DIALOGUES WITH INDUSTRY

Report out from Dialogue 4

Looking Ahead: New technology for the Ocean Decade

February 27, 2023

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Dialogue 4 Description

The fourth Dialogue brought together twenty-four (24) participants representing key stakeholders from industry, government, and academia (see list of the participants in Appendix 1) to discuss multi-sectoral ocean architecture, i.e., the integration of new observing networks and business models into the existing ocean observing environment. In preparation, the participants were provided the Industry Dialog Background Paper and the Use Case paper (Appendix 2).

The Dialogue was moderated by Chris Ostrander, Executive Director Marine Technology Society (MTS). The Use Case divided the Dialogue into two sessions: (1) New technology that will change ocean observing in the next decade and (2) Emerging Ocean information that will require new technology, skills, and business models. The participants provided feedback from an operational, technical, and/or policy perspective. The event was held on a non-attribution basis and this synthesis document is delivered correspondingly.

In addition, there were 226 observers. Both participants and observers were able to engage in the Dialogue. The first two hours were a facilitated discussion among participants with the observers providing input through the Q&A functionality of the video conference tool that was brought into discussion by the facilitator. The last thirty minutes were an open Q&A session among participants and observers.

This was the fourth and final Dialogue. The key takeaways and potential paths forward provide a foundation for subsequent dialogues.

Key Takeaways from the Dialogue

- **Observations from ships were broadly viewed as diminishing with the push towards a low carbon footprint and increased scalability.**

Increasing spatial and temporal scales of ocean observation also requires systems that can be scaled to large numbers, which is not practical using crewed vessels. In those regards, there has been increasing use of chemical, biological, and physical sensors on autonomous surface and underwater vehicles to generate data sets that replicate some of what a crewed ship can do, and autonomous systems such as drones, robots, and underwater vehicles can be used to collect data at higher frequency and resolution than traditional methods. However, a balance needs to be struck. While ships carry large, complex instruments that are necessary for high precision climate observations, it is also important to have a breadth of understanding of the patchiness and variability of the system which proxy measurements collected from autonomous systems offer.

- **A key transformation over the next decade will come from a new generation of observing technology that provides insights into biogeochemistry, ocean health, and marine life. This includes sensing new ocean variables that can improve forecasting to submesoscales.**

A new generation of sensors will increase insight into ocean biogeochemistry and its effects on the marine life’s health. In the future, these sensors may be able to detect toxic pollutants, and even the presence of specific species. For example, eDNA may help ascertain the vulnerability of marine diversity to climate change and the impact of that change on the distribution and migration patterns of marine life.

New ocean and sea-ice variables may allow us to better understand climate change and variability and improve weather predictions. Other inconspicuous or less obvious measurements such as the detection of wakes or chemical byproducts of combustion from ships, for example, can alert us to localized impacts associated with human activity. The incorporation of new variables such as these afford improvements in predictions and assessments about the ocean's health and anthropogenic impacts, which leads to better informed decisions about how to manage our ocean's delicate ecosystems.

- **Benefits associated with new sensor and platform technology will be further enhanced by improvements in data transmission.**

Marine broadband capabilities are expected to deliver advancements comparable to internet and connectivity innovations within terrestrial industries and installations. Analogous to the ubiquitous terrestrial use of GPS having low cost, widespread sensors combined with connectivity would be used to deliver new insight – the Ocean of Everything. However, we should find a balance between high-precision sensors for understanding processes, and cheaper, more widely distributed sensors that can give us an understanding of patchiness, trends, and variability in the ocean. It must be recognized that in the deeper ocean (say > 200 m) the vision of the Internet of Ocean Things is illusory. Communication, let alone real time communication, becomes exceedingly difficult and expensive with solutions depending on the provision of electrical power.

- **Use all existing and new private infrastructure.**

Pull in new ocean actors and put technology on them – such as renewable energy platforms, submarine cables, and commercial ships with more sensors. Especially seek to piggyback on emerging ocean industries as they are set up. Private companies are increasingly open to co-design activities and regulators can mandate the inclusion of observing capability.

- **Artificial Intelligence (AI) will play an important role in biological and ecological observing.**

The proliferation of air, sea, and space platforms, crowdsourcing, and other methods are providing increasingly more data to study our oceans. The use and adoption of AI will be critical for automating the analysis of this vast amount of data, especially for large underwater image and acoustic data sets. AI will also be critical for understanding complex relationships of ocean variables as they relate to local and global ocean challenges (i.e., climate change, ocean acidification, plastic pollution, harmful algal blooms, etc.) and making informed decisions to improve and solve these challenges.

- **It is vital to get the private sector involved in the New Blue Economy, but market expansion is likely to be based on specific uses.**

It is essential that commercial partners are engaged and that their perspectives, needs, and interests be incorporated into the development of the New Blue Economy data flows. By engaging the private sector, new and innovative ideas can be brought forward that can help to maximize the potential of the New Blue Economy. In addition, the private sector can provide access to capital, resources, and expertise that can be leveraged to accelerate growth in this space. New markets and innovation will be driven by specific applications such as marine carbon renewal sequestration (currently the subject of an ARPA-E call), wind farming, and other future needs.

- **The ocean observing community should be involved in the establishment of new protocols and conventions.**

Protocols for monitoring and utilization of ocean observations are being developed through international conventions such as the United Nations Convention on Biodiversity Beyond Areas of National Jurisdiction, and international initiatives such as the Taskforce on Nature-related Financial Disclosures, which is developing a risk management and disclosure framework for organizations to report and act on evolving nature-related risks. New regulatory needs such as ocean carbon dioxide removal can be a driving force. It is crucial that industry is aware of these developments and has the ability to inform developments whenever possible.

- **Attracting Talent to the Ocean Industry. More emphasis should be placed on involving Early Career Ocean Professionals (ECOPs) and ensuring that they are aware of the career opportunities in the New Blue Economy.**

Technology companies in the New Blue Economy are keen to attract more ECOPs. Academia is not the only route supporting sustainable development, biodiversity, and adaptation to climate change. There are many challenges in the private sector that need marine professionals. The links between the New Blue Economy and ocean academic institutions should be strengthened and more career alternatives made visible, however not only within marine science. The ocean technology sector should be able to attract talent from other technology sectors, as the potential careers are meaningful and rewarding. Many students are motivated by the potential to contribute to improved environmental or ocean outcomes and this is as possible in industry as it is in science.

Dialogue Purpose

MTS, GOOS, NOAA, and industry partners have identified a significant need to improve and expand communication to meet the demand for a resilient, and responsive global ocean observing, forecasting, and information delivery system.

To date, the ocean observing enterprise has been a largely research-focused effort driven by government investments, which has created a highly fragmented value chain. Increasing societal demands for ocean data for climate adaptation and mitigation, to sustainably manage ocean resources, and improve the forecast of extreme events to reduce loss of life and property, require a more rapid expansion of the ocean observing enterprise. However, the immaturity of the market significantly inhibits the speed and efficiency of system development. New commercial ocean observing services are finding opportunities to exploit, yet it remains unclear as to how these will interact with the established global and national observing operations, as coordinated under the GOOS. The observing system will continue to need new technology, but there remains no established way to fast-track promising technology candidates into existing systems.

GOOS, MTS, and NOAA, together with industry have co-designed these Dialogues for compact and meaningful dialogues with new and established companies, academia, and government to dismantle barriers and highlight opportunities towards achieving a mature and vibrant Ocean Observing Enterprise, through a thriving mix of the public and private technologies and players.

