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Quo Vadimus

The cross-cutting role of Ocean Decade Challenge 7 in achieving a sustainable and resilient global ocean observing system

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Abstract

With more than 90% of global warming occurring in the ocean, sea level rise doubling in the past 30 years, and the ever-increasing frequency and intensity of extreme events, ocean observations are essential for understanding and addressing some of these most pressing global challenges. Known observational needs can be addressed immediately by upgrading and expanding ocean observing capacity in under-observed areas such as polar regions, island nations and territories, coastal areas of developing countries, rapidly changing coastal systems, and the deep ocean. Enhancing existing and developing new cost-effective technologies for a range of user needs to maximize the reach of essential observations, supported by standardization and best practices for interoperability. Improved spatial and temporal coverage is urgently needed but also needs to be co-designed and fit-for-purpose. Democratizing access to ocean data and integrating artificial intelligence and machine learning into data pipelines can help unlock existing observational datasets into societally relevant, user-ready information. Recognizing that ocean observations are essential to the planet's health is a critical cultural shift we must embrace in the next decade. Join us—individuals, organizations, governments, and communities—in turning this vision into action to ensure a sustainable and resilient ocean for future generations.

Keywords: global ocean observing; technology and innovation; capacity building; new economic thinking

Evolution and coordination of ocean observing

The ocean has been a vital resource for food, transportation, cultural practices, and exploration, intertwining human civilizations with marine environments for tens of thousands of years. Scientific observations of ocean variables began less than two centuries ago. While these observations were not initially well coordinated nor distributed globally (Benway et al. 2019), it was an important yet relatively recent first step in ocean observing. Over the intervening years, a range of programs have been developed that provide observations and understanding of the ocean's key role in climate change, ocean ecosystem health, ocean pollution, weather forecasting and responses to natural disasters, conserving marine biodiversity and habitats, managing sustainable aquaculture and fisheries, and underpinning the blue economy (Rayner et al. 2019). Sustained ocean observations are also used to inform and monitor the outcomes of national policies and international agreements (Miloslavich et al. 2024).

Ocean observing has evolved from ship-based measurements to a vast global network. Programmes like World Ocean Database and mechanical bathythermographs were transformational for their era. We now have multi-platform networks which comprise Argo floats, ocean gliders, surface drifters, fixed buoys, to name a few. Sustained autonomous observing systems in the Southern Ocean, a vastly challenging, yet climatically critical region, have led to a surge in understanding of the interconnectivity between foundational ecosystems, its frozen landscape, and the fragility of Antarctic systems to shifts in climate. At the same time, the vast data we have gathered through ocean observing have led to groundbreaking discoveries about ocean workings and ecosystem function, discoveries which in turn have opened possibilities to new energy resources and pharmaceutical breakthroughs, enhancing the global economy.

Ocean observing programmes are mostly distributed strategically and prioritized to fill information gaps and address

societal needs. Coordination and frameworks of ocean observations and platforms are led by the Global Ocean Observing System (GOOS) of the Intergovernmental Oceanographic Commission (IOC)-UNESCO. GOOS is the global hub for ocean observing management, planning, and strategy focused on climate, weather and hazard warnings, and ocean health and sustainability.

The GOOS 2030 Strategy (IOC-UNESCO 2019, IOC-UNESCO 2022), the Framework for Ocean Observing (FOO, Lindstrom et al. 2012, Tanhua et al. 2019), and the decadal OceanObs conferences have articulated challenges that the current ocean observing system faces and proposed recommendations for expansion (Speich et al. 2019). We envision a roadmap for the next decade of ocean observing scaffolding on these global and community contributions (Miloslavich et al. 2024). The major challenges to achieve this vision are resourcing, human capacity, and diverse partnerships to enable equitable access to key observations, information and knowledge across the world's ocean and coastal regions (Weller et al. 2019). Expansion of the GOOS needs to be based on scientific, political, economic, and societal requirements that use observational data to generate products that can deliver actionable information.

A decadal vision for societally relevant ocean observing

Achieving sustainability and resilience of ocean observing globally is a marathon, not a sprint. Technology advances are enabling progress toward sustainable ocean observing, and the machine learning/artificial intelligence (AL/ML) era is positioning us at the verge of a leap forward in understanding what, where, and how much data are needed to address urgent and timely questions about our changing planet. Success relies on the transformation of human conscience that ocean observing is an essential service for society.

Recommendations for a sustainable GOOS occur across the value cycle of ocean observations, from societal requirements (both discovery-based and use-inspired), observations, products, and information delivery within three cross-cutting actions: fostering diversified partnerships to co-design observing systems, building a capable and trained workforce, and developing new, creative economic models to resource ocean observing efforts (Fig. 1). Specific recommendations which need to be tackled *synchronously* to achieve a vision of a sustainable and resilient GOOS are:

1. Cross-cutting actions for success

Foster diversified partnerships to co-design observing systems. Collaboration and integration will be needed across many key partners, from governments, intergovernmental organizations, policymakers, and the scientific community to the private sector, philanthropy, Indigenous peoples, and local communities. For example, within the private sector, ocean observations will be especially relevant and vital for ocean- and marine-related industries such as shipping, ocean renewable energy, insurance and reinsurance, blue carbon, and nature-based climate solutions, which combined have the potential for substantial contributions to the global economy (Hermes et al. 2022).

