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Foreword

This is a scoping report based on an expert workshop held to examine the scope and terms of reference of a proposed study on the economic potential of data from ocean observatories. The workshop was organized under the auspices of AtlantOS in cooperation with the OECD Ocean Economy Project Group, NOAA (USA) and the Institute for Ocean Research Exploitation Ltd. (Canada). It was held in conjunction with the AtlantOS AGM in Kiel, Germany from 27-28 June 2016 and was attended by approx. 25 experts.

This report should be seen as a follow-up to Deliverable 10.3 (D10.3) which summarizes the main issues raised by experts leading up to and including the above workshop justifying the need for a study on economic potential of data. The discussions summarized in D10.3 made it clear that there were many societal benefits expected from ocean observatories, however there was a lack of empirical evidence substantiating these expected benefits. Taking into account the findings summarized in D10.3, the present scoping report assesses in detail the context in which the proposed study will exist and the limits to what should be covered by the study.

As stipulated by the AtlantOS Description of Activities Task 10.5, this effort is the beginning of a broader effort to better understand the role of ocean data from in situ and space-based observatories in the ocean economy and its long-term outlook, including the creation of new jobs. This includes locating scientific ocean observatories in the “marine big data” value chains. Formally, this report was completed in partial fulfilment of the sub-contract arranged between KDM and the Organization for Economic Cooperation and Development (OECD) under AtlantOS (see AMD-633211-7). The OECD was specifically chosen for this task given its experience in carrying-out assessments. The experts from the OECD working with AtlantOS have, for example, recently published an assessment entitled *The Space Economy at a Glance* (2014).

Exploring the economic potential of data from ocean observatories

Scoping Report

based on the joint OECD Ocean Economy Group /AtlantOS project workshop in Kiel on 27-28 June 2016

Contents

Ocean observation plays a crucial role in our understanding of the ocean and its impact on the wider economy and on society. Over the past years, large public investments have been made to collect a wide range of data indicators that are essential for marine research.

At the same time, in light of tighter public budgets, the need to guide governments' priority-setting and decision making on large public investments becomes ever more important. Policy makers require more evidence-based information about the socio-economic impacts of ocean observation.

Building on the work conducted at the OECD in a wide range of ocean-related policy areas, this paper aims to briefly illustrate the value chain of ocean observation, and review the state of socio-economic impact assessments of ocean observations today.

The paper is based on the joint OECD Ocean Economy Group /AtlantOS project workshop in Kiel on 27-28 June 2016, which started exploring the economic potential of data from ocean observations.

Introduction

Ocean observation is necessary for society and the wider economy. With the help of data generated by ocean observation, various aspects of the ocean and its interrelations with the wider climate system can be measured, monitored and forecasted. This knowledge permits a greater understanding of the natural processes of the Earth system, which is crucial because it provides a baseline for our comprehension of the changes in ecosystems and the knowledge base upon which applied R&D can be developed. It is also important because ocean observation allows us to understand the long-term changes in marine ecosystems related to climate change and other human-made impacts. In addition, ocean observation provides knowledge on which a more integrated ocean management may be developed, since emerging ocean-based activities are likely to continue to grow and exacerbate pressures on the already stressed ocean environment. In return, societies are able to adapt their strategies for research and development activities in many ways – including the development of more sustainable technologies for ocean-based industries and national and international climate change adaptation strategies more broadly.

The costs of acquiring marine data through ocean observation are substantial. For example, for the collection of data by in-situ sensors, Europe spends EUR 1 billion per year, and for observations by remote sensors some EUR 400 million per year (JPI Oceans, 2014). The average fixed-point ocean observatory (including platform and sensors) requires an initial investment of around EUR 501 000, and incurs annual running costs (without network cooperation and data management) of roughly EUR 731 000 per platform (Cristini et al., 2016).

However, calculating the benefits can be challenging, not least due to the "public good" characteristic of ocean observation data and the many stakeholders involved. In addition, the studies differed considerably, including in terms of methodologies, scope, the time scales of return on investment, and geographical region. This made it difficult to compare or even aggregate their results.

Classifying the state of socio-economic assessment studies by the beneficiary of ocean observation data (Flemming, 2007; Rayner, 2016) has shown that the benefits are huge. Not only maritime-based industries but also land-based industries benefit from the data generated by ocean observation. For example, agriculture has been estimated to reap an annual benefit of USD 260 - 320 million from improved weather forecasts (Adams et al., 1995; Solow et al., 1998).

The first section of this paper defines ocean observing systems; section two illustrates the kind of value-chain involved and provides examples of the status quo of ocean observation systems on national, regional and global scale. The third section emphasises the importance of conducting socio-economic impact assessments and classifies different studies published over the past years. The fourth section aims to gather in the loose ends and sketches out some of the concrete next steps to develop a better international knowledge-base about the economic value of ocean observation data.

1. Definitions of ocean observation

There are different definitions of ocean observation systems. A standard definition does not yet exist. The scope of ocean observation varies widely, focusing more either on scientific research or operational service support.

Integrating the different attempts so far (see Table 1), ocean observation could be defined as a sustained integrated infrastructure system that is based on the data collection of physical, geological, chemical and biological variables, in order to understand, track and monitor the state of the ocean. This is necessary to describe and forecast developments of marine ecosystems, weather and climate, in order to support scientific marine research, and operational ocean services worldwide.

Table 1: *Overview of different definitions for ocean observation*

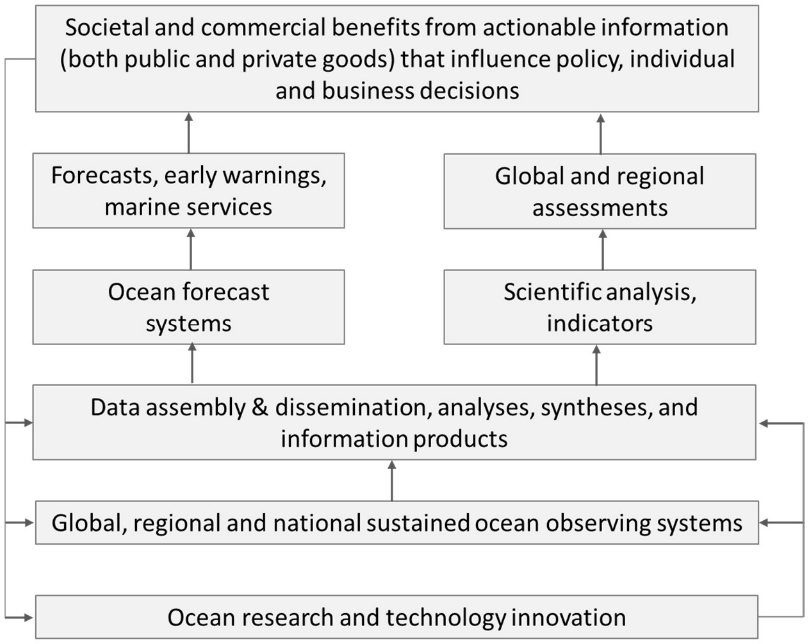
Agency / Organization	Definition	Objective
Norwegian Ocean Observatory Network (NOON)	Ocean observation aims at long-term monitoring of environmental processes related to the interaction between hydrosphere, geosphere and biosphere during global warming. Collecting that data enables the understanding of the dynamics related to climate change, different industries, such as fisheries and marine sediment transport processes, installations and pollution.	Primarily scientific
UNESCO	The objective of ocean observation is to monitor and collect data to improve the human use of the sea, its exploitation, management, and conservation.	Primarily scientific
National Oceanic and Atmospheric Administration (NOAA)	Observation system is an integrated network to collect and observe data that are used for predictive tools with a range of applications, including for the wider economy, the environment, and public safety.	Operational and scientific
Global Ocean Observing System (GOOS)	The global system for observations aims at modelling and analysis of marine and ocean variables to support operational services worldwide. The objective is to provide accurate descriptions of the present state and future conditions of the oceans, including living resources. In addition, to develop maritime, climate and weather forecasts, including changes in living resources in the oceans and seas, in order to better manage ecosystems and resources and conduct risk management from natural hazards and pollution.	Operational and scientific

Source: NOON (2016), UNESCO (2009), NOOA (2016), IOC-GOOS (2016).

2. Value chain of ocean observation

Prior to exploring the economic potential of data generated by ocean observatories, it is crucial to develop a common understanding of value chains, with the main types of observation systems and technologies. A variety of such value chains exist, generating social or commercial benefits (or indeed both), and offering public or/and private access. Mapping out the relevant value chain provides insights into the different end-users of ocean observation. This is essential to understanding the challenges in analysing socio-economic impact assessments. For illustration purposes, below is an example of a "generic" value chain

Figure 1: *Illustrative value chain of sustained ocean observing systems*



Source: Adopted from Rayner (2016).

