Contribution of the Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO) to the Secretary-General's Report on Oceans and the Law of the Sea pursuant to the topic of "Ocean Observing" being addressed by the twenty-second meeting of the Open-ended Informal Consultative Process on Oceans and the Law of the Sea

1. Executive Summary

A healthy and safe ocean is fundamental to our existence and way of life. It is fundamental to climate, weather, biodiversity, the livelihoods of billions of people, and is an increasingly significant component of many national economies. The Global Ocean Observing System, (GOOS), is leading the ocean community and creating partnerships to grow an integrated, responsive and sustained observing system. GOOS creates and supports the frameworks and infrastructure that coordinate ocean observing activities globally, including design, partnerships, evaluation, standards and data flow to key applications. We cannot manage what we cannot measure, observations are the underpinning of informed decisions about the future and the present state of the ocean.

Under GOOS, there are 12 global ocean observing networks, 12 observing networks focusing on the biological realm, 15 GOOS Regional Alliances, and 84 nations actively contributing to the system. Together these networks and systems deliver data to support users across climate, weather and hazard warnings, and ocean health. Ocean information from the GOOS observing networks and systems flows into supporting work across the UN System, it supports nations towards achieving the 17 Sustainable Development Goals, climate change adaptation under UNFCCC and IPCC, the Sendai Framework, WMO, the Convention on Biological Diversity under UNEP, and have the potential to play a critical role in the implementation of a future Internationally Legally Binding Instrument under UNCLOS for BBNJ.

While significant improvements have been made in the last decades in our ability to observe and understand the ocean, this falls well short of what will be required. The GOOS 2030 Strategy and the UN Ocean Decade provide the framework and the impetus to meet the combined challenges of climate change, biodiversity loss, expanding populations and coastal mega-cities, extreme weather events, and ocean and coastal resource management. We cannot create different systems to meet all of these challenges, we need to carefully invest in an integrated and responsive ocean observing system to serve multiple users. GOOS is the home of global ocean observing.

A number of key ocean observing challenges are laid out, with actions outlined as targets for meeting these challenges and as areas for coordinated investment. The broad-based need for ocean information in decision making will need to be matched by a more diverse support base to sustain observation infrastructures; a focus on support across UN Agencies and member states around these fundamentals would benefit all.

GOOS is led by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and co-sponsored by World Meteorological Organisation (WMO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC).

2. The Global Ocean Observing System

Meeting Global Needs

A healthy and safe ocean is fundamental to our existence and way of life. The ocean regulates Earth's climate and provides transport routes, food and essential space for recreation. More than half of the people in the world live near the coast, and countless communities rely on ocean resources for their economic, physical and social wellbeing.

The ocean is our common heritage and we have a global responsibility for its safe stewardship. It remains the least-known and least-visited part of our planet, and a generator of both wonder and ideas.

The ocean is changing. Climate change is shrinking ice cover and warming the ocean. It is provoking sea level rise, ocean acidification, deoxygenating large parts of the marine environment, and amplifying weather and climate extremes.

Economic losses associated with extreme weather and natural catastrophes are at record levels, and these are expected to increase with climate change. Extreme weather events, natural disasters, and the failure of climate change mitigation and adaptation, extreme weather, and biodiversity loss are seen as the three greatest risks for nations in the coming decade[1].

Teeming with abundant life, the ocean is an important source of food and livelihoods, with over three billion people in the world depending on it. Unfortunately, marine life and ocean health are declining. How rapidly this decline is happening and where it is the fastest are dangerous gaps in our understanding of global marine ecosystems. GOOS and its partners have recently identified significant knowledge gaps on the status of marine life[2].

Human pressure on the ocean is degrading habitats, increasing plastics and other pollutants, over-exploiting fish populations, and causing the death of coral reefs and wider declines in marine biodiversity. Without concerted action, these pressures will intensify in coming decades as the world's expanding population continues its march into coastal regions. At the same time, governments, policymakers, investors and communities – especially those in small island nations – are looking to the ocean for food security and economic opportunity.

Ocean information supports good policy and provides an evidence base for real-time decision-making, tracking the effectiveness of management actions, and guiding adaptive responses on the pathway to sustainable development. In addition to supporting sustainability, ocean knowledge and information have the power to generate profits and jobs

[1] World Economic Forum Global Risks Report 2022. Ranks global risk outlook, 1. Climate action failure, 2. Extreme Weather, 3. Biodiversity loss.

[2] GOOS and partners recent study published in *Frontiers in Marine Science* journal

in the marine economy. See the ocean information value chain - connecting observations to decisions - Figure 1.

Ocean observations are essential to enabling resilient and sustainable blue economies and allow us to better understand climate change and variability, and they improve our forecasting of climate, weather, ocean state, environmental hazards, and their impacts. Developing our ability to provide relevant information at global, regional, and coastal scales, is vital to addressing local needs and building resilience.

The Global Ocean Observing System in action

Examples from around the world of the impact ocean observations are having on policy, climate adaptation, conservation and management of marine life, and national economies.

- Evidence of ocean warming from the global array of Argo floats was part of the key evidence leading to the Paris Agreement, the legally binding international treaty on climate change adopted by the Parties at COP 21 in Paris in 2015.
- The UK Met Office is providing world leading long term hurricane forecasts through initialising its computer models with accurate ocean state observations. This quantification of hurricane risk at short to medium term is of great interest to the property and casualty insurance industry. Using these key ocean variables, from surface to deep ocean, enables the models to capture ocean circulation and improve prediction skill.
- Prediction of tropical cyclones is being improved in the United States and India through observations from multiple types of observing instruments, including drifters, gliders, Argo floats and moored buoys. These are providing observations in real-time along the projected tracks of tropical cyclones, observations that are assimilated into numerical weather prediction models. The impact on predictions has been seen in the USA and India, averting loss of life and supporting community preparedness.
- Whale numbers are falling, however reducing ship speeds has the potential to significantly reduce the number of whales that are killed through impact with shipping. Real-time data from autonomous buoys and gliders, together with smart sound analysis software, is now enabling real-time detection of whale species and opening the way for mandatory and voluntary shipping slow downs. Observing systems to inform shipping slow downs and the and the closure of some fishing areas, is being implemented in both Canada and the United States, and this technology is now also spreading further afield to Chile.
- Acoustic receivers around Australia's coast are now linked in a network that enables many different regional datasets to be combined. This gives resource managers information on the shifting and interstate migratory paths of high priority fish species (137 different species are tracked in total), and the relationship between different stocks; information that is invaluable for adapting fishing practice and conservation management to the changing ocean conditions.
- As the global aquaculture sector works to adapt to the increasing impacts of climate change, artificial Intelligence (AI) is supporting a new frontier in ocean observing. Global warming is shifting the distribution of organisms such as harmful algae and traditional observing technologies struggle to provide the volume of measurements required to track changing distributions of phytoplankton. In New Zealand, real-time