Develop and expand a capable and diversified workforce. A larger, diversified, skilled, and trained ocean observing workforce underpins the success and sustainability of an expanded ocean observing system (Miloslavich et al. 2019, Miloslavich et al. 2022). Training and capacity development will be critical across the observing landscape; from data collection to data analysis and modeling, and for data use and application across the coastal to deep ocean observing value cycle (Urban and Ittekot, 2022). Diverse skillsets developed from ocean observing are in growing demand in the private sector, and this workforce is an asset to the global economy.

Foster new economic thinking. Ocean observing directly benefits the blue economy. A clearly articulated value proposition for stakeholders, investors, and the broad range of users of these assets is required for transformation in ocean observing. Diversifying financing mechanisms for a sustained global ocean observing is just as critical, including resourcing for Small Island and Developing States and Least Developed Countries. Using inclusive economic models for ocean investment is fundamental to diversifying and accelerating investment in ocean observing, infrastructure, and developing capacity from new actors (Sumaila et al. 2021).

2. Strengthening of the framework for ocean observing

Co-designing the observing system with diverse partners (Requirements). Embracing the abilities and needs of different stakeholders focusing on co-design and partnerships, as well as collaboration with industry partners and other right holders and stakeholders (Elegbede et al., 2023, Proulx et al. 2021), to secure appropriate and impactful design across sectors.

Supporting and enhancing global observation capabilities (Observations). Upgrading existing observing capabilities and strategically expanding observation capabilities to critical under-observed regions such as polar regions, island nations and territories, coastal areas of developing countries, rapidly changing coastal systems, and the deep ocean (Miloslavich et al. 2024).

Leveraging technological and social innovations (Observations). Accessible and cost-effective technologies that are suitable to a range of users need to be continued and accelerated. A fundamental premise is the advancement of cutting edge technology for a variety of applications that will provide a return on investment for developers and industry. Technology barriers need to be lowered toward zero to ensure equitable access and use of observing assets. ML/AI tools will maximize use of existing data and provide user-ready information from integrated observations to democratize access and use. New collaborations across governments and non-government entities, academic institutions, Indigenous peoples, local communities, and the private sector will be vital to achieving these ambitions.

Improving translation of data into actionable and relevant information (Products). Data integration across systems and platforms to generate accessible products that can be transformative, actionable, and suitable for experts through to non-technical users will be required. The ML/AI era has the potential to advance data processing, product generation, distribution, reach, and discovery. Developing a pathway to unlocking existing but unavailable data (e.g. government and industry) and aligning with best practices (Carroll et al. 2021) should be prioritized to ensure broad access to more comprehensive products and information. Equally important will be enabling fit-for-purpose, long term data storage platforms.

Driving cultural change in ocean observing globally (Impact). Ocean observing must be recognized as an essential