Based on existing definitions, ocean observation can be separated into the main application fields that create added value: support of scientific research and analysis, support of operational services for commercial activities, as well as national and regional security. (The latter is not calculated in traditional benefit terms and will not be further analysed in this report.) Value chains generating social and / or commercial benefits will be illustrated below.

2.1 Ocean research and technology innovation

Marine research and technology innovation have been the initial drivers for ocean observation. Technological innovations in the field of ocean physics have made more sophisticated marine research possible, such as Argo floats and remote sensing. At the same time, marine research has required more advanced marine sensor technologies, with effects on improved bandwidth and access to broadband, better power systems for remote subsea operations and reduced costs for cabling.

The development of marine sensor systems in the field of marine biochemistry is probably among the biggest technological innovations (Mowlen, 2016). However, the availability of robust cheap sensor systems and the advancement of their technological readiness level can be challenging. Different combinations of funding models consisting of collaborations between public, private and academic-led funding may be helpful to improve the required access to finance.

Networks between ocean research institutes and technology providers have a key role in fostering the development of ocean observation systems. Among these collaborations is the Partnership for Observation of the Global Oceans (POGO). Its role is to present a partnership of different institutions involved in oceanographic observations, scientific research, operational services, education and training. The network can be central to the exchange of information from funding cooperation to comparing the technical compatibility among observing networks (POGO, 2016).

2.2 National, regional and global ocean observing systems

In the past years more sustained and integrated information systems have been developed on national, regional and global levels. Many nations have installed marine research infrastructure. Regions have combined their efforts to observe different parts of the ocean together and share and combine the collected data. Globally, frameworks have been developed to foster the growth of existing ocean observation systems and new single observation platforms in regions that were under-observed. Challenges include expanding the existing infrastructure, and creating better synergies among different systems and stakeholders.

2.2.1 National ocean observing systems

Efforts to establish national ocean observation systems have been continuously increasing. Almost every coastal country is involved in marine research and activities related to ocean observation, although the systems are not always equally developed. Whereas some countries, such as Australia, Canada and the United States and other OECD-countries demonstrate stronger expertise of observing activities, other countries are in the process of gaining still more experience. The following non-exclusive list demonstrates several national endeavours and different technology readiness levels around the globe.

Table 2: *Illustrative list of national ocean observing systems*

Country	Specifics
United States	The Integrated Ocean Observing System (IOOS) belongs to one of the most developed national observing systems: It consists of 11 regional alliances creating national coastal communities including the Great Lakes, the Caribbean, and the Pacific Islands and territories.
Australia	The Australian Integrated Marine Observing System (IMOS) has six regional nodes distributed around Australia.
Norway	The Ocean Observatory Network (NOON) aims at enabling sustainable monitoring and management of the marine environment; in particular, in the mid-ocean ridges and continental margins between Svalbard and Vesteralen.
Canada	Ocean Networks Canada has observatories in the Arctic, the Atlantic, in Coastal British Columbia as well as in the Northeast Pacific. The network consists of VENUS and NEPTUNE. Its coastal observatory VENUS is located in the Salish Sea and was the world's first cabled seafloor observatory that allowed researchers to connect in real time to undersea experiments and observations. The second network, NEPTUNE, has become the largest cabled ocean observatory today, and is located in the Northeast Pacific Ocean. Further expansion to areas of the Arctic is anticipated.
Ireland	INFOMAR is the national seabed mapping program led by the Geological Survey of Ireland. The Marine Institute also contains a sub-sea cabled observatory that allows real-time monitoring. SmartBay buoys are equipped with sensors to support operational monitoring of local weather, wave and environmental conditions and to

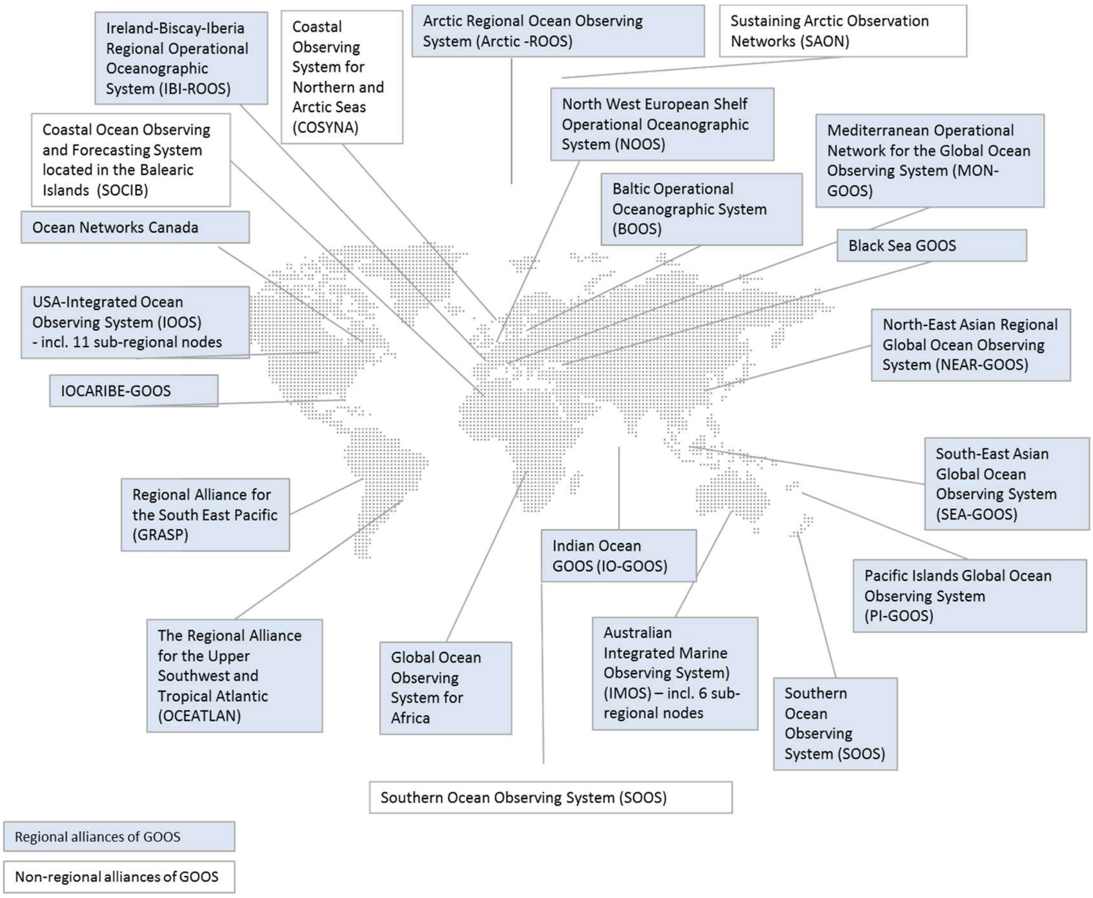
	facilitate a number of research projects. More ocean observation and marine research infrastructure is planned.
Portugal	The Portuguese Institute for the Ocean and Atmosphere (IPMA) conducts the implementation and development of ocean observation systems in Portugal. Portugal and North America share joint efforts to work together on autonomous multivehicle operations, sensors and software development for further observations of the North Atlantic.
France	France conducts ocean observation in the surrounding French coastal areas as well as in its French oversea s departments and territories. It is a combined effort of Mercator Ocean, Météo- France, Ifremer and CNRS. They run a wide-ranging infrastructure of ships, fixed and drifting buoys.
Italy	Italy has increased its competencies in the last years, lately also because of RITMARE, an Italian flagship project to create more synergies in marine research. As such, a first step has been made towards a national contribution to the European Integrated Ocean Observing System. The structure of the RITMARE ocean-observing system comprises a permanent - and a movable component.
Germany	Germany has a wide network of open ocean observatories in the Atlantic, Arctic/Antarctica, Indian Ocean and Pacific Ocean. Its research focus is on the Atlantic and the adjoining polar regions. Further research includes particularly the Asian monsoon areas.
United Kingdom	The National Oceanography Centre leads the national marine science, including sustained ocean observation. This includes the provision of major facilities (such as the Royal Research Ships and deep submersibles), and programmes of sustained observing, survey, mapping, data management and other functions.
Korea	On the Asian continent, the Korea-Global Ocean Observing System contains fourteen tidal stations, four ocean stations, two ocean buoys, a surface currents station, and an ocean research station.
Ukraine	The Ukrainian national system of marine coastal observations consists of 36 hydro meteorological stations located on the Ukrainian shores of the Black Sea.
Romania	In Romania a small set of observatories (three coastal observations, two offshore observations and six coastal meteorological stations) are in use.
Georgia	In the coastal zone of Georgia, five meteorological stations and three tide gauges are running.
Russian Federation	The Russian Federation has five hydro meteorological stations and a wave rider buoy as well as automated systems for meteorological parameters, sea level, and water temperature, waves in the coastal area, current speed and direction, temperature and depth.

