The Ocean Decade

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Vision 2030 White Paper

Challenge 7

Expand the Global Ocean Observing Systems

Version 1.0 - April 2024

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Intergovernmental Oceanographic Commission

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VISION 2030 WHITE PAPER

Version 1.0 – April 2024

CHALLENGE 7: SUSTAINABLY EXPAND THE GLOBAL OCEAN OBSERVING SYSTEM

Ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely and actionable data and information to all users.

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Acknowledgements

To be included in the final version

Acronyms

AI/ML	Artificial Intelligence/Machine Learning
CDR	Carbon Dioxide Removal
ECV	Essential Climate Variables
EOV	Essential Ocean Variables
FAIR	Findable, Accessible, Interoperable, and Reusable
FOO	Framework for Ocean Observing
G3W	greenhouse gas monitoring system (or Global Greenhouse Gas Watch)
GCOS	Global Climate Observing System
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
SDG	Sustainable Development Goal
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

1. Executive summary

1.1. Introduction and Scope of the White Papers

This draft White Paper has been prepared as part of the Vision 2030 process being undertaken in the framework of the UN Decade of Ocean Science for Sustainable Development. The Vision 2030 process aims to achieve a common and tangible measure of success for each of the ten Ocean Decade Challenges by 2030. From a starting point of existing initiatives underway in the Ocean Decade and beyond, and through a lens of priority user needs, the process determines priority datasets, critical gaps in science and knowledge, and needs in capacity development, infrastructure and technology required for each Challenge to ensure that it can be fulfilled by the end of the Ocean Decade in 2030.

The results of the process will contribute to the scoping of future Decade Actions, identification of resource mobilization priorities, and ensuring the ongoing relevance of the Challenges over time. The process identifies achievable recommendations that can be implemented in the context of the Decade, or more broadly before 2030 to achieve the identified strategic ambition and indicators that will be used to measure progress.

This draft White Paper is one of a series of ten White Papers all of which have been authored by an expert Working Group. Accompanied by a synthesis report authored by the Decade Coordination Unit, it will be discussed at the 2024 Ocean Decade Conference before being finalized and published.

1.2. Strategic Ambition of Ocean Decade Challenge No. 7

By 2030, envisioned success for Ocean Decade Challenge No. 7 is to have a clear roadmap to achieving a sustainable, co-designed, fit-for purpose, multidisciplinary, and geographically expanded global ocean observing system that delivers accessible data to all nations and users. Transforming ocean data into useful information will require integration across disciplines, across national observing systems, and across stakeholders, as well as the implementation of innovative and diversified alternatives to current technological, cultural, capacity building, and economic models, incentivising the private and philanthropic sectors.

A successful expanded ocean observing system will be achieved by strengthening and expanding the existing array of in situ and remote observing platforms and developing new or enhanced automated technologies, sensors and platforms to fulfill critical science and knowledge gaps. Some of these knowledge gaps include remote areas like the high seas and the Southern Ocean, hard-to-access areas like the deep ocean and polar oceans, and coastal areas in the Global South especially those areas experiencing rapid change, making sure that the capabilities of the observing networks provide spatial and temporal resolutions that are fit for purpose. Coordinating and democratizing the generation, access, processing, and use of ocean data, including developing AI integrated models and machine learning tools to extract more user-ready information from existing datasets, prioritized by their societal relevance and aligning with Essential Ocean Variables (EOVs) will be critical. A major success will be to have all data made Findable, Accessible, Interoperable and Reusable (FAIR).

Based on the above strategic ambition it is also suggested that the formulation of the Ocean Decade Challenge could be modified as follows: Sustainably expanding the global ocean observing system.

1.3. Key Recommendations to Achieve the Strategic Ambition

The following four recommendations have been identified to ensure that the strategic ambition is fulfilled, and success achieved for Ocean Decade Challenge No. 7.

1. Upgrade and expand ocean observing capacity in poorly-observed ocean basins: polar regions, the Global South, island-nations, and priority coastal systems. Thematic priorities for ocean

observing are weather (including events), hazards, ocean health and marine biodiversity and resources. Training and capacity development will be critical at all levels of the stream, from data collection to data analysis and modeling.

2. Increase national, regional and global coordination, focusing on co-design and partnerships. Improved coordination that uses the GOOS framework to ensure standards, best practices for an expanded global ocean observing system.
3. Develop and expand the use of autonomous technology, sensors and platforms. Ocean observing needs easy to use, reliable, robust and affordable technology. Technology and innovation underpin the democratization of generation, access and use of ocean observations.
4. Establish new and sustained financing mechanisms for global ocean observing, including resourcing for SIDS, LDCs. Use economic models for ocean investment to diversify and accelerate investment in ocean observing and infrastructure from new actors.