monitoring with automated underwater microscopes is providing aquaculture managers with the ability to respond quickly to harmful algal blooms.

- Across the Pacific Ocean, more than 10 million inhabitants in the Island States and territories are well-aware of the realities of life on the frontlines of climate change. In the face of challenges posed by sea-level rise, increasing extreme events, ocean warming and acidification, biodiversity loss and a variety of associated socio-economic impacts, these island communities are demonstrating adaptive capacity and resilience. Underpinning this resilience are the time-honoured traditional knowledge and practices that have enabled survival in these remote islands for millennia. However, the consequences of climate change have unprecedented impacts on ocean conditions, and strengthened resilience requires localized, reliable predictions and actionable information about ocean conditions. Pacific islands are recognising the importance of investing in oceanographic capacity, including in-situ observation systems. Four new wave buoys have been deployed in Fiji and New Caledonia in the last year, and other deployments are in the pipeline. To optimize the value of these new observations, the data they collect will be developed into decision-making products and tools for community users at the local level.

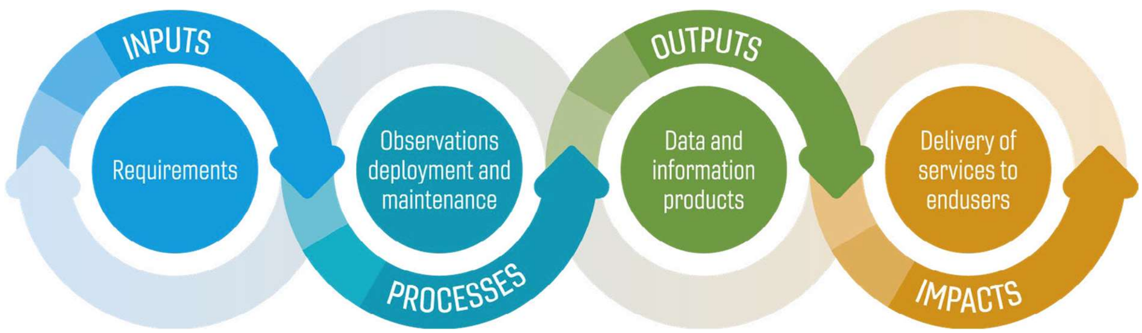

Figure 1: Observations generate value and impact for society through a 'value chain', from observations through assessments, forecasts or models, to services and applications, supported by data management, enabling many data sources to be combined, discovered and used. Feedback from users, modeling and assessment, and service providers about informational needs is a fundamental part of this approach. Supporting a 'value chain' approach ensures that information of value is delivered to end users and that a fit-for-purpose ocean observing system is evolved. Identifying key partnerships for delivery and adherence to FAIR[3] Data principles are vital to the function of this value chain.

Ocean information from the GOOS observing networks and systems flows into supporting work across the UN System, it supports nations towards achieving the 17 Sustainable Development Goals (not only 14, Life Below Water, but also at least 1, 2, 3, 7, 8, 9, 10, 11, 12 and 13 Climate Action), climate change resilience and adaptation under UNFCCC and IPCC, the Sendai Framework, particularly in tsunami detection, the WMO in weather, climate and hazard forecasting under its Earth System approach. In the biological space the observations feed into the Convention on Biological Diversity (CBD) under UNEP, as well as World Ocean Assessment and other regional ocean assessment processes, and have the potential to play a critical role in the implementation of a future Internationally Legally Binding

[3] FAIR Data Principles - data that is findable, accessible, interoperable, and reusable

Instrument (ILBI) under UNCLOS on conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction (BBNJ).

The fundamental role the ocean plays in our climate cannot be underestimated. Improving early warnings of floods, droughts, and severe storms – all predicted to increase in a warming world – will require expanded ocean observations. The sustainable development of the ocean economy, underpinned by ocean information, is an important future source of jobs and economic growth. In the future, an ocean economy, buoyed by growth in mariculture, renewable energy, sustainable resource development, climate adaptation and prediction will be a much larger component of our national economies.

GOOS as the global framework for ocean observation

The Global Ocean Observing System (GOOS) coordinates sustained ocean observing activities across the global ocean, to support the delivery of information to those taking decisions across climate adaptation and policy, regarding hazard warnings and weather, for marine resource management, and for marine transport and operations.

GOOS has three key delivery areas: climate, weather and ocean prediction, and ocean health. It is led by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and co-sponsored by World Meteorological Organisation (WMO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC).

GOOS Today

The GOOS community encompasses local, national and regional ocean observing systems and programmes, principal investigators, scientists and technicians undertaking sustained observations within national programs and global ocean observing networks, and the many individuals contributing to the work of GOOS. Through the work of its core team[4] GOOS leads the community in creating the frameworks and partnerships required to meet the needs of the diverse array of end users, across climate, weather and hazard forecasts, and ocean health.

