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Ocean Observing and the Blue Economy

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Sustained ocean observations provide an essential input to ocean scientific research. They also support a wide range of societal and economic benefits related to safety; operational efficiency; and regulation of activities around, on, in, and under seas and the ocean. The ocean economy is large and diverse, accounting for around US$1.5 trillion of global gross value-added economic activity. This is projected to more than double by 2030. Delivering this growth in economic activity is dependent on ocean observations. This review paper summarizes the projected changes in the scale and scope of the ocean economy and the role that observations, measurements, and forecasts play in supporting the safe and effective use of the ocean and ocean resources, at the same time as protecting the environment. It also provides an overview of key future work being planned to develop a better understanding of the present and likely future ocean economy and the role and value of ocean observations in its sustainable realization.

Keywords: ocean observations, ocean information services, ocean observing systems, blue economy, ocean economy, ocean technology

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INTRODUCTION

The ocean is a key source of food, energy, and minerals. It is the primary medium upon which global trade takes place. Approximately 40% of the world's population live in coastal regions and three quarters of the world's large cities are located on the coast. Coastal waters and regions are the location of a large proportion of global tourism and recreational activity.

Ecosystem services provided by the ocean play a pivotal role in human society. Hundreds of millions of people depend directly on the ocean for their food and livelihoods. We all depend on the ocean for provision of much of the oxygen that we breathe and for its controlling and moderating role in weather and climate.

In its report on the ocean economy, the Organisation for Economic Co-operation and Development (OECD, 2016) estimates that 2010 economic activities associated with the ocean amounted to around US$1.5 trillion. The OECD projects rapid growth in economic activity associated with the ocean, with ocean-based industries having the potential to outperform the growth of the global economy, both in terms of value added and employment. Their projections suggest that between 2010 and 2030 the ocean economy could more than double its contribution to global value added, reaching over US$3 trillion per annum.

The marine and maritime industries delivering this economic activity continue to undergo a profound transition. As well as the traditional industries of shipping, capture fisheries, tourism, and marine recreation; there is now large-scale industrial activity associated with exploitation

of offshore oil and gas, the harnessing of marine renewable energy, and aquaculture-based food production, as well as emerging new activities, such as ocean mining and marine biotechnology (**Table 1**).

In contrast to the terrestrial environment, the ocean represents a difficult and harsh environment in which to operate. Much of the economic activity around, on, in, and under the ocean would not be possible without data, information, and knowledge derived from sustained ocean observations, measurements, and forecasts, which underpin safe and cost-effective marine and maritime activity.

The ocean environment is subject to a complex range of pressures. Foremost are those related to ocean health: over-exploitation of marine resources, pollution, rising ocean temperatures and levels, ocean acidification, and loss of biodiversity. Unsustainable use of the ocean and its resources threatens the basis on which much of the world's welfare and prosperity depends. Here too ocean observations, measurements, and forecasts play a fundamental role in underpinning the scientific basis for national and international legislation to regulate the use of the ocean and protect the ocean environment. Sustained observations also provide the basis for monitoring of regulatory compliance and effectiveness as well as playing a key role in supporting the valuation of natural assets and ecosystem services. It is only through understanding this wider blue economy, which encompasses both the economic uses of the ocean and ocean resources, and the natural assets and ecosystem services that the ocean provides, that a truly sustainable ocean economy can be delivered.

As ocean scientific research and operational ocean information needs have grown in scale, the provision of the means to conduct ocean observations and measurements has become an important economic activity in its own right. The growth of the ocean economy is also driving the development of an important service sector comprising value-added intermediaries, who add value to public and private ocean observations, measurements, and forecasts, tailoring them for specific end-uses.

TABLE 1 | Established and emerging ocean-based industries (adapted from OECD, 2016).