Source: NOOA (2016), NOON (2016), ONC (2016), SmartBay (2016), Euro-GOOS (2016), JDN (2016), RITMARE (2016), Black Sea GOOS (2016).

2.2.2 Regional ocean observing systems

Regional ocean observing systems have been developed by political top-down structures, leading to the initiative of the development of observing systems and bottom-up initiatives, linking different existing national observing systems. Regional ocean observing systems present either sub-systems of a larger global framework or exist to complement that wider data collection, often for operational purposes. Figure 2 illustrates some of them.

Figure 2: *Different regional ocean observation systems*



Source: GOOS (2016), Euro-GOOS (2016), HZG (2016), SOCIB (2016).

Regional ocean observing systems operating within the context of GOOS

Thirteen regional observing systems, often consisting of sub-regions, are integrated in the larger framework of GOOS. This infrastructure covers around two thirds of the sea surface, with the goal of continuously expanding that coverage. These regional alliances support marine research and operational oceanographic services to different extents, depending on the technological development of the systems.

Euro-GOOS is a regional partner that oversees cooperation between five sub-regional alliances formed by 19 European countries. The regional partners observe the Baltic, Mediterranean and Black Sea, as well as parts of the Atlantic Ocean. These five sub-regional alliances include Arctic Regional Ocean Observing-System (Arctic-ROOS)[i], Baltic Operational Oceanographic System (BOOS), North-West European Shelf Operation Oceanographic System (NOOS), Ireland-Biscay-Iberia Regional Operational Oceanographic System (IBI-ROOS) and the Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS). In addition, Euro-GOOS promotes collaboration with the Black Sea GOOS.

More regional partners can be found in Asia, where the generated data have been helpful for a variety of industries and science. For example, the Indian Ocean GOOS (IOGOOS) has been providing data for the support of operational services, including maritime and coastal tourism and maritime transport (Leatherman, 1997). In South-East Asia, the Monsoon Onset Monitoring and its Social and Ecosystem Impact (SEAGOOS-MPMSEI) system have improved knowledge of Asian monsoons through air-sea observations over the Andaman Sea and the understanding of the requirements of ocean conditions for the role of the ocean in the monsoon onset (IOC, 2016).

In Latin America, the sustained regional ocean observation system for the Upper Southwest and Tropical Atlantic (OCEATLAN) is constituted by institutions in countries, such as Argentina, Brazil, and Uruguay. Next, in the Caribbean, many countries and island states[ii] have combined their efforts on integrated regional ocean observation (IOCARIBE-GOOS). At the moment, at least 448 stations from various operators, with the majority coming from national meteorology services, support observing activities in the Caribbean region (IOCARIBE-GOOS, 2016). Another island region, the Pacific Islands Global Ocean Observing System (PI-GOOS)[iii], provides information regarding the weather, waves, tides, winds, currents, water quality, inundation and beach safety for six Pacific Island regions (PI-OOS, 2016).

In Africa, the Regional Ocean Observing Framework System (ROOFS-Africa) is currently under development. The goal is to foster ocean observing and operational oceanography across 36 African coastal nations. The focus will be on coastal management, environment conservation, mitigation of natural disasters and the impacts of climate change, and the operational support of expanding economic activities in the African coastal and offshore zones. Agulhas, Somali, Benguela, Canary and Guinea, as well as the area in the Western Indian Ocean started with ocean observing activities, focusing mainly on marine conservation. Since then more countries have joined the efforts to provide operational support for the expanding economic activities in the African coastal and offshore zones (GOOS, 2016).

Other regional ocean observing systems that don not operate within the context of GOOS

There are also regional ocean observing systems that operate outside the context of GOOS, even though they are in the minority. The objective has often been to fill the needs of ocean observation systems for operational uses. An example of such an integrated ocean observing system focusing on the support of users of marine data of the North Sea and Arctic seas is the Coastal Observing System for Northern and Arctic Seas (COSYNA). Data users will be able to access the near-real time data from the various stations with one click via an application of the internet (HZG, 2016).
Another example for regional ocean observatories with a focus on operational oceanography is the Coastal Ocean Observing and Forecasting System located in the Balearic Islands (SOCIB). SOCIB is a multi-platform distributed and integrated system that provides streams of oceanographic data and modelling services to support commercial services in a European and international framework (SOCIB, 2016).

2.2.3 Global ocean observing systems

Global ocean observing systems are the result of international efforts of different marine research institutes and international organisations, such as the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), to develop more consistent, co-ordinated and effective observing activities of the oceans and coasts. They foster the implementation of new ocean observatories, and provide the overall framework for the integration of existing observation systems.

The Global Ocean Observing System (GOOS) presents the only reference system for an international framework for global ocean observation. The Global Ocean Observing System (GOOS) was developed under the umbrella of the Global Earth Observing System (GEOSS). The leading international founding organisations were the UNESCO-IOC and the World Meteorological Organisation (WMO).

Other collaborations of observing systems exist but they are subsystems of programmes that follow with a broader focus, such as terrestrial observing activities. Often they are developed with meteorological services and satellite programmes. Global ocean observing systems that include terrestrial observing are, for example, the Global Climate Observing System (GCOS) and EUMETSAT. The Global Climate Observing System (GCOS) is built by GOOS and a range of international organisations and programmes, including the WMO Integrated Global Observing System (WIGOS) and the Global Terrestrial Observing System (GTOS). EUMETSAT, a member of the Committee on Earth Observation Satellites (CEOS), conducts ocean observing on variables regarding the Ocean Surface Topography, Ocean Surface Wind, Ocean Colour and Atmospheric Monitoring. (EUMETSAT, 2016).

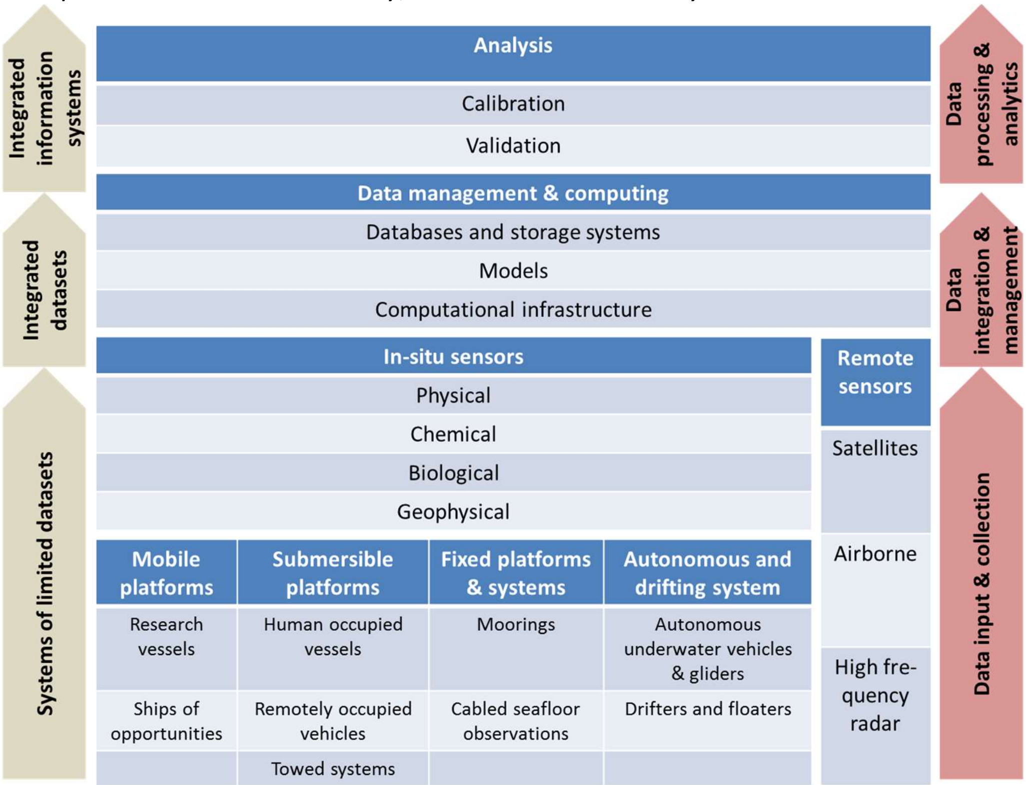
2.3 Data assembly, dissemination and analysis

Within ocean observing systems, data collection, assembly and analysis are among the most important segments of the value chain because they provide the ground work for the later applications of the data generated by ocean observation. It is necessary that the infrastructure for data assembly, dissemination and analysis develops in parallel with the growing scope and complexity of the different ocean observation systems.