Discussion Synthesis

Section 1: New technology that will change ocean observing in the next decade

The first session focused on new technologies for ocean observing – both, those that are reaching maturity now and those on the horizon that have yet to be developed and deployed. Rapid advances in materials science, power generation and storage, onboard processing and data telemetry, autonomy, and sensor systems are enabling moving us closer to an explosion in new ocean observing technologies.

The Whole Ecosystem as a Driver

The need to understand the entire ecosystem structure and function is driving transformation of the ocean observation enterprise in order to enable large-scale data collection. This includes advances in material science, sensor adaptations and adoptions, robust and lower-cost technologies, private-public partnerships, and education. The panel noted that efficiencies in ocean observing can be realized by:

- Highly distributed large spatial-temporal sensing;
- Use of new data sets from commercial sensors being distributed on the ocean; and
- Self-labeling ontology for ocean data so that systems and computer science techniques can be applied to analyze data.

Economic value and innovation will be driven by specific applications and requirements rather than general concepts, such as having more data and sensors everywhere. Wind farming, for example, will require permitting for certain environmental assessments and demand a particular set of measurements to be made on specified time and space scales. These needs will create opportunities for business development, system deployment, teaching, and offer a new generation of workers a compelling incentive to participate in the Blue Economy.

Despite some stove-piping in the ocean observing community, there is an opportunity for efficiencies and stronger coordination around innovation. GOOS has been working to encourage communication and coordination between different disciplines, but more community building is needed. In particular, the observation of marine biodiversity and marine life should be part of all existing or new platforms and initiatives, to ensure that their potential is explored, and the user requirements are understood.

Next generation sensors

Technology Advances

The biggest transformation in ocean observing will come from the new generation of sensors that provide insights into biogeochemistry, ocean health, and marine life. This will revolutionize scientific understanding and monitoring and enable new capabilities for ocean predictions and assessments. The key to new sensor technology lies in finding the right combination and application of sensors to address specific use cases, as no single sensor can provide a comprehensive solution.

The main challenge faced by instrument developers when measuring the Essential Ocean Variables (EOVs) is the wide variety of techniques used, many of which invoke the use of laboratory-based instruments and labor-intensive protocols. The challenge is to unify requirements with respect to specific measurement needs, and then meet those needs with a limited set of instruments and tools to reduce overall cost, labor requirements and infrastructure footprints. The EOV framework is a good way to drive requirements definition, but the current breadth of EOV measurement techniques poses a significant challenge that must be overcome.

Specialized sensors need to be designed for new ocean variables (OVs), such as biogenic or anthropogenic activity-based variables, like background noise from snapping shrimp, effluence from ships, regions of bioluminescence activity, and the chemical byproducts of combustion. Looking beyond their scalar (environmental) measurements, these parameters can offer insights into human activity and its impact. The molecular technology revolution is making its way into oceanography with technologies such as eDNA, DNA sequencing, biosensors, and antibodies, which will also enable new measurements and discoveries. Moving to more specialized measurement campaigns, augmented with sensors for new OV measurements, can help with improving the modeling and forecasting of submesoscale ocean features (< 100 km in size). Another challenge to recognize and address is the integration of these new measurements into long-term datasets that inform policy decisions. Validation will be required to ensure the accuracy, precision, and trust of these new data sources.

Low-Cost, Easy-to-Use

Advances in material science are enabling low size, weight, power, and cost (SWaP-C) sensors. A discussion focused on how the current model of deploying expensive instruments in the ocean, recovering them, and analyzing the data can be improved through cheaper, lower-spec sensor technologies. An example mentioned was the Defense Advanced Research Projects Agency (DARPA) ‘Ocean of Things’ program that utilizes integrated circuit (IC) sensors, such as cameras, accelerometers, GPS, temperature, and barometric pressure, to obtain high density, real-time measurements from surface floats on a commercial scale. These sensors are driven by the cell phone industry which provides a cost-effective solution.

The demand for cheaper and easier to use sensors will reduce the cost and ecological impact of research vessels. These sensors would allow researchers on ships to be more efficient, as well as allow the public (including fishermen, tourists, and tourist boats) to participate in ocean research. This would be beneficial for outreach and data collection where the sensors can be deployed from any ship with or without the help of researchers. These sensors would also have the potential to help disadvantaged communities globally by providing them with the necessary ocean information to participate in the New Blue Economy. A good use case is the future of water monitoring, where inexpensive sensors with standardized physical and software interfaces and virtual communication methods can be easily employed.

Even so, it is unlikely that in the next couple of decades, all existing EOVs will be addressed by small and cheap sensors, as some of the key technologies being observed are difficult to measure and require more advanced and expensive sensors. The outcome is likely to be a mix of small, cheap, and robust products, especially in the coastal environment, alongside a larger number of more complex products that require larger systems for making measurements. We should bear in mind the experience from manufacturers that low cost and easy to use sensors are a riskier investment, and thus there will need to be some aggregation of demand and lowering of investment risk to precipitate this change. The development cost of creating affordable disposable sensors is high, so for many applications, it is perhaps more realistic to focus on creating slightly larger, more expensive sensors in the short term to advance the field forward.

A balance needs to be struck between having enough measurements in the climate space and having accurate enough measurements. While large instruments on ships are necessary, it is also important to have a breadth of understanding of the patchiness and variability of the system. The cost of making measurements needs to be weighed against the need for accuracy and position. We are seeing a lot of new sensors being developed and integrated into established networks, such as biogeochemical (BGC) Argo and biology into the Global Ocean Ship-Based Hydrographic Investigations (GO-SHIP) program. We should find a balance between high-precision sensors for understanding processes, and cheaper, more widely distributed sensors that can give us an understanding of patchiness, trends, and variability in the ocean. The dilemma of having many less expensive and less accurate measurements versus a few very accurate and more costly measurements brings up the concept of system engineering. To optimize the system, there needs to be a way to combine different user requirements so that an optimal infrastructure can be established without having any stove pipes or silos in the design.

Other considerations of future sensors and monitoring systems include support for long-term environmental studies, impacts associated with geopolitical borders, and fishing vessels that may pick up sensors either purposefully or accidentally. Environmental sensitivity should be taken into consideration when deploying sensors to ensure that animals and other marine organisms do not find them desirable to consume. Finally, energy harvesting technologies should be considered in the design of smaller and cheaper surface sensors for more efficient monitoring of the environment.

While having the optimal sensor is necessary and desirable, more fundamental, especially in the deeper ocean context, is the provision of power, communication, and positioning, navigation, and timing (PNT). In most cases in sustained long term ocean sampling, the cost of these infrastructure services far outweighs the cost of the sensors. System engineering of the complete system is necessary to find a global optimal solution.

Autonomy

Perhaps the most impactful, nascent, or emerging technological transformation for the collection of the next decade of ocean observations are autonomous floats and vehicles including those that cruise on the surface (ASVs), underwater (AUVs), and their hybrids (AxVs). These advanced robotic vessels can operate autonomously or semi-autonomously, allowing them to collect data from the ocean for long periods of time without needing to be directly controlled by a human operator. This enables long duration missions in remote and harsh locations, vastly increasing the amount of data that can be collected.

These autonomous vehicles can be equipped with a wide range of instruments, sensors, and samplers (though limited by size, weight, and power specifications), allowing them to measure a range of variables such as water temperature, salinity, and even oceanographic features like seafloor habitats. They are increasingly being equipped with chemical, biological, and physical sensors/samplers to generate data sets that replicate a ship's capabilities. And they also enable complicated in situ biogeochemical experiments and can deploy other instruments such as buoys and floats, which can provide more detailed data.

