Ocean Decade

Vision 2030

White Papers

Challenge 7:

Sustainably Expand the Global Ocean Observing System

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

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Ocean Decade Vision 2030 White Papers

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.

Writing Team

The Intergovernmental Oceanographic Commission (IOC) of UNESCO, extends its sincere appreciation to the co-chairs and members of the Working Group for their leadership and commitment in the process of drafting and authoring the present document.

Co-chairs

Patricia Miloslavich	Australian Antarctic Division, Department of Climate Change, Energy, the Environment and Water
Joe O'Callaghan	Oceanly Science, University of Auckland

Working Group expert members

Jerome Aucan	Pacific Community Center for Ocean Science (PCCOS), Pacific Community-SPC
Mathieu Belbeoch	IOC/OSS
Peter Brickell	Queens University
Marcos Fontela	Spanish National Research Council
Aridane G. González	Instituto de Oceanografía y Cambio Global
Emma Heslop	IOC/OOS
Michelle Heupel	Integrated Marine Observing System (IMOS), University of Tasmania
Laura Lorenzoni	National Aeronautics and Space Administration (NASA)
Terry McConnell	IOC/OOS
Isa Olalekan Elegbede	Brandenburg University of Technology (BTU)
Nicholas Rome	University Corporation for Atmospheric Research
Erin Satterthwaite	Scripps Institution of Oceanography, UCSD
Irene Schloss	Austral Center for Scientific Research from the National Council of Scientific Research (CONICET)
Pierre Testor	Pierre and Marie Curie University
Steve Widdicombe	Plymouth Marine Lab

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[See "Writing Team" for the list of contributing authors and their organisational affiliations.]

Contents

Acronyms

AI/ML	Artificial Intelligence/Machine Learning
BBNJ	Biodiversity Beyond National Jurisdiction
CARE	Collective Benefit, Authority to control, Responsibility, Ethics
CBD	Convention on Biological Diversity
CDR	Carbon Dioxide Removal
ECV	Essential Climate Variables
eDNA	Environmental Deoxyribonucleic acid
EEZ	Economic Exclusive Zone
EOV	Essential Ocean Variables
FAIR	Findable, Accessible, Interoperable, and Reusable
FOO	Framework for Ocean Observing
FVON	Fishing Vessel Ocean Observing Network
G3W	Greenhouse Gas Monitoring System (or Global Greenhouse Gas Watch)
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
IMOS	Integrated Marine Observing System (Australia)
LDC	Least Developed Countries
OSE	Observing System Experiments
OSSE	Observing System Simulation Experiments
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SOFF	Systematic Observations Financing Facility
TRUST	Transparency, Responsibility, User focus, Sustainability, Technology
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

White Paper 7 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 ambition is to provide a unified approach to action spanning ten Challenges in the Ocean Decade. Each Challenge evaluated existing initiatives underway in the Ocean Decade and relevant communities. Through a lens of priority user needs, the Vision 2030 process was used to determine priority datasets, critical gaps in science and knowledge, and needs in capacity development, infrastructure and technology required for each Challenge. The white paper identifies achievable recommendations that can be implemented and indicators to measure progress in the Ocean Decade to achieve the strategic ambition of Challenge 7. **Recommendations include expanding global ocean observation capabilities, the translation of observations into information, fostering diversified partnerships, building a capable and diversified workforce, and emphasising a new economic thinking for resourcing ocean observing.** It is anticipated that these will provide focus for future Decade Actions, be used to identify investment in observing priorities, and to evaluate and monitor progress of the Challenges in order "to deliver the science we need for the ocean we want" by the end of the Ocean Decade in 2030.

1.2 Strategic Ambition: Challenge 7

The strategic ambition is to **develop** an operational, comprehensive, and resourced system that **delivers** priority observations and information to **guide** mitigation and adaptation responses to climate change, **sustains** ocean health within a sustainable blue economy, and **facilitates** informed decision-making for science, business and society.