Figure 3 illustrates the different steps involved in assembling, disseminating and analysing the data generated by ocean observation. First, essential ocean variables on physical, biological and chemical parameters are collected by a wide range of in-situ and remote sensors that are installed on different platforms. It is always important to develop observing designs that present the optimal mix of shipboard and autonomous observations as well as the best cost-efficient combination exploiting the synergies between remote and in-situ observations (Roemmich et al., 2016). In the final step, the data is integrated, validated and analysed to develop user-friendly applications.

Much has improved in the past 15 years regarding infrastructure and the necessary consensus on common standards on issues such as data formats, real-time and delayed mode quality control, and data distribution. Examples are the GODAE (Global Ocean Data Assimilation Experiment), Argo (Array for Real-time Geostrophic Oceanography) and GHRSST (Global High Resolution Sea Surface Temperature).

Figure 3: *Steps involved in data assembly, dissemination and analysis*



Source: Adopted from EC (2013).

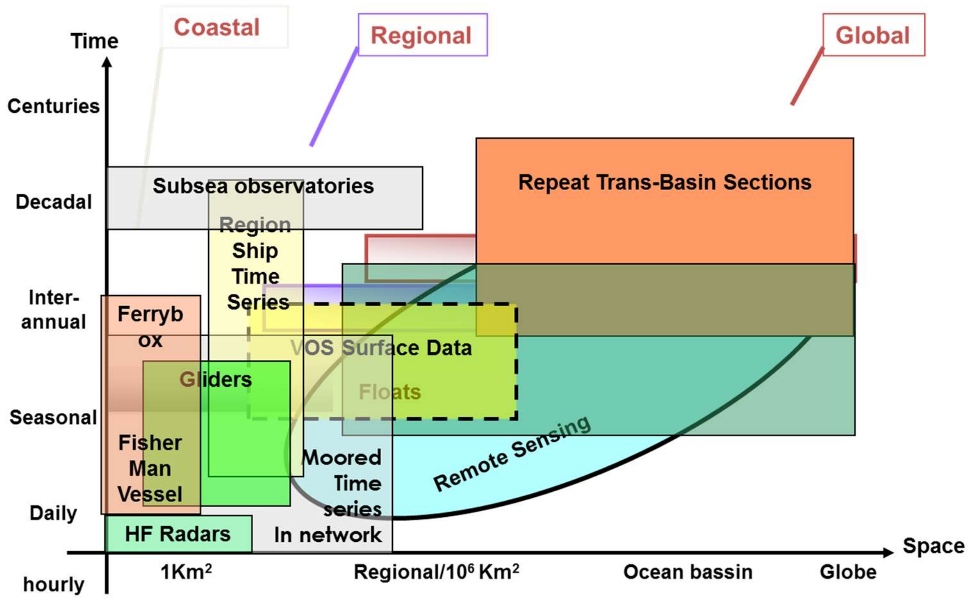
2.3.1 Data collection and assembly

The collection of data has become more comprehensive and consistent over the past years through more innovative marine sensor technologies and the focus on “Essential Ocean Variables” (Visbeck, 2016); however, further efforts are required. The efficiency of the data collection can be increased by an active integration and synthesis of multi-platform approaches and multi-vehicle operations. This would help to meet some of the observational challenges, such as ice zones, the deep ocean and boundary currents (Mowlen, 2016). In addition, in the future, continuous effort should be on expanding the global geographical coverage of ocean observing systems from of around two thirds to almost 100% (Fischer, 2016; Visbeck, 2016).

Overall, it is necessary that each element of ocean observing is internationally co-ordinated in regard to its design and planning, implementation and data management. Observation programmes should therefore be selected in co-ordination with the requirements for global sampling, and then be implemented to the national strategies (Roemmich et al., 2009).

The technology of the different ocean observation tools varies in cost, sophistication, maturity, geographical use, and time durability, but they are all complementary. Whereas some tools are used globally, others are designed to be used locally. Often a combination of diverse sensors and systems from different communities are used to collect the necessary information (see figure 4).While satellite observations provide the broadest scale, they are usually only capable of observing the surface. Other technologies also permit observation and mapping of the seafloor, remote areas, and areas covered by sea ice. Research vessels are important to verify the data collected by autonomous systems, but at the same time research vessels are infrequent and limited in their geographic coverage. Over the past decades, autonomous systems, such as autonomous floaters and gliders have quickly developed, permitting observation ranges of between several square kilometres in coastal areas to ocean regions. However, they do not cover complete ocean basins or the entire ocean, for which satellite technology is used.

Figure 4: *Ocean observatories take place from coastal to regional to global without real frontiers*



Source: Visbeck (2016).

Due to the different costs of ocean observatories, the collection of data is related to distinguished rhythm and frequency. While Argo floaters cost on average around EUR 15 000 per floater, they are estimated to deliver annually around 105 000 profiles (but the observations remain in the upper 2 km) (Ravichandran, 2011). Satellites can track surface currents near coastlines around every fifteen minutes, which would lead to around 35 000 observations. By contrast, ship-based observation is more capital-intensive and therefore less frequent: Estimates for global ship-based observing activities from the sea surface to the sea floor are less than 103 profiles per year. Nevertheless, the expenses for ship-based ocean observation are justified due to their ability to measure many parameters with high accuracy (Roemmich et al., 2009).

The following presents examples of different types of sensors and platforms, including in-situ sensors on autonomous and drifting systems, fixed platforms and on ships, as well as remote sensors on satellites. Even though the selection is far from complete, it illustrates the diversity of the existing in-situ and remote sensors worldwide.

In-situ sensors on autonomous and drifting systems

Autonomous and drifting systems, such as, for example, profiling floats, glider technologies, and tagged marine animals, play a central role in subsurface ocean observation (Roemmich et al., 2009). Profiling floats are among the best technologies to sample the global oceans. At the same time, they present a very cost-effective way for high-quality broad-scale profile data (Argo, 2016). While the traditional Argo floats have been able to provide samples of the subsurface (up to 2000 m), including temperature, salinity, sea pressure and deep currents, many new floats have the capacity to measure a variety of biochemical parameters such as chlorophyll and dissolved oxygen. Pilot versions of "Deep Argo" floats are likely to expand sampling right down to the ocean floor (Roemmich et al., 2009).

Glider technology has proven to be useful for regions where high spatial resolution is required, such as boundary currents, water mass formation sites, marginal seas, and straits/chokepoint sections (Testor et al., 2010). Deployed in swarms, they provide near real-time high spatial and temporal resolution data, which can complement the data of the ARGO network (see "European Gliding Observatories Action").

The use of miniature electronic data recorders and transmitters, tagged on marine animals, ranging from 6-g salmon smolts to 150-ton whales (Block et al., 2016), have further improved the collection of ocean data by in-situ sensors. The advantage of using aquatic animal species lies in the collection of high-resolution physical oceanographic data from regions that are inaccessible to other ocean observing technologies, at relatively low costs. Regions where the use of animal tags is interesting include especially high altitudes, such as polar oceans beneath seasonal or permanent sea ice (Charrassin et al., 2008; Coasta et al., 2008) or remote atolls such as those in the Northwest Hawaiian Islands. In addition, the animals reach areas where floats are pushed away, such as in upwelling zones, and are able to cross political boundaries and different national exclusive economic zones (Block et al., 2016). By choosing and tagging the appropriate marine animal, the collected data can fill 'white spots' in the global data collection (Roemmich et al., 2009).

In-situ sensors installed on fixed platforms

In addition, in-situ sensors are installed on fixed platforms, such as moorings, tide gauges and buoys. Over the past years, OceanSITES has developed a global network of multidisciplinary stations in the deep-water in order to track and measure the full depth of the ocean from air-sea interactions down to a depth of 5 000 meters below sea surface. This is done often in real-time. One sub-element, the Global Tropical Moored Buoy Array (GTMBA) provides real time data on the upper ocean physics and meteorology across the tropical Indian, Pacific and Atlantic oceans. That information is used to improve forecasts for the El Niño/Suthern Oscillation, the Indian Ocean Dipole, tropical Atlantic climate variability, as well as many other phenomena (McPhaden et al., 1999). The Global Sea Level Network (GLOSS) presents a network that measures, with the help of tide gauges, the worldwide level of the water level at the sea surface. GLOSS consists of 290 sea level stations around the world that monitor long-term climate change and oceanographic sea level variations (GLOSS, 2016).

