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Title Cost and value of multidisciplinary fixed-point ocean observatories

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Abstract

Sustained ocean observations are crucial to understand both natural processes occurring in the ocean and human influence on the marine ecosystems. The information they provide increases our understanding and is therefore beneficial to the society as a whole because it contributes to a more efficient use and protection of the marine environment, upon which human livelihood depends. In addition the oceans, which occupy 73% of the planet surface and host 93% of the biosphere, play a massive role in controlling the climate. Eulerian or fixed-point observatories are an essential component of the global ocean observing system as they provide several unique features that cannot be found in other systems and are therefore complementary to them. In addition they provide a unique opportunity for multidisciplinary and interdisciplinary work, combining physical, chemical and biological observations on several time scales. The fixed-point open ocean observatory network (FixO3) integrates the 23 European open ocean fixed-point observatories in the Atlantic Ocean and in the Mediterranean Sea. The program also seeks to improve access to key installations and the knowledge they provide for the wider community, from scientists, to businesses, to civil society. This paper summarises the rationale behind open ocean observatories monitoring the essential ocean variables. It also provides an estimate of the costs to operate a typical fixed-point observatory such as those included in the FixO3 network. Finally an assessment of the type of data and services provided by ocean observations and their value to society is also given.

Keywords Ocean; observations; costs; value; data; services

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Table 1: Summary table of some cost-benefit analysis reviewed.

Reference	Observing system	Document type	Focus region	Objectives	Main conclusion
Stel & Mannix (1996)	Seawatch Europe	Research paper	Europe	To report & discuss some results of a benefit-cost analysis of the Seawatch System	Off-shelf in situ regional observing systems like Seawatch carry the benefit of being able to be deployed in different areas (i.e., they are not dependent on the location) and number (i.e., multiple systems can be installed). For this reason it is difficult to calculate the general costs, but easy to identify benefits
Busalacchi (2009)	TOGA	Conference Proceeding	USA	To carry out a cost-benefit analysis for the TOGA programme after 10 years of implementation	The program was a sound use of resources that will provide a real economic return between 13% and 26%
Adams et al. (2000)	Integrated Sustained Ocean Observing System (ISOOS)	Report	USA	To review the economic benefits of an integrated sustained ocean observing system (ISOOS) and the rationale for its support by the US government	Integrated data collection generates additional benefits that are not available for individual observatories
Kite-Powell et al. (2005)	Regional coastal ocean observing system	Report	USA	Preliminary investigation of magnitude of potential economic benefits that can be realized by deploying a network of ocean observing systems throughout the coasts of US	Benefits from investments in ocean observations are likely to exceed the costs. Ocean observing systems have the largest benefits when the information they provide is used by the largest possible groups
Australia Academy of Technological Sciences (2006)	Australia GOOS	Report	Australia	To demonstrate that investing in the GOOS represents value for money in terms of the considerable and diverse benefits to communities and industries	The report assesses the potential benefits of improved weather forecast deriving from better ocean observations for some industries: agriculture, oil production iron production, fishing and flow-on benefits for the rest of the economy. Net benefits are assessed as $616 million/year
Vancouver Board of Trade (2012)	Ocean Networks Canada	Report	Canada	To analyze the costs and benefits of the three components of Ocean Network Canada (ONC)	ONC is of substantial importance in terms of its economic impact
IOC-UNESCO (2010)	Sustained Arctic Ocean Observing System	Brochure	Arctic	Motivate broadly the need for ocean observations in the Arctic ocean	An ocean observing system must be created in the Arctic to provide services to the society with attention to the needs of specific users.

Table 2: Essential Ocean Variables (EOVs) as defined by the GCOS (WMO, 2003).

Surface	Sea-surface temperature (SST) Sea-surface salinity (SSS) Sea level Sea state Sea ice Current Ocean colour (for biological activity) Carbon dioxide partial pressure (pCO2)
Sub-surface	Temperature Salinity Current Nutrients Carbon Ocean tracers Phytoplankton

Table 3: Estimate of annualised cost of a typical full-depth Eulerian observatory (adapted from Lampitt et al., 2011).

ITEM	Unit cost	Number	Capital	Capital	Consumables and	Operational cost per	Other	Annual
	k€ (per item or month)	items or person months	k€	k€/year	k€/year	k€/year	k€/year	k€/year
Meteorological package	14	1	14	2.8	8	4		14.8
Surface buoy	30	1	30	6	1	8		15
T/S/P	7	20	140	28	0.5	4		32.5
ADCP current profiler	30	1	30	6	0.2	8		14.2
Fluorescence	8	2	16	3.2	0.2	4		7.4
Oxygen	4	4	16	3.2	0.1	8		11.3
Nutrient	25	2	50	10	0.8	12		22.8
pCO2	15	2	30	6	0.6	12		18.6
pH	15	2	30	6	0.6	12		18.6
Irradiance	20	2	40	8	0.5	12		20.5
Acoustic release	6	1	15	3	0.1	8		11.1
Buoyancy	3	30	90	18	0.2	4		22.2
Wire/rope/anchor	20	1			20	4		24
Telecom	6	1			6	8		14
OTHER COSTS								
Ship time (20 k€/day for 5 days/yr)							100	100
Transport/travel							20	20
PERSONNEL								0
Coordination	12	2				24		24
Data management	8	10				80		80
Data interpretation and publication	10	18				180		180
Technician	8	10				80		80
Annual running cost of standard observatory			**501**	100.2	38.8	292	120	**731**

Table 4: Estimate for the annual cost of a network of 23 observatories such as FixO3 network. The average contribution from the European Commission (EU) for the FixO3 network is included for comparison.

