

Inventory of OceanObs'19 Recommendation Gaps in the UN Decade of Ocean Science for Sustainable Development

Arctic Observing System

Recommendation: Arctic observing planning and implementation should draw on the principles of co-production, co-design and co-management of observing systems, with inclusion of Indigenous and local communities from the outset.

Blue Economy and Sustainable Development

Recommendation: Establishing a catalogue of case studies of the socioeconomic benefits of ocean observations, measurement and forecasting, so that they can be readily accessed, grouped and extracted. **Possible Relevant UN Decade:** MPAs as sentinel sites for ocean conservation, science, and literacy, U.S. NOAA (Contribution)

Building an International Transparent Ocean Community

Recommendation: Transparent Ocean Initiative will greatly contribute to the UN Decade of Ocean Sciences for Sustainable Development by providing vital information relevant to the development goals.

Capacity Building

Recommendation: Create a community of practice for those working in capacity development to share resources, catalogue existing efforts, create a unified agenda and funding request, obtain funding, and ensure sustainability of efforts.

Recommendation: Align efforts with community needs and realities – make sure training matches available equipment, create regionally specific best practices including for import/procurement of equipment, ensure easy and sustainable maintenance.

Climate Change and Variability

Recommendation: Augmentation and refined definition of the Global Climate Indicator framework: towards a comprehensive Earth system view.

Recommendation: Achieve accuracy targets for EOVs / ECVs to provide ocean related global climate indicator at required accuracy.

Recommendation: Reduce capability gaps for EOVs / ECVs measurements under the ocean related global climate indicator framework.

Community Building and Dialogue

Recommendation: Increase level of funding & resources available for strategic user engagement & outreach activities, including economic studies to identify & prioritize engagement and co-development needed for highest societal impact observations and products/services.

Data Integration with User Products

Recommendation: Funding agencies of ocean observing systems need to align funding to meet the demands of data management, long-term stewardship, and training by participation in e.g., IODE, ESIP, E2SIP, CODATA, RDA.

Recommendation: To qualify user products, a quantified measurement uncertainty should be added to each measurement result entered into ocean observation systems.

Design and Implementation of a Global Harmful Algal Bloom Observing System

Recommendation: The integrated observing system should fill the need for sustained, automated, near real-time information on biology, including HAB species & toxins, and improved forecast systems that address the HAB-risk warning requirements at global & regional levels.

Recommendation: The system will scale up from regional networks to global framework through interregional technology & product development to address societal needs while sustaining multidisciplinary and climate-quality datasets to ascertain long-term trends in HABs.

End-User Engagement: A Perspective From China

Recommendation: Support tailored best practices for technological innovation, particularly at local and regional levels.

Recommendation: Create coordination/collaboration network or portal as a mechanism to facilitate regional, institutional, and thematic partnerships.

Environmental DNA in Ocean Observing

Recommendation: Build a coordinated, distributed eDNA monitoring network leveraging existing programs; include acoustic, optical, traditional and other environmental measurements when possible.

Recommendation: Greatly expand current genomic reference libraries for marine species prioritizing groups based on user needs (EOVs, commercially important, invasive, etc.).

Fostering an Ocean-Literate Generation: An Approach at the Interface of Science Outreach and Communication

Recommendation: Implementation of “marine-friendly” curricula in terms of school courses and textbooks as well as teacher trainings (at all levels, from primary to tertiary; in all countries; in an understanding-based manner).

Global Observing System for Marine Debris

Recommendation: A comprehensive global observing & information system is necessary to evaluate sources/sinks, abundance, trends, risks and the efficiency of reduction measures and finally to get the problem under control.

Recommendation: To achieve fundamental understanding of the issues of marine debris, develop efficient in situ observation technology, remote sensors, models and monitoring strategies, involving citizen scientists when possible.

Governance Needs

Recommendation: We recognize that OO governance is multi-level with many centers (polycentric). Engage them all to analyze gaps, harmonize principles, improve learning & sharing, and conflict resolution, and develop the network of actors.

Recommendation: We want to have collective impact with our stakeholders; let’s build a common agenda, ways to measure it, mutually reinforcing activities, continuous communication, and backbone support (collective impact model).

Recommendation: Commission a working group, including ocean observers, and governance experts, to develop a revised governance system based on ideas presented at OceanObs’19.

How Research Institutions Will Enable Innovation for the Global Ocean Observing System (GOOS) Over the Next Decade

Recommendation: Strengthen relationships between federal entities and research institutions to improve overall observing systems.

Recommendation: Increase lifetime of floats and increase accuracy and stability of sensors.

Indigenous Ocean Governance

Recommendation: Formally recognize the traditional knowledge of Indigenous peoples worldwide as well as the articles within the United Nations Declaration on the Rights of Indigenous Peoples.

Recommendation: Negotiate paths forward to design, develop, and carry out ocean observing initiatives; and share responsibility and resources.

Innovation in Ocean Observing Platforms and Infrastructure

Recommendation: Establish international working groups to address key infrastructure areas and data harmonization across platforms: ASVs, AUVs, Moorings, Cable systems, Acoustic Systems.