The GOOS Observations Coordination Group (OCG) strengthens implementation of 12 global ocean observing networks. Together these networks deliver common data streams

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[4] There are seven elements to the GOOS core team:

- GOOS Steering Committee: a multinational body that provides direction to the GOOS core team in implementing its strategic objectives and building outside partnerships.
- Expert Panels: The Physics and Climate, Biochemistry, and Biology and Ecosystems Panels are vital for identifying user needs and evaluating the system.
- The Observations Coordination Group: the OCG strengthens GOOS implementation by coordinating the system through twelve global observing networks and OceanOPS.
- The Expert Team on Operational Ocean Forecast Systems: ETOOFS guides initiatives to improve capacity, quality and interoperability of ocean model forecast products.
- GOOS Regional Alliances: GRAs identify, enable and develop GOOS ocean monitoring and services to meet regional and national priorities.
- Projects: advancing innovation and expanding the observing system, services and product delivery by expanding into new areas and capabilities.
- The GOOS Office: The GOOS Office team works full time to enable the GOOS core to function and to enable connection across the observing enterprise.

from a range of the different ocean and above ocean observing platforms (Figures 2). These include established networks such as Argo, drifting and moored buoys (under DBCP), and sea-level gauges (under GLOSS), as well as ‘emerging’ networks such as OceanGliders, and the animal bourne sensors network (AniBOS), see Figure 2.

Eighty-six countries support these 12 global ocean observing networks, with some 8,900 in situ observing platforms in operation - see the Ocean Observing System Report Card 2021 - monitoring a broad range of Essential Ocean Variables (EOVs, see below). The OCG works across the global networks to support integrated system design, efficiency, and the timely delivery of high-quality ocean data; best practices, technological innovation, and the evolution of networks to meet future requirements are important parts of this work. All 12 of the global ocean observing networks under the OCG contribute data to climate applications and many in real-time for weather and hazard warnings - see table. GOOS is our eye on the ocean in the face of climate change and adaptation[5] (Figure 3).

The GOOS BioEco Panel supports the development of observing networks in the biological realm, it coordinates 13 BioEco networks, such as microbes, phytoplankton, fish, marine mammals, macroalgae and seagrass. These 13 networks monitor biological and ecosystem EOVs (see Figure 4), and play a critical role in addressing the information needs of 24 international conventions and multilateral agreements.

A technical coordination team at OceanOPS supports the implementation of GOOS through the integration and harmonization of metadata – basic information about data that makes it easier to find and use. This metadata management allows for accurate monitoring of ongoing global ocean observing activity across the 12 OCG networks, and helps to ensure that data and metadata can be delivered to stakeholders.

Fifteen GOOS Regional Alliances (GRAs), support and coordinate implementation at a regional level. with the mandate to connect “Global to Regional to National level”. GRAs coordinate across national systems to solve regional priorities, differing by need, resources and culture. These interact with each other to learn and share best practice in implementing observing systems.

GOOS has 3 Expert Panels for physics and climate, biogeochemistry, and biology and ecosystems, that synthesize across requirements and provide guidance on observing system design and Essential OceanVariables (EOVs). GOOS uses the Essential Ocean Variables (EOVs) concept to systematically identify the observations that are the most relevant, cost effective and technically feasible, to provide vital ocean information across a range of issues and ocean observing platforms (see figure 4). When EOVs are identified, the GOOS Expert Panels create and share a series of recommendations, which include what measurements are to be made, observing options and data management guidelines, see the EOV Specification Sheets at www.goosocean.org.

There are EOVs in areas of human impacts such as the emerging Marine Debris (marine plastic). Monitoring marine plastics will be an area that will require investment once GOOS and its partners have developed a global agreement for a Marine Debris EOV (expected

[5] Read more about the ocean observations and climate change in the GOOS Climate Brief**.**

later in 2022). We will need an Integrated Marine debris Observing System (IMDOS) to work to enhance observations from existing networks, coordinate data flow and to ensure delivery of products integrated with remote (satellite) observations, and for the development of new observing technology in this area.

The GOOS Expert Team on Operational Ocean Forecast Systems (ETOOFS) guides actions towards improving capacity, quality and interoperability of ocean model forecast products. ETOOFS connects observations, ocean models and users, as operational ocean monitoring and forecasting becomes increasingly important in supporting climate, maritime services, biodiversity and blue economy. Ocean forecasting systems and products are used for maritime ship routing, coastal harbor planning and management, search and rescue, oil spill response and management, and other coastal disaster risk reduction activities.

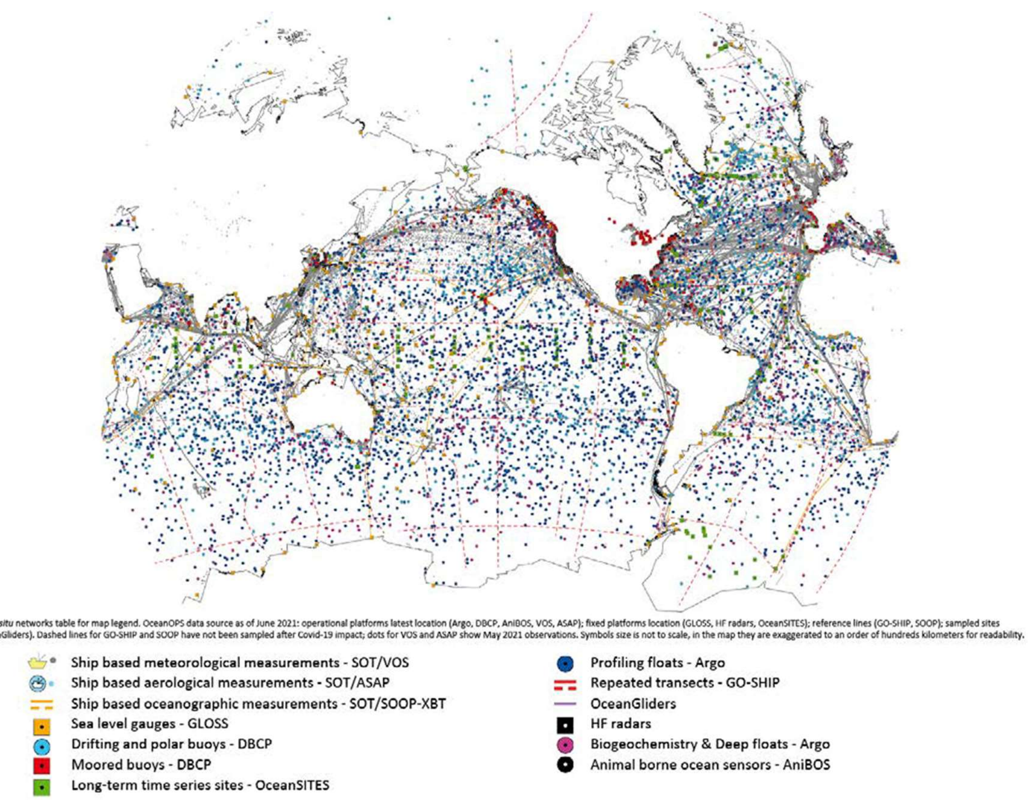

Figure 2: The 12 global ocean observing networks coordinated under GOOS Observation Coordination Group