In-situ sensors on ships

In spite of the technological innovations of different marine sensor technologies, in-situ sensors on ships remain one of the key methods for obtaining high-quality, high spatial and vertical resolution. Shipboard hydrographic data provide often the quality standard against which the data from floats and other autonomous platforms are compared. This is important to detect and correct possible systematic errors.

Ocean observation on ships is conducted either by research vessels or commercial ships on a voluntary basis. There is a worldwide network of commercial ships that voluntarily collects data about ocean observation by virtue of arrangements between many national meteorological services and commercial ships. While the meteorological services receive data generated by ship-based ocean observation, the ships have in return access to the instrumentation and weather forecasting for free. That is the case, for example, of the Voluntary Observation Ship scheme (Kent et al., 2010). Other examples for commercial ships involved in ocean observation include the Ship of Opportunity Program, consisting of a large fleet of cargo ships (Goni et al., 2010) and the Ship Observation Team

(SOT, 2016). Exemplary for research vessels are the International Ocean Carbon Coordination Project (IOCCP), which collects information on surface water partial pressure of carbon dioxide (pCO2) to quantify the spatial and temporal (seasonal, inter-annual, decadal) patterns of carbon uptake and release (IOCCP, 2016).

Remote sensors

Remote sensors are complementary to the measurement of ocean variables from in-situ sensors since they collect a wide range of additional data samples. These include wave directions, oil spills, ocean colour, surface winds and sea ice topography including the ice thickness, ice coverage, drift, and melt pond fraction (Roemmich et al., 2009). The complementarity and accuracy of their data collection makes remote sensors the benchmark for the validation of ocean and climate studies. In addition, they are essential for real-time observing by functioning as a receiver for data from in-situ sensors, such as Argo floaters. For example, the Group for High Resolution Sea Surface Temperature provides high-resolution data about changes in the global sea surface temperature through the use of satellite imagery (GHRSST, 2016). Other satellite sensor programmes track global sea level changes which are the basis for regional and global mean sea level trends.

2.3.2 Data management and processing

Ocean observation requires data management to integrate data from different observation platforms and networks described in the sections above. Often, data management is distributed among several institutes. However, that makes data management not only more difficult, it also requires system interoperability in data formats, metadata protocols, and modes of data delivery, as well as quality checks and open data policies (Belbeoch et al., 2010).

The analysis of these millions of observatories requires automated processes and combined efforts from scientists and engineers. Cluster structures, often in combination with universities, and automated processes can be beneficial in that sense.

"European Marine Data Observation Network" (EMODnet) is an example of an initiative to assemble fragmented and inaccessible marine data to interoperable and contiguous data streams. In such a system, the data is often processed in physically distributed repositories, while the user connects to a portal where he can query the data without knowing where the data physically reside (Pouliquen et al., 2009). Another example is "SeaDatanet" that provides online data from 36 countries to service providers (SeaDatanet, 2016). On an international level, the programme "International Oceanographic Data and Information Exchange" (IODE) integrates, archives and assesses the quality of millions of ocean observations in over 80 oceanographic data centres (IODE, 2016).

2.4 Scientific and operational applications

The improved predictability of the interactions between the ocean and atmosphere is useful for scientific and operational applications. Scientific applications are mostly long-term forecasts about the ocean, climate, storms, tsunamis, ocean waves, sea-ice monitoring and any other future climatic changes (Cristini et al. 2016). Typical stakeholders are from academia and governments.

By contrast, operational applications include weather forecasts for the improved operability of industrial, commercial and economic activities, including maritime traffic, energy industries, capture fisheries and aquaculture. In the UK, for example, the sectors that used the data from ocean-observation were oil/gas (39%), renewable energy (18%), environmental monitoring (10%), defence-related business (8%), academic (6%), ports and harbours (6%), security (5%), other sectors (e.g., water distribution & treatment, leisure, mining, subsea, etc.) (8%) (O'Neill & Carlisle, 2014).

There are several providers for applications of both kinds, often overlapping with data management centres. One example for an application provider is the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), a joint commission of the UNESCO-IOC and the World Meteorological Organization (WMO) (Nolan, 2016). The objective is to support the development, enhancement and delivery of climate services related to the marine atmosphere and coastal and deep oceans. In addition, the commission assists marine meteorological and oceanographic services to support ocean-based industries.

2.5 Societal and private benefits

The use of data applications leads to improved information about a situation, benefitting both society and the economy. Societal benefits of ocean observation include the better understanding of the changes in marine ecosystems (UN, 2015a) and the current health of the oceans (IPCC, forthcoming). That knowledge is essential to draft national and global policy agendas, such as the ocean-related Sustainable Development Goals (in particular SGD 14) (UN, 2015b). In addition, the increased knowledge about the Earth's system and climate change helps to prepare society for risks, such as storms, droughts, rainfall anomalies, wet seasons (Hoerling & Schubert, 2009; Cury, 2008).

Private benefits are the result of improved decisions for commercial operations. For example, operational maritime industries are able to prepare for storms and adapt to changed conditions through the use of support tools, such as weather forecasts, GPS, enhanced geodesy[1] and nautical charts. The forecasts about the maritime conditions, including tides, wave directions and currents, help maritime traffic, fisheries and the energy industries in gaining higher productivity results and improved economic performance.

Finally, there are effects that are both beneficial for society and commercial activities. Increased emergency and safety through flood early warning systems, reduced pollution and improved food supplies, result in fewer accidents which can be regarded as beneficial for both society and the private sector (Rayner, 2016; Flemming, 2007).

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1 Geodesy is the branch of mathematics dealing with the shape and area of the earth or large portions of it (Oxford Dictionary).

Alternatively, social and commercial benefits can be divided between “use-benefits” and “non-use benefits”, as outlined in Table 3. “Use-benefits” include the direct or indirect use of the knowledge or data gained through ocean observation. “Non-use benefits” are the benefits of improved environmental resource management, resulting in a healthier ocean that will create value for future generations (bequest value), others (altruistic value) as well as oneself (option value). Additionally, “non-use benefits” result from the knowledge of the existence of the changes in marine ecosystems.

Table 3: *Use-benefits and non-use benefits of ocean observation*

Type of benefit	Sub-components of benefits	Applications	Examples of improvements
Use benefit	Direct use	• Marine weather forecasts of sea-state and meteorological conditions	• Renewable energy • Defence-related operations • Agricultural use • Energy management • Coastal management • Facilities planning • Disaster risk reduction • Public health risk reduction • Search, rescue • Other sectors (e.g. conservation, mining, subsea technologies)
		• Long-term monitoring in climate and ocean modelling	• For improved environmental management of marine, coastal and land operations • Improving the management, mitigation, and adaptation of environmental change and climate; global environmental policy
	Indirect use	• Book and newspaper readers • TV and documentaries audiences	• Understanding of marine ecosystems as part of sustained life on Earth
Non-use benefit	Option value	• As “use benefits”, only in the future	• Better protection of the marine environment for future individual use
	Altruistic value	• Long-term monitoring in climate and ocean studies for scientific research and strategic planning	• Better protection of the marine environment for the use of others
	Bequest value		• Better protection of the marine environment for the use of future generations
	Existence value		• Better protection of the marine environment for the sake of their existence

Source: Adapted from Cristini et al. (2016).

3. Socio-economic impact assessments of ocean observations

Socio-economic impact assessment can assist in anticipating the benefits of ocean observation. There are a variety of evaluation techniques, including cost-benefit analysis, surveys for self-assessment, as well as statistical and empirical analysis. The following presents an economic rationale for socio-economic impact assessment of ocean observation, and a categorisation of the state of impact studies published in the past years.

3.1 Economic rationale of valuing data generated by ocean observation

Based on the value of information approach (Kite-Powell, 2005), the actual value of ocean observation lies in the improved information that is gained through forecasts, now-casts or near real-time information. The value of data is therefore the effect of the reduced uncertainty over a situation which leads to expected benefits (or reduced costs), compared to the situation when the data are not available (see Kite-Powell, 2005; Weiher, 1998). This information can improve a societal decision (e.g. adaptation to rising sea levels in areas prone to inundation) and a decision related to commercial activities (e.g. optimization of shipping routes in ice-free Arctic in summer).