Recommendation: Pilot a sustained multipurpose acoustic network for passive monitoring, tomography, underwater positioning and communication in an integrated Arctic observing system, with eventual transition to global coverage.

Recommendation: Transition telecom+sensing SMART subsea cable systems from present pilots to trans-ocean implementation, to address climate, ocean circulation, sea level, and tsunami and earthquake early warning, ultimately with global coverage.

Integrated Ocean Observations I

Recommendation: Make sure we're measuring the same, important EOVs in comparable ways across geographic scales to inform societal, management and scientific needs.

Recommendation: Expand colocated EOV measurements to include biological and biogeochemical parameters.

Integrated Ocean Observations II: Diverse Stakeholder Needs

Recommendation: Develop new mechanisms within the FOO to ensure that the observing system is truly multipurpose and multidisciplinary and serves diverse stakeholders. This may include developing new categories of EOVs connected to human activities.

Integrated Ocean Observations III: Across Disciplines and Networks

Recommendation: Report progress towards the desired global ocean observing system through biennial reporting to the United Nations using EOVs as a reporting framework.

Recommendation: Ensure that observing networks contributing to the global ocean observing system provide updated metadata on progress towards full maturity under the FOO, as well as their data to the relevant open and FAIR regional and global databases.

Modeling and Assimilation Innovation

Recommendation: Promote investment for organizing workshops, training programs, and targeted meetings in order to enhance the communication between observational and modeling/Data Assimilation (DA) communities.

Recommendation: Encourage Observation System Experiments (OSEs) and Observation System Simulation Experiments (OSSEs) to identify best practices.

NASA's Decade of Ocean Observation From Space

Recommendation: Case studies can highlight the value of ocean observing information products so that nations will want to commit to sustained ocean observing activities.

Observing Technology Innovation: Platforms and Technology

Recommendation: Stakeholders & funding agencies need to promote early & consistent connection & dialogue amongst researchers, engineers/technologists & data science communities at the inception of observing programs to ensure that objectives and requirements are met.

Recommendation: The ocean observing community must establish a stronger pipeline for innovators from engineering, computer science, data science, and material science.

Recommendation: Distributed and extensive ocean obs platforms/systems are required to increase community emphasis on turning prototype tools & individual sensors into integrated platforms & production systems using best practices in systems engineering & data management.

Observing Technology Innovation: Satellites

Recommendation: Promote synergy and coordination between agencies for (1) multiple sensors, platforms and disciplines for an integrated virtual constellation to observe the ocean's small rapid scales globally, and (2) for in-situ Calval infrastructure.

Ocean Partnerships for Sustained Observing

Recommendation: Identify willing champions and experts to facilitate a network of advisors and collective impact organizations that help with trans-sector partnership development and maintenance at national to regional to global scales.

Recommendation: Create a framework for partnership building that provides guidance for research institutions, countries, philanthropies, etc. that wish to establish programs around ocean observations, products, and/or services.

Ocean, Weather, and Climate Forecasting

Recommendation: Develop in partnership with the observational community a framework to perform observational impacts studies.

Recommendation: Enable a regular ocean observation impact forum for all applications, including user/sector needs.

Open Source Software Revolution

Recommendation: Resources aimed at developing the knowledge & experience necessary to use & develop open source software will enable more scientists to benefit from the advantages of open source software.

Recommendation: Identification of existing & development of new methods that provide credit for publishing open source software is important for acceptance of open source software. These include inclusion of software digital object BinderHubs, reporting GitHub activity.

Powering the Blue Economy: Energy Innovation for Ocean Observations

Recommendation: Overcoming power limitations in ocean observing could provide tremendous value by providing new data streams and enabling new capabilities: proactive monitoring; high res BGC data; gliders that run climatology lines; further discussion.

Recommendation: Reducing the timescale of design cycles is a major challenge for further innovation to integrate marine energy and observing platforms. Solutions include: linking communities; improving access to testing sites; more time for deep thinking.

Traditional Knowledge Building

Recommendation: Build up capacity within the scientific community to understand and value indigenous and other knowledge systems.

Recommendation: Connect initiatives and exchange success stories and challenges to develop a framework for Community Supported Observation and to give Community Supported Observations a voice in the Global Ocean Observing Community.

Uncertainty Quantification

Recommendation: We should train ocean observers and modelers in statistical terminology and techniques for the purpose of uncertainty quantification.

Recommendation: Building on existing efforts, we should produce a series of peer-reviewed and open-access documents that define and recommend strategies and best practices for uncertainty quantification in ocean observing.

Recommendation: Research programs should require and fund routine uncertainty estimates on ocean observations and derived products, and should fund dedicated efforts to develop freely available resources (software and databases) for uncertainty quantification.

OceanObs'19 Recommendations and Their Relevant UN Decade Programs, Contributions, and Actions

A Sustainable, Fit-for-Purpose Ocean Observing System: Responding to User Needs

Recommendation: Feedback processes with identified users and resource stakeholders are needed from the beginning, and should be reviewed on an ongoing basis to identify what is fit-for-purpose for users and societal benefit (and to adjust as needed).

Relevant UN Decade: Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Recommendation: Case studies can highlight the value of ocean observing information products so that nations will want to commit to sustained ocean observing activities.