Autonomous vehicles are becoming increasingly capable and cost-effective, making them an ideal tool for ocean observation and exploration. The panel discussed the use of multiple platforms for data collection, with a focus on affordability, ease of use, and improved efficiencies. It was agreed that autonomy could provide a more attractive price point, leading to the collection of more dense data. The key to successful autonomous systems lies in the interplay of multiple components, such as sensors, mission planning, and others. The trends point towards more efficient, autonomous vehicles that use energy harvesting, battery technology, and autonomy to reduce the need for carbon-producing ships. For deep AUVs removed from the surface, one can take land electric vehicles as an example, requiring intermediate charging stations to enable full utilization of their potential, based on sharing submarine telecom cables for their power and communications, also supporting PNT.

Adoption of Artificial Intelligence

In the next decade, ocean science will benefit from the data-driven AI revolution with a proliferation of platforms, such as imaging satellites, autonomous systems, and imagery platforms, collecting large amounts of data. We expect to see the use and adoption of AI have a transformative impact over the next five years due to the increasing power and lower costs of technology platforms (per the above sensor and platform discussions). Companies will be better able to develop and drive AI enabled solutions, leading to real paradigm shifts in the industry.

The use of machine learning to analyze data and the idea of the internet at sea (at least at the sea surface) are two key changes that will shape the future. However, a key challenge when using AI learning algorithms is the need for sufficient training and metadata. Underwater imagery provides a limited view but a rich source of information. Going forward, we can expect to see more of this kind of imagery used for exploration and research. One panelist recommended that self-labeling ontology of ocean data be used. This is a type of ontology that uses a combination of natural language and artificial intelligence to automatically label digital information with descriptive terms. This is often used to improve search engine optimization, provide context to data and documents, and organize large amounts of data.

It was suggested that well-funded AI programs, such as those within the Department of Defense (DoD), use ocean data as proxy data for their classified projects. This will expose ocean data sets to more students and can serve to get them interested in the ocean sciences. In addition, Augmented reality (AR) was suggested by one panelist as a game changer in how humans can interact with the ocean. AR is a technology that enhances a real-world environment with virtual objects or information that appear in the physical world. It combines real-world elements with digital content, providing an interactive experience for users.

Data

The biggest transformation in the application of ocean observations, including science and social and economic benefits, will be realized if the government, the private sector, and academia nationally and internationally converge on standards for data formatting, data sharing, and interoperable, linked databases.

Organizing information and data is critical for sharing and transferring oceanographic data across disciplines, especially for biological research. We need to focus on improving this process and making sure it is done effectively across the board. Schema on read and on write are two approaches to making the most of data coming from sensors and platforms. Currently, there is a bias towards only using one's own data and not integrating or assimilating data from other sources. However, there is potential to create great synergy between these different sources of data. The lack of data in the field of biology was discussed and it was hypothesized that the problem is not a lack of data, but rather the difficulty of digitizing the data that has been historically collected. This problem can be addressed by determining the applications the data is needed for, and the questions it will answer.

The biggest challenge in collecting biological data is consistency and standardization, which is difficult to achieve due to the lack of digitization. This puts biological data further behind the curve when compared to data from geophysics and oceanography. The challenge for conservationists is to make biological data accessible and engaging, while also making sure it is meaningful and relatable to other data sets. Investment in data solutions is essential for enabling interoperable ocean observing information across disciplines, and this needs to be taken into consideration when discussing biological data. This includes discussing data formats, metadata requirements, and data flows. The panel suggested forming a task force to create parameters and standards for global data requirements and applications. The task force could take advantage of the collective knowledge of the group.

The panel also believes that there is a very significant opportunity to develop a Blue Economy sector on value added data management. Specifically, the data management needs for the government, academic, and private sectors are so significant, that a robust value-added industry may be developed. This could include small-scale vendors including under-represented groups servicing needs for data digitization, translation to standard formats, interoperability of databases, and database linkages. These services, once integrated, will revolutionize information management and digital twin implementation.

Ocean observing has the potential to be greatly enriched through co-design and a focus on the local needs for ocean observations. This presents a challenge in terms of connecting with communities to get feedback and inform investments, but it is a necessary step. This must be an iterative process to prioritize data collection and technology development while considering the perspectives of industry on what the needs are for ocean observing data. Crowdsourcing ocean observation data is an increasingly popular way for oceanographers to collect data. Examples include measurements on surfboards, air quality measurements on land, and measurements on sailing yachts.

Internet in the Ocean

The internet has been a disruptive force in terms of data gathering and transmission and has been one of the main challenges in terms of ocean observation as it is not accessible there in the same way. Satellites can be used to help ocean science due to their global coverage and frequent imaging of the Earth. Specifically, Low Earth Orbit (LEO) satellites make it possible to have improved access to broadband communications in the ocean space, allowing for global, reliable, and faster communications than ever before. This can enable the “Internet of Things”, cloud computing, and highly intensive edge computing capabilities.

It is important however not to oversell this. Radio communication does not extend below the sea surface. Communication, especially real time communication becomes extremely difficult below the surface, and is usually power intensive.

Power and Communications

For the deep sea, power is the fundamental limiting infrastructure service as all other services are derived from power. Providing power and communication to the deep sea is a major cost and logistical constraint that limits ocean observing. Subsea cable technology can help address this issue by providing a cost-effective and sustainable means of access and persistent observations over long periods of time. This eliminates the need for expensive ship visits for data collection and/or battery replacement. Recent developments in combining highly reliable commercial telecom with sensing supports this view (i.e., SMART Cables). Further, sharing telecom infrastructure for this purpose is a perfect example of the Blue Economy in action. The concept can be extended from a few basic sensors to the level of “nodes” providing more capability such as AUV docking stations and long range acoustic navigation and tomography.

Four truly autonomous instruments, the discussion also focused on the importance of sensors’ power consumption and sometimes large battery demands, and how applying for funding for batteries can be an issue.

Net Carbon Zero

The move to net zero emissions is going to push the design of observing systems away from crewed ships, as they are costly and not very carbon efficient. This will lead to an increase in the use of uncrewed systems.

Human Capacity

Human capacity is the ability of a person to think, learn, understand, and use various kinds of knowledge and skills to successfully perform tasks and activities. It involves the ability to reason, plan, problem solve, make decisions, and other cognitive functions. The panel discussed that a fundamental need is the development of human capacity through better organization of learning strategies and training of scientists to meet the needs of industry and government.

The connection between oceanography and technology needs to be improved so that multiple career pathways are visible. Many students are motivated by the potential to contribute to improved environmental or ocean outcomes, and this is possible in industry as well as non-profit science/engineering settings. To improve this connection, coordinated educational systems need to be implemented that include interoperability and standards. This would create a more robust connection between the two entities on a global scale.

There is also a need to develop a curriculum to engage high school students in local water bodies and encourage them to pursue STEM-related careers. The curriculum would involve short classes or field trips and enable students to make an impact in their environment through activities such as chemical sensing and bottom sampling. The goal is to foster student interest in the field and empower them to take ownership of their environment.

Systems of Systems

In some cases, the ocean observing enterprise requires very specific measurements at specific times, at specific scales, with specific targets in mind. This entails a system of systems approach in which different components work together to achieve the desired results. A good example is marine carbon dioxide removal for selling carbon credits, where a measurement reporting and validation strategy is needed to underpin that enterprise.