Established	Emerging
Capture fisheries and aquaculture	Open water aquaculture
Seafood processing	Deep- and ultra-deep-water oil and gas
Shipping	Offshore wind energy
Ports	Ocean renewable energy
Shipbuilding and repair	Marine and seabed mining
Offshore oil and gas (shallow water)	Maritime safety and surveillance
Marine manufacturing and construction	Marine biotechnology
Maritime and coastal tourism	High-tech marine products and services
Marine business services	Others
Marine R&D and education	

This review paper summarizes work on the scale, scope, and likely future trajectory of the ocean economy; the role that ocean observations have in underpinning this growing economic activity while ensuring protection of the marine environment; and the role of technology producers and intermediary service providers in enabling ocean observation capabilities and the delivery of operational benefits to those that use the ocean and ocean resources.

THE OCEAN ECONOMY

The following overview is derived from the OECD *Ocean Economy 2030* report (OECD, 2016). This report describes the global ocean economy and its likely future growth trajectory building on an extensive body of published work. The comprehensive bibliography contained in the OECD report provides a valuable resource for those seeking a better understanding of the body of work supporting production of this report.

The OECD report describes the ocean as the new economic frontier, holding the promise of immense resource wealth and with great potential for boosting economic growth, employment, and innovation. It recognizes the role of the ocean in many of the global challenges facing the planet in the decades to come from world food security and climate change to the provision of energy, natural resources, and improved medical care. While the potential of the ocean to help meet these challenges is huge, the report also recognizes that the ocean is already under stress from over-exploitation, pollution, declining biodiversity, and climate change. Realizing the potential of the ocean will therefore demand responsible, sustainable approaches to its economic development.

The blue economy encompasses ocean-based industries (for example, shipping, fishing, offshore wind, and marine biotechnology) and the natural assets and ecosystem services that the ocean provides (for example, fish, shipping lanes, and CO_2 absorption). As these two aspects are inextricably inter-linked, the OECD report addresses many aspects of ecosystem services and ecosystem-based management as well as focusing on the ocean-industry dimension.

The global ocean economy, measured in terms of the ocean-based industries' contribution to economic output and employment, is significant. Preliminary calculations based on the OECD's Ocean Economy Database value the ocean economy's contribution in 2010 very conservatively at US$1.5 trillion, or approximately 2.5% of world gross value added. Offshore oil and gas accounted for one-third of total value added of the ocean-based industries, followed by maritime and coastal tourism, maritime equipment, and ports. Direct full-time employment in the ocean economy amounted to around 31 million jobs in 2010. The largest employers were industrial capture fisheries with over one-third of the total, and maritime and coastal tourism with almost one-quarter.

Economic activity in the ocean is expanding rapidly, driven primarily by developments in global population, economic growth, trade, rising income levels, and the impact

of technological advances. An important constraint on the development of the ocean economy is the current deterioration of ocean health. As anthropogenic carbon emissions have risen over time, the ocean has absorbed much of the carbon, leading to ocean acidification. Sea temperatures and sea levels are rising and ocean currents shifting, resulting in biodiversity and habitat loss, changes in fish stock composition and migration patterns, and higher frequency of severe ocean weather events. The prospects for future ocean development are further aggravated by land-based pollution, in particular agricultural run-off, chemicals, and macro- and micro-plastic pollutants that feed into the ocean from rivers, as well as by overfishing and depleted fish stocks in many parts of the world.

Looking ahead to 2030, many ocean-based industries have the potential to outperform the growth of the global economy as a whole, both in terms of value added and employment. The OECD projections suggest that between 2010 and 2030, on a business-as-usual scenario basis, the ocean economy could more than double its contribution to global value added, reaching over US$3 trillion. Particularly strong growth is expected in marine aquaculture, offshore wind, fish processing, and shipbuilding and repair. Ocean industries also have the potential to make an important contribution to employment growth. In 2030, they are anticipated to employ approximately 40 million full-time equivalent jobs under a business-as-usual scenario. The fastest growth in jobs is expected to occur in offshore wind energy, marine aquaculture, fish processing, and port activities (**Table 2**).

