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Open Access Earth System Science Data Discussions

Unifying global ocean data: an urgent call and roadmap

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Abstract

The ocean faces escalating stress from warming, acidification, deoxygenation, biodiversity loss, and pollution. Robust ocean data are indispensable for advancing fundamental research and for generating the actionable knowledge urgently needed for society to navigate a changing planet. We have entered a new era in which scientific progress and critical societal decisions hinge on our capacity to integrate and synthesize data across institutions, national borders, observation platforms, and disciplines. Yet the global ocean data landscape remains deeply fragmented, constrained by institutional silos, inconsistent standards, and outdated policies. Here, we introduce a modernized framework for global ocean data management built on four foundational pillars: policy-driven integration, unified direction through alignment with scientific needs, sustainable long-term stewardship, and rigorous version control. Realizing this vision will require coordinated action on three fronts: (a) reforms to remove policy barriers to data sharing; (b) sustained engagement with the scientific community to develop research-aligned metadata schemas, controlled vocabularies, and data standards; and (c) long-term investment in globally integrated, interoperable data infrastructure. Together, these efforts will enable seamless global data integration, open new horizons in ocean science, and strengthen economic resilience for present and future generations.

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The ocean is the largest and most consequential component of the Earth system, yet it faces escalating stress from warming, acidification, deoxygenation, biodiversity loss, and pollution (Richardson et al., 2023; Findlay et al., 2025). Robust ocean data are indispensable not only for advancing fundamental research but for underpinning practical applications, including weather forecasting and early warning systems, maritime safety, marine ecosystems and biodiversity, food security, and the growing ocean economy (Chai et al., 2026).

Technological advances have substantially expanded the spatial and temporal coverage of Earth observations, ushering in a new era in which scientific progress and critical societal decisions hinge on our capacity to integrate and synthesize data across institutions, national borders, observation platforms, and disciplines (IOC-UNESCO, 2025). However, the current global ocean data landscape remains deeply fragmented, divided by institutional silos, inconsistent standards, and outdated policies that prioritize national interests over open access (Haimson et al., 2025). This disjointed model hinders data reuse and integration and undermines the actionable knowledge urgently needed by policymakers and resource managers to navigate a changing planet (Brett et al., 2020). To address this challenge, we introduce a modernized framework for global ocean data management that will enable seamless global data integration, advance our understanding of the rapidly changing ocean, and support economic resilience and well-being for present and future generations.

What data management is—and is not

Designing effective data strategies requires a shared understanding and consistent implementation of the FAIR principles, ensuring that data are Findable, Accessible, Interoperable, and Reusable (Borgman, 2015; Wilkinson et al., 2016). However, "data management" is often mischaracterized or conflated with data-driven research. At its core, data management encompasses critical functions: (i) archiving data in trusted, long-term repositories with version control; (ii) creating and maintaining rich metadata that document data collection and enable discovery; (iii) applying controlled vocabularies to promote consistency and enhance discoverability; (iv) assigning persistent identifiers and supporting data citation to ensure reproducibility, attribution, and impact tracking; and (v) providing services that make data discoverable and accessible to users.

In contrast, downstream data-related research activities, such as synthesis, climatology construction, algorithm development, and model development, are essential hallmarks of scientific inquiry but do not fall under the umbrella of data management. Like all research activities, they depend on robust data management services to access high-quality input data and ensure that their outputs are FAIR-compliant. Failing to distinguish between these roles risks diverting resources away from foundational data infrastructure and obscuring the vital role of data management in supporting ocean research and broader applications.

Critical roadblock: fragmentation

The current global ocean data management landscape suffers from deep fragmentation. This issue stems from funding mechanisms that promote siloed data management, outdated and inconsistent data policies across institutions and agencies, and geopolitical barriers that restrict seamless international data sharing (Brett et al., 2020; Haimson et al., 2025). As a result, datasets are scattered across repositories with incompatible metadata schemas, inconsistent controlled vocabularies, and divergent data standards. This lack of standardization creates a chaotic "Tower

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of Babel" effect, limiting scientists' ability to discover, integrate, and synthesize data, and ultimately hindering scientific progress.

Transformative framework to unify ocean data

To propel modern ocean research forward, a fundamental overhaul of global ocean data management is essential, with data reuse and synthesis as core objectives. The proposed framework is built on four foundational pillars:

1. **Policy-driven integration:** Nations are recommended to systematically review and revise their regulatory and policy frameworks in support of a unified global approach to ocean data management. This involves:
    - Transitioning from disjointed, agency-specific strategies to cohesive national and trans-national plans
    - Eliminating barriers to cross-border data sharing
    - Encouraging publicly funded data to be deposited in interoperable repositories aligned with international metadata schemas, controlled vocabularies, and data standards.

    Nations with limited resources should prioritize removing policy barriers that prevent scientists from accessing trusted international data centers.
2. **Research-aligned model:** The new framework should place scientific data needs at its core, ensuring unified direction and preventing repository-driven fragmentation. This requires close collaboration with researchers to:
    - Develop comprehensive, cross-disciplinary, and broadly applicable metadata templates that allow individual communities to adopt relevant subsets (Jiang et al., 2015).
    - Create discovery-oriented controlled vocabularies that separate attributes, such as units and measurement contexts, to enhance data discoverability (IOC-UNESCO, 2010; Leadbetter and Vodden, 2016).
    - Standardize shared terminology, calculation methods, quality control flags, and missing value indicators (Jiang et al., 2022).
3. **Sustainable long-term stewardship:** Preserving data over the long term requires sustained investment in resilient, geographically distributed infrastructure, with secure replication across both online and offline systems (Phillips et al., 2013). This should be recognized as a mission-critical function, distinct from the day-to-day data accessibility. Data assembly centers (DACs) lacking archival capabilities should partner with trusted archives to ensure systematic and secure replication, with digital object identifiers (DOIs) minted by archives rather than DACs.
4. **Rigorous version control:** Dataset publications should follow the same stringent standards as peer-reviewed journal articles: each published version should remain immutable, with updates generating new versions. A structured DOI framework should link all versions

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under a parent DOI, providing default access to the latest release while preserving the complete version history.

The path forward

Ocean data management is currently at a critical juncture. Over the coming decades, progress in ocean research, from understanding biogeochemical cycles to safeguarding marine biodiversity, will hinge on our ability to integrate observations at a global scale. This requires a fundamental shift in how we design and implement ocean data systems, moving beyond fragmented, repository-centric practices towards a cohesive research-aligned model that prioritizes data reuse, synthesis, and collaboration among researchers, data managers, and end-users.

Achieving this vision requires actions along three fronts. First, the Intergovernmental Oceanographic Commission (IOC) is well positioned to lead a policy-driven global initiative to dismantle data-sharing barriers and foster interoperability across ocean data systems (IOC-UNESCO, 2013; IOC-UNESCO, 2024). Second, ongoing engagement with the research community is essential to ensure that data management practices align with scientific needs by adopting data frameworks developed by and for the scientific community, including metadata schemas, controlled vocabularies, and data standards. Third, sustained investment in a globally integrated, interoperable infrastructure, anchored in existing networks such as the International Oceanographic Data and Information Exchange (IODE), including its National Oceanographic Data Centers (NODCs) and Associate Data Units (ADUs), will be pivotal to success. Together, these efforts will enable seamless global data integration, drive innovation and open new horizons in ocean science.

Data Availability: Does not apply.

Code Availability: Does not apply.

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