1.4. Key Milestones and Indicators for the Strategic Ambition

The key milestones and indicators that will be used to measure advance of the strategic ambition include:

By 2030:

- Having identified the key gaps areas requiring observations and identified the key partnerships, processes, and resources needed to carry them out.
- Having developed the governance structure for the international coordination of the observing system, strengthening the GOOS Management Team (including OceanOPS), unifying coordination components and data nodes.
- Having established a new set of ocean indicators, building on the Essential Ocean Variables, that are co-designed with stakeholders.
- Having identified and initiated the partnerships needed for the development and deployment of innovative observing technologies (e.g. autonomous technology, sensors and platforms) that are easy to use, affordable, reliable and robust.
- Having identified the case by case (e.g. national/regional) stakeholders and initiated the development of a fit-for-purpose business case and economic model that will provide the resources and capacity needed to empower countries and people to participate in the implementation of ocean observations for the global system, transitioning away from solely proprietary approaches and incentivising the private and philanthropic sectors in affordable, open access, ocean technologies

2. Introduction to Challenge 7

Challenge 7 is the foundation on which other Decade challenges depend, rendering it a highly cross-cutting and fundamental Challenge underpinning the broader Decade vision. Ocean observations play a vital role by supplying essential data for comprehending and tackling diverse issues related to the ocean such as early warning of hazards like tsunamis, storm surges and extreme waves, and for weather forecasting, critical for human safety and all marine operations. Ocean observations are pivotal in supporting and facilitating progress across all facets of the UN Ocean Decade through creating baselines and understanding the state and trends in ocean conditions. They contribute to a value chain that leads to informed decision-making, the adoption of sustainable practices, and the development of resilience for both the oceans and coastal communities.

The Global Ocean Observing System (GOOS) is a cornerstone of knowledge, enabling sustainable management of aquatic resources, underpinning the blue economy, and ensuring we keep the pulse of ocean health. Ocean observations provide critical information for climate change mitigation and adaptation, ocean ecosystem health and pollution severity/extent, forecasting and responding to disasters, conserving marine biodiversity and habitats, and managing aquaculture and fisheries sustainability (Rayner et al., 2019).

Challenge 7 leverages the existing GOOS. To successfully position the global community in a way that it can advance and expand multidimensionally the GOOS beyond 2030, it must leverage what has been accomplished to date.

2.1. Background - The Global Ocean Observing System

Sustained observations of ocean variables began with the Western Channel Observatory in the English Channel in 1903 and since then, a diversity of programs continued to be established throughout the 20th century (Benway et al., 2019). The GOOS was established in 1991 by the Member States of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The World Meteorological Organization (WMO), UN Environment Program (UNEP), and the International Science Council (ISC) later joined as sponsors. GOOS is the global hub for ocean observing expertise, management, planning and strategy focused on climate, weather and hazard warnings, and ocean health. The GOOS 2030 Strategy (IOC-UNESCO, 2019) aims to (1) Deepen engagement and partnership from observations to end users to advance the use and impact of the observations and demonstrate their benefits, (2) Deliver an integrated, 'fit-for-purpose' observing system built on the systems approach outlined in the Framework for Ocean Observing (FOO, Tanhua et al., 2019), and (3) Building for the future through innovation, capacity development, and evolving good governance.

GOOS contributes and coordinates ocean observing activities with the Global Climate Observing System (GCOS) of the WMO, General Bathymetric Chart of the Oceans (GEBCO), the IOC Tsunami Warning Center, the satellite community, including the orbiting Carbon Observatory, and the Dialogues with Industry UN Ocean Decade action process, providing information, knowledge and solutions to scientists, stakeholders, and public and private enterprise.

GOOS is an instrumental coordinating element of the OceanObs decadal conferences which bring together scientific, technical, and operational communities involved in the planning, implementation, and use of ocean observing systems. These conferences started in 1999 and have been key to communicate progress, promote plans, and to define advances in ocean observing in response to societies' needs (Speich et al., 2019). As examples, the Argo system of autonomous floats derived from discussions and agreements at OceanObs99, the FOO was developed at OceanObs09 providing a strategy for defining and implementing integrated physical, biogeochemical, and biological observing needs based on Essential Ocean Variables (EOVs), and OceanObs19 provided a collection of 140 Community White Papers

(https://www.frontiersin.org/research-topics/8224/oceanobs19-an-ocean-of-opportunity/articles) providing key recommendations for global ocean observing within the backbone of information, innovation, integration, and interoperability. Some of the main recommendations include:

- Sustaining observation of EOVs for various applications.
- Addressing capability gaps in coverage, sampling, accuracy, and measurement of under-measured variables.
- Developing cost-effective strategies and accelerating technology infusion for sensor, platform, and network advancement.
- Facilitating governance integrating observational capabilities under the GOOS framework.
- Improving links between users and observing systems, including private sector involvement and feedback loop reinforcement.
- Innovating data and information services to meet diverse user needs and Big Data challenges.
- Enhancing best practices in sensor development, data curation, and delivery.
- Strengthening capacity building and knowledge integration across the ocean observing value chain.
- Fostering international collaborations, coordination, and free data access for responsible observing system governance.