A number of countries are engaged in the production of satellite accounts seeking to describe and quantify ocean economy-related activity at a national level. Meetings have been held to seek to harmonize the basis for these studies. These include the Center for the Blue Economy *ocean summit on reaching consensus on national ocean accounts* hosted by the Middlebury Institute of International Studies in 2015, a follow up meeting sponsored by the Chinese National Marine Data Information Center in 2016, and the *new approaches to evaluating the ocean economy symposium* held at the OECD in November 2017, with lessons learned and outcomes summarized in the OECD report *Rethinking Innovation for a Sustainable Ocean Economy* (OECD, 2019).

OCEAN OBSERVING IN SUPPORT OF A SUSTAINABLE OCEAN ECONOMY

The ultimate beneficiaries of ocean observations are end-users whose activities or businesses benefit from ocean data and information in terms of better scientific understanding of the ocean, improved safety, economic efficiency gains or more effective regulation of ocean use, and the protection of the ocean environment.

End-users of ocean data and information fall into four main types:

- *Science end-users* who undertake research activities that rely in whole or in part on sustained measurement and observation of the ocean.
- *Operational end-users* who make use of ocean data and information to support operational needs related to safety, economic efficiency, and protection of the environment.
- *Policy end-users* who require sustained ocean data and information to support policy formulation, monitoring of policy compliance, and assessment of policy effectiveness.
- *Public end-users* who have a general interest in the ocean or make use of ocean data and information in support of their leisure activities or recreational pursuits.

The role of the scientific community is twofold when it comes to ocean observations. Science is not only a user but also the major producer of ocean observations. Scientific interest initiates ocean observation. It also motivates the development of suitable and efficient measurement instruments, from individual sensors to complex observing systems. Science end-users make use of sustained ocean observations to underpin the data and information needs of many different research areas. Examples are the use of ocean data and information in support of research into

TABLE 2 | Overview of estimates of industry-specific growth rates in value added and employment 2010 and 2030 (OECD, 2016).

Industry	Compound annual growth rate for GVA between 2010 and 2030	Total change in GVA between 2010 and 2030	Total change in employment between 2010 and 2030
Industrial marine aquaculture	5.69%	303%	152%
Industrial capture fisheries	4.10%	223%	94%
Fish processing	6.26%	337%	206%
Maritime and coastal tourism	3.51%	199%	122%
Offshore oil and gas	1.17%	126%	126%
Offshore wind	24.52%	8 037%	1 257%
Port activities	4.58%	245%	245%
Shipbuilding and repair	2.93%	178%	124%
Maritime equipment	2.93%	178%	124%
Shipping	1.80%	143%	130%
Average of the total ocean-based industries	3.45%	197	130
Global economy between 2010 and 2030	3.64%	204	120

understanding physical, chemical, and biological processes in the ocean or the scientific study of the role of the oceans in weather and climate.

As users of ocean observations, scientists develop methods to edit and analyze the data and derive insights on the ocean and its dynamics. These insights contribute to society's knowledge pool and are used to develop, for example, forecasts, assessments, and recommendations for decision makers. Science also lays the groundwork for policy and operational use of ocean observations.

Operational end-users make use of ocean data and information to support strategic decision making and operational planning. For example, an offshore oil and gas company might use information products derived in part from ocean data and information to support the optimum and safe design of a facility or to help plan safe drilling activities.

Policy end-users depend on ocean data and information to help inform the drafting of effective legislation to ensure safety of life or property, protection of the environment, or regulation of the use of ocean space and ocean resources. Ocean data and information are further needed to monitor compliance with the resulting legislation (for example, monitoring to determine beach closures under the US Environmental Protection Agency Clean Water Act). Ocean data and information also deliver benefits in terms of measuring policy effectiveness, for example, determining the effectiveness of a policy to reduce concentrations of a harmful pollutant requires long-term monitoring to determine whether the policy is delivering on this goal.

The public at large is an important stakeholder in the ocean economy and end-user of ocean data and information. Surfing, sailing, diving, sport fishing, and coastal tourism are all significant ocean economic activities. Those engaged in these recreational and leisure activities increasingly make use of open access and commercial ocean data and information products.