Such a system is envisioned to be co-designed, fit-for-purpose, multidisciplinary, geographically expanded, responsive, and sustainable in time, delivering ocean observations to all nations and users, prioritising societal needs. Transforming ocean observations into accessible information will require integration across disciplines, across national observing systems, along the value chain, and across stakeholders. Innovative technology approaches and a diversified set of actors and approaches will be required for success. The Global Ocean Observing System (GOOS) of IOC UNESCO can provide the implementation framework for Challenge 7 and the UN Ocean Decade provides the opportunity and vehicle for transformation.

Five recommendations have been identified to fulfil the strategic ambition of Ocean Decade Challenge 7.

1. **Act now on known observational needs.** Upgrade and expand ocean observing capacity in poorly-observed areas such as polar regions, island nations and territories, coastal areas of developing nations, coastal systems that are rapidly changing, and the under-observed deep ocean. Thematic priorities for ocean observing by 2030 should focus on key climate risk and adaptation needs, extreme events, coastal services for ocean management, ocean carbon, marine pollution, biogeochemistry, and biodiversity.
2. **Adopt new economic thinking**. Establish new and sustained financing mechanisms for global ocean observing, including resourcing for Small Island Developing States (SIDS) and Least Developed Countries (LDCs). Use economic models for ocean investment to diversify and accelerate investment in ocean observing and infrastructure from new actors.
3. **Partnerships are key.** 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 a sustainably expanded GOOS. Diversify partnerships across sectors (economic, public, private, and philanthropic) and embrace the abilities and needs of the different stakeholders to co-design, co-develop, and co-deliver observations that translate into the information required by these sectors.

4. **Technology and innovation will be a pillar.** Integrate and harmonise observations across observing platforms (*in situ*, satellite, emerging networks). Develop innovative *in situ*, autonomous and cost-effective technologies to maximise reach, ensuring standardisation and best practices. Technology barriers still need to be lowered to ensure everyone has equitable access to observing technology and has the ability to use these assets. Artificial Intelligence (AI) and Machine Learning (ML) tools will provide user-ready information from integrated observations to democratise information for users.

5. **Expanded, capable, and diversified workforce.** Expand and diversify the workforce of skilled and trained ocean professionals. Training and capacity development will be critical across the observing 'ecosystem' outlined in the Framework for Ocean Observing (FOO), from data collection to data analysis and modelling, and for data use and application.

2. INTRODUCTION

Ocean observations are the foundation for the value chain that provides the information and services for sustaining a healthy blue economy, and for protecting people and places. Challenge 7: Sustainably expanding the global ocean observing is a cross-cutting challenge, fundamental to the success of the Ocean Decade vision "the science we need for the ocean we want". Ocean observations play a vital role by supplying essential data for understanding and tackling diverse issues related to the ocean such as climate risk and adaptation needs, extreme events, coastal services for ocean management, ocean carbon, marine pollution, biogeochemistry, and biodiversity. 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 GOOS is a cornerstone of knowledge, enabling sustainable management of marine resources, underpinning the blue economy, and ensuring we monitor ocean health. Ocean observations provide critical information for climate change mitigation and adaptation, ocean ecosystem health, pollution severity and extent, disaster forecasting and response, conservation of marine biodiversity and habitats, and aquaculture and fisheries sustainable management (Rayner et al., 2019). Challenge 7 leverages the existing GOOS Strategy and what has been accomplished to date but highlights what still requires major planning, resourcing and uptake by policymakers to maximise its societal benefits and to address the needs of a rapidly changing planet.

2.1 Background - The Global Ocean Observing System

Sustained observations of ocean variables began with Voluntary Observing Ships (VOS) some 150 years ago. The earliest example of a sustained observatory, beginning in 1903, is the Western Channel Observatory in the English Channel and since then, a diversity of observing programmes have been 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. Today 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, Lindstrom et al., 2012), 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 define advances in ocean observing in response to societal 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.

Co-authors of the OceanObs19 white papers were affiliated mostly to European (42%) and North American (37%) organisations, with 8% affiliated to Oceanian, 8% to Asian, 3% to South American, and 2% to African organisations showing the global imbalance in ocean observing capacity. 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.