The OceanObs19 white papers also provided a clear picture of global research and capacity gaps, as co-authors of these papers were affiliated mostly to European (42%) and North American (37%) organizations, with 8% affiliated to Oceanian, 8% to Asian, 3% to South American, and 2% to African organizations. Countries with the highest number of co-authors were the USA, France, UK and Australia which are also the countries with significant investment in ocean observations. The papers also provided a picture of thematic gaps, as the main topics covered were related to ocean physics, followed by ocean modelling and forecasting, satellite observations, biodiversity, infrastructure, climate, technology, data management and best practices, blue economy, capacity building, and geographic priorities for ocean observing.

Fulfilling Ocean Decade Challenge 7 will require a fully integrated and sustainable global observing system supporting the entire value chain, from observations, through data management systems, scientific analysis, and forecasting, to end-users via information, data, and decision-making services. Implementing such a system will require a significant leap in the level and effectiveness of partnerships across all stakeholders (IOC-UNESCO, 2022).

2.2. Importance and relevance of Challenge 7 for sustainable development

Ocean observations, along with the workforce supporting and relying on observing systems, form the foundation of information delivery for decisions on the sustainable development of the ocean and the blue economy. The adoption of multi-disciplinary observing strategies at local, regional, and global scales is needed by several Sustainable Development Goals (SDGs), particularly SDG 14—Life Below Water. Of the eight specific targets of SDG 14, at least six benefits directly from long-term observations: stop pollution, manage and restore ecosystems, minimize ocean acidification, stop illegal fishing, conserve 10% of ocean areas, and increase scientific knowledge (Weller et al., 2019). Additionally, an expanded GOOS will also support the enhancement of livelihoods and income (SDG 1), food security (SDG 2), improvements in health and well-being (SDG 3), clean energy production (SDG 7), advancing industry, innovation, and infrastructure (SDG 9), building sustainable cities (SDG 11), and mitigating climate change action (SDG 13). Currently two-thirds of the global marine climate change sector that is valued at US$52bn relies on ocean observations (World Ocean Initiative, 2024a).

Ocean observations are the underpinning of vital information needed by global governance reporting mechanisms, such as the United Nations Framework Convention on Climate Change (UNFCCC) through the Intergovernmental Panel on Climate Change (IPCC) reports, and play a crucial role in reporting against

the Convention on Biological Diversity (CBD) Global Biodiversity Targets, the Biodiversity Beyond National Jurisdiction or “BBNJ Treaty, and the Sendai Framework for Disaster Reduction among others.

To underpin sustainability in the blue economy, ocean industries, especially in new sectors, need ocean data to support and attract investment into start-ups and new initiatives. These include the traditional food (e.g. fisheries) and mineral resource extraction (e.g. deep-sea mining), but also the more new, non-extractive resources such as genetic resources and medicines from the sea, renewable energy, reducing CO2, sea water desalination to generate fresh water, development and use of autonomous vehicles in naval operations, and coastal development (Weller et al., 2019).

Regional-scale economic valuations by the Australian Integrated Marine Observing System (IMOS) have shown a $4.70 return for every $1 spent reflected in improved management of commercial fisheries, more accurate weather forecasting, natural disaster and extreme weather preparedness (IMOS, 2021). These economic assessments should broaden to incorporate human impacts and values to evaluate and monitor the delivery of ocean information for societal needs.

2.3. Methodology used for strategic ambition setting

The ocean is becoming increasingly important for society. The GOOS, developed through international cooperation, while a strong foundation for global and regional ocean observing networks, faces serious constraints due to funding limitations, limited cooperation among users, an insufficient technically skilled workforce, and lack of standardization. In this paper we will articulate a strategic ambition to strengthen and expand the GOOS in the long term, along with a roadmap with the next steps that need to be implemented in the coming years to set the path to achieve such long-term ambition.

To develop this strategic ambition and roadmap, we (1) reviewed the vision and strategic objectives of the GOOS 2030 Strategy, (2) analysed the major recommendations of the OceanObs19 papers, (3) interviewed ocean observing experts, stakeholders, and data users, (4) surveyed the ocean observing needs of the Ocean Decade Programmes and Projects that are actively involved in Ocean Observing, and (5) synthesized the ocean observing needs of the other nine Vision 2030 Working Groups.

The integration of these provided a clear picture of current activities, the growing demand for new fit-for-purpose deployments, the need to expand and diversify the user base and engagement of stakeholders aiming for a broader constituency committed to sustainable use and blue economy principles, the need to advocate for new resources, and the need for legal and regulatory frameworks to incentivize change.