ITEM	k€ (per item or month)	items or person months	k€	k€/year	k€/year	k€/year	k€/yea r	k€/year
Network coordination (project management)	10	12						120
Data management (including data interpretation and publication)	8	12						96
Annual running cost of observatory network (23 sites)			**11523**	2304.6	892.4	6716	2760	**12889**
Annual average contribution from EU (7 M€/4 yrs)								**1750**

Table 5: Some possible developments from ocean observations. Adapted from O'Neill & Carlisle 2014.

Sociological	Technological
▪ Recognition of climate change ▪ Fears about environmental damage ▪ Public interest about ocean environments ▪ Fears about ocean-related hazards ▪ Security fears ▪ Environmental stewardship	▪ More advanced sensors on the market ▪ Improved bandwidth & access to broadband ▪ Better power systems for remote subsea operations ▪ Reduced costs for cabling ▪ More off-the-shelf solutions
Economic	**Political & Legal**
▪ Increasing private sector spending on environmental monitoring ▪ Public sector investment in innovation as driver of economic growth ▪ Increasing natural hazards insurance claims ▪ Pollution insurance claims ▪ Investments in pharmaceutical industry ▪ New markets in emerging economies	▪ Demand for environmental security ▪ Need for marine spatial planning ▪ Sustainable development of marine resources ▪ Need for international oversight of deep ocean resources for common good

Table 6: Total economic value (TEV) for Eulerian ocean observations. Adapted from Ozdemiroglu & Townend, 2005, and including Flemming, 2001, and Dexter and Summerhayes, 2010.

Type of benefits	TEV components	Ocean observations information and data	Improved use of resources through improved information
Use benefits	Direct use	▪ Long-term monitoring and forecasting ▪ Scientific research ▪ Marine-related operations (e.g., ship routing) ▪ Other (cost of substitute data)	▪ Oil/gas ▪ Fishing operations and fisheries utilization ▪ Renewable energy ▪ Environmental monitoring ▪ Defence-related operations ▪ Agricultural projections ▪ Energy management ▪ Coastal management ▪ Facilities planning ▪ Academic ▪ Disaster risk reduction ▪ Public health risk reduction ▪ Ports and harbours ▪ Security ▪ Search and rescue ▪ Other sectors (e.g., conservation, mining, subsea technology)
	Indirect use	▪ Books and newspaper readers ▪ TV and documentaries audiences	Functions of marine ecosystems as part of sustained life on Earth
Non-use benefits	Option value	Same as use benefits, but projected for the future	Better protection of the marine environment for future use by the individual
	Altruistic value	Time series (monitoring)	Better protection of the marine environment for others to use
	Bequest value		Better protection of the marine environment for future generations to use
	Existence value		Better protection of marine habitats and species for the sake of their existence

Table 7: Benefit assessment framework for Eulerian ocean observations, as those provided by FixO3 observatories. Adapted from Ozdemiroglu & Townend, 2005, including Flemming, 2001.

Raw data	Uses	Purpose of use	Benefits and beneficiaries	Benefit estimation
Ocean observations	▪ Physical ▪ Chemical ▪ Biological ▪ Biogeochemical	▪ Daily forecast ▪ Seasonal prediction ▪ Long-term monitoring ▪ Scientific research ▪ Marine-related operations ▪ Other	▪ Research organizations ▪ Government departments ▪ Public sector agencies ▪ Education, media ▪ Environmental consultancies ▪ Climate services ▪ Oil and gas explorations ▪ Subsea services providers ▪ Mining	▪ Scores and weights of importance (prioritization) ▪ Market price paid for ocean data ▪ Proxies to market price (cost savings, value added, contribution to revenue, share of budget, cost for alternative) ▪ Willingness to pay

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Southampton, 24 May 2016

Dear Dr. Smith

Please find enclosed our copy-edited manuscript "Cost and value of multidisciplinary fixed-point ocean observatories" and confirmation that each copy-editing requirement was implemented.

Please let me know if any further copy-editing is needed.