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 sustainable management and conservation of the ocean and for 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 benefit directly from long-term observations: stop pollution, manage and restore ecosystems, minimise 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 underpin information and knowledge 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 and the Kunming-Montreal Global Biodiversity Framework, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments, the new UN Agreement under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Biodiversity Beyond National Jurisdiction (BBNJ Agreement), and the Sendai Framework for Disaster Reduction, the High Ambition Coalition to End Plastic Pollution, among others.

Sustainability of the emerging blue economy requires ocean observations to support and attract investment into start-ups, grow new initiatives as well as to support evolving use of longstanding activities (e.g. fisheries and mining). Observations and knowledge will support non-extractive resource alternatives such as genetic resources and medicines from the sea, renewable energy initiatives, CO2 reduction efforts, sea water desalination for freshwater generation, coastal development projects, and support for any national naval operations (Weller et al., 2019).

Regional-scale economic valuations by the Australian Integrated Marine Observing System (IMOS) have estimated a $4.70 return for every $1 spent, as 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

In this paper we articulate a strategic ambition to strengthen and sustainably expand the GOOS, along with recommendations for next steps and implementation for success to 2030 and beyond. The GOOS, developed through international cooperation, faces constraints due to funding limitations, limited cooperation among users, an insufficient technically skilled workforce, and insufficient levels of standardisation.

Development of the strategic ambition and tangible recommendations for Challenge 7

used a multi-pronged approach. 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) synthesised the ocean observing needs of the other nine Vision 2030 Working Groups.

The integration of these analyses provided a picture of current activities, showing the growing demand for new, fit-for-purpose deployments, the need to expand and diversify the user base and engagement of stakeholders aiming to foster 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.

2.4 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 and sustained *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 organisations, and programmes (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 for substantial contributions to the global economy in the near future (World Ocean Initiative, 2024). Table 1 outlines key users and some of their needs and priorities for an expanded GOOS.

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

USER	OCEAN OBSERVATION 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), Early Warnings for All. 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 Global Greenhouse Gas Watch (G3W) initiatives 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 harmonised

	network, and (5) improve and extend in situ measurements needed to estimate surface fluxes (heat, wind stress).
Offshore wind industry	Observations are required for site selection, ecosystem monitoring, system design of resilient structures, operational optimisation for safe operations.
Shipping industry	Observations of sea conditions for safe maritime operations, decarbonization of the shipping industry by optimising vessel performance and routes.
Blue carbon industry	Observations of coastal ecosystems health (mangrove, seagrass beds, macroalgal communities) and carbon storage capacity for establishing marine protected areas.
Ocean renewable energy industry	Observations of wave patterns, tidal currents, and other ocean conditions are needed to design and place energy devices (e.g. turbines, converters), optimise energy production, and optimise the durability and safety of the installations.
Marine CDR industry	Observations of carbon dynamics are needed for suitable CDR locations, 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

Ocean Decade Actions

There are eleven (11) 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. Ocean observing comprises one-third of the total endorsed Ocean Decade Actions with 91 Decade projects affiliated to these 11 Programmes.

Observational priorities of the Decade Programme and Projects were identified using the GOOS EOV framework via a survey. Physics EOVs, in order of priority, were surface and subsurface temperatures followed by ocean heat flux, sea level and sea ice. Phytoplankton biomass was the prioritised 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 prioritised biogeochemical EOVs. Regardless of ambition or priorities identified, it's sobering to note that an estimated 68% of endorsed Ocean Decade Activity is underfunded 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', a GOOS UN Ocean Decade action co-designed with the Marine Technology Society and industry, 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.