Relevant UN Decade:

Recommendation: Take into account existing pieces, commitments and regulations for developing a fit-for-purpose ocean observing system.

Relevant UN Decade:

An Ocean of Data: NOAA's Roles in Marine Extreme Events and Hazards

Recommendation: Bring in core mission stakeholders earlier on in the development of research and technology so that we are developing around needs and, in tandem, providing the necessary communication and education from the onset.

Relevant UN Decade: Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Recommendation: The architecture of ocean observations are changing. Be more adaptive to changing technology and focus efforts on transitional systems while maintaining data records.

Relevant UN Decade:

Recommendation: Research to operations transitions are key in developing systems with broad reaching impacts and societal benefits, and should be a focus from the onset of research questions to support issues and needs on multiple scales.

Relevant UN Decade:

Arctic Observing Systems

Recommendation: By 2029 the Arctic should prominently demonstrate it has a fully developed, implemented and sustained ocean observing system that meets – at a minimum, earth system prediction needs – but also meets other critical Arctic societal benefits.

Relevant UN Decade: Navigating the New Arctic, U.S. NSF (Contribution)

Recommendation: Development of an Arctic node or regional alliance under the umbrella of a global observing framework such as GOOS should be given serious consideration by the Arctic community.

Relevant UN Decade: Navigating the New Arctic, U.S. NSF (Contribution)

Recommendation: Arctic observing planning and implementation should draw on the principles of co-production, co-design and co-management of observing systems, with inclusion of Indigenous and local communities from the outset.

Relevant UN Decade: NONE

Blue Economy and Sustainable Development

Recommendation: Fostering transdisciplinary research – active cooperation between economists, other social scientists and the ocean scientific communities.

Relevant UN Decade: Global Ocean Oxygen Decade, GEOMAR (Programme); Marine Life 2030, Smithsonian (Programme); MONACO EXPLORATIONS (Contribution)

Recommendation: Mapping ocean observations' value chains in cooperation with interested data repositories, as to inform practitioners and policy-makers with original evidence-based analysis on the growing links between ocean observations and many sectors of the economy.

Relevant UN Decade: ForeSea - The Ocean Prediction Capacity of the Future, OceanPredict (Programme)

Recommendation: Establishing a catalogue of case studies of the socioeconomic benefits of ocean observations, measurement and forecasting, so that they can be readily accessed, grouped and extracted.

Relevant UN Decade: NONE (Possibly: MPAs as sentinel sites for ocean conservation, science, and literacy, U.S. NOAA [Contribution])

Building an International Transparent Ocean Community

Recommendation: Transparent Ocean Initiative will greatly contribute to the UN Decade of Ocean Sciences for Sustainable Development by providing vital information relevant to the development goals.

Relevant UN Decade: NONE

Recommendation: It is essential to integrate observations, process studies and prediction/projection, so as to meet multiple demands of end users.

Relevant UN Decade: ForeSea - The Ocean Prediction Capacity of the Future, OceanPredict (Programme); Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); CoastPredict - Observing and Predicting the Global Coastal Ocean, University of Bologna, University of Miami/RSMAS, SOCI and CSIC-IMEDEA (Programme)

Recommendation: Strengthened effort is needed to meet challenges of effective communication between science and research community and the general public.

Relevant UN Decade: The Hydrous presents: The Decade of Ocean Empathy, The Hydrous (Programme); Bertarelli Foundation Marine Science Programme, Bertarelli Foundation (Contribution); Piping Hot x UN Decade of Ocean Science for Sustainable Development, Piping Hot Australia (Contribution); The Ocean Decade Image Bank and Toolkits, The Ocean Agency (Contribution), Universeum Ocean Science Lab, Universeum - Ocean Science Lab (Contribution)

Capacity Building

Recommendation: Create a community of practice for those working in capacity development to share resources, catalogue existing efforts, create a unified agenda and funding request, obtain funding, and ensure sustainability of efforts.

Relevant UN Decade: NONE

Recommendation: Align efforts with community needs and realities – make sure training matches available equipment, create regionally specific best practices including for import/procurement of equipment, ensure easy and sustainable maintenance.

Relevant UN Decade: NONE

Recommendation: Create venues and opportunities for dialogue about capacity development between scientists, high level decision makers, local implementors, and other stakeholders.

Relevant UN Decade: Cultural Heritage Framework Programme, Ocean Decade Heritage Network (ODHN) (Programme); Ocean Voices, Nippon Foundation Ocean Nexus Center, EarthLab, University of Washington (Programme)

Climate Change and Variability

Recommendation: Augmentation and refined definition of the Global Climate Indicator framework: towards a comprehensive Earth system view.

Relevant UN Decade: NONE

Recommendation: Achieve accuracy targets for EOVs / ECVs to provide ocean related global climate indicator at required accuracy.

Relevant UN Decade: NONE

Recommendation: Reduce capability gaps for EOVs / ECVs measurements under the ocean related global climate indicator framework.

Relevant UN Decade: NONE

Community Building and Dialogue

Recommendation: Develop common principles and best practices for user engagement, which are tailored to the different target audiences (e.g., specific demographics, indigenous communities, industry sectors, regulators, emerging service sector, etc.)