3. Strategic ambition setting

3.1. Analysis of user needs and priorities

The range of users for ocean observations is vast, encompassing diverse needs and priorities; from local to regional to global following the principle of ‘think globally, act locally’, and from national to international, informing national management and policies, and informing international commitments and treaties as articulated in Section 2.1. Integrated *in situ*, airborne, and satellite ocean observations in coastal and open oceans will continue to be required for understanding how the ocean works. Key users include governments, intergovernmental organizations, and programs (e.g. WMO, GCOS), policymakers, the scientific community, technology developers, marine networks, the private sector, philanthropy, society, and indigenous communities. Within the private sector, ocean observations will be especially relevant and vital for the offshore and wind industry, for shipping, ocean renewable energy industries, insurance and reinsurance industry, blue carbon industry, and the marine Carbon Dioxide Removal (CDR) industry which altogether have the potential to outperform the global economy in the near future (World Ocean Initiative, 2024a).

A summary of the needs and priorities for some key users of an operational ocean global observing system are outlined in Table 1.

Table 1. Some key users of an operational ocean global observing system and their priorities.

User	**Priorities**
WMO	Developed through WMO Rolling Review of Requirements (RRR) which offer informed guidance on the key priorities necessary to bridge the gaps between observation requirements and existing capabilities delivers requirements based on operational service (national weather prediction and climate) needs for observations across all earth domains, and major initiatives e.g. greenhouse gas monitoring system (G3W). Current priorities: include for member states to maintain observation of sea level pressure, sea surface temperature and above ocean upper air measurements within their Exclusive Economic Zones (EEZ). From G3W to support an operational G3W for climate needs (ocean carbon, biogeochemical and biological cycles),
GCOS	GCOS requirements are for ocean observations for climate applications, GCOS assess status and provide guidance for the improvement of global climate observations based on Essential Climate Variables (ECVs) across ocean, cryosphere, atmosphere, and land for prediction and adaptation (link to UNFCCC). Current priorities include: (1) increase ECV measurements in the deep ocean, under the ice and marginal seas, and coastal zones, (2) add biological and enhanced biogeochemical sensors to existing networks, and establish a baseline of plankton distribution and phenology, (3) develop and implement plan to operationalize collection and delivery of surface ocean CO_2, (4) coordinate the existing nitrous oxide (N_2O) ocean observations into a harmonized network, and (5) improve and extend in situ measurements needed to estimate surface fluxes (heat, wind stress).
Offshore wind industry	Ocean data is required to choose locations and monitor ecosystems, design resilient structures, optimize operations based on wind and wave conditions, and ensure safe operations.
Shipping industry	Ocean data on weather patterns and sea conditions is critical for safe maritime operations and also aids to the decarbonization of the shipping industry (Green shipping) by helping maximize vessel performance, optimize routes, reduce fuel consumption, monitor emissions, and ensure safe operations.
Blue carbon industry	Ocean data on coastal ecosystems health (e.g. mangrove, seagrass beds, macroalgal communities) and carbon storage capacity is key to establish marine protected areas.
Ocean renewable energy industry	Ocean data on wave patterns, tidal currents, and other ocean conditions are needed to design and place energy devices (e.g. turbines, converters), optimize energy production, and optimize the durability and safety of the installations.
Marine CDR industry	Ocean data on carbon dynamics is needed to identify suitable locations for CDR projects, to assess the effectiveness and environmental safety of carbon removal methods and to track and report on the carbon credit trade.

Ocean observations underpinning the success of the UN Ocean Decade

The UN Ocean Decade actions

There are eleven UN Ocean Decade Programmes with ocean observing as a main component. Their key focus areas are co-design of observing capacity, coastal ocean resilience, deep ocean, air-sea fluxes, biodiversity, and bathymetry. Within these 11 programmes, there are 91 affiliated projects making almost one third of the total endorsed Ocean Decade Actions.

The results of the survey that we carried out to these ocean-observing related projects prioritized the observation of surface and subsurface temperatures followed by ocean heat flux, sea state and sea ice among the physical EOVs. Phytoplankton biomass was the prioritized biological EOV followed by observations of ecosystem biomass at higher trophic levels and assessing carbon sink distributions, including mangroves, seagrass, and macroalgal areas. Dissolved oxygen, inorganic nutrients, and inorganic carbon were the prioritized biogeochemical EOV. Regardless of ambition or priorities identified, it's sobering to note that an estimated 68% of endorsed Ocean Decade Activity is under-funded or has no funding at all.