Sincerely

Luisa Cristini

Comments from the editor (authors responses in *italics*):

1. Eliminate use of first person ('we' in Abstract and text;
All sentences where first person was used have been rephrased.
2. Abstract should be a single paragraph;
Implemented
3. Table .) not (table. for bracketed references;
Implemented
4. page 5 bottom line: should be 'maintaining';
Implemented
5. subhead 4 and page 11 para 3 line 1: should be 'such as'.
Implemented

Cost and value of multidisciplinary fixed-point ocean observatories

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Cost and value of multidisciplinary fixed-point ocean observatories

Abstract

Sustained ocean observations are crucial to understand both natural processes occurring in the ocean and human influence on the marine ecosystems. The information they provide increases our understanding and is therefore beneficial to the society as a whole because it contributes to a more efficient use and protection of the marine environment, upon which human livelihood depends. In addition the oceans, which occupy 73% of the planet surface and host 93% of the biosphere, play a massive role in controlling the climate. Eulerian or fixed-point observatories are an essential component of the global ocean observing system as they provide several unique features that cannot be found in other systems and are therefore complementary to them. In addition they provide a unique opportunity for multidisciplinary and interdisciplinary work, combining physical, chemical and biological observations on several time scales. The fixed-point open ocean observatory network (FixO3) integrates the 23 European open ocean fixed-point observatories in the Atlantic Ocean and in the Mediterranean Sea. The program also seeks to improve access to key installations and the knowledge they provide for the wider community, from scientists, to businesses, to civil society. This paper summarises the rationale behind open ocean observatories monitoring the essential ocean variables. It also provides an estimate of the costs to operate a typical fixed-point observatory such as those included in the FixO3 network. Finally an assessment of the type of data and services provided by ocean observations and their value to society is also given.

Keywords

Ocean; observations; costs; value; data; services

Highlights

- Fixed-point observatories are essential to measure Essential Ocean Variables
- The annual cost for operating a typical observatory is about 730,000 Euros
- Benefits of investing in sustained ocean observations are higher than the costs
- Benefits are economic, environmental and social
- Data from integrated networks generates more benefits than fragmented systems

1. Introduction

Sustained ocean observations are crucial for a variety of reasons, but their value is often not well recognized by the general public in comparison to, for example, meteorological observations. Unlike in meteorology, where requirements for data and services are largely driven by their contribution to protection of life and property, there is as yet no single big issue of immediate public concern to drive a variety of ocean observations in a sustained manner spanning multiple funding and political cycles (Dexter & Summerhayes, 2010). This means that national governments see no compelling reason to invest sufficiently in observing the ocean, a global commons, and a large proportion of observations remains mostly funded through short-term research-driven programmes (Lampitt at al., 2011).

As the benefits of sustained ocean observations are often unclear because they seem not to produce products of direct relevance to society, the analysis of the benefits deriving from ocean observatories products is useful to clarify the value of these data and services. Ocean data are important via their contribution to increased forecast model skill and to the improvement and validation of forecast models. Among the applications are: ocean and climate prediction, prediction of tsunamis, storm surges and ocean waves, sea-ice monitoring and prediction, and future climatologies. Operational applications, on time scales of days to weeks, include coastal and offshore engineering design, ocean forecasting related to national defence and civilian protection, shelf and coastal predictions, information for maritime and off-shore industries, safety and search and rescue. Climate prediction involves understanding the links between ocean and atmosphere (Dexter & Summerhayes, 2010).

Cost-benefit analyses have been carried out for some ocean observing systems, e.g., Seawatch Europe, TOGA, the Integrated Sustained Ocean Observing System in the United States, and Ocean Network Canada, with the aim to discuss their value in relation to the services they provide or are planned to provide. The general conclusion of these reports is that the benefits of investing in sustained ocean observations are expected or proven to be higher than the costs, especially on the long-term and if the outcoming information is used by the largest number of end-users (Table 1).

Table 1 here

The information synthesised by previous cost-benefit analyses however is limited. The benefits of a well-coordinated programme of ocean observations are widely accepted, but the ability to quantify these benefits remains a challenge (Ozdemiroglu & Townend, 2005). Estimates of economic benefits from ocean observing activities to date have largely been based on simple assumptions about the improvement that better information may be able to generate in the aggregate level of economic value produced by commercial and recreational marine activities (Kite-Powell et al., 2005 & Kite-Powell et al., 2008).

International efforts to establish and sustain continuous ocean observations started in the late 1980s and comprise a variety of systems all contributing to the Global Ocean Observing System (GOOS)[1]. GOOS is a permanent global system for observations and analysis of marine and ocean variables to support operational ocean services worldwide. It provides accurate descriptions of the present state of the oceans, including living resources, continuous forecasts of the future sea conditions, and the basis for forecasts of climate change and variability. GOOS is an international multipurpose initiative, providing the ocean part of the Global Climate Observing System (GCOS)[2].

1 http://www.ioc-goos.org/

2 http://www.wmo.int/pages/prog/gcos/index.php

Within GOOS, OceanSITES[3] is the worldwide system of long-term, open ocean reference stations monitoring the full depth of the ocean, from air-sea interface down to 5,000 meters. The network complements other *in situ* observation data by extending the dimensions of time and depth.

The Fixed-point Open Ocean Observatory Network (FixO3)[4] is the European contribution to OceanSITES. The network integrates 23 fixed-point ocean observatories in the Atlantic Ocean and the Mediterranean Sea providing a quantity of multidisciplinary marine measurements. The network includes all the European fixed-point observatories that provide multidisciplinary observations on long term in the open ocean and that represent well the surrounding area. The project is an international collaboration of 29 partners funded by the European Commission over four years started in September 2013. The main objectives of the programme are: (1) to provide high-quality ocean data open to the public, (2) to improve access to these infrastructures and data products and (3) to research better ways to make observations and link these to data from other observing systems.