Hybrid sensor systems that detect and record multiple disparate events simultaneously are expected to become more common in the future, making them an economical and practical choice for research organizations in the field of disaster management. Good examples utilize cabled observatories and buoys for decadal ocean observation of physical parameters, seismic recording, tsunami detection, and surface meteorological data (e.g., Dense Oceanfloor Network System for Earthquakes and Tsunami (DONET) and S-net in Japan, India Ocean Observing System, in-progress SMART Atlantic CAM in the NE Atlantic off Portugal, and many others).

Section 2: Emerging Ocean information demands will require new technology, skills, and business models.

Moving to a multi-sectoral ocean observing architecture requires technical, cultural, and financial shifts.

Addressing the Real Needs

In the short-term, the key to making science and technology more accessible involves utilizing data and information technology. Over the long term, the only way to address social, political, and economic problems is by creating a linkage between science and problem-solving for society early in the education process.

There is an opportunity to focus innovation on addressing real needs in the ocean, such as local observation needs, and enabling decisions for sustainable use of marine resources. The conversation around ocean observing needs to expand to include more targeted conversations about how to best reach and speak to users of ocean observing information. This presents a challenge, but it is necessary to build connections between industry, science, and government implementers of ocean observing systems. This will require an iterative approach to developing ocean observing activities and prioritizing data collection and technology development. The ocean observing community is discussing data usage and access, and there is an opportunity for a productive conversation between them and industry about what data is needed and how it can be used to drive innovation and new technological development.

However, there are political and human aspects of data that need to be addressed, such as standards and reluctance to share. Education plays an important role in linking human needs to data collection, including collecting biological, social, and economic data about our lives.

There is a challenge with real-time data sharing so that data can be used for improved forecasts and measurements of carbon uptake, for example, which is difficult. Using open-source tools that promote transparency and integrity in conversations about carbon removal is key. Cloud computing can play an important role in this, as there are many open-source efforts currently available. There is a challenge and an opportunity in developing these tools to make them more efficient, and accessible and to facilitate data sharing.

The answer to the question of how to incorporate new technology into ocean observing is to start by determining the requirements. This includes understanding what needs to be observed and the essential ocean variables. Then, established technologies and techniques can be used to move from one platform or instrumentation to the next to ensure that time series are kept for long enough.

There is an economic incentive to understand the marine carbon cycle, however, it is not supported at the company level and is instead government driven. To bridge the gap between the commercial and government aspects, it is necessary to create a system that is rigid enough to create a time series to understand the ocean, but also agile enough to take up new technology for both observations and data interpretation.

The technology push for ocean observing systems should involve metrics that are built into government or philanthropic funding for developing new technologies. Additionally, the market pull must be addressed in terms of how regional and global systems can incentivize the adoption of data from private industry.

Let us widen the conversation and invite more people to the table who are innovating in the marine space, especially from small and medium enterprises. For example, there is a new technology that can survey areas as large as a million football fields in the most rugged coral reef marine systems in the world, yet we have difficulty even having a conversation with anyone about it. Opening this conversation could lead to important developments in the protection of marine biodiversity.

Experts are needed to provide insight into how the community can align with investments in the industry and what the main industry needs are.

The United Nations is the starting point for building a multinational ocean enterprise and addressing ocean science needs. We need to use the United Nations Decade as a tool to bring attention to the human ocean nexus and to get the attention of those in finance, business, banking, and insurance. This could be done through dedicated initiatives. Nations need to identify their societal, economic, and ocean-related needs, and the UN can help consolidate the necessary ocean science. Additionally, nations need to be educated on how to use plug and play systems and seabed-mounted systems, as well as how to crowdsource data. We need to emphasize the importance of tech transfer in our message to the UN and other policy programs. Researchers, scientists, and industry need to be clear and concise about what they are asking for and the value they are delivering to end users when participating in larger programs and stories with the UN.

An example of a successful “marriage” of diverse UN organizations to bear on the ocean observing problem is the Joint Task Force for SMART Cables. The International Telecommunications Union (ITU) saw SMART Cables as a topic worthy of promotion as a “green activity” (in 2010) for its members, combining telecom and sensing. They worked together with WMO and IOC to form the JTF to facilitate the introduction and implementation of the concept, as illustrated by the abovementioned Portuguese system, and recent European Union funding for international cable connectivity including SMART capability.

We can leverage the growth of industries over the next decade to connect secondary needs with ocean observations, providing data and information to help fill the gaps that currently exist. For example, connecting industry to ocean observing and seeing how academic and industry interests overlap or have gaps.

Understanding AI

Although AI offers great promise to the oceanographic community, it brings many challenges. In fact, AI is sometimes referred to as “augmented intelligence” (or intelligence amplification, “IA”), where data scientists use machines to infer actionable insights and make better decisions in a safer and more informed manner. Augmented intelligence requires skilled professionals who have knowledge of AI, the ability to innovate, and the ability to act. This is essential for the successful implementation of AI-driven solutions.

Applying AI to some areas, such as data analysis and predicting outcomes, can be very useful but AI cannot yet replace human intelligence in other areas, such as the chemistry of seawater. AI is often hampered by the need for a large training set that has been characterized by humans. Taxonomy from images is a good example. A promising solution to address this is to use computers to generate clean training sets for training and machine learning. Another challenge is the fragmentation and the lack of sharing due to the scattered data across different labs and organizations. Underwater acoustics is a good example where large very large datasets have been collected over decades. To address this an infrastructure to facilitate data sharing could be implemented.

Adopting and Trusting New Data and Technologies

The introduction of new technologies in the ocean industry is a difficult process often met with reluctance due to the complexity and longevity of the existing infrastructure. Methods are needed to help facilitate the transition of new sensor and infrastructure [or platform] technology from the lab to the market, to help cross the “valley of death.” There is a need for standards and quality assurance processes to be established for new sensor technologies to ensure trust and successful adoption. This could involve running programs in parallel using older technologies to validate the new technologies. Ultimately, if these data are to be used for statutory monitoring or policy needs, it is important to make sure the precision and accuracy of the sensors are reliable. Collective demos and testbeds are needed to show how new technology can be used. One example that was pointed out was repurposing a decommissioned offshore platform in the Gulf of Mexico. Plans are being made to use the platform as a testbed for research in AI while conducting fish farming operations.

Other ways to help accelerate adoption are collective purchasing and pre-financing contracts. The former allows for the pooling of resources to purchase needed equipment, while the latter provides money to developers to speed up the development process. Markets outside of oceanography can support scale. The oceanographic community should work with these markets and conduct collective demonstrations to qualify new technologies.

Data Needs and Challenges

The ocean science and marine science community should start to consider what the users of their data need, and how to integrate technology into all outlets – like offshore wind, wave energy, fisheries and aquaculture, insurance, shipping, fashion, and so on. By understanding the motivations of their users, the community can create new and innovative ways to observe the ocean. It was pointed out that the oceanographic community should learn from the weather prediction community, where set standards and conventions are followed by all meteorological agencies around the world. Regardless of the brand of instrument, data are integrated through the global telecommunication system (GTS) and made available reliably, round-the-clock in near-real-time. For the oceanographic community to achieve this, a mandate is needed to organize and fund local and national entities to formulate standards and produce data in a way that is useful for forecasting life and the ocean.

It is difficult to observe life in the sea, making it difficult to understand the scale of coherency needed to measure things like carbon flux and primary production. Edge computing and communications between devices could help, but we must further understand the scale of observation needed to say something quantitative. We need to invest in more expensive technologies and develop adaptive measurements to better inform our models so that we can better predict biological phenomena.