Ocean Decade Vision 2030 Challenges

Information and knowledge from ocean observing is critical to fulfil the ten Vision 2030 challenges. In Table 2, we have summarised 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 Challenges.*

CHALLENGES	RECOMMENDATION
1, 2, 4, 5, 6, 9	Leveraging technological advances (including machine learning) and develop autonomous and cost-efficient monitoring systems.
2, 6	Implementing innovative biological monitoring techniques (e.g. eDNA, bio-logging, imaging, drones, etc.).
2	Expanding observations to fill knowledge gaps (e.g. deep sea, vulnerable habitats, data-poor regions).
3, 4, 8	Enhancing accessibility and availability to interoperable and standardised near real-time data, as well as to data analysis and visualisation tools.
5	Monitoring of marine CDR.
6	Integrating meteorological, seismic and geophysical, hydrological, seabed and bathymetry, geological, biological, ecological, and human health data.
6, 8	Prioritising societally relevant datasets to identify and address underlying data gaps and interoperability issues.
10	Increasing emphasis on co-design with knowledge rights holders, local communities, stakeholders, social sciences and society.

2.5 Elements of the Strategic Ambition for Challenge 7

The expansion of GOOS is based on scientific, policy and societal requirements that depend upon observational data to generate products that can deliver actionable information. All of the steps in the value chain will require the establishment of partnerships, an adequate and trained workforce, and the resources to support the system (Figure 1).

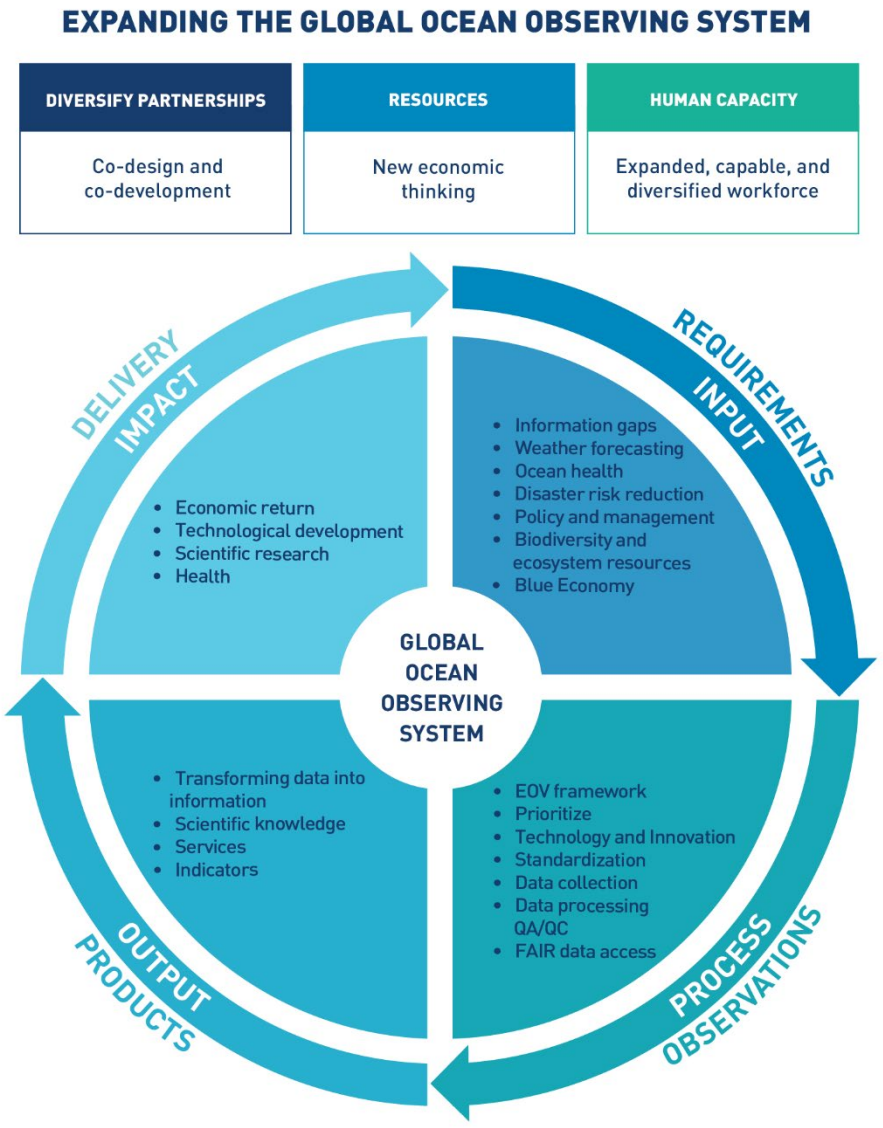

Figure 1. The value chain of ocean observations, from requirements to delivery, and the three overarching components needed across the value chain.