Recognizing that a full estimate of the cost incurred for operating a fixed-point ocean observatory is difficult, as is an assessment of the economic benefits deriving from Eulerian observations, this paper wants to:

1. Emphasise the rationale behind Eulerian time series monitoring essential ocean variables (EOVs).
2. Provide an estimate of the costs for a typical open ocean observatory of the kind of those included in the FixO3 network
3. Examine the services and products derived from Eulerian ocean observations such as those provided by observatories within the FixO3 Network.

The paper is directed at the European Commission (as the FixO3 project funding entity), as well as to governments of countries supporting sustained ocean observations and policy-makers in general.

The structure of the paper follows its objectives. In the next section the EOVs are defined and the unique benefits of Eulerian observations are emphasised.

The third section gives an estimate of the running costs of a typical fixed-point observatory such as those included in FixO3. An approximate evaluation of the annual cost for the whole network is also provided in comparison to the financial contribution from the European Commission.

The fourth section provides an assessment of the data products and services provided by ocean observations to examine the purpose of using this kind of ocean observation, who are the end-users of the outcoming information, and what type of benefits ocean observations provide.

The fifth and last section summarises the paper's conclusions and recommendations.

2. Rationale for Eulerian observations

Long-term observations of the chemical, biological and physical properties, circulation intensity and patterns, and of the exchange of heat, freshwater, and momentum between the ocean and the

3 http://www.oceansites.org/

4 http://www.fixo3.eu/

atmosphere are essential to understand the ocean's role in the global climate. The GCOS established a list of the Essential Climate Variables (ECVs) that are both currently feasible for global implementation and have a high impact on the requirements of forecasting climate change. For the oceans these are listed in Table 2 as provided in the Second Report on the Adequacy of the Global Observing System for Climate in support of the UNFCCC (WMO, 2003).

Table 2 here

More recently the Framework for Ocean Observing (2009) supported a refinement of observing requirements that respond to societal needs for ocean information in the context of: 1) climate (e.g. ocean temperature for warming, carbonate system for CO2 uptake); 2) biodiversity (e.g. bio-optics for algal taxa); 3) fisheries (e.g. ocean circulation, temperature, salinity and oxygen for larvae dispersion and development); and 4) private sector activities (e.g. sea floor mapping for resource extraction, storm surge statistics for offshore installations, low oxygen occurrences for offshore aquaculture).

Within GOOS, three panels provide advice on EOVs for physics, biogeochemistry and biology & ecology, respectively. While the physical variables have been defined over a period of more than 20 years since before the initiation of GOOS and GCOS, the EOVs for biology and ecosystems are still under discussion aiming to have a similarly developed list as for physics in 2019. The increased attention to ocean health, biodiversity and human interactions with the marine environment suggest an increasing role in the future for multidisciplinary observatories similar to those operated in FixO3.

EOVs are monitored in a variety of ways and with a variety of instruments, including satellites, gliders, floats, ships and fixed point (Eulerian) observatories.

Eulerian observatories are unmanned platforms which incorporate sensors for in situ measurements of water and sediment properties or for monitoring of processes. They may also collect samples of water, fauna or solids. This has the advantage of shared logistics and possibility for interdisciplinary observations such as on the relationship between physical, chemical and biological properties. Eulerian observatories provide a direct means to examine the complex interrelations between processes and properties at various scales. They allow for a more comprehensive understanding of the properties of different components of a system that vary in time to gain insight into the interactions between the different components, and therefore of how the system functions as a whole. They also help determine if the system is changing on a longer time scale, which may be related to anthropogenic activity (Lampitt et al., 2009).

Eulerian observatories constitute one component of an ocean-atmosphere measurement network whose measurements of the EOVs enhance our abilities to understand, model and predict global climate change. Strengths of Eulerian observatories include (Send et al. 2001; Lampitt et al., 2009):

- Providing information at high vertical and temporal resolution from the atmospheric boundary layer, down through the ocean mixed layer, to the abyss, on time scales of minutes to years.
- A large range of measurements thus providing many linked variables at one place.
- Observation of ocean features having small spatial scales may be more effectively carried out with coherent arrays of fixed instruments or integrating techniques between fixed instruments

- Continuous measurements combined over long times with ship-based sampling programs and high-accuracy analysis work requiring laboratory procedures, such as chemical, optical, and biological research.
- Instruments may be corrected for sensor drift using post-recovery laboratory calibration and ship-based in situ measurements.
- Providing calibration information for freely drifting instruments and for remote sensing data (wind stress and surface chlorophyll, salinity and other properties).
- Development and testing new instrumentation.
- Provision of a platform for sensors and samples which are large and/or demanding of high power requirements.
- Required for studies in circumstances characterised by high-power demand, real-time data supply, sample collection, location's depth below the maximum range of floats and gliders, benthic boundary layer studies and seafloor processes

The principle demerits of Eulerian observatories are that they are expensive to operate, they do not provide information on mesoscale variability and usually do not currently provide fine resolution of vertical trends in variables. Developments of mooring based profilers may provide this facility soon. Finally they are subject to damage by storms and by shipping if they have a surface buoy.