Several of the Ocean Decade Programmes have co-design with users as an integral part of the process. GOOS has co-designed with other partners and stakeholders three UN Ocean Decade programmes: (1) the Ocean Observing Co–Design, (2) Observing Together, and (3) CoastPredict. The Ocean Observing Co-Design Programme has a series of Exemplar Projects working at the nexus of high societal need and maximum impact of ocean observations that could provide insights and strategies to scale up the GOOS for key areas of urgent societal need, including ocean carbon for climate and CDR policy, improving prediction of tropical storms and marine heatwaves, and the impact of major boundary systems on regional weather and marine resources. The CoastPredict Programme has already identified within its 120 pilot sites a series of priority impact areas, these being adaptation and mitigation of impacts of climate change on coasts including indicators of sea level, temperature, biochemistry, biodiversity, and increasing capacity in disaster risk reduction by providing real-time forecasting of extreme events. Identifying and implementing pathways for the data to reach users will be key for the success of these programmes.

The forum ‘Dialogues with Industry’, another GOOS co-designed UN Ocean Decade action initiated the discussion of multi-sectoral integration of new observing networks and business models, with Blue Fund investors in the private sector of ocean technology and solutions noting the need for more ocean and bathymetric data in order to reduce the risk of their investment.

The UN Ocean Decade Vision 2030 challenges

Information and knowledge from ocean observing is critical to fulfill the ten Vision 2030 challenges. In Table 2, we have summarized the main recommendations related to the need for ocean observations derived from the other nine white papers.

Table 2. Summary of the main recommendations relevant to ocean observing derived from the other nine White Papers (Challenges #1,2,3,4,5,6,8,9,10).

Challenges	Recommendation
1, 2, 4, 5, 6, 9	Leverage technological advances (including machine learning), and develop autonomous and low-cost monitoring systems
2, 6	Implementing innovative monitoring techniques (e.g. eDNA, bio-logging, imaging, drones, etc.)
2	Expansion of observations to fill knowledge gaps (e.g. deep sea, vulnerable habitats, data poor regions)
3, 4	Enhance accessibility and availability to interoperable and standardized near real time data, as well as to data analysis and visualization tools
5	Monitoring of marine CDR
6	Integration of meteorological, seismic and geophysical, hydrological, seabed and bathymetry, geological, and human health data
8	Prioritize societally relevant datasets to identify and address underlying data gaps and interoperability issues.
10	Improved integration and inclusion across stakeholders (e.g. indigenous communities) and across science, social science, communications, and outreach approaches

3.2. Elements of the Strategic Ambition for Challenge 7

3.2.1. Priority datasets

Well-defined and prioritized datasets will have clear connections to ocean services and societal needs as well as be 'foundational observations' (observations that can be used for multiple purposes) that create benefits for numerous users, facilitate specialized knowledge or products or can be applied for management or policy setting.

Weather forecasting should be the benchmark for a future ocean observing system where reliable services are provided and expanded based on need and capability, with the ability to provide very local information and long-term forecasting. We are approaching the stage where enough stakeholders, especially large businesses such as the insurance industry, see significant value in ocean weather to start a conversation on engagement.

Priority observations and EOVs identified in regional ocean observing plans need to be consolidated for a global prioritization. The FOO (Tanhua et al., 2019) provides the structure for priority datasets to be FAIR, integrated and interoperable for national, regional and global needs. Engagement with various sectors

about industry data, traditional ecological knowledge and citizen science will enrich and support a more integrated perspective to key ocean datasets. Measurement priorities and EOVs should evolve and be forward-looking, informed by other Decade challenges and emerging ocean needs. We also need to do a better job of linking observations with tangible actions associated with mitigation or adaptation. From a climate perspective we are perhaps beyond the point that we need observations to evidence there is a climate problem, we now need data to guide the ways in which we are going to respond in terms of mitigation and adaptation. We should prioritize funding towards observations that can be linked to tangible actions, rather than those that just continue to document a known problem that we can't respond directly to.

Five years into the 2030 Strategy, GOOS has made good progress. Additional key considerations out to 2030 include addressing the priorities articulated by the other nine Ocean Decade challenges and the endorsed Decade programmes (Table 2, Section 3.1).

3.2.2. Knowledge generation and sharing

Knowledge generation and data sharing will require fit-for-purpose co-designing and agreements with key stakeholders to ensure that objectives and requirements are met and there is a clear understanding of the benefits of data access and information products.

Dialogue between sectors (e.g. academic, government, industry, etc.) can help accelerate the development of efficient resilient ocean observing infrastructure and user services (Willis et al, 2024) to deliver information through tailored data products, and indicators that respond to multilateral needs.

At the local level, collaboration with local citizens and indigenous communities is needed to gather valuable feedback, leveraging traditional knowledge, recognizing the role they have played for generations in ocean stewardship and understanding, and establishing meaningful and respectful partnerships as declared in the "Aha Honua" (Proulx et al., 2021). Some indigenous communities have already made significant progress in revolutionizing ocean modeling and observations and building a bridge between traditional knowledge and science, focusing on long-term planning and on shared benefits (e.g. the Moana Project in New Zealand, Souza et al., 2023).

