OceanObs'19 Community White Paper Synthesis
A summary of recommendations

Community White Papers (CWPs) have been an integral part of the OceanObs conference series, garnering the collective knowledge of the community to evaluate and propel the efficacy of our global and regional ocean observing networks. During the early planning stages of OceanObs'19, the community was invited to submit abstracts that address improving connections between end-users and providers of ocean observations, opportunities for more integration at the global and regional levels, and the conference themes, and provided a forward-looking vision for the next decade. The community responded with an overwhelming number of concepts and ideas: 430 abstracts written by an estimated 2,400 authors from over 60 countries. The OceanObs'19 program committee reviewed the abstracts and asked the authors to collaborate and refine their concepts into 140 CWPs. Here we provide a synthesis of the 104 papers that were available at the time of writing. This synthesis will be used to inform conference goers, among many other documents available.

The ideas in this synthesis are extracted from the *summary recommendations* made by the community white papers. As such, they are an amalgamation of a range of individual views, but they do not necessarily represent the whole picture, either across the ocean observing community, nor do they address gaps that may not have been identified through the white paper process. Moreover, many underlying themes emerged from the CWP recommendations, which this synthesis attempts to capture; however, citations are included for the reader to refer to the individual CWP for further details.

The primary conference topics of Information, Innovation, Integration, and Interoperability along with the overarching question of Governance are uniquely reflected in the submitted OceanObs'19 CWP recommendations. Observing systems are evolving alongside the exponential growth in ocean data, with emphasis on monitoring essential ocean variables to understand the complexity of the physical, chemical, and biological processes. Balancing this growth in ocean information with increasing desire for accurate and reliable information, the ocean observing community faces new challenges related to data storage and accessibility, along with meeting those needs in more remote places below the ocean surface and across the planet.

Based on recommendations provided by lead authors, which were reviewed by the program committee members, along with the peer reviews to the CWPs, the following synthesis summarizes the high-level recommendations with respect to the topics of Information, Innovation, Integration, Interoperability, and Governance in ocean observing systems moving forward into the future.

Week-long Themes
Governance and Interoperability

The themes of "Governance" and "Interoperability" focus on future improvements to ocean observing systems. As we advance technologically, collect volumes of data exponentially, and continue expanding observations globally; the need for more robust communication and governance grows to sustain observing networks. The recommendations in this section are meant to address the following questions:

Governance: *How do we continue to provide advocacy, funding and alignment with best practices and designate responsibility for product definition, including production and timely delivery at the appropriate scales?*

Interoperability: *How can we better communicate among observing systems to deliver products for users that follow usability and other best practices across the globe?*

Recommendations

Governance

1.1 Scale: Focus development and implementation of observation systems on **regional scales** due to the unique **needs of** both **local environments** requiring modified technologies (e.g., Arctic versus tropical observing systems) as well as the **capacities of local communities** to support science and technology (Barth et al., $Smith_A$ *et al.*, Snowden *et al.*, Cross *et al.*, Kaiser *et al.*, Obura *et al.*, Tilbrook *et al.*, McCurdy *et al.*).

1.2 Management: Establish **regional ocean management** organizations to **coordinate among international ocean governing bodies**, and therefore expedite progress towards sustainable management of the oceans (Hartman *et al.*).

1.3 Evaluation: Develop **common observation evaluation systems** to ensure **universal standards** for observing system effectiveness ($Sloyan_A$ *et al.*, Kent *et al.*, Bontempi *et al.*).

1.4 Communication: Focus needs to be placed on the development of **communication materials**, especially as they relate to the **development of policy** surrounding ocean observing and monitoring outcomes (Cross *et al.*, Levin *et al.*, Obura *et al.*, Wenhai *et al.*, Powers *et al.*, Vance *et al.*).

1.5 Data: Efforts need to be made in the **accessibility of data and the associated documentation**. The **Findable, Accessible, Interoperable, Reusable (FAIR) principles** of data should be encouraged among all observing systems (Miguez *et al.*, Levin *et al.*, McCurdy *et al.*, Vinci *et al.*, $Tanhua_B$ *et al.*, Pearlman *et al.*, $Sloyan_B$ *et al.*).