Because almost all our theoretical structure of the ocean's circulation is built in the Eulerian framework the utility of moored measurements is great. Scientific research enabled by continuous monitoring of EOVs at fixed-point observatories includes (Send et al. 2001):

- Investigation and monitoring of water mass formation and transformation
- Establishment of air-sea flux reference sites
- Measurement of transport and variability of major current systems
- Investigation of the variability of the ocean's interior
- Combination of physical, chemical and biological observations for multidisciplinary and interdisciplinary research

Despite the recent major technological advances in both floats and gliders and their sensors, fixed-point observatories remain essential. Although sensors and samplers are becoming reduced in size and their power requirement has decreased, most remain still too demanding to be used on mobile autonomous platforms for prolonged periods. Eulerian observations are particularly critical in benthic and sub-seafloor environments (Lampitt et al., 2009).

The best way to take advantage of Eulerian observatories is to integrate them into network, such as FixO3, that share common standards both in terms of technology and procedures, but also in terms of data management and harmonization. The next essential process is for the data to be integrated with data from other observing systems such as gliders, floats, ships of opportunity and satellites (Lampitt et al., 2009).

3. Cost estimate for a typical fixed-point observatory

The issue of sustained funding for Eulerian observatories remains a major challenge, largely because of the high costs involved in setting up and maintain such observatories in the open ocean, which have been so far covered by the single institutions operating the observatories or by national programmes.

In assessing the cost of ocean observations it is necessary to distinguish between capital and running costs, the first being investments in equipment and capabilities and the second maintaining of equipment and costs for delivery of products. It is common to annualise capital costs so that they can be amalgamated with running costs to generate full costs year by year.

Our estimate of the annualised cost to operate a typical fixed-point observatory designed to measure specifically the GCOS ECVs is based on that provided by Lampitt et al. (2011) in a position paper in the frame of the EuroSITES programme[5]. The following characteristics are assumed for the standard observatory:

- Is moored in water depth of 3000m
- Is constructed of a steel wire and rope (50:50) combination
- Has a commercially available surface buoy with standard meteorological sensor package –e.g., wind speed and direction, humidity, air and sea surface temperature, atmospheric pressure, and wave height and period
- Uses an Iridium telemetry system
- Has full biogeochemical sensor packages sample at two key depths, one near the surface in the mixed layer and one in the permanent thermocline
- Has twenty physical sensors (temperature, salinity, pressure) used to resolve the seasonal evolution of the mixed layer and to obtain a suitable amount of observations below the current Argo operation depth (2000 m)
- A minimum of one annual research cruise (5 days on site) is required to maintain the standard infrastructure

The cost estimate is itemized in Table 3. The initial investment (capital cost) for a fully equipped (platform and sensors) Eulerian observatory is estimated at 501 k€. The annualised running cost of the standard observatory is estimated at 731 k€/year.

Table 3 here

Considering the 23 sites included in FixO3 network the total capital cost of the FixO3 Network (23 observatories) can be estimated at ca. 11.5 M€ (Table 4), and the cost of operating the whole network (including costs for network coordination and data management) can be estimated at ca. 17 M€/year.

Table 4 here

The costs related to the individual observatories, however, do vary substantially, depending on the type of infrastructure, local conditions, ship availability, distance from the coast, mooring design,

5 European Ocean Observatory Network: http://www.eurosites.info/

maintenance sampling frequency and sensor configuration. Therefore these estimates should be taken as indicative only.

The upfront cost of data capture and archiving is approximately half of the total cost of generating basic products. However many of these data products may not be delivered until many years after the initial investment (Ryder, 1997).

The FixO3 programme received 7 M€ funding from the European Commission (EU) over four years. The funding is not used to maintain the 23 individual observatories, but for coordination, support, and research and development activities. It is useful however to relate the average annual contribution from the EU (1750 k€) to the estimated annual cost of running the network (17029 k€). The EU contribution represents about 10.2% of the cost associated to operating the network.

4. Value of ocean observations such as those provided by the FixO3 observatories

Society's needs for a network of *in situ* ocean observing systems cross many areas of environmental science. Ruhl et. Al. (2011) review the science themes that benefit from data supplied from ocean observatories, which span from physical oceanography to marine ecology to transformative ocean and earth sciences.

The maritime and ports sector, which facilitates the transportation of around 90% of world trade, employs more than 13 million people worldwide and contributes more than $400 billion (ca. 357 bn€) per annum to world economies (Marine and Ports Review[6]). Between 3% and 5% of input to the European GNP is generated directly by marine-based industries and services that exploits a vast range of marine and coastal resources. The value added directly by these activities is of the order of $140- 230bn/yr (ca. 125-200 bn€/yr). The industries and services are subject to uncertainty, loss of efficiency, and direct costs and damage caused by the conditions of the marine environment (Flemming, 2001). Improvement of the short- to medium-term prediction services for ocean conditions would improve the value of maritime industries and services by a few percent. If we take 1% as a conservative estimate, the value added to the GNP of the EU by a prediction system is of the order of $1.4-2.3bn/yr (ca. 1.2-2 bn€/yr) (Flemming, 2001).