However, numerous studies have noted that valuing data generated by ocean observation needs to overcome many obstacles (Flemming, 2001b; Brown, 1997; Weiher, 1999). Those challenges include the following:

A wide range of governmental and research initiatives – at multiple local, national, regional and global levels - are involved in ocean observation worldwide, however, they follow different, sometimes even competing, mandates and interests. Whereas the majority of mandates aim to improve marine research and to support operational services with the help of meteorological services, some mandates tend to follow security objectives while surveying national coasts.

Further, due to the complexity of the research and increasing ocean observation activities worldwide, a lot of data have been collected but in many cases data collections are still incompatible. Hence, further efforts are required regarding a better harmonisation of different formats, nomenclature, baselines and other standards.

In addition, evaluation capacity remains weak and fragmented in most countries. Often, the standards for evaluation are not well defined, and the evaluation as well as follow-up processes and monitoring of consequences are not well integrated. This is related to the lack of official data on value-added and employment of marine science in national statistical offices. To overcome these challenges, it is helpful that outside evaluators and stakeholders outside research establishments get involved (Jolly, 2016) and companies provide information on their use of ocean observation data through industry surveys (Willis, 2009).

Considering the length, complexity and multiplicity of the value chain(s) in ocean observation, it remains difficult to identify the total benefits, either as a total aggregated figure or as a breakdown in subcategories. This is related to the growing and diverse set of agents involved along the value chain. At the beginning of the value chain are providers of physical facilities and data infrastructure, as well as ocean observation operators who develop the technical equipment and run the operations. The large initial investment for the infrastructure (e.g. platforms, in-situ and remote sensors, etc.) come mainly from the public domain but can be co-funded with the private sector or can be sub-contracted to private companies (Nolan, 2014; Hanlon, 2016). The private sector alone would have difficulties to recoup the investment of initial capital costs (Weiher, 2008).

In such a complex and diverse value chain with many different agents involved, it is challenging to estimate the costs for each ocean observatory individually as well as on a global scale. On a micro level, it would require disaggregating the cost of global or regional ocean observations into a set of sub-costs, such as capital investment, duration, and running costs[2]. Hereby, it is important to consider different proportions because the costs can vary substantially depending on the type of infrastructure, sensor technology, sampling frequency and sensor configurations (Ryder, 1997). Similarly, on a macro level, the global cost calculation is challenging because it would require analysing sunk costs or shared costs of multiple beneficiaries (Flemming, 2001).

Governments, ocean scientists and ocean businesses have different interests in ocean observation, which can result in different rights of the data. In most cases, data may be provided for free to the public; however, data rights may be also overlapping, competitive, and restricted. In case the data need to be purchased, the added value of private data requires another calculation.

Where data are offered for free and with unrestricted access, the "public good" character of ocean observation data creates some caveats in the measurement of the benefits. In principle, ocean observation is based on the ideas of open and free exchange of data, international collaboration and coverage of areas under and beyond national jurisdiction. This makes the data, once produced, non-exclusive and non-rival because it can be provided to additional users at unrestricted levels and at zero marginal cost (Fischer, 2016).

3.2 Review and classification of socio-economic impact assessment studies

A number of socio-economic impact assessments have been undertaken to estimate the value of data generated by ocean observation. Among these studies, many public investment decisions in Europe and elsewhere have been based on the assumption that the benefits of ocean observation exceed the costs, and might be "much higher" than expected (see Flemming, 2007). However, a robust socio-economic justification including different scenarios and assumptions of a net present value figure, broken into diverse beneficiaries and sub-sectors with different characteristics and time-frames, is still missing (see Flemming, 2007).

As the beneficiaries of ocean observation can vary between governmental agencies, academia, private companies and individuals, the calculation of public and private benefits requires per definition distinct approaches and measurement techniques (Rayner, 2016). Literature suggests classifying and separating these studies between their socio-economic end-users (Flemming et al., 2007) and major public / private benefits: public good benefits, private benefits, and the combination of public and private benefits (Rayner, 2016). Table 4 provides an overview.

2 The costs involve for example purchase of equipment, deployment costs, ship operations, maintenance and replacement of equipment, satellite launch costs, equipment planning, design costs, costs for communications and data processing, modelling centres, computers, product deliver etc.

Table 4: *Separation between socio-economic beneficiaries / end-users*

Private / public benefit	Category of beneficiary	Examples
Private	Market driven efficiency information	Marine weather forecasts of sea-state and meteorological conditions, planning of medium-term and long-term commercial operations.
Private and public	Improving environmental management of marine, coastal and land operations for commerce and government agencies	Clean beaches and sea bathing water, pollution management, marine conservation, establishment of marine protected areas.
Public	Guidance for European and Euro-global policy on environmental and welfare issues, improved regulations, non-market values and public good benefits	Long-term reviews to improve regulations, such as implementation of regulations on water quality, public health, biodiversity, etc.
Public	Planetary public goods, improving the management, mitigation, and adaptation of environmental change and climate; global environmental policy on the grand scale	International knowledge-base which allows to respond to sea level rise on Pacific Islands, Bangladesh, and the Nile Delta; global degradation of coral reefs; the knock-on effects of the complete seasonal melting of the Arctic sea ice, or changing patterns of rainfall.

Source: Adoped from Flemming et al. (2007), Rayner (2016).

By applying different categories of end-users / beneficiaries of ocean observation data, different individual benefits within one class can be evaluated in the same way, and the experiences and techniques can be transferred to another. Hence, the following aims to classify the existing studies reviewed in the major categories public good benefit studies, private / commercial benefit studies and studies that asses both.

3.2.1 Public good benefit studies

There are very few studies that can be allocated to the first category of studies on *public good benefits.* The often cited studies from the consulting companies Pricewaterhouse Cooper (2006) and Booz & Company (2009) belong to this category. However, these examples are a limited representative of that category as they were conducted for the Global Monitoring for Environment and Security (GMES) observing system which conducts ocean and terrestrial observation. Nevertheless, they are mentioned by way of illustration. In both cases, the results are that climate change adaptation leads to the highest monetary benefits. For example, Pricewaterhouse Cooper (2006) estimated that climate change adaptation would contribute to around a half of the total annual benefits, roughly EUR 14 billion.

3.2.2 Private benefit studies

Compared to public benefit studies, there is a wide field of *private benefit studies*; however they differ in their industrial, geographical and methodological scope. The following gives more insights into the range of diverse approaches.

Studies addressed some commercial benefits but none of them addressed the full range. The majority of the studies cited focused on the benefits for one industry, such as agriculture (Adams et al., 1995; Altalo, 2000; Sassone and Weiher, 1997; Weiher et al., 1999; and Solow et al., 1998), whereas very few studies included the commercial benefits for more sectors (Zillmann et al., 2006; Dumas & Whitehead, 2008). In addition, the studies differed in their geographical scope (i.e. local, national, and regional) from a study, for example, of a whole continent such as Australia (see Zillmann et al., 2006), to a relatively small region, such as the Gulf of Mexico (Kaiser & Pulsipher, 2004).

Finally, the methodology often differs, and very few studies have conducted a comprehensive methodological estimation of the total economic value of data generated by ocean observation. In some cases a full cost-benefit analysis was published, while other studies measured only one side (i.e. either costs or benefits) (see Woods et al., 1996). Someome studies included real cost figures, while other studies used the 1% rule as an approximation of the total costs (Kite-Powell, 2009; Woods et al., 1996).

Different methodologies used for private benefit studies

The following shows examples of different methodological approaches of private benefit studies. They can be grouped in three categories: cost-benefit analysis, 1% approximation and industry surveys.

Some cost-benefit studies have been conducted for ocean observation systems in different regions (eg. TOGA, The Integrated Sustained Observing System in the United Stated, the Ocean Network Canada and Seawatch Europe) (see Table 4). These studies not only provide technical details on how the studies have been conducted, they also indicate helpful comparisons of the net discount rate[3.] On a national scale, the Cost-Benefit study of the Australian Ocean Observation System pointed out that the services provided by improved weather, climate and ocean forecast for a range of Australian industries (i.e. agriculture, oil & gas, iron ore, and fishing) would create net benefits of around AUS 616 million per year (Zillmann et al., 2006). On a local level, the study of the application of PolarSAR data to services within the sea ice could generate a benefit-cost ratio in the range of around 1.7:1 (Holt-Andersen & Schumacher, 2004).

[3] The highest benefit cost ratio would result from a combination of low discount rates and benefits that can be realized immediately without a delay of time. Flemming (2001) from Euro-GOOS recommends using a discount rate that comes close to 1%.