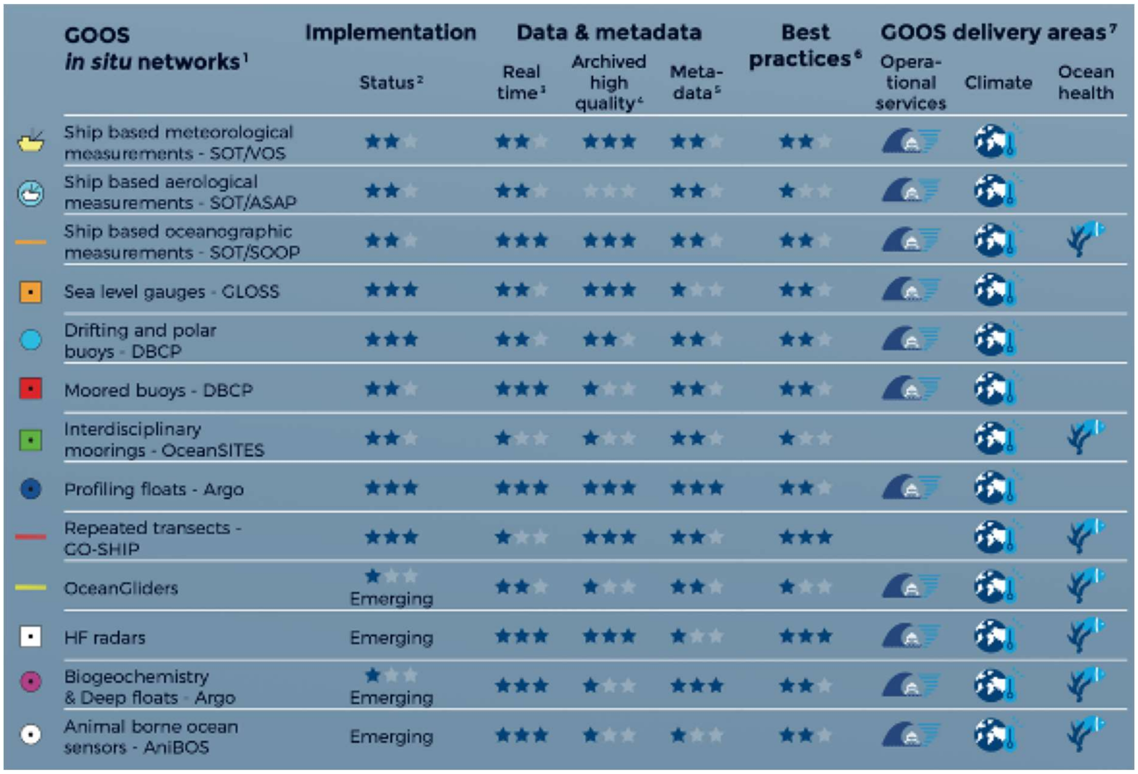

Figure 3: (1) see Network Specification Sheets www.goosocean.org. (2) Status vs. target, targets external when available, e.g. GCOS climate targets. (3) Real time data available on WMO GTS or other global internet based data node, (4) Archive high quality data available (self assessed), (5) Minimum metadata required by OceanOPS, (6) Best practices available, community reviewed and easily accessible across all EOVs measured and all stages of the data lifecycle (7) GOOS delivery areas.

- *Profiling floats: Now an array of 4000 autonomous floats profiling the ocean to 2 000 m, sampling temperature and salinity for climate, seasonal forecasts and ocean heat content assessment / * Deep and Biogeochemical (BGC) Argo missions are emerging to extend the capacity of floats in depth (to 6000 m) and BGC.*
- *Drifting and polar buoys: An array of 1500 drifting buoys that observe surface atmospheric pressure, temperature and currents over the global ocean and are indispensable for global to regional weather forecasts. Seal Level Pressure observations are essential in numerical weather prediction delivered by meteorological agencies around the world.*
- *Moored buoys: Network of about 400 moored buoys that observe multiple atmospheric and oceanographic parameters, mainly in coastal and tropical areas, for regional weather forecast and ocean operations.*
- *Ship based meteorological measurements: A large fleet of voluntary observing ships that measure marine meteorological parameters for marine weather forecasting and safety at sea, the records go back 150 years and are also used in climate research.*
- *Ship based oceanographic measurements: The Ship of Opportunity Program focuses on underway measurements from voluntary observing ships, including XBT temperature profiles to 1000 m depth, sea surface temperature, salinity and pCO2, on repeated transects or reference lines.*
- *Ship based aerological measurements: The Automated Shipboard Aerological Programme collects upper-air profile data for operational applications and global climate studies, using voluntary ships. Sea level gauges: A network of 290 sea level observing stations supporting high-quality long-term time series of sea level for climate research, marine operational use, and hazard warnings.*
- *Animal borne ocean sensors: A network of instruments deployed on marine animals to provide ocean profiles of temperature and salinity, as well as behavioral data for sustainable management.*
- *Repeated transects Research vessels providing high quality data collected to the full depth and width of the ocean, on reference lines repeated every decade. They are the benchmark for other dataset calibration, climate studies such as carbon cycle studies and marine biogeochemistry and fuel many scientific applications.*