Interoperability

1.6 Engagement: Public engagement, from the use of **citizen science** to **public forums** and **workshops** on the use and implementation of observational data, needs to be emphasized to ensure we are creating **products that are accessible and sustainably target the needs of the user community** on all scales (Cross *et al.*, Angove *et al.*, Iwamoto et al. MacKenzie *et al.*, Meinig *et al.*, Wang *et al.*, Todd *et al.*, Roemmich *et al.*, Buck *et al.*, Simoniello *et al.*).

1.7 Collaboration: Workshops and working groups need to focus on the cross- and trans-disciplinary use of observational systems. Observation systems need to focus on a "**Fit-for-purpose" design** to ensure **multiple effective uses for a single observing framework** ($Sloyan_B$ *et al.*, Benway *et al.*, Obura *et al.*, She *et al.*, Canonico *et al.*, Anderson *et al.*).

Daily Themes
Tuesday: Information

The outcome theme of “Information” focuses on the opportunities to define user needs, thereby highlighting potential pathways to increase access to observational data and enhance product delivery pathways. It includes the need to conduct a gap analyses and system reviews to determine whether adequate channels exist to characterize science and technology requirements, define what data are needed to better serve user communities, and guide the evolution of observation systems to create ocean-related products. The recommendations in this section are meant to address the overarching question of:

How do we meet future user needs?

The recommendations for addressing the outcome theme of “Information” were based on the information of 37 CWPs. With increasing reliance on forecasting systems and the need for knowledge informing sustainable use of the ocean, the amount of information regarding our oceans that is also accessible to the user community has been on the rise. These recommendations reflect this importance by highlighting the value and effectiveness gained from using systematic evaluations supported by a common standard from the end-user community. The recommendations suggest that doing so will ensure the development of future technologies and observing systems that are sustainably implemented and useful to the user community. (Sloyan$_A$ *et al.*, Kent *et al.*, Bontempi *et al.*, Roemmich *et al.*, Todd *et al.*, Benway *et al.*). The need for increased user buy-in and support must be established as the authors reflect on the increased need for higher spatial and temporal resolution data to increase forecasting accuracy and provide valuable details on dynamic ocean processes (Boas *et al.*, Vinogradova *et al.*, Morrow *et al.*, Smith$_A$ *et al.*, Szuts *et al.*).

Recommendations

2.1 Technology Development: Generate a **research and development roadmap** for developing low-cost *in situ* sensors for biogeochemistry- and ecosystem-related variables by enhancing related technologies (Wang *et al.*, Fennel *et al*., She *et al.,* Jamet *et al.*). **Better strategies for funding and engagement** of different sectors need to be enacted to secure capable partners in this effort (Wang *et al.*, Williams *et al.,* Schmidt *et al.*, Janzen *et al*., Vinogradova *et al.,* Smith$_A$ *et al.*).

2.2 Governance: Encourage **global coordination and effective governance** of **open and sustained data mechanisms/systems**. These should be focused on expansions for supporting best practice discovery, access and training, and preferably be guided by an international organization, such as the Intergovernmental Oceanographic Commission (Pearlman *et al.*). Such global networking and coordination should also be implemented to minimize regional gaps in all aspects of observing and governance (Obura *et al*., Straneo *et al.*).

2.3 Data: Create a **standardized protocol to facilitate transformation from observing to information and users**, which is best done through co-design and communication at the level of intermediate users or downstream service providers (e.g., the Copernicus Marine Service perspective) (Traon *et al.*, She *et al*., Bange *et al.,* Newman *et al*., Vance *et al.*, Powers *et al.,* Freeman *et al.*).

2.4 Evaluation: Enhance **data modeling- and assimilation-based observing system evaluation** efforts through closer collaborations between observers, modelers, and users (Fujii *et al.*, Ostrander *et al.*). Quality control and assurances of all current and implemented systems is needed (Kent *et al.*).

2.5 Emerging Needs: Better information needs should be researched in the **emerging service sectors,** such as the blue economy and maritime safety, to better serve sustainable development goals (Angove *et al.*, Stroker *et al.,* Domingues *et al.,* Goni *et al.,* Turk *et al.*). Fit-for-purpose designs are needed to address the emerging needs for biological observations which leverage existing multi-disciplinary and multi-sectoral partnerships, integrates biology with physical and biogeochemical ocean observations and. maximizes access to data and information products (Barth et al., Canonico *et al.,* Lombard *et al.,* Batten *et al.,* Capotondi *et al.,* Anderson *et al.*).

