GMCOI	Global Maritime Community of Interest
GMF	Global Maritime Forum
GPS	Global Positioning System
HIMB	Hawaiʻi Institute of Marine Biology
IAS	Intelligent Autonomous Systems
IUU	Illegal, Unreported, and Unregulated
JTF	Joint Task Force
LIDAR	Light Detection and Ranging
LORAN	Long Range Navigation
MDA	Maritime Domain Awareness
MEC	Munitions and Explosives of Concern
ML	Machine Learning
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NMIO	National Maritime Intelligence-Integration Office
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School
NSA	National Security Agency
ODNI	Office of the Director of National Intelligence
ONI	Office of Naval Intelligence
ONR	Office of Naval Research
ONRG	Office of Naval Research Global
PTU	Power Transfer Unit
RADM	Rear Admiral
R&D	Research and Development
RDT&E	Research, Development, Testing and Evaluation
RTK	Real-time Kinematic
SBU	Standard Branch Unit
S&T	Science and Technology
SMART (cables)	Smart Monitoring and Reliable Telecommunications (cables)
SMART (Ala Wai)	Strategic Monitoring and Resilience Training (Ala Wai)
SpaceX	Space Exploration Technologies Corporation
SST	Sea Surface Temperature
UARC	University-Affiliated Research Center
UAV	Uncrewed Aerial Vehicle
UH	University of Hawaiʻi
UHM	University of Hawaiʻi at Mānoa
UNCLOS	United Nations Convention on the Law of the Sea
US	United States
USCG	United States Coast Guard
USV	Uncrewed Surface Vehicle

List of Figures

8 November 2021

Dear Admiral Zukunft,

Thank you for your wonderful keynote address during the 2021 Global Maritime Forum (GMF). Your remarks on the technological evolution in the maritime domain truly helped set the tone for our ensuing panel discussions. Your presence was invaluable and motivated participants to focus on the latest opportunities, challenges, and threats we face in the maritime domain.

As we continue efforts to improve maritime security, I hope we will find further opportunities to collaborate. Without a doubt, we must work together to develop new approaches and systems to stay ahead of maritime threats.

The GMF would not have been the success it was without your personal involvement. Again, thank you for your support.

Sincerely,

Thank-you, Admiral!

R. C. Copley
Rear Admiral, U.S. Navy
Director, National Maritime
Intelligence-Integration Office

ACKNOWLEDGEMENTS

Thank you to all of those who made the GMF 2021 a reality! The GMF 2021, like its predecessors, aimed to convene a community of interest for in-person information sharing guided by experts with specific technological knowledge and successes. Because of the COVID-19 pandemic, we instead leveraged recent technological advances in virtual communications to accomplish the overarching objectives of the forum. The first-ever fully virtual GMF brought together a world-class group of keynote speakers, panel moderators and panelists. The GMF 2021 included multiple breakout sessions and technology demonstrations achieved using videos and narrated photography. We are sincerely grateful for the patience and persistence of the organizers. Most special thanks to the participants from around the globe who took time to share their experiences, knowledge and findings from working in the maritime domain. Without them, the GMF 2021 would not have been possible.

Agenda

DAY ONE

Welcome and Administrative Notes
Ms. Mekisha Marshall, Chief Science and Technology Advisor / Department Head, NMIO
Dr. Margo Edwards, Director, ARL at UH

Opening Remarks and Keynote Introduction
RADM Curt Copley, Director, NMIO

Keynote Address
ADM (ret.) Paul F. Zukunft

Session 1: Seafloor Infrastructure and Technology

Working Group Collaboration

DAY TWO

Keynote Introduction
Josh Levy, ARL at UH Uncrewed Aerial Vehicle Analyst

Keynote Address
Dr. Chip Fletcher

Session 2: Climatological Influences on the Undersea Domain

Working Group Collaboration

DAY THREE

Session 3: Autonomous Influences on the Undersea Domain

Virtual Technology Demonstrations

Closing Remarks
RADM Curt Copley, Director, NMIO

Global Maritime Forum 2021

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