2.5.1 Priority datasets

Well-defined and prioritised 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 specialised knowledge or products or can be applied for management or policy setting.

Addressing climate change mitigation strategies and (near) real-time observations for decision-making capability for weather, ocean hazards and health should be the benchmark for a sustainably expanded GOOS. Reliable services are provided based on need and capability, with the ability to provide local information and forecasting for safety. 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.

In some regions ocean observing plans are developed or are being formulated, and these priority observations should be consolidated for any global prioritisation. Engagement with various sectors about industry data, knowledge rights holders, local communities and citizen

science will enrich and support a more integrated perspective to key ocean datasets. Observing 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 where we need observations as evidence there is a climate problem. Rather, ocean data to guide mitigation and adaptation responses is required. Funding priorities should be directed towards observations that can be linked to tangible actions.

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). The FOO (Lindstrom et al., 2012; Tanhua et al., 2019) provides the structure for priority datasets to be FAIR, TRUST (Transparency, Responsibility, User focus, Sustainability, Technology), CARE (Collective Benefit, Authority to control, Responsibility, Ethics), and integrated and interoperable for national, regional and global needs.

2.5.2 *Knowledge generation and sharing*

For knowledge generation to be fit-for-purpose, co-design with key users and stakeholders is required to ensure that an expanded GOOS meets a prioritised range of societal requirements. In addition, dialogue between sectors (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.

Collaboration with indigenous knowledge holders and local 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 revolutionising ocean modelling and observations and building a bridge between traditional knowledge and science, focusing on long-term planning and on shared benefits (Souza et al., 2023).

2.5.3 *Infrastructure and process requirements*

The current GOOS networks and their respective status are described in Annex A. To address expanded requirements, we need more of what we have and better, co-developed by scientists, 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. This can be achieved through OSE (Observing System Experiments) and OSSE (Observing System Simulation Experiments), which test the value of current observation types using data denial experiments but are currently computationally expensive and not widely used. Finally, integrating these elements to provide a 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 effort from the international community, in particular around data access and information sharing. Encouraging and facilitating exchange of information related to modelling advances among local communities will also be essential

to enhance the predictive capability around marine applications and services. Integrated, analysis-ready ocean observations and tools will democratise data for use in island nations, developing capacity-reduced countries. Improving our ocean observations along with our data processing and analysis capabilities through 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 standardisation, cost efficiency, data interoperability, and realising opportunities provided by new collaborations across regions, communities, and technologies. For this, the GOOS coordination and management infrastructure, currently consisting of approximately 20 people (including the OceanOPS operational centre), will need to increase commensurate to the dimension of the challenge, making sure 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 work in concerted with GOOS. The GOOS coordination and management team also needs to rely on a larger decentralised workforce where nations effectively contribute resources and in-kind support to this coordination body.

2.5.4 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, mobilisation of ocean finance tools and market incentives to strengthen and enable a transition to increased ocean investment is needed. Such strategic partnerships and collaborations across sectors should lead to locally adapted solutions, encourage the adoption of sustainable practices and investments in green technologies, and policies that ensure equitable access and benefit distribution among all stakeholders, particularly marginalised communities, and Indigenous Peoples. 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 standardised 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).

Linking observations to requirements delivers more useful and impactful information. Strengthening existing partnerships and building new national and international partnerships to share responsibilities in co-design, co-development, and co-delivery of usable products, 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 programmes, 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 additional social, political, and economic sectors.