Wednesday: Innovation

The outcome theme of “Innovation” seeks to identify new developments, technologies and practices aimed at addressing the needs of the user community and enabling visionary new science. The recommendations in this section are meant to address the overarching question of:

How can we spur innovation in observing technologies, products, and user services?

The recommendations for addressing the outcome theme of “Innovation” were based on the information of 18 CWPs. Growing needs for increased data resolution, sustainable observations, and accessible products is spurring progress in innovation. Research and development of sensing technologies needs to be continuously encouraged and funded, working towards innovative solutions that address growing needs. Key areas of focus should include: developing low-cost, high-value platforms; increasing lifespan/runtime of systems; increasing efforts in the sector of autonomous sensing; and tightening linkages between remote and *in situ* observations (Massagram *et al.*, Ponte *et al.*, Roemmich *et al.*, Whitt *et al.*, Traon *et al.*). Focusing on regional issues, the polar regions play a key role in ocean dynamics and the global climate yet are some of the most limited regions in terms of observations. Their harsh environments have made implementing the observing technologies used in the rest of the world difficult. Technology to withstand these environments should be pursued to ensure that we bridge important knowledge gaps in these important and rapidly changing regions (McCammon *et al.*, Smith_A *et al.*, Goni *et al.*). A broad focus on these ideas is key in developing the targeted outcomes needed to address and steer innovation.

There are many gaps identified in technology and innovation. The CWPs touched upon unmanned systems, especially unmanned surface vessels (USVs), remote sensing, cabled systems, drifting buoys, high frequency radar, sea level measurement and some system of system concepts. The diversity of the CWPs is notable, few reinforce each other but all present strong arguments for their particular technology.

Recommendations

3.1 Technology Development: Update existing observing systems with new sensors and technologies, such as **biosensors** and those that can collect **wave data** and measure **biogeochemical variables** (Chen *et al.,* Whitt *et al.,* Morrow *et al.*). Operators must **keep track of new sensor technologies and propose new fields of research and monitoring,** such as environmental studies, marine litter, and marine noise.

3.2 Remote Sensing: Provide better *in situ* support for **satellite technologies** (Chen *et al.,* Whitt *et al.,* Morrow *et al.*)**.** Continue to **sustain satellite derived SST time-series** and further develop drifting buoys to calibrate SST (O’Carrol *et al.*). Artificial intelligence techniques and **integrated physical-biological satellite sensors should be developed** to open a new window for interdisciplinary studies of the ocean, including exploring **the role of small mesoscale and sub-mesoscale dynamics** in the ocean circulation (Chen *et al.,* Morrow *et al.*).

3.3 Improved Observations: The ocean observation community should make strides to incorporate additional measurements into observational frameworks. The use of **cabled subsea systems** and the inclusion of **ocean bottom pressure** as an essential ocean variable should be considered (Howe *et al.*). The community should commit to sustained, systematic and complementary **global and coastal measurements of sea level** and its components to understand observed variability and change, constrain longer term projections, and improve the skill of forecasting and early warning systems (Ponte *et al.,* Benveniste *et al.*). The development of **coastal observing networks based upon cameras** should be encouraged (Sloyan_A *et al.*).

3.4 Platform Concepts: Focus on **low-cost, ubiquitous solutions** to platform development accessibility, thus expanding the ocean observation community to better reach the public and STEM education systems. An international workshop should be convened to establish community consensus on the needs and priorities for unmanned surface vehicles in the global ocean observing network and their contributions to forecast models. There should be more creative designs to **extend the reach and reduce costs of autonomous systems** (Sloyan_A *et al.*).