3.2.3. Infrastructure and process requirements

The current global ocean observing infrastructure is described in Annex A. To address expanded requirements, we need more of what we have and better, co-developed by scientists, end-users, and industry, ensuring that they are fit for purpose (see Section 3.2.6.). New processes for the co-design of observing systems need to be developed, as envisioned in the Ocean Decade Programmes Ocean Observing Co-Design and CoastPredict. At a basic level this involves processes to work in an iterative way across observing, modelling and user communities, to deliver useful services. Currently we lack defined processes and the collaborative links to do this. At a more advanced level this also requires some evaluation of observing system design, such as can be achieved through OSE and OSSE (Observing System Experiments, Observing System Simulation Experiments, which test the value of current observation types using data denial experiments), these are currently computationally expensive and not widely used, or statistical methods. Finally integrating these elements to provide some notion of value or return on investment will be important for the longer-term sustainability of ocean observing.

Investment in enhanced data processing and modelling capabilities will be required with an expanded ocean observing system. Data interoperability to enable data fusion is also critical. This will require efforts from the international community, in particular around data access and information sharing; encouraging and facilitating exchanges of information related to modelling advances among communities will be also essential to enhance the predictive capability of all communities around aquatic applications and services.

Integrated, analysis-ready ocean observations and tools will democratize data for use in island nations, developing capacity-reduced countries. Improving our ocean observations along with our data processing capabilities and the use of AI will be fundamental to contribute to the Digital Twin Ocean (https://digitaltwinocean.mercator-ocean.eu/).

Better coordination among various systems should be facilitated by GOOS to ensure standardization, cost efficiency, data interoperability, and realizing opportunities provided by new collaborations across regions, communities, and technologies. For this, the GOOS coordination and management infrastructure, currently consisting of 20 people, will need to increase commensurate to the dimension of the challenge, making sure they work in a concerted way with the recently established Decade Coordination Offices (DCOs) for Ocean Observing and for Ocean Data Sharing, and with the Decade Collaborative Centre (DCC) for Ocean Prediction.

3.2.4. Resources and Partnerships

Significant resources are required to support each of the elements of the strategic ambition. Current investment in ocean observations and infrastructure are inadequate to support a sustainable ocean economy. The cost of inaction is high (USD $200bn, Sumaila et al., 2021) and will grow annually due to climate change. New economic thinking is required to tackle the resourcing issue. Collective action through multi-sector collaboration, private-public partnerships, mobilization of ocean finance tools and market incentives to strengthen and enable a transition to increased ocean investment is needed. For less developed regions, especially those with large Exclusive Economic Zone (EEZ) to Gross Domestic Product (GDP) ratios, the establishment of a funding mechanism, such as an Ocean SOFF (similar to WMOs SOFF - Systematic Observations Financing Facility - focused on the ocean) to actively address observational gaps and capacity, could be a plausible avenue. The expansion of the standardized UN System for Environmental Economic Accounting frameworks that account for environmental protection to include ocean finance information for countries would be the next logical step (Eli et al., 2020).

Strengthening existing partnerships and building new national and international partnerships to share responsibilities and increase global participation is key. The current GOOS has been evolving for more than 30 years expanding its focus to become multidisciplinary and to include coastal areas. This expansion enhanced opportunities for collaboration and fostered the establishment of global networks, national programs and regional alliances. While such expansion was driven by scientific and societal needs, it was undoubtedly championed by institutional leaders who committed their time and expertise to serve the international ocean science community. These champions had the knowledge, the vision, and the influence within their institutions and countries to make things happen. Achieving the 2030 ambition will require many more champions, diversified across all social, political, and economic sectors.

3.2.5. Capacity development and exchange needs

Quality data can only be acquired, analysed, and modelled by properly trained people using reliable technology and best practices (Miloslavich et al., 2018). Of special importance is to improve our capacity to transform these quality data into useful information for use by non-experts. To meet the demands of a global observing system, we need to train an army of people in a broad range of skills. This will require developing new curricula and strengthening and expanding upon existing training programs (e.g. the Ocean Teacher Global Academy - OTGA; the Partnership for the Observation of the Global Ocean - POGO and Scientific Committee on Oceanic Research - SCOR fellowship in ocean observations, IOC Ocean Literacy) for data collection, serving, accessibility, analysis, communication, and engagement, promoting innovation for data collection, processing and synthesis (Miloslavich et al., 2022), ensuring our systems can support both private and public sector development of information services (Willis et al. 2024). Ocean observing training programs or curricula also need to be co-designed and locally supported to address national

priorities to ensure community buy-in, meaningful participation, and future sustainability of the system, ensuring observations can be applied to their specific interests, for example national fisheries, tourism, ocean health and/or other blue economy priorities (Urban and Ittekot, 2022).