Supporting all of these end-uses are the means to make ocean observations and measurements and the capacity to turn the resulting data into useful actionable information. These activities are in of themselves an important component of the overall ocean economy comprising:

- *Providers* of observing system infrastructure;
- *Producers* of ocean observations;
- *Intermediate users* who tailor ocean data or information for a specific end-use.

Providers of observing system infrastructure include manufacturers of sensors, instruments, and platforms; those building, launching, and operating satellite systems; providers of the cyber infrastructure that interconnects observing system components; and organizations that develop and maintain the data management systems, software tools, and models that are used to help turn data into useful information.

Producers of ocean observations are primarily public organizations. Ocean observation is conducted by a variety of national, regional, and international institutions and initiatives on different spatial scales. Many countries have installed marine research infrastructure and ocean observatories. Regions have combined their efforts to observe different parts of the ocean collectively and to share and combine collected data.

Under the aegis of the Global Ocean and Observing System (GOOS) and the Global Earth Observation System of Systems (GEOSS), efforts in establishing national ocean observing systems have been progressively increasing. Almost every coastal country is involved in marine research and activities related to ocean observation. Examples of mature ocean observing systems are the Australian Integrated Marine Observing System, the Canadian Ocean Networks, the Japan Oceanographic Data Center, the European Global Ocean Observing System (EuroGOOS), and the associated Copernicus Marine Environmental Monitoring Service (CMEMS) as well as the US Integrated Ocean Observing System (IOOS). Additionally, the Canadian IOOS was established in March 2019 to further develop and integrate ocean research and observing networks into a national system to support the coastal economy and build resilient coastal infrastructure.

In addition to this public sector activity, many business end-users of ocean observations commission their own sustained data collection to support operational needs where these cannot be met through the use of publicly available operational ocean data and information. In these instances, end-users generally place contracts with specialist ocean measurement businesses who undertake such work on their behalf. In some cases, public organizations also contract to private companies in similar ways.

Intermediate users are public and private organizations that add value to ocean data and information tailoring it for specific end-uses. In this context it is important to recognize that delivery of end-user benefit is often not a simple linear end to end service chain. More usually, benefits are delivered by multiple organizations merging and mashing different sources of data and information to derive a product useful for a particular purpose. Growth in the ocean economy is driving the development of a significant service industry meeting the specialist information needs of different sectors.

UNDERSTANDING THE CONTRIBUTION OF OCEAN OBSERVATION TO QUANTIFYING THE BLUE ECONOMY

The economic and societal benefits underpinned by ocean observations, measurements, and forecasts are large. However, they are difficult to quantify. There have been no comprehensive global attempts to describe and quantify these benefits, although numerous case studies have sought to understand and quantify socioeconomic benefits associated with the use of ocean data in support of specific ocean uses or regulatory measures. In aggregate, the cost of obtaining and using ocean observations is almost certainly only a small percentage of the value of the benefits derived.

Recent work by the OECD has sought to collate and summarize the existing literature concerning the benefits of sustained ocean observations (OECD, 2019).

Science remains a crucial driver for most ocean observations. Observations and measurements derived from diverse platforms (e.g., *in situ*, research vessels, satellite remote sensing) contribute to advancing fundamental knowledge on the ocean, weather, and the climate, directly and via their use in driving, calibrating, and verifying ocean, atmospheric, and climate models. In the Intergovernmental Oceanographic Commission's (IOC) Global Ocean Science Report (IOC, 2017), around 80% of data centers that provide ocean observation data, products, and services named scientific communities as their most important end-users.

Many of the societal benefits associated with improved science are not readily associated with economic value, partly because they do not flow through markets and do not generate economic benefits in and of themselves. For this reason, the literature has often considered ocean observations data to be a public good, the benefits of which are difficult to identify and value. Despite the relative complexity of valuing societal benefits, a number of recent studies have used a range of methodologies to do so. Further valuation of societal benefits is of particular importance to undertaking a thorough assessment of the value of ocean observing systems and is of crucial importance to any future overall economic assessment.