2.5.5 Capacity development and exchange needs

Expanded and diversified cohorts of ocean professionals must be commensurate with a sustainably expanded GOOS by 2030. Ocean observations can only be acquired, critiqued and used by a skilled and trained workforce (Miloslavich et al., 2018). To meet the demands of an expanded global observing system, we need to train an army of people in a broad range of skills. This will require developing new curricula, as well as strengthening and expanding upon existing training programmes across the FOO (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). Locally developed training and innovation will ensure ocean-focused capacity is suitable for the relevant community, country, or sector (Miloslavich et al., 2022). By incorporating local knowledge through meaningful community co-design and participation, we can ensure observations are applied to priorities. This approach will be critical for the future sustainability of the system (Urban and Ittekot, 2022).

Encouraging the sharing of software, analytical tools, and capabilities (including training on use) will significantly reduce the need to duplicate effort. Similarly, the development of tools that are nimble and can run on mobile platforms will expand their usage. Partnering with cloud processing to handle the heavy lifting of data analysis will also be helpful to overcome on-the-ground capacity challenges. Disseminating tools and information in multiple languages would allow stakeholders across geographic regions, particularly in developing countries, to access and use observations for local solutions. Capacity building across the FOO is needed so that users including policy and decision makers are better equipped and confident using ocean data to inform their actions. As a community, the observing system facilitates knowledge exchange across all stakeholders by developing data-sharing standards, platforms, and systems accessible to all, including the private sector. This collaborative effort supports sustainable development of the Blue Economy addressing societal needs collectively.

The socio-economic value of ocean observations is significant, but it still lacks 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.

2.5.6 Technology and innovation solutions

The current ocean observing technology market is relatively small, fragmented, and focused on developed countries. Assets such as research vessels and other *in situ* observing platforms are distributed very unequally. We need to work to define our technology needs, discuss potential solutions with the private sector, and provide some idea of market size (Willis et al., 2024). The Argo programme revolutionised global observing and knowledge of the ocean-climate interplay, and is embarking on another step-change to OneArgo. Evolving the robust Argo platform using innovative technology approaches is an excellent demonstration of being responsive to changing user needs around ocean warming below 2000m (DeepArgo) and ocean carbon storage (BGC Argo). 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. Other established and emerging networks within GOOS (e.g. Ocean Gliders and Fishing Vessel Ocean Observing Network, FVON) are ready or close to ready for ocean forecasting of extreme events in coastal and ocean systems. Aggregating these efforts and focusing

technology development around community priorities (e.g. harmful algal bloom prediction or dynamic ocean management) is achievable to operationalise by 2030. Investments must be organised around needs if we want commercial production of easy to use and cost-effective technologies.

Barriers in technology and innovation will need to be lowered and ideally removed to ensure equitable access and use of ocean observing globally. Certainly, cost-effective technology for observing and managing assets will allow better uptake in SIDS and LDCs. Observing technologies will be more accessible when used together with AI and ML tools so that observations are more quickly translated into information for a range of users (indigenous, local community, science, industry). Integrating observations across platforms in an automated, operational way would democratise the access and use of ocean observations. Providing multi-disciplinary knowledge of ocean ecosystems contributes to a better understanding and prediction of ocean change and impacts on coastal communities.

3. 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 must be built in synchrony with the GOOS 2030 Strategy, be based on the Framework for Ocean Observing (FOO), and take into account recommendations from the OceanObs19 conference, with a vision towards OceanObs29 and the remainder of the Ocean Decade. Challenge 7 is integrative by nature and successfully achieving its milestones to 2030 and beyond cannot happen in isolation (Figure 2).

3.1 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 visualisation 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.

3.2 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 (2025).
2. Having identified and initiated the public-private sector partnerships needed to seek the resources for the development and deployment of innovative observing technologies (2026)
3. Having identified the pathway to unlock key existing but unavailable data and making it FAIR (2027).
4. Having developed the governance structure for the international coordination of the observing system,

strengthening the GOOS Management Team (including OceanOPS), unifying existing and new decentralised coordination components and data storage nodes (2026)

5. Having established and prioritised a new set of ocean indicators, building on the EOVs, that are co-designed with stakeholders (2028)
6. Having developed priority skills, suitable training programmes and resourcing to strengthen and expand human capacity (2029).