Encouraging the sharing of software, analytical tools, and capabilities (including training on their use) will significantly reduce the need to replicate effort. Similarly, the development of tools that are nimble and can be run on mobile platforms will expand their use; partnering with cloud processing to have the heavy lifting of data will also be helpful to overcome on the ground capacity. Disseminating the results in multiple languages will also be essential for the different stakeholders across geographic regions, particularly in developing countries, as well as to leverage Indigenous, traditional, and scientific knowledge to bring innovative approaches to ocean related problems affecting society. There also needs to be capacity building and training for policy and decision makers to better equip them to feel more confident about using ocean data and knowledge to inform their actions. As a community, the observing system facilitates knowledge exchange across all stakeholders and developing data-sharing standards, platforms, and systems accessible to all, including the private sector, and jointly supports sustainable Blue Economy development addressing societal needs.

The socio-economic value of ocean observations is significant, but it still lacks that recognition, and its full power has yet to be unlocked. Human capital is at the core of economic expansions and sustainability of assets, and developing and executing ocean observing plans hand in hand with private industry and governments will be critical to ensure sustainability of observing assets and its worldwide distribution. This will require dedicated personnel with the adequate expertise to build those bridges at national and international levels. This goal should be worked with input from Challenge 5.

3.2.6. Technology and innovation solutions

The current ocean observing technology market is relatively small, fragmented and focused on developed countries. We need to work to define our technology needs, discuss with the private sector potential solutions, and provide some idea of market size (Willis et al., 2024). The Argo float and the Voluntary Observing Ships (VOS) programmes revolutionized ocean observation massification and are now ready for another big leap. The evolution of Argo into OneArgo will expand observations to polar oceans, marginal seas, the full ocean depth and include biogeochemical measurements. More ocean gliders and ships (e.g. more collaboration with industry such as the Fishing Vessel Ocean Observing Network - FVON) and expanded animal tagging and tracking are needed. We also need new technology that is more rapidly tested and implemented with agreed best practices and data flow (e.g. eDNA, Imaging FlowCytobot), along with the development of low-cost technological innovations and sensors, automated platforms, or alternate observational proxies.

While there is potential to evolve a wide array of new or enhanced automated technologies (e.g. uncrewed surface and subsurface vehicles, drones, satellites), the largest advances will come via aggregated demand for technology tied to priority observations for societal needs. If we want commercial production of easy to use and/or low-cost technologies or to speed the development in key areas, we must invest consciously and be more organized around our needs internally.

The use of existing and new technologies, when used in conjunction with innovative AI/ML approaches will optimize ocean observing. Integrating time-resolved satellite remote sensing measurements from active/passive platforms with sustained autonomous profiling measurements, airborne campaigns, and ship-based measurements will further enable the reconstruction of ocean ecosystems and contribute to a better understanding and prediction of ocean change and impacts on coastal communities.

4. Milestones and measures of success

The Ocean Decade aims to achieve social and economic wellbeing through transformative ocean science solutions. Sustainably expanding the GOOS underpins the seven proposed outcomes of the Ocean Decade by delivering accessible, timely, actionable data and information to all users. Challenge 7 is integrative by nature and cannot happen in isolation. The challenge 7 Roadmap to 2030 will have the following milestones and measures of success:

4.1. Milestones

Milestone 1. Improved and expanded observing capabilities globally, specifically in developing nations and under-observed ocean regions using standards and best practices.

Milestone 2. Developed products that translate data into usable information and knowledge for a range of users. This will include integrating data, streamlined, and improved online portals and visualization tools.

Milestone 3. Deployed innovative technologies, sensors and platforms that have complemented existing observing programmes and, together, have filled priority data gaps.

Milestone 4. Accelerated and diversified investment in ocean observing, infrastructure, training and capacity development with the use of economic models for ocean investment.

Milestone 5. Sustained existing partnerships and built new international partnerships across the public and private sectors which combined have shared and strengthened responsibilities for ocean observing.

Milestone 6. Increased and diversified the global ocean observing workforce so that it truly reflects all aspects of the ocean observing value chain.

4.2. Measures of success

1. Having identified the key gap areas requiring observations and identified the key partnerships, processes, and resources needed to carry them out.
2. Having identified the pathway to unlock key existing but unavailable data and making it FAIR.
3. Having developed the governance structure for the international coordination of the observing system, strengthening the GOOS Management Team (including OceanOPS), unifying coordination components and data storage nodes.
4. Having established and prioritized a new set of ocean indicators, building on the EOVs, that are co-designed with stakeholders.
5. Having identified and initiated the public-private sector partnerships needed to seek the resources for the development and deployment of innovative observing technologies.
6. Having developed priority skills, suitable training programmes and resourcing to strengthen and expand human capacity.