- *OceanSITES: a network of more than 300 long-term, open ocean/deep sea mooring that act as climate reference stations measuring dozens of ocean parameters across, physical, biogeochemical and biological realms. They monitor variables from the ocean surface to the full depth of the ocean.*
- *High Frequency Radar (HF Radar): Network of 150 operational stations measuring high frequency coastal surface currents for assimilation into prediction systems and coastal operational services, such as coastguard and ports.*
- *OceanGliders: Network of some 200 autonomous underwater vehicles profiling the ocean to 1,000 m on regular missions, ofen transecting key ocean features such as ocean boundary systems. Ocean gliders collect a range of EOvs from the coast to open ocean that are used for storm forecasting, global boundary currents, ocean health and ecosystems.*

Physics	Biogeochemistry	Biology and Ecosystems*
Sea state Ocean surface stress Sea ice Sea surface height Sea surface temperature Subsurface temperature Surface currents Subsurface currents Sea surface salinity Subsurface salinity Ocean surface heat flux	Oxygen Nutrients Inorganic carbon Transient tracers Particulate matter Nitrous oxide Stable carbon isotopes Dissolved organic carbon	Phytoplankton Zooplankton Fish Marine turtles Birds Mammals Hard coral Seagrass Macroalgal Mangrove Microbe (*emerging) Invertebrate (*emerging)
Cross-disciplinary		
•Ocean colour	•Ocean sound	•Marine debris (*emerging)

Figure 4: The GOOS Essential Ocean Variables (EOVs). EOVs are identified under the 3 GOOS Expert Panels, based on the following criteria :

- *Relevance: The variable is effective in addressing the overall GOOS Themes – Climate, Operational Ocean Services, and Ocean Health.*
- *Feasibility: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.*
- *Cost effectiveness: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.*

*Many EOVs are also Essential Climate Variables (ECVs), as defined by the Global Climate Observing System (GCOS) and a number of GOOS OCG networks measure both marine atmospheric and oceanic EOVs and ECVs. * Note: BioEco EOVs measure biomass and diversity, abundance and distribution, cover and composition, or cover and composition, as appropriate to the EOV.*

Looking forward

While we have made significant improvements in our ability to observe and understand the ocean over the past three decades, our current efforts fall well short of what will be required.

The vision of the GOOS 2030 Strategy[6] is for ***a truly integrated global ocean observing system that delivers the essential information needed for our sustainable***

[6] www.goosocean.org/2030Strategy

development, safety, wellbeing and prosperity. Implementing the Strategy will demand a step change in the level and effectiveness of partnerships across the scientific and end user communities. It will also need a deep commitment to building human capacity and a more multi-disciplinary observing system capability. Meeting the innovation challenges associated with building a fully integrated global ocean observing system, reliance on intergovernmental and government funding – even from the richest of nations – will be insufficient. Backing and expertise from the private sector, including the inspiring contributions of philanthropists, are needed.

The UN Decade of Ocean Science for Sustainable Development (the Ocean Decade) has the potential to play a major role in fulfilling the transformative ambitions of the GOOS 2030 Strategy. Proclaimed in 2017 by the United Nations General Assembly, the Ocean Decade is structured around ten Ocean Decade Challenges and aims to convene diverse actors in collective efforts to design, implement, resource and use transformative ocean science for sustainable development. One of the Ocean Decade Challenges specifically identifies the need to ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely and actionable data and information to all users. Sustained and fit for purpose ocean observations will also be key to the fulfilment of the majority of the remaining challenges, including for example those related to the ocean climate nexus, ecosystem management, marine pollution and resilience. The Ocean Decade has already increased the level of partnership required and has been successful in harnessing increased levels of interest in these global challenges from beyond the scientific community, including industry and the philanthropic sector. Ocean observations and predictions are the foundation of much of the exciting work the Ocean Decade will carry out. GOOS will provide vital infrastructure to integrate ocean observing and forecasting actions under the Ocean Decade.

3. Challenges

There are a number of significant challenges to achieving the vision for 2030; these are both observational - in terms of coverage - and structural - in the coordination, partnerships and infrastructure needed to deliver high quality, sustained and fit-for-purpose observations to those that need them.

Below are highlighted some areas for current high impact action. These are highlights from GOOS's core work towards deep and comprehensive change. The GOOS Implementation Plan provides a comprehensive view of initiatives across the 11 Strategic Objectives.

Observational challenges to meet societal needs:
GOOS recommends a significant uptick in support to address these key observing gaps:

- **Global Carbon Ocean Observing System:** The ocean is the largest reservoir of carbon in the Earthsystem, after rocks and sediments. It stores 100x heat and 50x carbon dioxide of the atmosphere. Currently, the ocean is taking up about 25% of the CO_2 emitted by the burning of fossil fuels - that is the amount of CO_2 that would be emitted if one billion people decided to board planes and take a circuit around the Earth. The global ambitions for a net-zero carbon emissions by 2050 are based on the assumption that the ocean will continue absorbing CO_2 at the current rates, however as our climate changes it is far from certain if this will continue, this represents the most significant unknown in climate change policy. We need to know how the ocean processes that store carbon from the atmosphere year on year will change and any investment in large-scale carbon dioxide removal (CDR) urgently needs an ocean baseline[7].

- **Extreme weather:** The likelihood and severity of extreme weather events is increasing as the earth's climate changes. Already climate attributable fires, droughts, floods, hurricanes and heatwaves are impacting society and economies. The number of such disasters has multiplied by five-fold in the last 50 years. We need to enhance our existing global ocean observing networks and identify the combination of technologies to deploy ahead of extreme weather to fuel more accurate forecbioloasts from a responsive system.

- **Coast:** The coast is where most human society feels its interaction with the ocean, the livelihoods of millions of people directly depend on sustainable activities in the coastal zone, but climate change is causing species migration, marine heatwaves, and increased flooding - to name a few of the impacts. At the same time as an increase in the coastal populations and the emergence of coastal megacities adding human pressures. Going into the coast increases the complexity of observations, habitats and users, this needs integrated observing and information delivery solutions.

