An Integrated Approach to Coastal and Biological Observations

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Maritime economy, ecosystem-based management and climate change adaptation and mitigation raise emerging needs on coastal ocean and biological observations. Integrated ocean observing aims at optimizing sampling strategies and cost-efficiency, sharing data and best practices, and maximizing the value of the observations for multiple purposes. Recently developed cost-effective, near real time technology such as gliders, radars, ferrybox, and shallow water Argo floats, should be used operationally to generate operational coastal sea observations and analysis. Furthermore, value of disparate coastal ocean observations can be unlocked with multi-dimensional integration on fitness-for-the-purpose, parameter and instrumental. Integration of operational monitoring with offline monitoring programs, such as those for research, ecosystem-based management and commercial purposes, is necessary to fill the gaps. Such integration should lead to a system of networks which can deliver data for all kinds of purposes. Detailed integration activities are identified which should enhance the coastal ocean and biological observing capacity. Ultimately a program is required which integrates physical, biogeochemical and biological observation of the ocean, from coastal to deep-sea environments, bringing together global, regional, and local observation efforts.

Keywords: integrated observing, fit-for-purpose integration, parameter integration, instrumental integration, coastal observation, biological observation, ocean observation, coordinated observation

INTRODUCTION

The coastal ocean is the water body from the shelf-break to the shore, including estuary waters. Presently about 40% of the world's population live within 100 km of the coast. Anthropogenic activities within the watershed and the newly emerging maritime economy initiatives severely affect the coastal water. Monitoring of the coastal seas, therefore, becomes essential in providing marine information services for the maritime economy, for protection of marine environment and ecosystems and for climate change adaptation and mitigation. Coastal ocean observing has been developed in either national or regional level in the past decades, e.g., in Europe, United States, Australia, Japan, and China. Several papers or books discuss integrated and global observing systems (Malone and Cole, 2000; Babin et al., 2008; Liu et al., 2015). Early coastal monitoring components were designed to fit for specific purposes, e.g., operational applications, climate monitoring, environmental assessment, or fishery management. The monitoring activities were also carried out by different sectors with specific governmental mandates. In the last decade, integrated coastal ocean observing systems have been designed and developed to fit for multiple purposes. The US IOOS (Integrated Ocean Observing System) is a national observing infrastructure to cover the coastal shelf sea waters of the United States, managed by several regions. The IOOS was designed to provide data to support multi-purpose applications, ranging from operational services, climate change adaptation, maritime economy to ecosystem-based management, with a timely, operational data delivery (Corredor, 2018). In Australia, the Integrated Marine Observing System (IMOS, Hill et al., 2009) is similar to the United States system but was designed as a research infrastructure. Since major data streams of IMOS are delivered timely, they are also useful for operational forecasting and management of marine natural resources, etc. An important feature of both IOOS and IMOS is that they were built upon modern technologies e.g., gliders, high frequency radars, and animal borne instruments which have been identified as emerging technologies for future GOOS (Global Ocean Observing System) coastal and biological observing (Moltmann et al., 2019). In Europe, the European Regional Operational Oceanography Systems (ROOSs) also have integrated these technologies. In addition, ferrybox and shallow water Argo profilers are extensively used (She, 2018; Le-Traon et al., 2019). The ROOS observations were designed for operational oceanography, but can also be used for almost all other purposes, due to their operational online delivery, open and free access. There are significant efforts in integrating the ocean observing in the operational oceanography community. In the coastal ocean, the future integration aims to improve the cost-effectiveness and support the development of operational ecology (She et al., 2016) and seamless modeling (forecasting, reanalysis, and projection).