Relevant UN Decade: Cultural Heritage Framework Programme, Ocean Decade Heritage Network (ODHN) (Programme)

Recommendation: Co-develop tailored value propositions and use cases for ocean observing with user groups.

Relevant UN Decade: Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action)

Recommendation: Increase level of funding & resources available for strategic user engagement & outreach activities, including economic studies to identify & prioritize engagement and co-development needed for highest societal impact observations and products/services.

Relevant UN Decade: NONE

Data Integration with User Products

Recommendation: Funding agencies of ocean observing systems need to align funding to meet the demands of data management, long-term stewardship, and training by participation in e.g., IODE, ESIP, E2SIP, CODATA, RDA.

Relevant UN Decade: NONE

Recommendation: To qualify user products, a quantified measurement uncertainty should be added to each measurement result entered into ocean observation systems.

Relevant UN Decade: NONE

Recommendation: Data providers should strive to use web services with well described and open APIs to distribute and make their data accessible to human and machine consumers to enable data products downstream.

Relevant UN Decade: The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution)

Design and Implementation of a Global Harmful Algal Bloom Observing System

Recommendation: The ocean observing community must advance an end-to-end global observing system that responds to marine related societal needs and provides improved, advanced warnings of harmful algal blooms (HABs), in particular.

Relevant UN Decade: Ocean Biomolecular Observing Network (OBON), The Partnership for Observation of the Global Ocean (POGO) (Programme); The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission: Advanced satellite measurements of the sea and sky, NASA (Contribution)

Recommendation: The integrated observing system should fill the need for sustained, automated, near real-time information on biology, including HAB species & toxins, and

improved forecast systems that address the HAB-risk warning requirements at global & regional levels.

Relevant UN Decade: NONE

Recommendation: The system will scale up from regional networks to global framework through interregional technology & product development to address societal needs while sustaining multidisciplinary and climate-quality datasets to ascertain long-term trends in HABs.

Relevant UN Decade: NONE

Ecosystem Health and Biodiversity

Recommendation: Integrate biological observations into the global observing system as an integral and necessary component of ocean ecosystem science and understanding.

Relevant UN Decade: Ocean Biomolecular Observing Network (OBON), The Partnership for Observation of the Global Ocean (POGO) (Programme); Marine Life 2030: A Global Integrated Marine Biodiversity Information Management and Forecasting System for Sustainable Development and Conservation, Smithsonian Institution (Programme)

Recommendation: Implement available technologies for biological observing now, maximizing access to biological data and information to quantify, explain, and forecast biodiversity changes.

Relevant UN Decade: Digital innovation Hand-in-Hand with fisheries and ecosystems scientific monitoring, FAO (Action); The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission: Advanced satellite measurements of the sea and sky, NASA (Contribution)

Recommendation: Advance decadal plans for a fully encompassing global ocean observing system that integrates biology, biodiversity, physical and biogeochemical observations.

Relevant UN Decade: Global Ocean Biogeochemistry Array (GO-BGC Array), U.S. NSF (Contribution); Deep Ocean Observing Strategy, DOOS (Programme)

End-User Engagement: A Perspective From China

Recommendation: Improve coordination at and across different levels of ocean observing through enhanced dialogue with observers and users, for example through a consolidated network or portal.

Relevant UN Decade: Digital Twins of the Ocean - DITTO, GEOMAR (Programme); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Recommendation: Support tailored best practices for technological innovation, particularly at local and regional levels.

Relevant UN Decade: NONE

Recommendation: Create coordination/collaboration network or portal as a mechanism to facilitate regional, institutional, and thematic partnerships.

Relevant UN Decade: NONE

Environmental DNA in Ocean Observing

Recommendation: Build a coordinated, distributed eDNA monitoring network leveraging existing programs; include acoustic, optical, traditional and other environmental measurements when possible.

Relevant UN Decade: NONE

Recommendation: Develop internationally accepted practices for marine eDNA collection, analysis, processing, sample archival and data management.

Relevant UN Decade: IOGP Environmental Genomics Joint Industry Programme, The International Association of Oil and Gas Producers (IOGP) (Contribution)

Recommendation: Greatly expand current genomic reference libraries for marine species prioritizing groups based on user needs (EOVs, commercially important, invasive, etc.).

Relevant UN Decade: NONE

Fostering an Ocean-Literate Generation: An Approach at the Interface of Science Outreach and Communication

Recommendation: Promotion of ocean literacy in order to engage people on the pathway to a sustainable interaction with the ocean.

Relevant UN Decade: MPAs as sentinel sites for ocean conservation, science and literacy, U.S. NOAA (Contribution); Piping Hot x UN Decade of Ocean Science for Sustainable Development, Piping Hot Australia (Contribution); Universeum Ocean Science Lab, Universeum - Ocean Science Lab (Contribution); Cultural Heritage Framework Programme, Ocean Decade Heritage Network (ODHN); Ocean Literacy With All (OLWA): the change we need for the ocean we want, IOC of UNESCO (Action); The Ocean Decade Image Bank and Toolkits, The Ocean Agency (Contribution)

Recommendation: Need to encourage ocean science outreach and communication activities and funding opportunities relevant to formal and informal educational environments in order to increase ocean literacy.