- **Marine Biodiversity:** In its many forms marine biodiversity provides a wide range of benefits to coastal and global communities. Vivid examples are coral reefs, seagrass and mangroves, which act as nursery grounds to the fish that local families rely on, and also reduce the impact of storms on coastal communities. Developing countries already suffer a disproportionate impact of the declines in the extent and quality of their marine resources. The opportunities for action through sustainable use and conservation are growing, but not all of these interventions will have positive outcomes if data are missing. Marine biodiversity observations have to be increased to support appropriate decisions and de-risk investment in interventions. The coverage of biological EOVs is incomplete and uneven, active long term observing programs in the global survey cover only 7% of the entire ocean surface[8], and some parts of the South American, Eastern European, Asian, Oceania and African coasts are especially underrepresented. The lack of information is often greatest in areas of high biodiversity with intense human pressures. The issue of declining marine biodiversity goes beyond one nation; the ocean is an interconnected system, to detect changes and understand their consequences we need an equally interconnected observing system, which is the prime goal of GOOS.

- **Deep Ocean Observing:** Less than 1 percent of the deep ocean seafloor has been sampled or monitored and most species remain undescribed, hence we remain

[7] Earth Information Day recording of the GOOS Co-Chair Anya Waite speaking about the need for carbon observations

[8] Through a global study GOOS and its partners recently identified the gaps in our observing on the status of marine life - Establishing the Foundation for the Global Observing System for Marine Life - https://doi.org/10.3389/fmars.2021.737416

largely ignorant of how deep-ocean ecosystems change in space and time, both naturally and in response to human activities. Understanding how much heat the globe is taking up and where (how deep in the ocean) is vital to predicting how much, and how fast, the earth will warm with increased greenhouse gas concentrations. Improved technologies and strategies are required in order to adequately manage this vast area. A global initiative is needed to address the important challenge of sustainably managing our deep ocean.

Structural challenges for delivering effectively and efficiently
GOOS also needs investment in the coordination and infrastructure to deliver the global impact required from any investment in ocean observing.

Support is needed now in these critical areas:

- **Design to deliver:** There are a number of existing and potential users of ocean observations that have no connection to GOOS, and therefore our ability to ensure delivery of essential information is impaired. To be responsive to more users and to evolve an efficient and fit-for-purpose system design, GOOS needs to improve the interfaces from ocean observing networks and data systems, to key intermediate users across climate, weather, hazard warning and marine operational services, and marine ecosystem health. GOOS needs to deepen the existing partnerships with the global climate and marine services community, and strengthen engagement with new partners, to develop strong connections across the ocean observation value chain.

- **Ocean Observing in the Ocean Decade:** There are 161 endorsed Ocean Decade Actions, a large number of which are directly contributing to meeting the Ocean Decade Challenge related to observations. Many of these actions have roots in GOOS, including the Observing Air-Sea Interactions Strategy (OASIS), Ocean Practices for the Decade, Marine Life 2030, the Ocean Biomolecular Observing Network (OBON), OneArgo, GO-SHIP Evolve, AniBOS, and Odyssey. GOOS is also leading three transformative Ocean Decade Programmes that address major gaps in the system and will deliver priority elements of the GOOS 2030 Strategy; Ocean Observing Co-Design, CoastPredict and Observing Together, which together focus on capacity development, revolutionizing observing and forecasting into the coast, and at the same time evolving system design to be increasingly user and application driven, with tools to evaluate ROI. Given its central role in global observations and the Ocean Decade, GOOS will play a strong coordination role throughout the Ocean Decade. This coordination role will be essential to the success of the Ocean Decade, but requires additional support.

- **Capacity:** There are profound gaps in our ocean observing coverage, these cannot be addressed solely by the States that are already contributing. We need to increase the number of countries actively participating in the global ocean observing, particularly developing the capacity of least developed countries and small island developing states that have enormous ocean area to GDP ratios. This will take action in several areas including; how we create the environment for support through action on EEZs and through mechanisms such as the WMO Data Policy and Global Basic Observing System (GBON), technological innovation in low cost observing solutions, and partnership with users in end-to-end initiatives that consider capacity in ocean observations, data systems, and forecasting to support needs in sustainable development, climate adaptation, marine spatial planning, and regional seas conventions.

- **Observing in EEZs:** In order to deliver the ocean information that society needs to face the challenges of climate change, safety at sea and coast, and sustaining healthy oceans, there is a need for an integrated and global ocean observing system, including observations in areas under national jurisdiction. Areas under national jurisdiction cover over one-third of the ocean and are essential for an effective global system. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) provides the legal basis for maritime areas under national jurisdiction with different rights and obligations for States and international organizations. Although UNCLOS provides the international legal framework for activities in the ocean, implementation raises challenges and requires States to facilitate Marine Scientific Research (MSR), including through providing clarity on how they regulate ocean observations and MSR activity in accordance with UNCLOS. The Advisory Board of Experts on the Law of the Sea (ABE-LOS) of the IOC worked on these issues between 2003 and 2009 and laid the foundation for the Argo notification scheme. This provides a practical solution through notifying States when Argo floats drift into waters under their national jurisdiction. However, many other observing implementers, including Argo in terms of deployments, still face important challenges when seeking consent to undertake ocean observations in waters under national jurisdiction. Thus in practice the implementation of UNCLOS by coastal States can impede the work of GOOS. A range of issues were raised at an Experts Workshop[9] in February 2020 and solutions discussed. The Global Ocean Observing System requires support through high level action by partner intergovernmental bodies in ocean issues, including IOC/UNESCO, WMO, DOALOS, and the United Nations General Assembly which has the competence to review developments in ocean and law of the sea matters.

- **Biological data infrastructure:** infrastructure and FAIR data practices are less well developed in the BioEco realm, despite the need for this data being as great as in the physical or biogeochemical realms[10]. This is in part linked to the more fragmented nature of biological observations. The BioEco data infrastructure needs to be addressed to support the delivery of data for local and global applications.