Table 4: *Summary table of selected cost-benefit (CBA) studies conducted for ocean observation systems*

Focus Region	Ocean observation system	Objectives	Results	Reference
USA	Integrated Sustained Ocean Observing System (ISOOS)	To review existing literature of CBA studies	The additional benefits of ocean observation arise if the systems are integrated and sustained	Adams et al. (2000)
USA	TOGA	To conduct a CBA after 10 years of having implemented TOGA	Return on investment between 13% and 26%	Busalacchi (2009)
Baltic, Barents Sea, Arctic sea route	PolarSAR	To conduct ex-ante a CBA to prove the return on investment.	The selection of the assumptions, including the Net Present Value, can vary the outcome.	Holt-Andersen & Schumacher (2004)
Arctic	Sustained Arctic Ocean Observing System	To demonstrate the need for ocean observation in the Arctic	It would be beneficial to install an ocean observation system in the Arctic.	IOC-UNESCO (2010)
USA	Regional coastal ocean observing system	Preliminary investigation into the installation of an integrated ocean observation system in the United States	Benefits are likely to exceed the costs.	Kite-Powell & Colgan (2005)
USA	The El Niño–Southern Oscillation (ENSO) Observing System	To estimate the economic efficiency of observing ENSO	The benefits, notably for agriculture, range between 13 and26% for return on investment	Sassone & Weiher (1997)
Europe	Seawatch Europe	To demonstrate the benefits of Seawatch Europe	The authors point out the flexibility of Seawatch, without calculating the benefits in detail.	Stel & Mannix (1996)
Canada	Ocean Networks Canada (ONC)	To analyse the costs and benefits of the three components of ONC	ONC is of substantial importance in terms of its economic impact from a number of perspectives.	Vancouver Board of Trade (2012)
Australia	Integrated Marine Observing System (IMOS)	To prove that investing in IMOS is economically efficient	Net benefits are estimated to be around AUS 616 million per year	Zillmann et al. (2006)

Source: Adams et al. (2000), Busalacchi, A.J. (2009), Holt-Andersen & Schumacher (2004), IOC-UNESCO (2010), Kite-Powell & Colgan (2005), Sassona & Weiher (1997), Stel & Mannix (1996), Vancouver Board of Trade (2012, Zillmann et al. (2006).

However, not all known studies were based on a cost-benefit analysis. Instead of assessing costs and benefits in detail, some studies have used a “1% measurement approach”, based on empirical evidence (Kite-Powell, 2005). They calculated the total sum of value-added, revenue or turnover of all industrial maritime activities to arrive at a percentage of gross national product, and then assumed that the weather and maritime forecasts lead to a 1% increase of gross national product. Based on that approach, productivity gains due to weather forecasts for operational services would be equal to around 1% of the total annual value-added of ocean-based industries (Kite-Powell, 2009; Woods et al., 1996).

A third methodological approach includes industry surveys for the self-assessment of the impacts of ocean observation stemming from operational services (ERISS, 2009). For example, the industry survey by NOAA on US business activity in ocean measurement, observation and forecasting estimated that the providers and intermediaries of ocean observation data in the United States contributed to revenues of around USD 7 billion per year (ERISS, 2016).

Industries scoring highest in private benefit studies

Even though it is hardly possible to compare the results of different studies due to their different methodological approaches, the analysis of the private benefit studies has shown that terrestrial agriculture was ranked among the commercial activities that would benefit most from ocean observation data (see Zillmann, 2006; Adams et al., 1995; Sassone and Weiher, 1997; Weiher et al., 1999; and Solow et al., 1998). One explanation is that agriculture is among the most climate sensitive industries and climate is the primary determinant of agricultural productivity (Weiher, 1999). The American agriculture industry is estimated to have lost around USD 1.5 – 1.7 billion due to the 1997-98 El Niño event, and USD 2.2 to USD 6.5 billion due to the 1998-99 La Niña events (Adams et al., 1999).

Table 4: *Examples of valuation studies measuring the annual benefits of ocean observation accruing to the agriculture industry*

Area	Benefit	Method	Source
United States	USD 323 million	Bayesian decision theory	Adams et al. (1995)
United States	No concrete benefit figure available; IRR values range from about 13 -26 %, which is higher than the opportunity cost of the capital absorbed (7%)	Cost-Benefit analysis	Sassone and Weiher (1997)
United States	USD 266 – USD 320 million	Bayesian decision theory	Solow et al. (1998)
Australia	AUS 241 million	Cost-benefit analysis	Zillman et al. (2006)

Source: Adams et al. (1995), Sassona & Weiher (1997), Solow et al. (1998), Zillman et al. (2006).

3.2.3 Studies that assess both public good and private benefits

Most of the studies reviewed calculated both private and public good benefits. They included the benefits of weather forecasts on different industries but they also considered the benefits of emergency response, crisis management, and search and rescue activities. Overall public benefits were estimated to be higher than the benefits for commercial and industrial activities (Kaiser & Pulsipher, 2004; Kite-Powell & Colgan, 2001, 2004; Dumas & Whitehead, 2005). The following gives examples of these higher estimated public benefits from ocean observation.

Kaiser & Pulsipher (2004) estimated that the annual benefits -- including more efficient search and rescue operations, and pollution management -- for the Gulf of Mexico region would range between USD 85 and 126 million. Dumas & Whitehead (2005) estimated that beach recreation and improved search and rescue activities contributed to the bulk of the benefits of the South East Atlantic Coastal Ocean Observing System (SEACOOS), which were around USD 170 million (measured in 2003 USD). Kite-Powell & Colgan (2001, 2004) obtained similar results for the United States (2004) and the Gulf of Maine (2001). In these studies, more efficient rescue and search operations contributed to the lion's share of the overall estimated benefits. The result that overall public benefits were estimated to be higher than private benefits was independent of the geographical scope of the study. Stel & Mannix (1996) proved the same for a regional study for the sub-system of the European part of the Global Ocean Observing System (EURO-GOOS), as Kite-Powell (2004) did on a national level for the United States.

4. Next steps

This section briefly outlines the next steps following the scoping paper and the joint workshop between the OECD and AtlantOS. The steps will be expanded upon in the next report.

The studies reviewed recommended to maintain marine research budgets (Cristini, et al., 2016) because the benefits of investing in sustained ocean observation were proven to be higher than the costs, especially in a long-term perspective and where the outcomes are used by the largest number of end-users. Sustaining marine research budgets for ocean observation was stated to be important for a wide range of reasons, including improved risk management that permits a better preparation for storms, droughts, rainfall anomalies, wet seasons and other risks related to weather and the changing climate. In addition, the studies confirmed the commercial benefits of ocean observation for both land-based and ocean-based industries, such as agriculture, energy industry, tourism and shipping.

However, a better international knowledge base is needed because in many cases, the economic information needed to estimate benefits is even today still fragmented. It must be priority to improve evidence-based information about the benefits and costs of ocean observations. The magnitude of the benefits of ocean observation data should be more accurately estimated with detailed studies of the specific connections between information and users. Additional research is needed to develop more precise estimates of benefits for specific observation systems, instruments, technologies and applications. That evaluation is important for decision-makers and citizens and should be done with reference to international benchmarks.

The community would benefit from more stakeholder involvement to gain more knowledge about the diffusion and use of ocean observation data in different economic sectors while balancing the tension between (scientific) relevance and social /economic impacts. In addition, it would be beneficial to agree on definitions, concepts and valuation methods, as well as best practices in measurement approaches, to support the community and guide governments' priority setting and decision making about these large public investments.

The timing and international context, including the G7 initiative on the seas and oceans, could be favourable to launch an activity focusing on the value of ocean observation. Building on OECD expertise in the fields of ocean-based industries, marine environment and impact assessment, the OECD Ocean Economy Group, in the Directorate for Science, Technology and Innovation (DSTI), aims to explore the economic potential of data generated by ocean observation and provide decision makers and the wider research community with an improved toolbox for economic measurement and to support the international knowledge base in relation to data usage of ocean observation, technical spill overs and diffusion of ocean observation data in the wider economy.

In detail, the project will explore the value of ocean observation through three work packages:

1. ***Considering the community of end-users:*** For better evidence-based information, more knowledge is necessary regarding the community of end-users of ocean data. In close co-operation with selected interested agencies that are responsible for delivering data and value added information, the objective would be to analyse ocean data downloads from institutional portals, to the extent that data can be tracked (i.e. data users, download purpose, intensity). This would provide a series of matrices, useful for the further application of value-of-information techniques.
2. ***Exploring spill-overs with bibliometrics:*** The activity would explore the diffusion of ocean observation data in different economic sectors via bibliometrics. Ocean observations are essential in marine science and diverse economic sectors, such as fisheries, aquaculture, maritime transport, and energy. However, a mapping of these interconnections and resulting potential spill-overs still does not exist.
3. ***Assessing socio-economic benefits of ocean observations:*** The activity would review definitions (e.g. types of ocean observations), concepts and valuation methods to assess the (mainly) public and private benefits of ocean observations. The aim is to build, in collaboration with the ocean observing community, families of case studies and to catalogue them, agree on best practices in measurement approaches of public benefits, and later diffuse them to the wider community. On the commercial benefit side, the project would build on lessons learned from existing industry surveys.