However, there are significant gaps in observations and cost-effectiveness in the existing online monitoring programs. On the other hand, there is already a significant amount of coastal and biological observations being collected for supporting ecosystem-based management and climate change adaptation and mitigation, as is coordinated by ICES (International Centre for Exploring the Sea) for fishery and regional conventions for environmental assessment in Europe and National Oceanic and Atmospheric Administration Fisheries in the United States. However, most of the data are delivered offline which do not fit the operational needs. There is an urgent need to integrate the online and offline monitoring programs to fill the observational and technological gaps. Instead of giving a comprehensive review of the existing coastal and biological observing, this paper aims at categorizing the "integrated observing" and how the existing gaps in coastal and biological observations can be filled through the integration. The integration discussed in this paper is at the scale of a regional sea basin, surrounded by one or more countries.
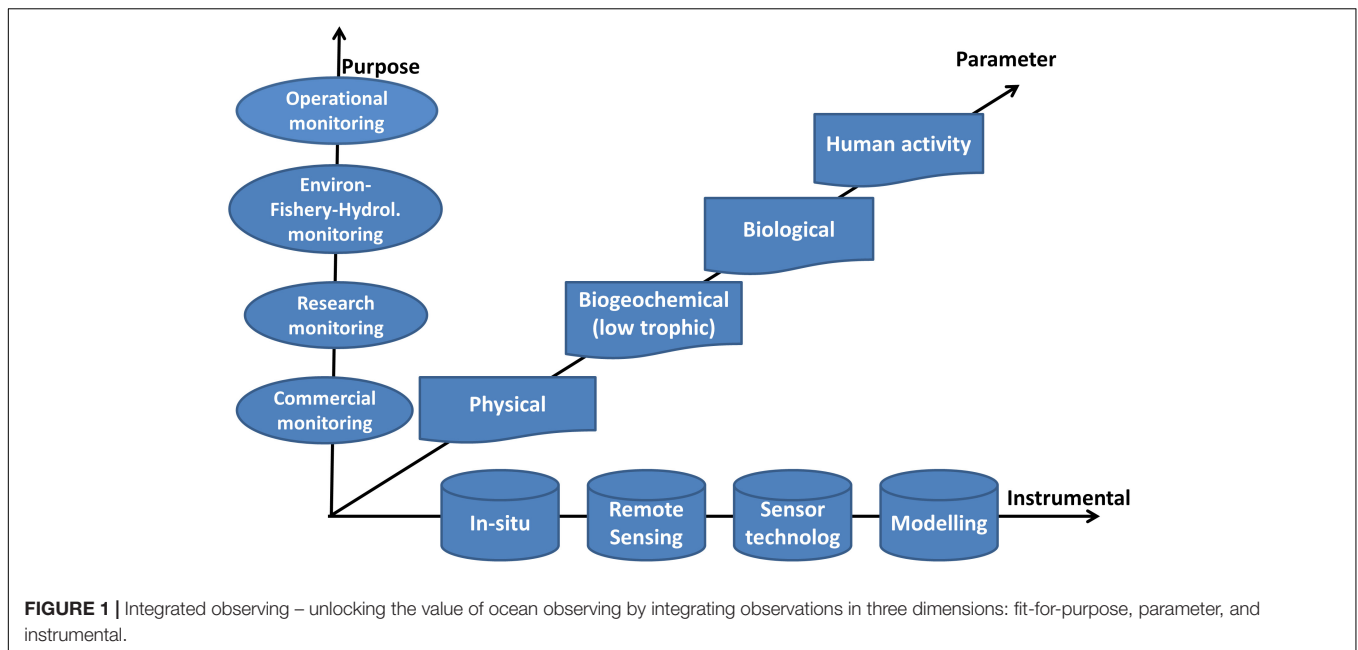
INTEGRATED COASTAL OCEAN OBSERVING

The integrated observing can be divided into three categories: fit-for-purpose integration, parameter integration, and instrumental integration, which addresses three stages of marine data value chain – observing, data management, and data usage. The fit-for-purpose integration is to integrate ocean observing from multiple sectors so that the observations can be measured for multiple purposes with improved data adequacy and cost-effectiveness. The parameter integration brings marine data of all parameters from air, water, biota, seabed to human activities together and makes them timely accessible. For the final data usage, the instrumental integration will produce the best monitoring products through integrating different monitoring components, e.g., in situ observations, remote sensing, and modeling. The three kinds of integration are illustrated in **Figure 1**. In order to maximize the value of the observing system, it is essential that the three kinds of integration are all addressed.

Fit-for-Purpose Integration

According to its purpose, ocean observing can be divided into governmental, research, and commercial activities. The governmental activity covers operational, environmental, fishery, and hydrological sectors. For a given sector, the observing is often coordinated at the regional sea scale via an "observational network" consisting of governmental agencies from different countries and/or regions, such as ROOSs and Northeast Pacific cooperation (Barth et al., 2019). Through enhanced coordination and integration among different governmental observing networks, research and commercial observing programs, the fit-for-purpose integration aims at filling the observation gaps and improving cost-effectiveness.