4. Opportunities to expand and strengthen the global ocean observing system

The following are ocean observing system initiatives designed to address the challenges outlined above, many challenges need more than action and many initiatives have impact across multiple challenges. The actions are from across GOOS, many are with partners, and

[9] Experts Workshop on Ocean Observations in Areas under National Jurisdiction
[10] OECD Science and Technology Working Paper: Value chains in public marine data: A UK Case Study

many are endorsed as transformational actions under the Ocean Decade. The final table provides a summary of the challenges and major initiatives that support change to aid targeting support across actions and specific challenges.

- **Ocean Observing Co-Design:** An endorsed GOOS Ocean Decade Programme which will develop a more user focused co-design process to evolve a truly fit for purpose, integrated, and responsive ocean observing system. Ocean Observing Co-Design will work with observing and forecasting experts, and key user stakeholders, to build a better design process, as well as infrastructure and tools, to allow sponsors to ask key questions about cost and benefit and receive clear answers. This will enable more effective decision-making on future observing system investment, including what gaps need to be addressed and which new technologies should be used. Co-Design will include the large range of ocean observing efforts already in place working together more closely, as well as actively involving the modeling, forecast, and services communities. The programme will use the concept of user area 'exemplars' to develop co-design around specific use areas such as extreme weather, carbon budget and marine heatwaves.

- **Observing Together:** An endorsed GOOS Ocean Decade Programme that will transform ocean data access and availability by connecting ocean observers and the communities they serve through enhanced support to both new and existing community-scale projects. By the end of the Ocean Decade, a substantial number of projects will exist that empower stakeholder communities to share more valuable observations and transform these so they are easily available and create real value. Observing Together will include learning and sharing mechanisms that enable successful local initiatives to be replicated worldwide. It aims to meet stakeholder needs and make every observation count.

- **Decade Coordination Office for Ocean Observing:** Support is needed to ensure investment in ocean observing actions under the Ocean Decade is efficiently spent and leads to lasting change and impact. Coordination is needed to ensure (i) coherency across Decade Actions focusing on observations; (ii) integration and exchange with Decade Actions and initiatives focusing on other themes that rely on information coming from observations; and (iii) integration of Decade actions into existing frameworks such as networks, data infrastructure, and communities of practice, (iv) integration across the Ocean Decade and GOOS, so that we build a sustained integrated observing infrastructure, (v) analysis and coordination to understand observing needs, gaps, and barriers to data flow. There is a risk that without smart coordination, a significant portion of each investment in observing under the Ocean Decade will go to waste and that the Decade will not lift the infrastructure to support the societal solutions developed. Support is needed for a GOOS Decade Coordination Office for Ocean Observing.

- **Biodiversity:** Addressing the gaps identified will require sustaining and expanding existing long-term observing programs, encouraging better communication and coordination between them, as well as connecting local programs into global systems. New capacity is also needed to fill priority gaps in underrepresented areas and developing countries, which are experiencing intense human pressure on their biological resources. Supporting the work of the **BioEco Panel** in developing capacity in less mature bioeco networks is important. **Marine Life 2030**, a Decade endorsed programme aims to unite existing and frontier technologies and partners towards a Global Integrated Marine Biodiversity Information Management and Forecasting System for Sustainable Development and Conservation, is also a key area for support. Working closely with the GOOS BioEco Panel it will develop a network of networks to link observing, management and policy stakeholders to build and exchange capacity for advancing society's grand challenges of managing activities for a healthy and resilient ocean and the vibrant and healthy society. **The Ocean Biogeographic Information System[11] (OBIS)**, established by the Census of Marine Life program and adopted by the IOC of UNESCO, is evolving as a strategic alliance of organizations sharing a vision to make marine biogeographic data, from all over the world, freely available via the internet and interoperable ocean data systems, such that any organization, consortium, project or individual may contribute to OBIS. GOOS identifies OBIS as vital evolving to the marine data infrastructure for biodiversity; it is closely linked to the work of the GOOS BioEco Panel, EOVs and BioEco networks. The endorsed Ocean Decade projects **GO-SHIP Evolve**, **AniBOS** and **Ocean Biomolecular Observing Network (OBON)** will extend biological observations from the existing networks and support an emerging biomolecular network.

- **CoastPredict:** An endorsed GOOS Ocean Decade Programme in partnership with the modeling community, which will revolutionise Global Coastal Ocean observing and forecasting. Co-designing the infrastructure needed, and offering open and free access to coastal information. CoastPredict will result in an integrated coastal and open ocean observing and modeling system and with improved, multidisciplinary, and extended range predictive capability for the coastal zone. By the end of the Ocean Decade, observations and modeling will be integrated in the coastal and open ocean.

- **Ocean Carbon Observatory:** Linking ocean carbon observation to effective climate targets. There are major potential changes in how carbon moves through the ocean system and we are not observing them at the resolution we need to inform our carbon targets. Several of the global ocean observing networks under GOOS Observations Coordination Group (OCG) observe carbon, but it is not enough - we need a more comprehensive carbon observing system. A first step along the way would be the development of an Ocean Carbon Observatory, designed to address fundamental questions about its current and future ability to do this, initially targeting the North Atlantic (30% carbon uptake) and the Southern Ocean.

- **Deep Ocean Observing Strategy:** A GOOS Project and endorsed Ocean Decade Programme, the Deep Ocean Observing Strategy (DOOS) is working to form a network of deep-ocean observing, mapping, exploration, and modeling initiatives, to observe and understand changes to deep ocean habitats and services. DOOS aims to provide the information needed to address critical scientific and management questions related to the climate, biodiversity and sustainability of the deep ocean.

[11] OBIS database: http://www.iobis.org

Enhancing existing ocean observing infrastructure through the Ocean Decade projects **OneArgo** and **GO-SHIP Evolve** will extend deep observations.