A comprehensive estimation of the economic benefits from ocean observations is still hindered by the lack of direct estimates of the value of ocean data for projected applications (Adams et al., 2000). The information needed to develop detailed estimates of the economic benefits of ocean observing systems is, for the most part, unavailable at this time. Both the development of the observing systems themselves and the economic information needed to estimate benefits are presently incomplete (Kite-Powell et al., 2008).

The key feature of the type of ocean observations provided by the observatories in the FixO3 Network is their multidisciplinarity. FixO3 observatories provide data on the physical, chemical and biological characteristics of marine waters from the ocean-atmosphere interface to the deep seafloor throughout the Atlantic Ocean and the Mediterranean Sea. The time-series provided by the observatories allow monitoring of long-term trends (decadal) and cumulative impacts. FixO3 observatories currently do or will in the future deliver long-term time series of the essential ocean variables (EOVs).

Additional to providing continuous ocean data in specific locations, 12 of the 23 FixO3 observatories also provide "service activities", i.e., ready-to-use data products in four main areas:

1. Ocean physics and climate change –e.g., water mass characterization, water column processes, thermodynamics, ice cover, climatology
2. Biodiversity and ecosystem assessment –e.g., distribution and abundance of marine life, ocean productivity, ecosystem function, living resources and climate feedback.
3. Carbon cycle and ocean acidification –e.g., global carbon cycle and elemental cycling within the ocean through both physical and biological processes

6 http://mediapack.marineandports.com/ (last accessed on 27 May 2015)

4. Geophysics and geodynamics –e.g., transfer from Earth's interior to the crust, hydrosphere and biosphere, fluid flow and gas seepage through sediments and gas hydrate, non-living resources, sediment transfer to deep sea and climate change

Service activities enable free access to data and knowledge provided by dedicated installations, including delivery of data in real time, near-real time and in delayed mode, to allow for a wide range of data products for multidisciplinary use and for derived information including time series ecosystem variables.

Another feature of FixO3 is a fund referred to as "transnational access". This provides financial and logistic support to access 14 open-ocean platforms and a shallow-water test site for research and technological development. This opportunity allows research groups and sensor developers who may not be involved at all with FixO3 to carry out experiments and trials on infrastructures and locations that would otherwise be unavailable to them. A typical scenario for technology developers is the need to test, integrate, validate or demonstrate developments in real conditions on operational settings, including open-ocean conditions, thus making the leap from laboratory-based developments to a fully qualified system, i.e. for successful missions operations. In such endeavours, access ocean infrastructures are a tangible asset for logistical and scientific support, saving several tens of thousands of Euros per development (as one day of operations including ship time at a fixed-point observatory costs on average ca. €980). Integrated observatory networks further enhance the possibilities by the diversity of physical, chemical and biological conditions available for testing, validating and demonstrating new products. From this perspective, the observatories become a "utility" just like any other good that is needed for economic development, quantifiable in terms of research and development cost-savings for manufacturers.

The purposes of using ocean observations and data products as those provided by FixO3 observatories include strategic research and societal applications enabling technical progress and economic growth. This research (oceanography, climatology) can be contrasted with basic research, which has an indeterminate payback period, and applied research, which is expected to provide benefits on time scales of 1-3 years. The research supported by FixO3 is needed to improve our understanding of ocean's role in the Earth system with one very specific objective to predict the consequences of anthropogenic forcing. Such research leads to considerable economic benefits, both direct and indirect, and investment in scientific research in general is recognized as a critical factor in economic growth (Salter & Martin, 2000). However, benefits of basic research are difficult to value because the ultimate use of data is difficult to predict (Adams et al., 2000). "Technical progress" combines the accumulation of basic knowledge (i.e., without any immediate application) with applied research and development (i.e., transforming basic knowledge into goods and services provided by the public and private sector). Estimates of the long-term contribution to economic growth from technical progress depend on the period chosen and the choice of statistic to measure economic growth. Technical progress can be seen as the single largest contribution to long-term economic success (Adams et al., 2000). Finally, ocean observations offer the prospect of a return to investment in research (Vancouver Board of Trade, 2012).

Ocean observations serve the development of new and improved models for marine conditions reports. Systematic collection and analysis of ocean data provide economic benefits to a wide range of users helping in a variety of purposes such as to detect and forecast oceanic components of climate variability, facilitate marine operations, manage ocean resources in a sustainable use and mitigate natural hazards (Adams et al., 2000).