The multi-network integration can be implemented in three stages: first, a fit-for-purpose assessment on data adequacy, appropriateness, and cost-effectiveness of the existing observational networks has to be carried out to identify the gaps. In Europe, the data adequacy assessment has been carried out by the EMODnet (European Marine Observational Data network) Sea Basin Checkpoint projects for eleven social-benefit areas (Míguez et al., 2019). Second, the harmonized sampling scheme should be designed to fill the gaps for all purposes. For example, through improvement of near real time delivery of

FIGURE 1 | Integrated observing – unlocking the value of ocean observing by integrating observations in three dimensions: fit-for-purpose, parameter, and instrumental.

ship observations from the offline monitoring programs, the data gaps for operational forecasting and interim reanalysis can be largely filled. However, the difficulty of harmonizing multi-networks should not be underestimated, in which significant institutional and community barriers should be overcome. The cost-effectiveness of the observing can be improved by optimal sampling strategy design, including cost-benefit analysis of the monitoring technology. Many sampling strategy design studies have been carried out, using methods ranging from statistical design e.g., Springtall and Meyers (1991), She et al. (2006), and Alvarez and Mourre (2012) to Observing System Simulation Experiments (OSSEs, Oke et al., 2015; She et al., 2017). However, these optimal sampling design studies were mainly dedicated for operational forecasting and reanalysis. Few of them have included cost-benefit analysis and fit-for-multi-purpose optimization. It should be noted that a significant amount of new knowledge and new observations will be needed for the optimization, which constitute the third stage of the implementation.

Parameter Integration

Fit-for-purpose integration improves observation adequacy, appropriateness, and cost-effectives. However, the required observations also have to be easily accessible by the users. In many cases, data exist but not available as they are managed by different sectorial data centers and also subjected to different data policies. This makes data sharing more difficult and data usage less efficient. Integration of marine observations across entire parameter spectrum can significantly improve the efficiency of the data use.

In Europe, the EMODnet (Míguez et al., this issue) is dedicated to integrate marine data across a full parameter spectrum – bathymetry, biology, chemistry, coastal mapping, geology, human activity, and physics. Recently emerging

variables e.g., riverine inputs, underwater noise, sediment grain size, marine litter, and other datasets have been added in the portals. It was found, by the EMODnet Sea Basin Checkpoint projects, that the high integration level of marine data, such as done by EMODnet, has greatly facilitated the user applications and unlocks the value of observations.

Instrumental Integration

The value of observations can only be realized when they are used. *In situ* observing (including sensor technology and sampling schemes), remote sensing, and modeling are three ways of tracking ocean conditions. The instrumental integration means to produce needed products by integrating these three tools, e.g., data assimilation. Although such integration has been developed for decades, most of the operational assimilation just started in this century and mainly for open oceans and for physical variables. In Europe, the most well-known instrumental integration effort is Copernicus Marine Environment Monitoring Service (CMEMS, Le Traon et al., this issue). The lack of integration in coastal ocean and biogeochemical variables may be attributed to several reasons, e.g., lack of efficient schemes assimilating high frequency and multi-scale coastal observations, lack of skills in models to resolve fine scale features and biogeochemical processes and lack of qualified observations. These issues are major challenges in the instrumental integration of the coastal observing system, which should be resolved in the future.

BIOLOGICAL OBSERVATIONS

Biological ocean observations are any data collected in a systematic and regular basis which are based on living ocean inhabitants.

Multiple Disciplinary Coordination and Integration

Existing data currently supporting biodiversity assessments vary at a range of spatial and temporal scales, often severely limiting our capacity to understand the intensity, drivers and consequences of biodiversity change, and to assess the effectiveness of management measures. The availability of technology to enable more cost-effective collection of larger volumes of biological data is improving, such as Flowcam, but investment is needed to ensure that the most effective approaches are deployed widely and in a coordinated fashion.

Ultimately a program is required which integrates observation on physical, biogeochemical and biological aspects of ocean ecosystems and which establishes standardized approaches so that data can be shared, synthesized, analyzed, and interpreted from a large scale, long term, whole-system perspective. This has been identified as a priority for biological observations and operational ecology by the European Marine Board (Benedetti-Cecchi et al., 2018) and EuroGOOS (She et al., 2016). Ocean observation must be made across disciplines, as physical forces induce biological and chemical effects, which in turn mediate other (sometimes severe) biological changes, in some cases feeding back into physical changes. Comprehensive observing systems must be interoperable to enable studies across different science domains and observing regimes. A multidisciplinary approach where different science communities interact is necessary to provide a coherent, integrated view of the results. It is vital to bring together and connect the different marine and maritime stakeholders (from research to environmental monitoring and industry) collecting biological ocean observations to drive efficiency and cost-effectiveness.

Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs)

A key step in developing a balanced and integrated program is the agreement of key variables on which to focus coordinated observation programs to inform on the status and trends of marine biodiversity. Two complementary frameworks are of note: GOOS (Global Ocean Observing System) EOVs and GEO BON EBVs. However, the EOVs and EBVs are a priorities list only and additional biological variables should be considered as needed. Biological EOVs and some of the marine EBVs are not new, but build on a long history of biological observations in the ocean. Several of them have been measured for decades worldwide and the availability of historical records is a key strength of the EOVs/EBVs.

There is still a clear challenge in reaching a threshold between overall scientific relevance, the needs for legislation without compromising the interoperability at global level, and the feasibility when defining the variables to be monitored. Thus, discussions and refinement of the two sets of essential variables are continuing and in 2016, the Marine Biodiversity Observation Network (MBON), the GOOS Biology and Ecosystems Panel, and the Ocean Biogeographic Information System (OBIS) signed an agreement to work together to enhance existing biological

observation scopes and capacities, to implement best practices and international standards, and to encourage open access and data sharing. MBON and the GOOS BioEco Panel have developed the implementation of biological EOVs and marine EBVs and increased the number of monitoring programs that include these variables (Miloslavich et al., 2018; Muller-Karger et al., 2018).

Even though these variables are designed to be global, engaging regional systems such as the European Ocean Observation System (EOOS) will be key to ensuring progress and maturation.

Sustainability and Fitness to the Purpose

Biological ocean observation is very fragmented and, despite progress in storage and dissemination of digital information, there is still reluctance to share data within the scientific community and industry, and among national authorities. Programs tend to be driven by scientific interest or local needs. It is thus essential to establish appropriate mechanisms to overcome these barriers and improve data integration and networking.

In order to capture adequately the effects of global change on biodiversity, long term observations in key areas are required (generally involving many nations distributed across continents with a sustained long-term commitment toward observations). Almost none of the global observation networks has sustained or secured funding for their activities (Borja et al., 2016). For the system to be "fit for purpose" with maximum efficiency, observations must be harmonized using standard protocols, techniques and appropriate platforms contributing to a global observatory network. This ensures interoperability and comparability, which are important characteristics of any observing system.

Similar to those at the global scale, regional observing networks must be sustainable and adjustable to evolving observing requirements. Sustained long time series are of paramount importance and new observing approaches are emerging as technology progresses, making it possible to measure new parameters and/or improve existing protocols. New emerging techniques are often refined within SCOR working groups with suggestions for standardize use (e.g., WG154 and 156).

Most of the existing biological observing stations and platforms are operating at a local level (within a national sea area, or a given bay or stretch of coast within a national territory). These areas are characterized by high variability in terms of spatial and temporal resolution and are monitored often with infrequent and/or sporadic operations. Observation methods are usually specific to the needs for that specific area, either as variants of existing methods or completely new and locally developed. Local observing requirements may dictate specific approaches and techniques, ensuring a good "fit for purpose," but conformity to agreed standards both in terms of the quality of the observations and the data must be in place to ensure scalability and comparability.

The largest proportions of marine biological data available to scientists today are generated by short-term monitoring or research activities (such as the length of a Ph.D. program), which are organized regionally or locally. The lack of coordination

and standardization in sampling and taxonomic identification techniques results in spatial and temporal gaps, that makes global scale synthesis extremely difficult.

To understand and manage global changes requires working across multiple geographical scales, which requires mechanisms for sharing expertise, protocols and data between and within scales. These mechanisms would help to minimize problems such as the general lack of and uneven distribution of taxonomic expertise among institutions and nations (Heip and McDonough, 2012). It is important to define and operate appropriate mechanisms tailored to the needs and characteristics of different scales as well as the links between them. Networking workshops for the definition of standards, inter-calibration exercises, labels of good practices and the exchange of staff are examples of such mechanisms.

DISCUSSION

This paper proposes an integrated approach for developing coastal and biological observing systems. Although the recently developed cost-effective, near real time technology such as gliders, radars, ferrybox, and shallow water Argo floats, can be used to generate operational coastal sea observations, integration with offline monitoring programs, such as those for research, ecosystem-based management and commercial purposes, is necessary to fill the gaps. Such integration should lead to a system of networks which can deliver data for all kinds of purposes.