Relevant UN Decade: Ocean Literacy With All (OLWA): the change we need for the ocean we want, IOC of UNESCO (Action); France's Priority Research Program "Ocean of solutions," IFREMER (Contribution); MPAs as sentinel sites for ocean conservation, science and literacy, U.S. NOAA (Contribution); Universeum Ocean Science Lab, Universeum - Ocean Science Lab (Contribution)

Recommendation: Implementation of "marine-friendly" curricula in terms of school courses and textbooks as well as teacher trainings (at all levels, from primary to tertiary; in all countries; in an understanding-based manner).

Relevant UN Decade: NONE

Global Observing System for Marine Debris

Recommendation: A comprehensive global observing & information system is necessary to evaluate sources/sinks, abundance, trends, risks and the efficiency of reduction measures and finally to get the problem under control.

Relevant UN Decade: NONE

Recommendation: To achieve fundamental understanding of the issues of marine debris, develop efficient in situ observation technology, remote sensors, models and monitoring strategies, involving citizen scientists when possible.

Relevant UN Decade: NONE

Recommendation: Build an integrated, standardized and harmonized collaborative network, using commonly accepted methods & definitions, whose structure (variables, coverage, and products) answers fundamental scientific questions and societal demands.

Relevant UN Decade: Flourishing Oceans - Plastics and Human Health, The Minderoo Foundation (Contribution)

Governance Needs

Recommendation: We recognize that OO governance is multi-level with many centers (polycentric). Engage them all to analyze gaps, harmonize principles, improve learning & sharing, and conflict resolution, and develop the network of actors.

Relevant UN Decade: NONE

Recommendation: We want to have collective impact with our stakeholders; let's build a common agenda, ways to measure it, mutually reinforcing activities, continuous communication, and backbone support (collective impact model).

Relevant UN Decade: NONE

Recommendation: Commission a working group, including ocean observers, and governance experts, to develop a revised governance system based on ideas presented at OceanObs'19.

Relevant UN Decade: NONE

How Research Institutions Will Enable Innovation for the Global Ocean Observing System (GOOS) Over the Next Decade

Recommendation: Strengthen relationships between federal entities and research institutions to improve overall observing systems.

Relevant UN Decade: NONE

Recommendation: Increase lifetime of floats and increase accuracy and stability of sensors.

Relevant UN Decade: NONE

Recommendation: Support science-based research during the development and sustained phase of platform-based observing systems.

Relevant UN Decade: International Ocean Discovery Program, U.S. NSF (Contribution)

Indigenous Ocean Governance

Recommendation: Formally recognize the traditional knowledge of Indigenous peoples worldwide as well as the articles within the United Nations Declaration on the Rights of Indigenous Peoples.

Relevant UN Decade: NONE

Recommendation: Establish meaningful partnerships with Indigenous communities, organizations, and Nations to learn and respect each other's ways of knowing.

Relevant UN Decade: Sustainability of Marine Ecosystems through global knowledge networks (SMARTNET), International Council for the Exploration of the Sea (ICES), The North Pacific Marine Science Organization (PICES) (Programme)

Recommendation: Negotiate paths forward to design, develop, and carry out ocean observing initiatives; and share responsibility and resources.

Relevant UN Decade: NONE

Innovation in Ocean Observing Platforms and Infrastructure

Recommendation: Establish international working groups to address key infrastructure areas and data harmonization across platforms: ASVs, AUVs, Moorings, Cable systems, Acoustic Systems.

Relevant UN Decade: NONE

Recommendation: Pilot a sustained multipurpose acoustic network for passive monitoring, tomography, underwater positioning and communication in an integrated Arctic observing system, with eventual transition to global coverage.

Relevant UN Decade: NONE

Recommendation: Transition telecom+sensing SMART subsea cable systems from present pilots to trans-ocean implementation, to address climate, ocean circulation, sea level, and tsunami and earthquake early warning, ultimately with global coverage.

Relevant UN Decade: NONE

Integrated Ocean Observations I

Recommendation: Make sure we're measuring the same, important EOVs in comparable ways across geographic scales to inform societal, management and scientific needs.

Relevant UN Decade: NONE

Recommendation: Expand colocated EOV measurements to include biological and biogeochemical parameters.

Relevant UN Decade: NONE

Recommendation: Improve observational capacity by making sensors and platforms more affordable and best practices universal.

Relevant UN Decade: Ocean Practices for the Decade, GOOS (Action)

Integrated Ocean Observations II: Diverse Stakeholder Needs

Recommendation: Develop new mechanisms within the FOO to ensure that the observing system is truly multipurpose and multidisciplinary and serves diverse stakeholders. This may include developing new categories of EOVs connected to human activities.

Relevant UN Decade: NONE

Recommendation: Develop incentives to reward data providers, and invest in Data Assembly Centers and Integrated Data Services with expert curation, to ensure that data from stakeholders are FAIR, open, and free, contributing to the ocean observing system value chain.

Relevant UN Decade: The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution)

Recommendation: Develop tailored communication strategies for the integrated observing system, to encourage stakeholder feedback and engagement processes. The strategies should include prioritization of ocean information and ocean observation needs.