Quality control and assurance is essential to effectively manage large data streams and new sensor technology. Improving the efficiency and quality of this process is necessary to ensure the accuracy of metadata. One outcome from a recent workshop, conducted by Schmidt Ocean Institute, on the barriers to data integration at global data centers was that metadata was being stripped before it reached the data center. Thus, it was recommended that industry hardwire metadata to sensors.

Education and Training

Marine science needs to be better coordinated and standardized, both on the educational and professional level. Collaboration is needed to develop a unified system of teaching and data processing. Establish programs that provide resources and technology to help train local scientists in areas with limited resources. This can enable data collection in areas that previously had none and give scientists the tools to continue making observations.

Ocean Literacy

Ocean literacy is the idea of understanding the ocean's influence on us and our influence on the ocean. This is an important topic that can be applied from early childhood education to higher education and professional fields. Ocean literacy worldwide is currently lower than expected. The UN Decade of Ocean Science for Sustainable Development (UNDOS) framework and the Ocean Panel for a Sustainable Ocean Economy are two good resources for ocean literacy. These resources focus on how businesses and finance sectors relate to the ocean. Interviews with hundreds of people from various industries and backgrounds over the past two years have revealed a limited understanding of the connection between the ocean and climate. This connection was recognized at COP (Conference of the Parties) last year. The task force on nature related financial disclosures, or TNFD, is an important opportunity for ocean literacy. Scientists need to figure out how to input scientific information about nature into this risk framework so that investors, financial institutions, and others can make informed decisions.

We are taking steps to achieve a large-scale approach to advancing the ocean agenda, but this requires a lot of resources and time. We can also investigate implementing this approach in small towns and communities. To reach broader audiences, it was suggested to focus on emphasizing the relevance of ocean science, knowledge of the ocean, and the ocean to everyone on the planet. This should go beyond just coastal regions and emphasize the role of the ocean in the larger economy. For example, remind land-locked farmers that the water that falls on the crops is from the ocean. Discuss how using observing systems can lower the cost of crop insurance and in turn lower the price of food, and that this is something everyone understands and is important in their daily lives. Ultimately, talking about the relevance and importance of improving our knowledge of the ocean and improving the lives of everyone on the planet will be what makes or breaks this decade.

One way to help address ocean literacy in undergraduate and graduate education is to have more DOD and well-funded programs from agencies such as DARPA and IARPA focus on ocean science problems as surrogate problems. These programs can use ocean science data and make it easier for people to understand, instead of using data from other areas such as cooking or social media. Ocean scientists could interact more with DOD elements to get ocean science problems and data sets ready for DARPA programs, which could lead to graduate students from multiple universities working on the same ocean science problem. This could increase ocean science literacy.

It is difficult to convince policymakers of the importance of ocean observations and the need for data to pass regulatory scrutiny.

We have discussed the need to articulate a value proposition and the technology needed to fill it but have not yet discussed how to visualize the complex data that comes from disparate sources. This data must be integrated and presented to decision makers and the public. The analogy of the weather system is used to explain the challenge of visualizing ocean biology data. It is noted that while there are many sensing systems that gather information and make predictions, there is no easy way to make this data interpretable and understandable to the public or resource managers. This problem has yet to be solved.

There is a need to create a unified brand to influence audiences related to ocean technologies and the blue economy. It is important to research the potential audiences and develop a brand that makes the technology attractive to potential backers.

Venture capitalists (VCs) and private equity investors have difficulty understanding the blue technology and blue economy literature. To address this, a centralized repository should be established that provides investors with a single source of reliable information. This would help legislative and congressional staff as well as investment analysts who often get overwhelmed by searching through multiple sites.

Attracting Talent to the Ocean Industry

The ocean observing sector is having trouble attracting talent largely due to a lack of knowledge of its existence worldwide. A group is trying to address this problem in the UK, but there is no policy initiative driving the growth of the New Blue Economy. In the US, there is more awareness of the ocean observing sector due to national agencies. However, in other countries, there is less investment in this sector and more investment in other industries, meaning that it is a challenge to make students and the next generation aware of the importance of the ocean observing sector. Creating a larger national pipeline of ocean talent requires scaling up the effort and initiatives, with multiple organizations and institutions working together to create a multifaceted set of opportunities for a larger cohort of people from different backgrounds. This will lead to a more agnostic program and community that can effectively develop a larger national pipeline of ocean talent.

Competing with larger high-tech companies for AI talent can be difficult, as people often go to those companies for higher-paying jobs. However, many people may not be aware of the interesting and meaningful alternatives available and the potential impact they could have. One way to increase awareness is by establishing cross-disciplinary projects at universities. Scientists can reach out to computer science departments to explore potential projects involving ocean data. Exposure to ocean science problems through AI can spark interest in those who may not have otherwise seen this type of problem, potentially inspiring them to pursue careers in science-based companies for the challenge and interest of the field rather than for monetary gain. The ocean observing community can also leverage investments from other more specific applications in the ocean space to compete with higher-paying Silicon Valley jobs. The aquaculture industry and offshore wind industry are two sectors with tremendous growth and job security for the near future and can be tapped into to develop a workforce pipeline. And although attracting talent is an obvious challenge, it also poses an opportunity as there is an increase in government influence, investment, and motivation for youth to get involved. The next generation of talent is critical for advancing a sustainability strategy that takes environmental, social and, governance (ESG) rules into consideration.

Cost Strategies

The lack of adequate funding to support the development and operations of vessels is a big challenge in the marine technology space. Important conversations need to be had about the cost of technology and operations.

Venture capital should be sought out to harden new technology and present it to the industry. The New Blue Economy presents a huge opportunity for the community to help push the ocean observing industry forward faster, but it needs more capital. Silicon Valley could be a great source of funding for New Blue Economy businesses, but the industry needs to be more connected to attract this capital.

Environmental Drivers

Industry has the incentive to be involved in environmental sensor programs as it provides business, employment, and potential for profit. Ecotourism and recreation could be used to encourage industry to help with sensor placement and recovery. Coastal waters are essential to many nations' economies, so there is a shared interest in developing programs to make the environment better for all.

Companies need to find ways to meet environmental regulations while minimizing costs, which has created a market for sensors. That is an interest in hearing more about aquaculture and environmental monitoring for regulatory compliance, which companies need to consider when building offshore wind farms or other components since ongoing environmental monitoring is required.

There is an urgent need to integrate new technologies to meet the challenges of net zero, new policy demands, and a lack of resources for marine monitoring. This has led to the need to make trade-off decisions about what data to collect and what to leave out. Integrating new technologies into monitoring and observing systems is necessary, but there is a risk aversion to doing so due to statutory reporting obligations. To ensure that the new technologies meet the needs, they must be run in parallel with existing technologies. This will come with additional costs and capacity issues which will need to be supported by the government.

We need to focus on the plastic pollution in the oceans and raise awareness of the issue by providing up-to-date information and data on how to protect the biodiversity of this vital part of the planet.

Leveraging Outside Industries

High-tech industry and ocean exploration can benefit from a stronger relationship, as it provides financial support, inspires employees, and creates platforms and supply chains. This connection can also accelerate the work being done in the ocean, such as the $12 billion USD electronic sensor sector which is resulting in low-cost sensors and platforms.

The SMART underwater cables initiative can be used as a model for other communities to emulate. This is an initiative to add environmental sensors to existing telecommunications cables to achieve power and internet on the seafloor with a 25-year life. One sponsor, the International Telecommunications Union, has set up a study group to establish standards for this new technology, as well as amending climate and disaster risk reduction Resolutions to incorporate SMART cables.