Integrated ocean observing systems provide data that improve short-term and seasonal forecast, ocean statistics, and assess climate change, producing benefits for people and businesses. Marine forecast and ocean data (e.g., currents and wave conditions, water temperature and streamflow, climatology of certain areas) are needed for maritime transportation, commercial fishing and ocean platforms design. Finally, ocean observations advance our understanding of fundamental processes relevant to global climate change such as heat transport and fluxes between ocean and atmosphere, heat transport within and between ocean basins, removal of carbon from the atmosphere, and sea level rise. Information from ocean observatories and oceanographic research will inform the policy-making process with high economic value at stake (Adams et al., 2000).

Among the beneficiaries of ocean observations is the private sector. This sector has increasing interest in using ocean observatories for environmental monitoring (O'Neill & Carlisle, 2014). Table 5 shows some of the external developments that present opportunities for ocean observatories in the sociological, technological, economic, and political and legal spheres.

Table 5 here

The breakdown of customers in the UK marine science and technology business in 2013 (that includes 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). In addition to those, the insurance industry uses improved climate models driven by ocean observations to adjust premiums.

Information derived from the data produced by ocean observations is sold in private markets. Once the costs of the basic data collection and storage are covered, the private sector can add value to provide custom data products and services that can be priced and sold. This can result in the creation of new firms and employment built around using, enhancing and selling information derived from ocean observations (Adams et al., 2000).

Ocean observations and opportunities such as FixO3's transnational access also enable knowledge transfer from research and technological development programs to applications in the areas of science and policy, commercialization and public outreach and engagement (Vancouver Board of Trade, 2012).

In general, ocean observations increase our understanding of the marine environment. Such improved understanding, in turn, is beneficial as it contributes to more efficient use and protection of the marine environment. The marine environment is an asset providing a flow of goods and services (physical, aesthetic, intrinsic and moral). The "total economic value" (TEV) is broken down in Table 6 for Eulerian observations. TEV is composed of "use benefits" and "non-use benefits". Use benefits are derived from the actual direct and indirect use of a good or service. The term "non-use benefits" means that the benefits derived from knowing that others (altruistic value) and future generations (bequest value) have access to a sufficient amount of goods and services and simply that the marine environment exists (existence value). Non-use benefits also include potential future use (option value). Ocean observations provide environmental information thus, as environmental resources, generate "non-market" or "external" benefits since they are not traded in actual markets and hence there are no market price data for them. Wider benefits to economy and society are derived by making better decisions with help of better information and are called "external benefits" (Ozdemiroglu & Townend, 2005).

Table 6 here

Table 7 offers a framework to assess benefits from fixed-point ocean observations as those provided by the FixO3 network.

Table 7 here

The information derived from ocean observing systems creates economic value primarily by leading to improved decision making by reducing the uncertainty associated with actions taken to use marine resources in some way, and with the resulting outcomes. Ocean observing data and the information derived from them reduce this uncertainty, and that reduction in uncertainty is economically valuable. The market value of the information is related to the extent to which it reduces uncertainty and to the economic resources at stake in the decision (Kite-Powell et al., 2005, Australia Academy of Technological Sciences, 2006 & Kite-Powell et al., 2008). Ocean observations provide information that is used primarily to create forecasts of future information or nowcasts of real time or near-real time information (Kite-Powell et al., 2005 & Kite-Powell et al., 2008).

The benefits provided by ocean observations can be referred to as "network externalities" because the value of an integrated, sustained and comprehensive system is many times that of the value of its scattered parts (Adams et al., 2000, Ozdemiroglu & Townend, 2005). This is indeed the case of the FixO3 network where expertise, best practices and tools are shared among partners to produce higher-impact results, e.g., joint scientific publications (e.g., Bensi et al., 2016). However, the very existence of network externalities means that that while many parties benefit from ocean observations, no one party has incentive in investing into them. This implies that sustained ocean observations need collaborative or public funding to exist (Ozdemiroglu & Townend, 2005).

Integrated ocean observing systems such as FixO3, make possible new applications to create informational values that could not be realized without integrated and sustained ocean observatories. The value of an integrated, sustained, and multidisciplinary ocean observations network derives from its ability to bring together scattered observations to create a comprehensive database of time-series from which trends can be measured and forecasts developed (Adams et al., 2000).

The financial value of multidisciplinary fixed-point ocean observatories cannot be accurately defined in a standard cost benefit analysis exercise because it involves the application of new technology whose commercial benefit is difficult to quantify. Multidisciplinary fixed-point ocean observatories can for example contribute to risk reduction of impacts on society from unusual weather events as a result of climate change. The increased demand for climate change data to support government policy decisions and insurance company risk analysis can be satisfied by ocean observatories. Climate change researchers will use observatory infrastructure because of the superior quality and real time availability of the data. Weather-related events in 2010 resulted in insured losses of $18bn (ca. 16 bn€) and overall losses of $ 65bn (ca. 57.5 bn€). [CITATION Mun10 \l 2057]. Globally loss-related floods have more than tripled since 1980 and windstorm natural catastrophes more than doubled with particularly heavy losses from Atlantic hurricanes. The typical annual variance in US GDP due to weather is $485 billion (3.4%)[CITATION Arn14 \l 2057]. Munich Re funds data acquisition and research by research centres, e.g., the Potsdam Institute for Climate Impact Research (PIK) and the Tyndall Centre for Climate Change Research. Munich Re includes elements of these scientific works in its risk evaluations for policy renewals. Data from ocean observatories will contribute to the reduction of insurance company exposure to losses and to the safety of coastal communities exposed to the risk of storm surge and unusual weather events.