3.5 Collaboration: Continue fostering **close collaboration between the private sector and the regional ocean observing community**, leveraging the strengths of each to fill regional observing and forecast gaps (Massagram *et al.,* Whitt *et al.*). A **broad variety of observations** need to be made with a long-term, sustained perspective, and integrated framework: Consider the value of broad ocean observations enabled by **teams of platforms/systems** (Benveniste *et al.*). The community should push forward the establishment of blue partnerships around the globe, make mutual efforts **to foster the new driving force of blue economy,** explore new markets, and explore topics promoting **sustainable development of the seafood sector** (Lu *et al.,* Meinig *et al.*).

3.6 Data: Data Assimilation practitioners should **make better use of existing observations**, particularly **using coupled data assimilation and other emerging approaches**. The ocean data assimilation and modelling communities must work with the ocean observing community to establish protocols for rapid communication and ingestion of ocean observing data to enhance data uptake, benefit, and assimilation (Penny *et al.,* Ponte *et al.*).

3.7 Governance: Form a working group of the established Data Buoy Cooperation Panel (DBCP) to focus on **best practices** and standards for sensor integration, verification and data delivery, validation-calibration procedures must be established in a more comprehensive and interoperable way for successful sustained observing (Meinig *et al.,* Palazov *et al.*). Provide **Guidance to technologists for integration into unmanned vehicles** (Meinig *et al.*).

Thursday: Integration

The outcome theme of "Integration" seeks to increase sharing of and access to ocean observation information with a focus on regional engagement, capacity building, and increased coordination of diverse information. The recommendations in this section are meant to address the overarching question of:

How can we balance user and operator needs, capabilities, and knowledge worldwide?

The recommendations for addressing the outcome theme of "integration" were based on the information of 41 CWPs. Many underlying themes emerged including: governance; cooperation; capacity building; indigenous knowledge; stakeholder interactions; data availability; observing best practice, technology development; and the Global Ocean Observing System (GOOS). As the global ocean observation community continues to grow, a focus on integrating platforms and information is necessary to maintain observational sustainability goals and make more robust use of observing resources. Capacity building in the ocean observation community is essential to ensuring greater adoption and proper use of observing systems that fully satisfy end-user needs. As the field of ocean observing continues to turn over, the community must focus on maintaining the longevity of these frameworks and facilitating seamless technology transitions as these systems become increasingly advanced and robust (Mackenzie *et al.*, Hartman *et al.*, McCurdy *et al.*, Obura *et al.*, Davidson *et al.*, Vance *et al.*). Along with maintaining systems, increased multidisciplinary efforts need to be encouraged to enable system designs that capture an increased amount of information from fewer platforms (Hartman *et al.*, Sloyan_A *et al.*, Sloyan_B *et al.*, Stroker *et al.*). Addressing these overall concerns can help create a more holistic and efficient observation community.

Recommendations

4.1 Collaboration**:** The ocean science community needs to **converge around global challenges and common objectives**, such as the **Sustainable Development Goals** and the **Paris Agreement** on the mitigation of extreme climate change (Mackenzie *et al*., Hartman *et al.*). Improving links between observing networks, modeling, and operational communities that use data to generate information products is necessary to meet the expanding requirements for multidisciplinary ocean observing (Todd *et al.*, Davidson *et al.,* Muelbert *et al*., Heimbach *et al.*).

4.2 Engagement: **Increase stakeholder engagement along the whole marine knowledge value chain** to understand and raise support for observing system requirements (Bailey *et al.*, Barth *et al.*, Iwamoto *et al.*, Levin *et al.,* Tanhua_A *et al.,* Roemmich *et al.*). Stakeholder engagement must include all those who stand to benefit from the enhanced capacity to **ensure ownership and commitment** to the process of ocean observing and its successes (Cross *et al.*, Simoniello *et al.,* Iwamoto *et al.,* O'Callaghan *et al.*). Additionally, it is important to **incorporate local and indigenous peoples and their knowledge** into the scientific process, which provide region-specific historical knowledge that grounds our understanding of the oceans and its importance to communities (Kaiser *et al*., Iwamoto *et al.,* Stewart *et al*.).

4.3 Scale: To integrate local through global scales, **regional alliances** bringing communities together should be set up to allow both bottom-up and top-down approaches (Barth *et al.,* deYoung *et al.*). Regional ocean management organizations should **establish ambassadors to coordinate among international ocean governing bodies** to assure the global scale is addressed (Hartman *et al.*).