An immediate opportunity is for ocean observing regional and national associations to coordinate with the emerging marine carbon dioxide removal (mCDR) industry, which could be worth hundreds of billions of dollars by 2050. An area of collaboration could be developing protocols for mCDR projects to ensure accurate ocean data collection.

Potential Pathways Forward

This Dialogue builds on the three previous Dialogues. The results from all Dialogues will be synthesized in a final summary paper for the series and a concise set of practical and implementable recommendations will result from the process. Below is an initial take on the key issues and potential pathways forward drawn from the fourth Dialogue.

We have discussed the importance of ocean observing, the data that can be collected, how to create a culture change, and how ocean policy requirements can influence our efforts. To achieve our goals, we need to bring together a whole community to brainstorm, plan and implement actionable strategies.

- **Promote more effective communications across different disciplines in the ocean community.**

Stove piping clearly exists in the ocean observing community where scientists from different disciplines are not communicating effectively with one another. For example, a physical oceanographer may not be aware of the research conducted by a marine biologist, and vice versa. This lack of communication can lead to duplication of efforts and a lack of collective understanding of the ocean environment. Reducing this will lead to huge opportunities for efficiency, stronger coordination around innovation, and more robust solutions.

- **Create and promote a unified brand focused on ocean technologies and the New Blue Economy to drive broader awareness and engagement in this field.**

A cohesive brand would help to capture the attention of the next generation of talent, innovators, investors, and entrepreneurs, many of whom may not have previously considered the ocean’s importance to everyday life. Additionally, such a brand would raise public awareness of the need to protect our oceans and their resources and increase understanding of the potential for innovation and growth within the blue economy. A unified brand could ultimately help to foster a sustainable and prosperous future for our oceans and the people who rely on them.

Classic shows such as Jaws, Voyage to the Bottom of The Sea, and Sea Hunt along with the discoveries of Jacques Cousteau have all helped to bring the ocean to the public eye in the past. We need to build on these to inspire a whole new generation to appreciate the wonders of the sea. Avatar 2 has the potential to be a catalyst for reigniting the public's fascination and excitement for the ocean with its stunning fantasy visuals depicting the beauty of the underwater world and its creatures. The recent Deep Five Expeditions and the successful search for a giant squid by Dr. Edie Widder have demonstrated the incredible potential of deep-sea exploration. Such expeditions and discoveries, which were once thought of as impossible, have become a reality thanks to the advancement of underwater technology made possible through the collaboration of experts from many fields, such as marine biologists, oceanographers, and engineers. This exciting exploration of the unknown can spark the imaginations of many and may help to create a new sense of awe and appreciation for the mysteries of the ocean. We need to leverage and better promote discoveries such as these and the technology behind them to create a unified brand that will connect everyone to the importance of our oceans.

- **Establish repositories that provide investors with a single source of reliable information.**

Venture capitalists (VCs) and private equity investors have difficulty understanding the blue technology and blue economy literature. To address this, it would be important to engage with these investors to understand what information they need and to establish and promote sources of reliable information. This would help legislative and congressional staff as well as investment analysts who often get overwhelmed by searching through multiple sites.

- **Improve private sector involvement in the ocean observing enterprise**

It has been identified that private sector involvement and science-industry collaboration will be central in developing the New Blue Economy. It, therefore, seems beneficial to establish a structured approach (e.g., a specific advisory board) towards private sector involvement/engagement within e.g., GOOS to achieve a transparent and efficient way of collaboration. Could the meteorological sector (WMO) act as a model in this regard?

- **Leverage industries outside of oceanography.**

Leveraging industries outside of oceanography can help to grow the New Blue Economy by adding different perspectives, resources, and skill sets. By combining their expertise and resources, these industries can help to develop new products, services, and technologies that can be used to drive economic growth in the blue economy. Additionally, these industries can bring their experience in developing and managing successful business ventures, which can provide guidance on how to create sustainable and profitable blue economy initiatives. Finally, they can help to raise awareness of the New Blue Economy and its potential benefits, which can help to attract more investors, businesses, and talent to the sector. These industries may provide examples and could be further targeted for enhanced ocean community collaboration: telecommunications, electronics, marine carbon dioxide removal, renewable energy, and shipping and transportation.

- **Inspire high-tech early career professionals to enter the workforce in ocean related jobs.**

Inspiring early career professionals in high-tech to get involved in ocean related jobs is important because it is an area of immense potential. High-tech professionals are needed to help solve the many challenges facing our oceans, such as overfishing, pollution, and climate change. With the right combination of knowledge and creativity, these professionals can help develop new technologies and solutions to help protect our precious marine resources. Additionally, the ocean economy is growing, creating new job opportunities and areas of innovation. By inspiring early career professionals to get involved in ocean related jobs, we can help ensure that our oceans are protected and preserved for future generations.

- **Facilitate the transition of ocean sensor technology from the lab to the market.**

The transition of ocean sensor technology from the lab to the market is vitally important because it is a key step in the development of technological solutions to the world's most pressing environmental issues. This transition includes the popular "Valley of Death" and is a difficult process that involves several factors. Factors include identifying the potential market for the technology, developing and testing prototypes, securing capital for production and marketing, and finally bringing the technology to the marketplace. Without taking this step, the ocean sensor technology developed in the lab would remain theoretical and unable to be used to address ocean-related problems. It is suggested to include lab to market and science-industry-linkage criteria as standard elements within publicly funded project evaluations to spur market development.

- **Expose AI experts outside of oceanography to ocean science problems.**

Exposing AI tech experts to ocean science problems is important because they can help develop innovative new solutions to some of the most pressing issues facing the ocean. AI tech experts have the potential to bring powerful new technologies to bear on ocean science problems and can help to develop more accurate models and forecasts that can better inform policy decisions. Additionally, AI tech experts can bring new perspectives and ideas to the field of ocean science, which can help to spur the development of new approaches to ocean management. This exposure may also inspire them to pursue careers in science-based companies for the challenge and interest of the field rather than for monetary gain. One suggestion made by the panel was to reach out to government organizations such as DARPA and IARPA, who frequently need to devise a surrogate example of a problem (which could be ocean-science related) for universities to work in an unclassified domain.

- **Establish a testbed or demonstration platform to conduct AI and other experiments for developing new ocean sensors and technology.**

It is important to establish a testbed or demonstration platform because it allows developers to set up controlled experiments and iterate through different configurations of the technology quickly and efficiently. This helps to reduce the risk of unexpected outcomes, as developers can see how their technology performs in a simulated or controlled environment before deploying it in real-world scenarios. Additionally, the testbed can be used to measure the performance of the technology and identify areas of improvement, allowing for an iterative development process. Finally, the testbed can be used to educate others about the technology, helping to spread knowledge and build confidence in the technology. Existing testbeds and platforms exist and can be utilized for multiple purposes.

- **Help develop a unified system of teaching and data processing that can also help train local scientists in areas with limited resources.**

A unified system of teaching and data processing is important because it helps to ensure that all students receive an equitable education, and that data is being used appropriately. This kind of system allows educators to access data quickly and accurately, track student progress, and make informed decisions. It also allows schools to create more efficient and effective classroom management strategies and use data to inform instruction and assess student performance. A unified system of teaching and data processing is essential for meeting the needs of all students and promoting equity in education.