Relevant UN Decade: Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Integrated Ocean Observations III: Across Disciplines and Networks

Recommendation: Increase regional & global coordination throughout the next decade, focusing on partnerships & improved communication; observational capacity including improved data sharing; an expanded funding base for sustained observations.

Relevant UN Decade: Ocean Practices for the Decade, GOOS (Action); Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution); Digital Twins of the Ocean - DITTO, GEOMAR (Programme); Ocean Voices, Nippon Foundation Ocean Nexus Center, EarthLab, University of Washington (Programme)

Recommendation: Report progress towards the desired global ocean observing system through biennial reporting to the United Nations using EOVs as a reporting framework.

Relevant UN Decade: NONE

Recommendation: Ensure that observing networks contributing to the global ocean observing system provide updated metadata on progress towards full maturity under the FOO, as well as their data to the relevant open and FAIR regional and global databases.

Relevant UN Decade: NONE

Modeling and Assimilation Innovation

Recommendation: Promote investment for organizing workshops, training programs, and targeted meetings in order to enhance the communication between observational and modeling/Data Assimilation (DA) communities.

Relevant UN Decade: NONE

Recommendation: Encourage Observation System Experiments (OSEs) and Observation System Simulation Experiments (OSSEs) to identify best practices.

Relevant UN Decade: NONE

Recommendation: Utilize model/DA for designing/redesigning observation network, and for planning observation field campaigns to improve modeled physical processes.

Relevant UN Decade: Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action)

NASA's Decade of Ocean Observation From Space

Recommendation: Feedback processes with identified users and resource stakeholders are needed from the beginning, and should be reviewed on an ongoing basis to identify what is fit-for-purpose for users and societal benefit (and to adjust as needed).

Relevant UN Decade: Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action)

Recommendation: Case studies can highlight the value of ocean observing information products so that nations will want to commit to sustained ocean observing activities.

Relevant UN Decade: NONE

Recommendation: Take into account existing pieces, commitments and regulations for developing a fit-for-purpose ocean observing system.

Relevant UN Decade: Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Observing Needs in the Deep Ocean

Recommendation: Extend deep-ocean observing capacities to the global scale as part of the UN Decade – addressing all deep-ocean-relevant EOVs and building on existing assets and networks.

Relevant UN Decade: Challenger 150 - A Decade to Study Deep-Sea Life, Deep Ocean Stewardship Initiative (DOSI) (Programme); Deep Ocean Observing Strategy, DOOS (Programme); One Ocean Network for Deep Observation, IFREMER (Programme)

Recommendation: Improve standardization of and access to deep ocean observing data, samples, and derived products.

Relevant UN Decade: Challenger 150 - A Decade to Study Deep-Sea Life, Deep Ocean Stewardship Initiative (DOSI) (Programme); Deep Ocean Observing Strategy, DOOS (Programme); One Ocean Network for Deep Observation, IFREMER (Programme)

Recommendation: Facilitate partnerships, collaboration, integration and capacity building across deep-ocean observing communities, including deep-ocean exploration, seafloor mapping and private sectors, through the Deep Ocean Observing Strategy.

Relevant UN Decade: International Ocean Discovery Program, U.S. NSF (Contribution); Challenger 150 - A Decade to Study Deep-Sea Life, Deep Ocean Stewardship Initiative (DOSI) (Programme); Deep Ocean Observing Strategy, DOOS (Programme); Joint Exploration of the Twilight Zone Ocean Network, National Oceanography Centre, UK (Programme); One Ocean Network for Deep Observation, IFREMER (Programme)

Observing Technology Innovation: Platforms and Technology

Recommendation: Stakeholders & funding agencies need to promote early & consistent connection & dialogue amongst researchers, engineers/technologists & data science communities at the inception of observing programs to ensure that objectives and requirements are met.

Relevant UN Decade: NONE

Recommendation: The ocean observing community must establish a stronger pipeline for innovators from engineering, computer science, data science, and material science.

Relevant UN Decade: NONE

Recommendation: Distributed and extensive ocean obs platforms/systems are required to increase community emphasis on turning prototype tools & individual sensors into integrated platforms & production systems using best practices in systems engineering & data management.

Relevant UN Decade: NONE

Observing Technology Innovation: Satellites

Recommendation: Enhance high-resolution coverage in space and time of satellite observations extending into the polar regions, coastal and regional seas, and in the equatorial band, whilst maintaining long-term continuity in the satellite observing system.

Relevant UN Decade: Committee on Earth Observation Satellites - Coastal Observations, Applications, Services, and Tools (CEOS COAST), U.S. NOAA, National Environmental Satellite Data and Information Service (NESDIS), Center for Satellite Applications and Research (STAR) (Contribution); The NASA Plankton, Aerosol, Cloud,

ocean Ecosystem (PACE) mission: Advanced satellite measurements of the sea and sky, NASA (Contribution)

Recommendation: Fly Missions to cover Gaps in observed ocean ECVs/EOVs where the technology exists: total surface currents, wave spectra, vertical plankton distribution.