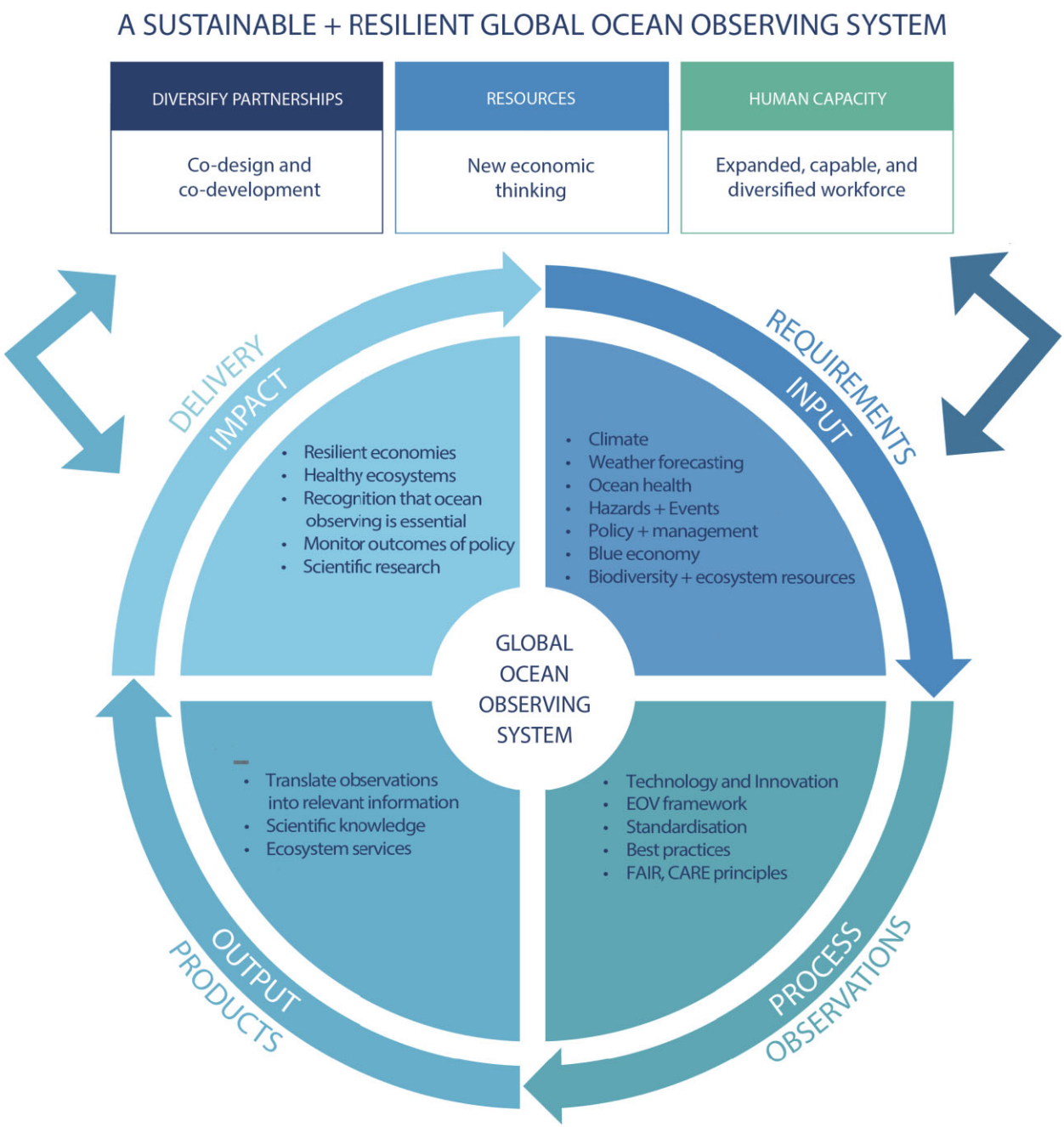

Figure 1. The value cycle of ocean observations, from information gaps, priority observations, scientific discovery to technological development, including three cross-cutting themes relevant to all steps in the value cycle. The process is iterative, nonlinear, and often occurs over many cycles.

need for everyday life. This requires improvements in local, national, regional, and global messaging and coordination that use the GOOS framework to ensure standards and principles are entrained into an expanded and interoperable GOOS (Moltmann et al. 2019).

Toward a future of sustainable and resilient ocean observing systems

An expanded ocean observing system must deliver accessible, timely and actionable ocean data and information to nations and users across all ocean basins. This improved system needs to be nimble and resilient to change yet allow for enhancements to improve global ocean observation capabilities that fill today's knowledge gaps and produce tomorrow's solutions. Transforming ocean data into useful information will require integration across disciplines, national and regional observing systems, and stakeholders. It will also require the implementation of innovative and diversified alternatives to current technological, cultural, capacity building challenges, and adopting new and collaborative resourcing models for ocean observing.

A dynamic, adaptive, and coordinated GOOS is essential to safeguarding healthy ocean environments, thriving ecosystems, and resilient coastal economies. Recognizing that ocean observations are essential to the planet's health is a critical cultural shift we must embrace in the next decade. We must act now to build and strengthen this system, ensuring a

sustainable and equitable relationship with the ocean for future generations. Join us—individuals, organizations, governments, and international communities—in shaping this vision and taking decisive action to protect our ocean and secure its future.

Looking ahead, AI-driven analysis and machine learning will further revolutionize ocean monitoring, optimizing data processing, predicting trends, and improving decision-making. As technology advances, we stand on the brink of unprecedented insights into our oceans, fostering a more sustainable future.

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Author contributions

This manuscript was written by members of the UN Ocean Decade Vision 2030 Working Group 7. Joe O'Callaghan: Conceptualization, Writing – Original Draft, Writing – Review & Editing, Project Administration; Patricia Miloslavich: Conceptualization, Writing – Original Draft, Writing – Review & Editing; Laura Lorenzoni: Conceptualization, Writing – Original Draft, Writing – Review & Editing; Erin Satterthwaite: Conceptualization, Writing – Original Draft, Writing – Review & Editing; Nicholas Rome: Writing – Original Draft, Writing – Review & Editing; Irene Schloss: Writing – Original Draft, Writing – Review & Editing; Michelle Heupel: Writing – Original Draft, Writing – Review & Editing; Isa Elegbede, Writing – Review & Editing; Marcos Fontela, Writing – Review & Editing.

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Data availability

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