Additionally, a unified system of teaching and data processing can help train local scientists in areas with limited resources by allowing for efficient and cost-effective access to educational resources. A unified system can provide access to remote lectures, online tutorials, and other educational materials from experts in the field, enabling scientists to learn from the best minds in the world without the need to travel or invest in expensive equipment. Finally, a unified system can provide access to data processing capabilities, such as cloud-based computing, which can help scientists in limited-resource areas to analyze complex datasets without the need for expensive hardware.

- **Promote data sharing in the ocean community.**

Data sharing in the ocean community is important for several reasons. First, it helps to ensure that ocean data is accurate and up to date. This data can be used to make important decisions related to ocean health, climate change, and other critical issues. Second, data sharing allows for the development of new technologies and programs that can be used to better monitor the health of the ocean. Finally, data sharing can foster collaboration and help to build relationships among ocean researchers, policymakers, and other stakeholders. By sharing data, ocean researchers can learn from one another and better understand the complexities of the ocean environment.

The panel discussed many of the following steps that can be combined to accomplish data sharing:

1. Establish clear policies and regulations for data sharing that are well-defined and widely accepted. The Intergovernmental Oceanographic Commission (IOC) could potentially do this.
2. Develop common standards for data collection and formats to ensure data compatibility and interoperability.
3. Develop a central repository for data sharing to make it easier for researchers and stakeholders to access data.
4. Create incentives for data sharing, such as grants or awards for data sharing efforts.
5. Set up data-sharing networks between research centers, universities, and government agencies.
6. Host data-sharing workshops and conferences to facilitate collaboration between stakeholders.
7. Provide training and support to ensure data is accurately collected and shared.
8. Utilize social media platforms to promote data sharing and collaboration.
9. Support open access initiatives to make data available to the public.
10. Use open-source tools, such as programming languages and cloud computing, to facilitate data sharing.

Appendix 1: Participants

Sector	Affiliation	Name
Public/Germany	GEOMAR Helmholtz Centre for Ocean Research Kiel	Toste Tanhua
Public/United Kingdom	Department of Environment, Food and Rural Affairs (DEFRA)	Rohan Allen
Public/USA	Department of Defense – Defense Research Project Agency (DARPA)	John Waterston
Public/USA	Department of Energy – Advanced Research Project Agency-Energy (ARPA-E)	Dan Rogers
Public/USA	National Oceanic and Atmospheric Administration (NOAA)/GOMO	David Legler
Public/USA	NOAA/Technology Partnerships Office	Genevieve Lind
Public/USA	NOAA/NESDIS/Center for Satellite Applications and Research	Guangming Zheng
Intergovernmental	Global Ocean Observing System (GOOS) through the US Integrated Ocean Observing System (IOOS)	Gabrielle Canonico
Academia	UIT The Arctic University of Norway	Benedicte Ferre
Academia	University of Hawaii	Bruce Howe
Academia	University of South Florida	Frank Muller-Karger
Industry	Guide Star Engineering LLC	Seibert Murphy
Industry	Kitware	Anthony Hoogs
Industry	L3Harris	Donna Kocak
Industry	Metron	Colleen Hahn
Industry	NatureMetrics	Samuel Stanton
Industry	RS Aqua	Ryan Mowat
Industry	Ocean Super Cluster – Canada	Susan Hunt
NGO	Carbonplan	Freya Chay
NGO	MBARI	Chris Scholin
NGO	Ocean Visions	Nikhil Neelakantan
NGO	National Oceanographic Center (NOC) – United Kingdom	Matthew Mowlem
NGO	Ocean Academy Australia	Jas Chambers
NGO	Schmidt Ocean Institute	Jyotika Virmani

Appendix 2: Use Case

Dialogue 4 | Looking Ahead: New technology for the Ocean Decade

Introduction

It is with worldwide recognition that healthy and safe oceans are fundamental for thriving ecosystems and resilient global and international economies. Efforts to advance robust and innovative ocean data collection and dissemination practices, and wide-reaching collaborative data sharing and analysis efforts, demand engagement, and partnerships between the public and private sectors.

The Global Ocean Observing System (GOOS) programme and the Marine Technology Society (MTS) cooperate with the National Oceanic and Atmospheric Administration (NOAA) to present Dialogues with Industry.[1] These four separately-scheduled dialogues convene experts from the public and private sectors to encourage stakeholder conversations that help all parties to share and understand barriers at each step of the ocean information value chain; from data collection instruments and techniques to data products and service delivery. The aim is to consider the current state of the market and to look toward the future and the opportunities it holds.

This paper will outline the scope, format, and proposed discussion topics for the fourth Dialogue with Industry.

Background and Scope

Historically, the lack of observations and data has been a major limitation in understanding the ocean and the impacts of human activities. Being able to accurately track and predict the complex processes that drive ocean variability over long durations is critical for assessing the dynamics in the ocean-climate nexus and for being able to maximize the opportunity for ocean-based solutions. Currently, governments and large-scale commercial interests are the primary consumers of ocean-based information and technology which has resulted in hyper-specific solutions that lack commercial applicability or ready transferability across applications and technology lock-in (High Level Panel). New technology is required to deliver an enhanced, expanded, and truly global system. From new high-tech and autonomous sensors and systems to new processing and delivery using AI, to enhanced predictions and decision-making using cognitive systems, to data storage and federation solutions, and including low-cost 'mass market' observing/monitoring capabilities. There is a fundamental need to understand technological drivers, and how to incubate and accelerate the delivery and integration of new technology into the global ocean observing system.

Many ocean information needs remain underserved, as societal needs for ocean information are rapidly rising, driven in great part by the need to address and adapt to

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[1] Please see the Background Paper for a detailed explanation of background, concepts and objectives.

climate change (the ocean plays a fundamental role in climate and therefore ocean data is of paramount importance), and also driven by and driving the development of sustainable ocean economies. This need is part of the impetus behind the UN Decade of Ocean Science for Sustainable Development (Ocean Decade), which is a global effort to transform the understanding of the ocean and application of ocean-based solutions, e.g., SDG 9: Industry, innovation, and infrastructure; SGD:13 Climate Action and SDG: 14 Life Below Water.

Ocean observations are critical to society and to realizing the Ocean Decade's vision of "the science we need for the ocean we want." Fortunately, innovations in ocean observing capabilities and networks have been opening new possibilities for understanding the ocean and for utilizing, sustainably, the full potential of ocean resources.

Further expansion and innovation can be significantly enhanced through growth and maturation of ocean observing markets, with both public and private investment playing a role to drive a paradigm shift toward greater interoperability and multi-purpose instrumentation. It will be important for this future ocean community to remain forward-looking to help make connections and continue to demonstrate the value of ocean observations. The ocean landscape is changing rapidly, and government and commercial operators alike will require vigilance, agility, and accountability as we move into the future.

Section I – New technology that will change ocean observing in the next decade

Traditional ocean observing systems were positioned in fixed locations to record data over long periods of time, such as cabled seafloor networks and moored buoys. In these systems, power is provided from shore stations, onboard batteries or generators, systems to scavenge energy from the environment, or a combination of these methods. Platforms of opportunity, such as ferry boats and ships, are being used to collect time series data over frequently traversed routes. Ocean "drifters" are more random in location, collecting data wherever the currents take them, whereas, autonomous platforms, including gliders, AUV/UUVs, and other surface and subsurface vehicles, are being used to collect data in more targeted or controlled locations. Lastly, remote systems in space are able to monitor and collect data on a global scale.