Relevant UN Decade: The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission: Advanced satellite measurements of the sea and sky, NASA (Contribution)

Recommendation: Promote synergy and coordination between agencies for (1) multiple sensors, platforms and disciplines for an integrated virtual constellation to observe the ocean's small rapid scales globally, and (2) for in-situ Calval infrastructure.

Relevant UN Decade: NONE

Ocean Best Practices

Recommendation: The OBPS, as a sustainable, scalable system for best practices, is important for ocean observing and should be capable of evolving with new technologies.

Relevant UN Decade: NONE

Recommendation: Establish community-based review capability for best practices.

Relevant UN Decade: NONE

Recommendation: There is a need for a convergence of best practices with similar objectives.

Relevant UN Decade: NONE

Ocean Partnerships for Sustained Observing

Recommendation: Identify willing champions and experts to facilitate a network of advisors and collective impact organizations that help with trans-sector partnership development and maintenance at national to regional to global scales.

Relevant UN Decade: NONE

Recommendation: Design and implement an international, organizational structure for the development and resourcing of global partnerships around Capacity Building and maintenance in ocean observations (and larger ocean science).

Relevant UN Decade: Ocean Practices for the Decade, IODE & GOOS (Action)

Recommendation: Create a framework for partnership building that provides guidance for research institutions, countries, philanthropies, etc. that wish to establish programs around ocean observations, products, and/or services.

Relevant UN Decade: NONE

Ocean, Weather, and Climate Forecasting

Recommendation: Develop in partnership with the observational community a framework to perform observational impacts studies.

Relevant UN Decade: NONE

Recommendation: Enable a regular ocean observation impact forum for all applications, including user/sector needs.

Relevant UN Decade: NONE

Recommendation: Align strategies of groups along ocean obs value chain, e.g. GOOS, OceanPredict, and BluePlanet.

Relevant UN Decade: Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action); Ocean Practices for the Decade, IODE & GOOS (Action); ForeSea - The Ocean Prediction Capacity of the Future, OceanPredict (Programme)

Open Source Software Revolution

Recommendation: Resources aimed at developing the knowledge & experience necessary to use & develop open source software will enable more scientists to benefit from the advantages of open source software.

Relevant UN Decade: NONE

Recommendation: Identification of existing & development of new methods that provide credit for publishing open source software is important for acceptance of open source software. These include inclusion of software digital object BinderHubs, reporting GitHub activity.

Relevant UN Decade: NONE

Recommendation: Support & further development of existing open source libraries that enable oceanographers to advance their science, including federal employees working on open source projects, funding work on libraries, or funding add-ons for grants.

Relevant UN Decade: The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution)

Powering the Blue Economy: Energy Innovation for Ocean Observations

Recommendation: Overcoming power limitations in ocean observing could provide tremendous value by providing new data streams and enabling new capabilities: proactive monitoring; high res BGC data; gliders that run climatology lines; further discussion.

Relevant UN Decade: NONE

Recommendation: Reducing the timescale of design cycles is a major challenge for further innovation to integrate marine energy and observing platforms. Solutions include: linking communities; improving access to testing sites; more time for deep thinking.

Relevant UN Decade: NONE

Traditional Knowledge Building

Recommendation: Build up capacity within the scientific community to understand and value indigenous and other knowledge systems.

Relevant UN Decade: NONE

Recommendation: Connect initiatives and exchange success stories and challenges to develop a framework for Community Supported Observation and to give Community Supported Observations a voice in the Global Ocean Observing Community.

Relevant UN Decade: NONE

Recommendation: Partnering with communities to develop mutual beneficial interdisciplinary projects with social sciences and indigenous knowledge systems.

Relevant UN Decade: Sustainability of Marine Ecosystems through global knowledge networks (SMARTNET), International Council for the Exploration of the Sea (ICES), The North Pacific Marine Science Organization (PICES) (Programme)

UN Decade of Ocean Science for Sustainable Development

Recommendation: Ocean Observing

Relevant UN Decade: Challenger 150 - A Decade to Study Deep-Sea Life, Deep Ocean Stewardship Initiative (DOSI) (Programme); CoastPredict - Observing and Predicting the Global Coastal Ocean, University of Bologna, University of Miami/RSMAS, SOCI and CSIC-IMEDEA (Programme); Deep Ocean Observing Strategy, DOOS (Programme); Marine Life 2030: A Global Integrated Marine Biodiversity Information Management and Forecasting System for Sustainable Development and Conservation, Smithsonian Institution (Programme); Observing Air-Sea Interactions Strategy (OASIS), OASIS (Programme); Ocean Acidification Research for Sustainability, Global Ocean Acidification Observing Network (GOA-ON) (Programme); Ocean Biomolecular Observing Network (OBON), The Partnership for Observation of the Global Ocean (POGO) (Programme); One Ocean Network for Deep Observation, IFREMER (Programme); Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action); A Transformative Decade for the Global Ocean Acidification Observing System, NOAA (Contribution); Committee on Earth Observation Satellites - Coastal Observations, Applications, Services, and Tools (CEOS COAST), U.S. NOAA, NESDIS, STAR (Contribution); France's Priority Research Program "Ocean of solutions," IFREMER (Contribution); Global Ocean Biogeochemistry Array (GO-BGC Array); IOGP Environmental Genomics Joint Industry Programme, The International Association of Oil and Gas Producers (IOGP) (Contribution); NASA Sea Level Change Science Team, NASA (Contribution)