- **Ocean Indicators:** The ocean is a complex and continuously evolving system of interwoven physical, biogeochemical and biological processes; in addition what happens in the atmosphere impacts the ocean and vice versa, and what happens on land in society increasingly impacts the ocean. The ocean is an integral part of our earth support system, and our approach to future management of the ocean should take an equally integrative view. Ocean indicators will become essential building blocks for GOOS in providing the data and information needed for holistic science based assessment and stewardship of the Ocean. They are key elements that link the three pillars of sustainable development – Environment, Society, Economy – and will play a central role in bridging the gap between raw ocean data and the information required for sustainable management. They will also be key for regular, comprehensive, and consistent reporting on the state, variability and change of the ocean. One key target for communicating these indicators will be the **State of the Ocean Report (STOR)**, which is now under development at the IOC. Work is underway in GOOS toward developing ocean indicators, with support from the G7 Future Seas and Oceans Initiative, initially to identify the framework for such indicators. This work will need partnership across policy, ocean planning and management, modeling and science. GOOS anticipate that within the next 3-5 years experts across the many areas of government that touch the ocean, for example environment, coastal planning, blue commerce, and fisheries, should increasingly have the informational support they need, to ask the right questions and take the right decisions.

- **'Citizen' Science:** Equipping and coordinating professional but non-science vessels with instruments for ocean observing is a cost effective way to increase coverage. GOOS already has networks based on ships of opportunity (Ships of Opportunity Team - SOT). There is a vast network of untapped and willing ocean professionals that go to the far reaches of the ocean, including racing yachts, fishing, diving, cruise and commercial vessels. Shipping giant Maersk and the Ocean Volvo Race are already leading the way in supporting ocean observations from their vessels, however we need investment to coordinate and technogize this low cost global ocean observing potential. Ocean Decade endorsed projects **Odyssey,** lead by OceanOPS, and **Sailing4Science** are potential vehicles for this, targeting capacity development, cost effectively increasing the number of observations, and societal involvement in observing.

- **Cross-UN action on EEZs**: The Ocean Observations in Areas under National Jurisdiction Workshop Workshop Report[12] noted that coordinated action by IOC/UNESCO, WMO, DOALOS, and the United Nations General Assembly should be considered. IOC will address the recommendation of the Report at the IOC Executive Council in June 2022. WMO, DOALOS and the United Nations General Assembly are encouraged to consider the recommendations; there are roles to play in developing an expression of best practice for national implementation of clearance

[12] Ocean Observations in Areas under National Jurisdiction Workshop Report available here

procedures for the taking of sustained ocean observations in EEZs; and in raising awareness of the issues and the value gained from ocean observations, nationally and globally, especially in the context of the aims of the Ocean Decade. There is a role for WMO in considering how resolutions could be supportive in highlighting the need for sustained ocean observations from EEZs, and for DOALOS in assessing appetite from Member States to develop an update to the Guide to the Implementation of the Relevant Provisions of UNCLOS.

- **WMO Data Policy and GBON:** The new WMO Data Policy is a significant step in supporting the free exchange of ocean information. For the first time, ocean data and the GOOS Essential Ocean Variables are called out in this WMO Unified Policy. The new policy also has the potential to influence national policies, thereby opening up inter-agency sharing and coordination of ocean data at national levels.The ocean data aspects of the policy were developed in collaboration with the GOOS community, and specify that all physical GOOS Essential Ocean Variable (EOVs) and GCOS Essential Climate Variables (ECV's) data collected as part of GOOS are classed as core data that shall be exchanged on a free and unrestricted basis, while the exchange of all other observed biogeochemical and biological/ecosystems GOOS EOVs and GCOS ECVs is recommended (WMO Unified Data Policy Resolution can be found here). WMO Members have asked that ocean observations be considered a part of the WMO Global Basic Observing Network (GBON), and GOOS considers observations from mature networks ready for this commitment. This would have the potential to support capacity development in nations with less observing infrastructure through the Systematic Observations Financing Facility (SOFF) and other mechanisms. This is an area where WMO could work with GOOS to support the development of ocean observing capacity.

Highlighted ocean observing challenges and key initiatives to meet them

Challenges	Key Initiatives	O/S
Global Carbon Ocean Observing	Ocean Carbon Observatory, Ocean Observing Co-Design	O/S
Extreme weather	Ocean Observing Co-Design, Citizen Science, OASIS	O/S
Coast	CoastPredict, Cross-UN action on EEZs	O/S
Marine biodiversity and data infrastructure	GOOS BioEco Panel, Marine Life 2030, OBIS, GO-SHIP Evolve, AniBOS, Ocean Biomolecular Observing Network (OBON)	O/S
Deep Ocean Observing	DOOS, OneArgo, GO-SHIP Evolve	O
Design to Deliver	Ocean Observing Co-Design, Ocean Indicators, CoastPredict, Observing Together, State of the Ocean Report (STOR)	S
Ocean Observing in the Ocean Decade	Decade Coordination Office for Ocean Observations	S

Observing in EEZs	Cross-UN action on EEZs, WMO Data Policy & GBON	S
Capacity	Observing Together, WMO Data Policy & GBON, Decade Coordination Office for Ocean Observations	O/S

Figure 5: Summary of the challenges and the major initiatives that support change, many initiatives support multiple challenges. O/S columns note the challenge is observational (orange) or structural (blue), however the solutions are most often a combination of the two O/S.

The broad-based need for ocean information in decision making should be matched by a more diverse support base, including from industry, philanthropy, environment, energy, shipping, fishing and aquaculture, sustainable development, and climate sectors. This support can take different modalities, it can be through direct provision of funds via IOC, WMO and the Ocean Decade, through national investment in infrastructure or supporting initiatives that are part of the key solutions, or through the in-kind provision of personnel to support coordination, management and development. Investment in these initiatives is investment in the future, and as many of these projects are at the leading edge of ocean science and support national innovation.

Our ocean, seas and coastal regions are critical to life on Earth, and a rapidly expanding 'blue economy', estimated to be worth $2 trillion per year, according to most estimates. The cumulative impacts of climate change, development, pollution, and overfishing are placing considerable stress on our marine environment. We now know that the trajectory of change and damage threatens the future of our planet and all those that live on it. Support across these initiatives would fundamentally shift the dial for ocean management, laying foundations for an operational ocean observing system in the service of society and science, and securing information flow for future decision making.