The duration of the collection is often power dependent. Systems connected to a power station can operate 24/7; whereas other power sources require various duty cycles of operation depending on the mission duration. Examples of marine power sources include diesel generators, alternative fuels (including biogenic methane), lithium batteries, saltwater batteries, fuel cells, solar cells, wind generators, and power generated from ocean waves, currents, tides, and temperature, salinity, or pressure changes.

The community has been discussing that ocean sensors need to fit for purpose and expand the number and types of essential ocean variables that need to be collected. To be able to collect the amount of information required by the Ocean Decade, and the United Nations Sustainable Development Goals, these sensors need to be more robust, lower cost and have the ability to sense for greater lengths of time. The ocean observing community should also recognize the impact that it is having on the ocean that we are observing, and future observing systems should take sustainability into consideration.

As we go through this discussion, in general we are looking for examples of technologies that can be drawn from other fields that can support future marine technologies and vice versa are there technologies we are developing that can be adapted in other fields.

Discussion topics

- What do you see as the most impactful nascent or emerging technological transformation that will enable the collection of next decade of ocean observations? Is it a system, specific technology, or group of technologies? Is it the application of an approach or hardware from another industry? Or something entirely different? For example -
  - New power systems
  - Sensor technologies - low SWaP-C, long-term deployments, new modalities, etc.
  - Autonomy
  - New platforms
  - Use of submarine fiber optic cables – monitoring ocean and seismic data from existing seafloor cables and/or adding sensors into telecommunications repeater hardware (SMART - Science Monitoring And Reliable Telecommunications) to take advantage of the large and capable submarine cable industry, etc.
  - Expanding applications for dual-use – i.e., monitoring for science and offshore energy utilizing the same infrastructure
  - Community run (non-science expert) solutions
  - Machine-to-Machine collaborations to extend ocean observing capabilities – e.g., AUVs and UAVs collecting data and offloading it to USVs for exfil.
  - Communications systems - opportunities to use space satellites, AIS, VOO
  - Infrastructure - subsea, renewable energy, etc.
  - Uncrewed systems - air/sea/space subsystems
- A few speakers have noted challenges in observing biology.What other challenges and opportunities exist for developing technologies to meet the needs of understanding biodiversity, chemical, and biological EOVs? Also, the activity-linked biogenic and anthropogenic variables that John noted.
- What are your thoughts on:
  - Given the public good nature of the ocean information is there a need for some level of government regulation e.g., to maintain a 'basic' level of service - if so, what does this look like; or
  - Given the nature of ocean processes and interactions - i.e., need for long time series 10, 20, 30 years sustained observations how should we view/evolve the integration of new technology (especially new disruptive technology) into our sustained ocean observing system? OR both?
- What can be done to make ocean observing less impactful on the ocean?
  - What renewable power sources can be used?
  - How can we ensure that ocean observing equipment does not contribute to the growing marine debris problem? Are there examples from hurricane prone areas?
  - What materials can be used?

Section II-Emerging Ocean information demands will require new technology, skills and business models.

The role of ocean observations has long been recognized in the forecasting of, preparation for, response to, and recovery from extreme weather events and natural disasters. With today's computer technologies, Earth observation data are combined with economic and demographic data to improve disaster responsiveness and minimize disruption to the local economy. It is important to understand the ability of the Ocean Enterprise to provide the information needed to maintain crucial public services, enable new discoveries, and advance knowledge. Modeling and data assimilation, algorithm development, artificial intelligence (AI), and high-performance and cloud computing offer the potential to improve the value of ocean observations for users, creating incentives and opportunities for the private sector to develop value-added products, services, and applications. AI and machine/deep-learning techniques, including deep neural networks, have advanced considerably in recent years and have driven new commercial developments, tools, and utilities in fields as wide ranging as medicine, self-driving cars, social media, and finance. The increase in accuracy and applicability of AI has been significant in the private sector, driven by its efficiency, cost-effectiveness, and auto-learning features. Until recently, the adoption of AI to process ocean observation data has lagged. AI is now increasingly being applied with promising results, including the development of applications with predictive capabilities.

Moving to a multi-sectoral ocean observing architecture requires technical, cultural and financial shifts. Cultural issues stem from the reluctance of national/government agencies to cede control of data that they have previously collected. There are concerns about how this shift will impact academia and intergovernmental agreements. There is however growing recognition that funding for future ocean observing systems, platforms, data and information are increasingly coming from outside of the government with blue venture capital and philanthropic organizations having greater roles.

Discussion topics

- Considering the rapid maturation of and widespread use of AI, computer vision, edge computing, digital twins, and similar technologies, what are the challenges that need to be overcome in leveraging these capabilities to advance the entire ocean observing enterprise?
- A few folks have brought up workforce development and student training -- What investments are needed to develop the workforce to meet the demands of a new Blue Economy based on ocean information?
- A few folks have brought up workforce development and student training -- What investments are needed to develop the workforce to meet the demands of a new Blue Economy based on ocean information?
    - Are there existing Universities/Colleges/Training programs that you consider a model for training the Blue Economy workforce?
    - How do we engage and directly support new talent in the ocean observing enterprise (esp. folks new to our sector computer and data engineers)
- A few folks have mentioned different angles of the issue of technology transition and integration of new sensors in the community -- Recognizing that industry acquisition and observing efforts move quickly, government and academia move somewhat slower, and the ocean processes we are trying to characterize sometimes require decades of sustained observations--how should we view and/or evolve our approach to deploying and integrating new and disruptive technologies into observing systems?
- What discrete recommendations have we not yet discussed that help to accelerate the creation, adoption, and deployment of new ocean observing technologies?

- How can advances in cloud computing be used to advance the new Blue Economy?
- What skills are needed to develop the workforce to meet the demands of a Blue Economy and a new Blue Economy based on ocean information and how do we support them?
  - Are there existing Universities/Colleges/Training programs that you consider a model for training the Blue Economy workforce?
  - What are the opportunities for engaging and directly supporting (funding, mentorship) new people in the ocean observing enterprise- early career, underrepresented groups, new sector representatives (engineers, AI/data)?
- How is the role of national/government agencies as the majority provider changing by 2030? For example, funding from national/government agencies has historically been viewed as the early source of funding e.g., “seed” funding - will this be the case going forward?
- Are there specific opportunities that are ripe for growth and/or new partnerships (e.g., marine carbon sequestration, shipping/marine transportation, renewable energy)? How can industry, governments, and non-governmental organizations capitalize on those opportunities to create market value? Are there lessons learned from other “start-up” sectors that could be applied to the blue economy?
- Given the public good nature of the ocean information, is there a need for some level of government regulation e.g., to maintain a 'basic' level of service - if so, what does this look like?

Appendix 3: Planning Team

Sector	Affiliation	Name
Public - Australia	Bureau of Meteorology	Boris Kelly-Gerreyn
Public - United States	NOAA	Brittany Croll
Public - United States	NOAA	Kelly Spalding
Public – United States	NOAA	Liz Tirpak
Intergovernmental	GOOS	Emma Heslop
Intergovernmental	GOOS	Laura Stukonyte
Industry	Kongsberg Maritime	Peer Fietzek
Industry/NGO	L3 Harris/MTS	Donna Kocak
Industry	South Seas Science Consulting	Sebastien Boulay
NGO	IMOS	Michael Heupel
NGO	MTS – India	R. Venkatasen
NGO	MTS	Chris Ostrander
NGO	MTS	Monica Ostrander
NGO	MTS	Zdenka Willis
NGO	Society for Underwater Technology (SUT)	Ralph Rayner

The Global Ocean Observing System

marine technology SOCIETY

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

DIALOGUES WITH INDUSTRY

Report out from Dialogue 4

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