Oil companies are also interested in ocean observatories as tools for environmental monitoring and regulatory compliance. There is a realisation that there are significant natural periodic variations in the deep ocean environment where oil companies are currently installing seafloor production facilities. It is important for the oil companies to prove that these variations are not related to their production activities. BP installed ocean observatories adjacent to production facilities at their Greater Plutonio deep-water development area in West Africa, and at a distance from the producing facilities. This will allow them to compare environmental conditions and identify natural versus anthropogenic effects and achieve environmental compliance. Production at the Greater Plutonio Development Area is about 240,000 barrels of oil per day (Flow Control Network[7]). At the current low oil price of $44 (ca. 39€) per barrel that equates to revenue of over $10.5m (ca. 9.3€) per day. A temporary shutdown of production due to environmental non-compliance at a similar production facility would be costly. An ocean observatory with an operating cost of about €730,000 per annum reduces the risk of significant revenue loss due to issues related to environmental non-compliance.

5. Conclusions

This paper presented the rationale behind Eulerian time series monitoring essential ocean variables (EOVs). It also provided an estimate of the costs for a typical open ocean observatory of the kind of those included in the FixO3 network. Finally it examined the value of services and products derived from Eulerian ocean observations such as those provided by observatories within the FixO3 Network.

Eulerian observatories are essential to address a variety of issues, from the role of the ocean in the climate system to turbulent mixing and biophysical interactions, from ecosystem dynamics and biodiversity to fluids and life in the ocean crust. Seafloor observatories in particular, offer the opportunity to study multiple, interrelated processes over a wide range of time scales from episodic processes to global and long-term processes (Lampitt et al., 2009).

The capital cost of setting up a typical fully-equipped Eulerian observatory of the kind of those included in the Fixo3 network is estimated at 501 k€, while the annual costs for operating it are estimated at 731 k€/year (Lampitt et al., 2011).

A more rigorous estimation of the cost of global or regional ocean observations would involve summing a wide range of sub-costs such as purchases of equipment, deployment costs, ship operations, maintenance and replacement of equipment, satellite launch costs, equipment planning and design costs, communications and data processing, modelling centres, computers, and product delivery for each observatory in the network. Each component has a different proportion of capital investment, duration, and running costs. Aggregation of these costs requires that each component is analysed to see whether there are multiple beneficiaries who should share the cost, hidden overheads, sunk costs, or might be developed anyway for other purposes (Flemming, 2001).

7 http://www.flowcontrolnetwork.com/bp-starts-production-at-greater-plutonio/ (last accessed on 20 May 2016)

Several cost-benefit reports show that the benefits of investing in sustained ocean observations that provide the essential ocean variables (EOVs) are expected or proven to be higher than the costs, especially on the long-term and if the outcoming information is used by the largest number of end-users.

Identified benefits from ocean observations include: (1) economic benefits to the users of ocean data such as reduced operational costs and avoided damage from weather events or ocean conditions; (2) environmental benefits such as better resources management coming from use of current marine data; and (3) social benefits such as better understanding of the marine environment (Ozdemiroglu & Townend, 2005). All these kind of benefits improve human welfare and can be referred to as economic benefits.

There is a compelling economic argument for operational oceanography to provide forecasts of ocean currents, salinity, temperature, water levels, and other parameters to be supported on a sustained basis, within operational budgets. All reports point to sustain the present marine research budgets, recognize the significant potential benefits and the significant effort that scientists and support staff made in successfully implementing the current system (Australia Academy of Technological Sciences, 2006).

Data provided by integrated networks such as FixO3 generates benefits not available with fragmented observatory systems (Adams et al., 2000). The FixO3 network of open ocean observatories provides continuous measurement of EOVs from the air-sea interface to the deep seafloor throughout the Atlantic Ocean and the Mediterranean Sea. These time-series of ocean data can be used for a variety of purposes by research institutions and the private sector. The project also offers opportunities to access ready-to-use data products (Service Activities) and infrastructures (Transnational Access) allowing for even more valuable benefits to the wider ocean community including governments and industry.

The magnitude of ocean observing information benefits 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 observing systems, instruments, technologies, and applications. Operators of regional observing systems should incorporate in their operational plans strategies and activities to measure the economic benefits of their products and services. (Kite-Powell et al., 2005 and Kite-Powell et al., 2008).

Successful cost-benefit analysis depends upon having access to detailed information about the costs of the infrastructure but also on how a particular industry uses forecasts, and how the data were obtained on which the forecast was based. The values of the benefits which may accrue from single industries or sectors cannot be aggregated into total national or regional benefits unless standardised methods and assumptions are used (Flemming, 1997).

Even partial benefit assessments however help with supporting the case for investing in ocean observations as it is not necessary to know all the costs and benefits involved (Ozdemiroglu & Townend, 2005).

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