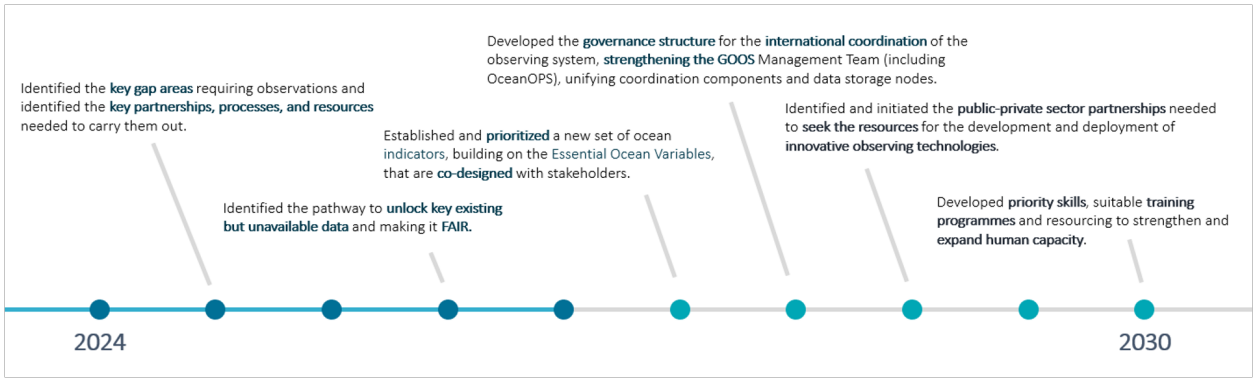

Figure 2. *Measures of success for Challenge 7 on Sustainably expanding the Global Ocean Observing System.*

4. SUCCESS TO 2030 AND BEYOND

By 2030, envisioned success for Ocean Decade Challenge 7 is to have achieved the key milestones articulated in section 4.1 and implemented the key recommendations articulated in section 1.2.

Beyond 2030, a successful fully expanded ocean observing system is envisioned to have achieved:

1. Sustained and expanded geographic coverage of the existing array of *in situ* and remote observing platforms, especially in remote and understudied regions (e.g. the high seas, the deep ocean, the polar oceans, the coastal areas of developing nations), 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.

2. The development of new, enhanced and cost-efficient technologies, sensors and platforms to fulfil critical science and knowledge gaps.

3. Strengthened international coordination and collaboration frameworks for the generation, access, processing, and use of ocean data, including developing artificial intelligence (AI) models and machine learning tools to extract more user-ready information from existing datasets, prioritised by their societal relevance and aligning with Essential Ocean Variables (EOVs). A major success will be to have all data made Findable, Accessible, Interoperable and Reusable (FAIR), TRUST (Transparency, Responsibility, User focus, Sustainability, Technology), CARE (Collective Benefit, Authority to control, Responsibility, Ethics).

4. Grown and diversified workforce through training, capacity development and knowledge sharing initiatives, involving coastal communities and stakeholders to actively participate in ocean monitoring and management.

5. Established sustained funding mechanisms for the ocean observing system, akin to those supporting meteorological observations, ensuring long-term operational continuity and resilience against science funding

uncertainties. This stable financial support would enable ongoing maintenance, upgrades, and expansion of observation networks, contributing to the sustainability and effectiveness of ocean monitoring efforts beyond the Ocean Decade.

6. Transformed public engagement and awareness on ocean (and climate) issues leading to greater support for sustainable ocean management policies and initiatives.

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Annex A: Ocean observing platforms and GOOS Status 2023

There are currently close to 8000 in situ ocean observing platforms monitored by the GOOS operational centre 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 14 global ocean observing networks that vary in stage of implementation (Figure A1:GOOS, 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 and metocean properties with an expansion of biogeochemical data in recent years.

Related to national programmes and/or regional networks, GOOS is organised 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 programme budgets, with EuroGOOS having a member fee base.

Figure A1: GOOS, Ocean Observing Report Card 2023, produced by OceanOPS

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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 thevision and mission of the Ocean Decade.

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