Recommendation: Knowledge of ecosystems

Relevant UN Decade: CoastPredict - Observing and Predicting the Global Coastal Ocean, University of Bologna, University of Miami/RSMAS, SOCI and CSIC-IMEDEA (Programme); Fisheries Strategies for Changing Oceans and Resilient Ecosystems by 2030, Gulf of Maine Research Institute (Programme); Global Ecosystem for Ocean Solutions (GEOS), Ocean Visions (Programme); Global Ocean Oxygen Decade, GEOMAR (Programme); Ocean Acidification Research for Sustainability, Global Ocean Acidification Observing Network (GOA-ON) (Programme); Sustainability of Marine Ecosystems through global knowledge networks (SMARTNET), International Council for the Exploration of the Sea (ICES), The North Pacific Marine Science Organization (PICES) (Programme); Digital innovation Hand-in-Hand with fisheries and ecosystems scientific monitoring, FAO (Action); The NASA Plankton, Aerosol, Cloud, ocean

Ecosystem (PACE) mission: Advanced satellite measurements of the sea and sky, NASA (Contribution); Marine Life 2030: A Global Integrated Marine Biodiversity Information Management and Forecasting System for Sustainable Development and Conservation, Smithsonian Institution (Programme); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action)

Recommendation: Ocean data and information system

Relevant UN Decade: GEOTRACES, U.S. NSF (Contribution); Integrating Coastal Wetlands Data into Greenhouse Gas (GHG) Inventories for Developing Countries: A New International Blue Carbon Initiative, U.S. NOAA and Department of State (Contribution); The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution); Values of the Ocean - a 10 area Decade Programme for protection and sustainable use of the ocean, The Research Council of Norway's Ocean Secretariat (Contribution); CoastPredict - Observing and Predicting the Global Coastal Ocean, University of Bologna, University of Miami/RSMAS, SOCI and CSIC-IMEDEA (Programme); Digital Twins of the Ocean - DITTO, GEOMAR (Programme); Digital innovation Hand-in-Hand with fisheries and ecosystems scientific monitoring, FAO (Action)

UN Sustainable Development Goals

Recommendation: Capacity building for students and early career professionals to understand the Agenda 2030, the SDGs and the international momentum of the oceans in a more holistic and integrated way considering the oceans as a socio-ecological system.

Relevant UN Decade: Early Career Ocean Professionals, Ocean Decade Informal Working Group for Early Career Ocean Professionals (Programme); AGU: Mentoring365: UN Decade of Ocean Science

Recommendation: Increase the capacity of developing countries to produce continued observations that are fit-for-purpose of their policy concerns but at the same time useful to inform at the global level.

Relevant UN Decade: Integrating Coastal Wetlands Data into Greenhouse Gas (GHG) Inventories for Developing Countries: A New International Blue Carbon Initiative, U.S. NOAA and Department of State (Contribution); Challenger 150 - A Decade to Study Deep-Sea Life, Deep Ocean Stewardship Initiative (DOSI) (Programme); Cultural Heritage Framework Programme, Ocean Decade Heritage Network (Programme);

Sustainability of Marine Ecosystems through global knowledge networks (SMARTNET), International Council for the Exploration of the Sea (ICES), The North Pacific Marine Science Organization (PICES) (Programme); Global Estuaries Monitoring (GEM) Programme, State Key Laboratory of Marine Pollution, City University of Hong Kong (Programme); Ocean Acidification Research for Sustainability, Global Ocean Acidification Observing Network (GOA-ON) (Programme); Ocean Voices, Nippon Foundation Ocean Nexus Center, EarthLab, University of Washington (Programme); Pacific solutions to save our ocean: an integrated ocean science programme towards a healthy Blue Pacific Continent to sustain future generations, South Pacific Community (SPC) (Programme); Ocean Observing Co-Design: evolving ocean observing for a sustainable future, GOOS (Action); Bertarelli Foundation Marine Science Programme, Bertarelli Foundation (Contribution)

Recommendation: Enforce national and international efforts to connect scientists and statistical offices to ensure that the best available data and information are reported to support the achievement of the SDG targets.

Relevant UN Decade: Digital Twins of the Ocean - DITTO, GEOMAR (Programme); Observing Together: Meeting Stakeholder Needs and Making Every Observation Count, GOOS (Action); The World Ocean Database Programme (WODP): Openly discoverable, accessible, adaptable, and comprehensive digital global profile oceanographic data of known quality, U.S. NOAA (Contribution)

Uncertainty Quantification

Recommendation: We should train ocean observers and modelers in statistical terminology and techniques for the purpose of uncertainty quantification.

Relevant UN Decade: NONE

Recommendation: Building on existing efforts, we should produce a series of peer-reviewed and open-access documents that define and recommend strategies and best practices for uncertainty quantification in ocean observing.

Relevant UN Decade: NONE

Recommendation: Research programs should require and fund routine uncertainty estimates on ocean observations and derived products, and should fund dedicated efforts to develop freely available resources (software and databases) for uncertainty quantification.

Relevant UN Decade: NONE