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Annex A: Ocean observing platforms and GOOS Status 2023

There are currently around 8000 in situ ocean observing platforms monitored by the GOOS operational center OceanOPS (www.ocean-ops.org). These platforms are operated by 84 countries via 300 programmes and deliver more than 120,000 observation bulletins daily. Investment in ocean science effort falls to a handful of developed countries (USA, Japan, Australia, France, Jolly et al., 2020).

Ocean observing platforms include systems of buoys, moorings, profiling floats, ships (merchant, academic, fishing), gliders and other uncrewed systems (e.g., sail drones), drones, planes, land-based stations (e.g., global sea level), satellites, HF radars, deep sea cables, and animal borne sensors measuring mostly physical data and some biogeochemical data. A constellation of satellites complements these in-situ observations, achieving a much broader spatial coverage (Hermes et al., 2022).

There are 13 global ocean observing networks that vary in stage of implementation (Figure A1: OceanOps, Ocean Observing Report Card 2023]. There are over 600 Biological observing programmes operated by 71 countries identified through the GOOS BioEco portal. Across the 12 biological and ecological Essential Ocean Variables (EOVs) we see a ten-fold increase in the amount of species observations being shared with open platforms like the Ocean Biodiversity Information System (OBIS).

The current major contributions to the GOOS include: the Argo profiling float array of close to 4,000 floats; moored and drifting buoys, sustained time series sites, moorings coordinated by OceanSITES; ship-based repeat hydrography through GO-SHIP; shipboard sampling along lines repeated every 5 to 10 years; tide gauges; and ocean and meteorological sampling from merchant ships (Weller et al., 2019). These are primarily physical ocean properties with an expansion of biogeochemical data in recent years.

Related to national programs and/or regional networks, GOOS is organized in thirteen GOOS Regional Alliances (GRAs) which enable and provide monitoring services meeting their regional and national priorities (Moltmann et al., 2019). The GRAs governance, observing and data processing capabilities, and resourcing are very heterogeneous. Of the GRAs, only the US Integrated Ocean Observing System (IOOS) and the Australian Integrated Marine Observing System (IMOS) have national program budgets, with EuroGOOS having a member fee base.

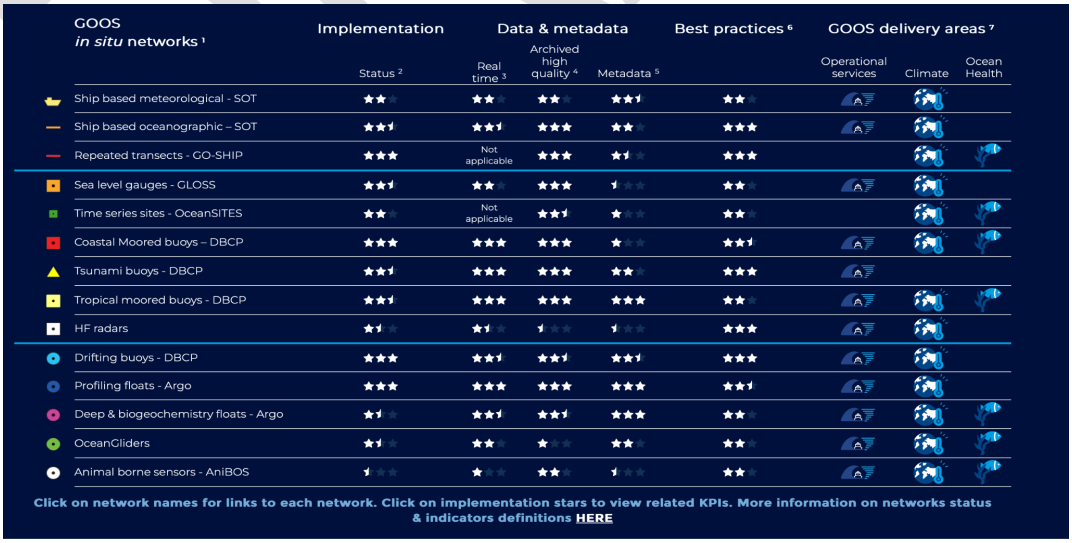

Figure A1: OceanOps, Ocean Observing Report Card 2023

United Nations Decade of Ocean Science for Sustainable Development (2021-2030)

Proclaimed in 2017 by the United Nations General Assembly, the UN Decade of Ocean Science for Sustainable Development (2021-2030), provides a convening framework to develop the scientific knowledge and partnerships needed to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean. The Ocean Decade is coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Established during the Preparatory Phase and to continue throughout implementation until 2030, the IOC's Ocean Decade Series will provide key documentation about this global initiative and aims to serve as a primary resource for stakeholders seeking to consult, monitor and assess progress towards the vision and mission of the Ocean Decade.

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

https://oceandecade.org/