This output will be useful to stakeholders in government, the ocean community and economists. More details will follow in a sub-project proposal which will be presented at the Steering Board Meeting on 8-9 December 2016 in Paris.

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Appendix

Table A-1: Overview of studies assessing the benefits of ocean observation data

Type of beneficiary (public/private)	Integrated information systems	Evaluation-study	Methodology	Results	Impact
Public benefits	Global Monitoring for Environment & Security (GMES) = Earth Observation (EO) programme	PWC (2006), Main Report Socio-Economic Benefit Analysis of GMES	Stakeholder survey	PWC states that the benefits of implementing full GMES would yield around Euro 28 billion/ year, biggest effect was estimated to be in climate change adaption (more than Euro 13 billion)	Positive response in the EC, initiated the work of a Cost Benefit Analysis of GMES 5 years later.
Public benefits	Global Monitoring for Environment & Security (GMES) = Earth Observation (EO) programme	Booz & Company (2011), Cost Benefit Analysis of GMES	Cost-benefit analysis based on a strategic evaluation framework	Developed framework which is based on an understanding of the space and EO sectors, and the role EO infrastructure plays for better managing environment and security issues	Wide impact on the understanding of ocean observation for climate change adaptation.
Private benefit	Integrated Marine Observing System (IMOS)	Zillmann (2006), Economic of Australia's Ocean Observation System, Benefits and Rationale for Public Funding	Cost-benefit analysis	Benefit was AUS 616.9 million compared to AUS 27.3 million, Benefit-cost ratio (22.6).	Demonstrated the high value-for money of ocean observation, and commissioning of a more comprehensive CBA.
Private benefits	The El Niño–Southern Oscillation (ENSO) Observing System	Sassone & Weiher (1997), Cost-benefit analysis of TOGAS and the ENSO Observing System	Cost-benefit analysis	Benefits to the USA, principally to agriculture, equivalent to a 13-26% return on investment.	Supported following funding for climate forecasting R&D efforts
Private benefits	The El Niño–Southern Oscillation (ENSO) Observing System	Solow et al. (1998), The Value of improved El Nino-Southern Oscillation (ENSO) Prediction to US Agriculture	Empirical study based on Bayesian Decision model	Assuming that future benefits are discounted at an annual rate of 6%, the net present value to the agricultural sector of a high skill ENSO prediction operating over 10 years is around USD2 billion.	One of the first studies demonstrating the benefits of weather forecasts for the agriculture industry.
Private benefits	PolarSAR data (Area is the northern hemisphere with focus on the	Holt Andersen and Schumacher (2004),	Cost-benefit - Analysis	Benefit: cost ratio, discounted to NPV at 3%, is approximately 1:1; modified to make a more	Ex-ante study which proofed that the the project is beneficial

	Baltic, Barents Sea, and northern Arctic sea route))			generous assessment of costs, this becomes 1.7:1.	
Private benefits	Integrated Ocean Observing System (IOOS)	Willis (2009), The Business Case for Improving NOAA's Management and Integration of Ocean and Coastal Data	Cost-benefit analysis	The analysis indicates that an investment in DMAC would likely generate a NPV between USD38 and USD60 million dollars over a 15-year period.	Triggered continuous efforts on ocean observatories in the USA.
Private / public benefits	Gulf of Mexico	Kaiser & Pulsipher (2004), The potential value of improved Ocean Observing Systems in the Gulf of Mexico	Sum of the benefits of improved OOS for each activity $V(R) = \sum_A \varepsilon\ (A)\ V$, where ε is the benefit of improved OOS of the value of an activity $V\ (A)$	The study estimates the value of the benefits derived from improved ocean observation systems was estimated to range between USD 85 million and USD 126 million.	Demonstrated a case when the theoretical framework of Kite-Powell was applied.
Private / public benefits	Euro-GOOS	Woods *et al.* (1996), The Strategy for Euro-GOOS	1% rule	110-190 bn Euro/year	Added one more economic argument to develop Euro-GOOS.
Public / private benefit study	Seawatch Region (Sub-system of Northern European EUR-GOOS)	Stel & Mannix (1996), A benefit-cost analysis of a regional Global Ocean Observing System: Seawatch Region	Cost-benefit analysis	Estimated annual benefits in the 100s of million of dollars – perhaps an order of magnitude greater than annual costs.	Triggered the discussions for funding of Seawatch
Public / private benefits	Gulf of Maine OOS (GoM-OOS) (subsystem of US-IOOS)	Kite-Powell & Colgan (2001), The potential economic benefits of coastal ocean observing systems: the Gulf of Maine	"Value of information" (estimated willingness-to –pay method and 1% increase, 1% decrease method)	They estimated total potential annual benefits in excess of USD30 million for the region, with the bulk of these benefits coming from lives saved due to improved effectiveness of search and rescue Operations.	Induced follow-up studies
Public / private benefits	Southeast Atlantic Region (subsystem of US-IOOS)	Dumas & Whitehead (2008), The potential economic benefits of integrated & sustainable Ocean Observation Systems:	Consumer-surplus Method, 1% increase in expenditures, 1% decrease in costs	The annual economic benefit of the data from the regional ocean observing system was estimated around USD 170 million (measured in 2003 USD).	Proofed economic viability

		Southeast Atlantic Region			
Public / private benefits / background documents	The El Niño–Southern Oscillation (ENSO) Observing System	Weiher (1999), Improving El Nino Forecasting: The Potential Economic Benefits	compilation of documents	Climate sensitive industries account for nearly 15 percent of GDP. The aggregate economic impacts of the recent El Niño were likely in excess of USD 10 billion.	Impact unknown but assumed to be moderate since most of the papers were already published somewhere else.
Background and scoping document	Euro-GOOS	Flemming (2007), SEPRISE Socio-Economic Analysis. Scoping Report	Cost-benefit analysis	Economic valuation on the ocean observation data itself has not been carried out yet but assumption of 1% positive effect.	Supported proposal for EUR-GOOS
Background document	Euro-GOSS	Flemming (2001), Dividends from investing in Ocean Observations: A European perspective	Background study for conducting a Cost-benefit analysis	Confirming the economic valuation of EURO-GOOS	Fostered ongoing collaboration promoted by EURO-GOOS to maximise the benefits from investments
Background document	Integrated Ocean Observing System (IOOS)	Adams et al. (2000), The Economics of Sustained Ocean Observatories: Benefits and Rationale for Public Funding	Literature analysis	Conclusion is that substantial investment is justified, benefits are "large", without being very precise, and little attempt to quantify costs.	Triggered more applied economic impact studies to better quantify the benefits.

Source: PWC (2006), Booz & Company (2011), Zillmann (2006), Sassone & Weiher (1997), Solow et al. (1998), Holt Andersen & Schumacher (2004), Willis. (2009), Kaiser & Pulsipher (2004), Woods et al. (1996), Stel & Mannix (1996), Kite-Powell & Colgan (2001), Dumas & Whitehead (2008), Weiher (1999), Flemming (2007), Flemming (2001), Adams et al. (2000).

[i] The members of the regional ocean observation system in the Arctic come from 16 different marine research institutions from nine European countries (e.g. Denmark, Finland, France, Germany, Iceland, Norway, Poland, United Kingdom and Sweden). A good overview of the different stakeholders in the Arctic has been developed by the Arctic Data Ecosystem Map, a project by the University of Colorado (see http://arcticdc.org/products/data-ecosystem-map).

[ii] These are Antigua & Barbuda, Bahamas, Barbados, Belize, Brazil, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, France, Grenade, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, the Netherlands, Nicaragua, Panama, St. Kitts & Nevis, St. Lucia, St. Vincent & the Grenadines, Suriname, Trinidad & Tobago, United Kingdom, United States of America and Venezuela.

iii The PacIOOS region includes the U.S. Pacific Region (Hawaiʻi, Guam, American Samoa, Commonwealth of the Northern Mariana Islands), the Pacific nations in Free Association with the U.S. (Republic of the Marshall Islands, Federated States of Micronesia, Republic of Palau), and the U.S. Minor Outlying Islands (Howland, Baker, Johnston, Jarvis, Kingman, Palmyra, Midway, Wake).