There are a wide diversity of operational products and services based on sustained ocean observations. Based on the OECD literature review, weather forecasts (36%), sea state forecasts (21%), and climate forecasts (7%) are the products and services most taken up for operational use. Some of the traditional operational user groups include navies and coastguards, offshore oil and gas industry, commercial shipping fisheries, and aquaculture. User domains benefiting from ocean observations and covered the most by the literature do not paradoxically mirror the distribution of these traditional user groups. This is because much of the work on quantifying these areas exists only in the "gray" literature rather than as peer-reviewed material. The socioeconomic assessments consider primarily aquaculture and fisheries (13%), agriculture (9%), environmental management (8%), tourism and cruises (8%), pollution and oil spills (8%), military, search and rescue (8%), and commercial shipping and maritime transport (8%).

While ongoing efforts are to be commended and recent progress has been made on mapping operational user communities, data on intermediate and end users are often not collected. To date, only one systematic study of national commercial intermediary activity has been completed in the form of the National Oceanic and Atmospheric Administration (NOAA) Ocean Enterprise Study (Rayner et al., 2018) which sought to quantify the scope, scale, and value of commercial provider and intermediate user activity by US companies.

NEXT STEPS

A thorough assessment of the value of ocean observations requires further effort in identifying and understanding the different communities of intermediate and end-users, their use of ocean observations and the associated benefits, based on common standards for the evaluation process. Quantifying socio-economic benefits of ocean observing activity in support of the ocean economy will support a stronger argument for the sustainability and improvement of ocean observations.

The following steps could contribute to achieving this:

Increased efforts among providers of ocean observations to track user groups, their downloads, and use of the data would help identify associated marketable and societal values. This would involve improved identification and mapping of end-users, both scientific or operational. Dedicated surveys of end-users of ocean observations could be a useful tool to further characterize users, the products and services they require, and the benefits they realize by using ocean observations. These surveys could be conducted in co-operation with open data platforms, such as the Australian Open Data Network, CMEMS, EMODnet, or US IOOS, with their user bases as the target survey groups. CMEMS already gathers some of this information through its user registration process.

A more thorough and detailed analysis of dedicated value chains for some of the main products and services derived from ocean observations could also contribute to a more robust valuation of socioeconomic benefits. There are useful efforts underway at international and national levels (e.g., work by IOC, NOAA, and under the European AtlantOS project, as well as a recently commenced project being undertaken by US IOOS Regional Associations) to survey their users. Convening an expert meeting specifically on lessons learnt from mapping user groups and value chains would be very useful for the ocean observing community.

Studies differ considerably in spatial and temporal scope, methodology used, and user domain considered. The ocean observation community would benefit from international standards or guidelines for the valuation of ocean observations. This would simplify the comparison of different studies and allow the aggregation of results. There are several general challenges when assessing the benefits of ocean observations, e.g., the public good character of many ocean observations, complex value chains, and taking stock of a variety of stakeholders. Comparing the results of individual studies can be complicated by varying temporal, sectoral, and spatial scales applied in the assessments. Improvements in methodologies are, however, possible. The weather and the environmental policy communities have both tested and paved the way for useful and proven value of information techniques that may be applicable to ocean observations.

In conclusion, recent years have seen a rapidly growing awareness of the importance of our seas and ocean as a key natural resource and engine of economic growth. Harnessing and simultaneously safeguarding the ocean economy require deeper knowledge and much more data than are currently available. The OECD has an ambitious workplan for the 2019–2020 period

aimed at better understanding key aspects of the ocean economy and the use of ocean observations. Following on from OECD's current study on the socioeconomic valuation of sustained ocean observations, this work will include targeted questionnaire-based surveys aimed at gaining a better understanding of who uses data from sustained ocean observations and measurements.

AUTHOR CONTRIBUTIONS

RR: preparation of section "Ocean Observing in Support of a Sustainable Ocean Economy" and compilation of overall review. CJ: contributions from OECD. CG: contributions to section "Understanding the Contribution of Ocean Observation to Quantifying the Blue Economy."

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