For the ecosystem-based management, the space for integration is huge. For example, in Europe, Marine Strategy Framework Directive (MSFD) and Marine Spatial Planning Directive (MSPD), aiming at reaching Good Environmental Status (GES) and planning on sustainable of marine resources, will be implemented in the following decade by the EU Member States. As the implementation is at national level, each member state needs a comprehensive monitoring program which provides hydrography, biogeochemical, biodiversity observations, and also human activity data. These national monitoring programs can be harmonized at regional sea level, together with operational and research infrastructure to improve the cost-effectiveness. In order to effectively filling the gaps for the stakeholders, it is essential that the entire ocean observing value chain should be addressed with the three kinds of integration (fit-for-purpose, parameter, and instrumental).

It is also important to think how the integrated observing should be implemented. The three stages of integrated approach proposed in this paper can be used to fill the gaps. For the fit-for-purpose integration, coordinated observing for multiple observational networks can be a good start point. EOOS, as a future coordination framework of European ocean observing, has issued a call for action to the EU Member States: "*Countries should coordinate all national marine and coastal data collection efforts to improve efficiency, and identify priorities and gaps to meet policy and societal needs.*" (EOOS conference in November 21–23, 2018, Belgium, Brussels). It is expected that such basic integration of observations at national level will form a solid base for the fit-for-purpose

integration. For the parameter integration, existing data policies should be further evolved to ensure open, free and timely access to government-funded observations, as well as engagement of research and commercial observations. Instrumental integration is currently significantly limited for the biogeochemical and biological variables: comparing to hydrographic variables, their observations are much sparser, models have much higher errors and species-dependent, and monitoring technologies also less efficient. New observations should be added with cost-effective sampling strategy. In addition, ecosystem models and innovative monitoring technologies should be further developed to facilitate the instrumental integration.

Based on the above discussion, a promising solution is to carry out an integrated observing program at regional sea level to fill the observational, technological and knowledge gaps by implementing all three kinds of integration.

Institutional barriers in different monitoring sectors, data management, and research communities are major obstacles when implementing the integration. Due to limit of space and extensive scope of the barriers, detailed analysis on the barriers is not given in this paper. We recommend readers to further specify the potential barriers in their own interested areas and systems. Timely delivery of biological observations is an important issue in developing operational ecology. It should be emphasized in the implementation of the three kinds of integration.

RECOMMENDATIONS

Support integrated observing for coastal and biological observations as an efficient way to unlock value of the ocean observations, and as a key component of GOOS, by developing a program which integrates observation on physical, biogeochemical and biological aspects of ocean ecosystems and which establishes standardized approaches so that data can be shared, synthesized, analyzed, and interpreted from a large scale, long term, whole-system perspective. Specific recommendations for the three kinds of integration are:

Fit-for-Purpose Integration
- Identify the observation and technology (cost-effectiveness) gaps via fit-for-purpose assessment.
- Harmonize ocean observing from fragmented purposes to make them suitable for multiple purposes, fill the observation gaps and improve cost-effectiveness by barrier-breaking, coordination, sampling design, and technology innovation.
- Sustain long time series observation and new emerging observing approaches as technology progresses, making it possible to measure new parameters and/or improve existing protocols.
- Fill observation and relevant knowledge gaps by implementing new, community observing capacities, e.g., through a sustained and cost-efficient research infrastructure at regional level.

- Contribute to a global observatory network, using standard protocols, techniques, and appropriate platforms, and ensuring quality, scalability, interoperability and comparability, especially for biological observing.

Parameter Integration

- Support parameter integration to deliver efficiently and timely marine observations in the entire spectrum of ocean variables and significantly improve the efficiency of the data use.
- Bring together and connect the different marine and maritime stakeholders (from research, operational service, environmental assessment to commercial activities), developing common data policy to engage data providers from different sectors for wider data access.
- Support integration initiatives, like the EMODnet, EOOS and the agreement between MBON, the GOOS Biology and Ecosystems Panel, and the OBIS; to facilitate user applications and unlock the value of observations.

Instrumental Integration

- Support instrumental integration to deliver the best monitoring products through integrating different monitoring components – *in situ*, satellite, and modeling.
- Filling knowledge gaps for the development of coastal and ecological services, e.g., biogeochemical and biological data assimilation, uncertainty in ecological models, optimal sampling design methodology.

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