4.4 Continuity: There needs to be **a consistent set of guidelines to frame best practices for future ocean observing system reviews**, building upon the collective experience of past and ongoing efforts, potentially using a regional certification process to assure consistency (Sloyan_A *et al.*). An emphasis on identifying, sharing, and following lessons learned and best practices across the observing community is also needed (Snowden *et al.*).

4.5 Capacity Building: An **ocean observation capacity development strategy** must be sustained and enhanced with stronger partnerships, new funding models, innovative technologies, and new training approaches (Muelbert *et* *al.,* Tilbrook *et al.*). The community must develop global capacity supporting collection, analysis, and interpretation of ocean observations, especially in areas with fewer coastal and ocean observing assets, such as developing or resource-poor countries (Garcon *et al.,* Mackenzie *et al.*). Enacting **national and international legislation** that promotes and develops capacity building and technology transfer is needed to realize these goals (Hartman *et al.*). Adapt solutions to ensure they work for all, such as low-bandwidth versions of websites or locally hosted data repositories to enable access broadly across all communities (Kaiser *et al.*, Buck *et al.).*

4.6 <u>Data</u>**:** Data sets should be increasingly interoperable, allowing for **more integration and comparison among existing and new datasets** (Evans *et al.,* Buck *et al.*). To ensure interoperability, data should utilize **Findable, Accessible, Interoperable and Reusable (FAIR) principles**, in a **timely way** with appropriate associated **metadata** (Levin *et al.,* $Tanhua_A$ *et al.*, Buck *et al.*, Miguez *et al.*). There is a need to move beyond data portals to **service-based architectures** that include information on data provenance, persistent data set and product IDs, cybersecurity protection, and empower communities to develop services that serve their specific needs (Buck *et al.*, Miguez *et al.*, Ardhuin *et al.*).

4.7 <u>Technology Development:</u> **New technologies that allow for better integration and greater value from data should be embraced and promoted.** Technology advances should include:

- Frameworks around the data analytics, the Internet of Things and Artificial Intelligence approaches to big data. (Nichols *et al.*)
- Provision of bandwidth and power to submarine cables. (Trowbridge *et al.*)
- Working with technology developers to improve the availability, affordability, reliability, and longevity of floats, autonomous sensors, and other observing technologies. ($Sloyan_B$ *et al.,* Roemmich *et al.,* Woelfl *et al.,* $Smith_C$ *et al.*, Gonzalez-Pola *et al.*)
- Integration of data across time series and platforms (Davidson *et al.,* Jeong *et al.*) A global operational program of underwater gliders (deYoung *et al.)*

A **cost-benefit** should be determined in tandem with new technology development for the **maintenance of observing systems that have proven their long-term value** (Foltz *et al.*).

4.8 <u>Emerging needs:</u> The global community should routinely **review the ocean observing value chain** activities by evaluating the:

- requirement setting process, ($Tanhua_A$ *et al.*)
- coordination of observing systems, (Tilbrook *et al.,* Howe *et al.*)
- data management and information products. (Garcon *et al*.).

Fora are needed to foster international community development, bringing the observations, governance, services, research, private sector, and end-user communities together to guide evolution of observing systems as user requirements change (Iwamoto *et al.*, Woelfl *et al*., Benway *et al.*).

4.9 <u>Improved Observations:</u> The increasing focus on coupled ocean atmosphere prediction leads to the need for **additional observations with collocated information**. Including:

- Direct flux estimates and boundary layer measurements of **ice, ocean, waves, currents and winds.** (Cronin *et al.*, Ardhuin *et al.)*
- **Biogeochemical** and **biological parameters** along with integration with physical and chemical observing systems and modelling initiatives. (Anderson, *et al.*, Canonico *et al.*, Bailey *et al.*, Roemmich *et al.,* deYoung *et al.,* Benway *et al.,* Foltz *et al.*)
- **Surface currents at mesoscales**, improved **vertical resolution** to compute advection and net surface heat flux and resolve biologically relevant processes, and expanded **monitoring of the deep ocean** are needed. (Boas *et al.*, Levin *et al.*)
- Increased observations in polar oceans ($Smith_D$ *et al.,* Stewart *et al.*)

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