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EXECUTIVE SUMMARY

The potential for growth of the Arctic Blue Economy is increasing due to climate change, fast technological development and strong demands from the global economy. Such development will however put severe stress on the vulnerable Arctic environment and there is a growing consciousness among nations surrounding the Arctic to ensure a responsible and sustainable development of Arctic Blue economy, which calls for a science-based management approach. Mandatory for such an approach is good knowledge and understanding of the Arctic Ocean environment and ecosystem, which demands a well-coordinated, integrated, sustained fit-for-purpose Arctic Ocean Observation System.

The design of a proper Arctic Ocean Observation System is recommended to follow the concept outlined in the "Framework for Ocean Observations" (UNESCO, 2012). This will require a strong international coordination and governance structure responsible for dialog with users and stakeholders, sustained funding, maintenance of observation requirements (spatiotemporal resolution, quality, timeliness), technology development, free and open access to data.

An important component of the design process is an assessment of the costs and value of the observing system i.e., justify that the benefit exceeds the costs.

Costs are easier (although not unproblematic) to quantify than the benefits. OECD (Organisation for Economic Co-operation and Development) has in recent years, in cooperation with various ocean observing communities, started to establish ways to quantify the value of ocean observations and proposes some pragmatic approaches.

It is therefore recommended that the management of the future Arctic Ocean Observation System works closely with experts from OECD on the establishment of a robust cost-benefit analysis methodology for the Arctic Ocean.

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1. Introduction

The Global Ocean has a strong and multidimensional influence on our planet. Interacting with atmosphere, cryosphere, land and biosphere it directly influences human health and welfare. The Global Ocean has been termed the world's seventh largest economy[1] (recently valued at US$24 trillion[2]) providing a crucial source of food, water, energy and raw materials and acting as a medium for tourism, transport and commerce.

The aim of this report is to present a preliminary analysis of the economic potential associated with ocean observatories in support of Blue Economy activities in the Arctic Ocean. The methods and findings obtained in the H2020 AtlantOS project and in the OECD (Organisation for Economic Co-operation and Development) reports on benefits of ocean observations, together with published analyses of blue growth potential in the Arctic form the basis for the analysis.

Blue Economy and Blue Growth are concepts that over the past decade has become commonly used when discussing businesses and economical activities related to the use of seas and coasts, but what is actually meant by these concepts? At the beginning they simply referred to "*any economic activity in the maritime sector*" which is still a comprehensive description. The understanding of Blue Economy and Blue Growth has, however, evolved over the years, having different definitions provided by various organisations[3]:

- *World Bank: Sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem.*
- *European Commission: All economic activities related to oceans, seas and coasts. It covers a wide range of interlinked established and emerging sectors.*
- *The Commonwealth of Nations: An emerging concept which encourages better stewardship of our ocean or 'blue' resources.*
- *Conservation International: Blue economy also includes economic benefits that may not be marketed, such as carbon storage, coastal protection, cultural values and biodiversity.*
- *The Centre for the Blue Economy: It is now a widely used term around the world with three related but distinct meanings - the overall contribution of the oceans to economies, the need to address the environmental and ecological sustainability of the oceans, and the ocean economy as a growth opportunity for both developed and developing countries.*
- *United Nations representative: Blue Economy is an economy that comprises a range of economic sectors and related policies that together determine whether the use of ocean resources is sustainable. An important challenge of the blue economy is to understand and better manage the many aspects of oceanic sustainability, ranging from sustainable fisheries to ecosystem health to preventing pollution. Secondly, the blue economy challenges us to realize that the sustainable management of ocean resources will*

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[1] http://www.nature.com/news/oceans-are-worth-us-24-trillion-1.17394

[2] http://wwfintcampaigns.s3.amazonaws.com/ocean/media/RevivingOceanEconomy-REPORT-lowres.pdf

[3] https://en.wikipedia.org/wiki/Blue_economy

> *require collaboration across borders and sectors through a variety of partnerships, and on a scale that has not been previously achieved. This is a tall order, particularly for Small Island Developing States (SIDS) and Least Developed Countries (LDCs) who face significant limitations." The UN notes that the Blue Economy will aid in achieving the UN Sustainable Development Goals, of which one goal, 14, is "life below water".*

Blue Economy includes, on top of the traditional ocean activities related with the use of the ocean such as fisheries, tourism or maritime transport, also emerging industries like marine renewable energy, aquaculture, seabed extractive activities and marine biotechnology and bioprospecting. Blue economy and related Blue Growth, also attempts to embrace ocean ecosystem services that are not directly captured by the market but provide indirect significant contribution to economic and human activity, like carbon sequestration, coastal protection, waste disposal, and protection of marine biodiversity.

The United Nations (ADAC el al, 2019) has categorized six major sectors of Blue Economy presented below together with some industry examples for each of them:

1. Harvesting and trade of living marine resources
    a) Seafood harvesting
    b) Aqua culture
    c) Mariculture
    d) Marine biotechnology and bioprospecting
2. Extraction and the use of non-living resources
    a) Extraction of minerals (seabed mining)
    b) Extraction of energy sources (oil and gas)
    c) Freshwater generation (desalination)
3. Renewables
    a) Wave energy
    b) Ocean thermal energy
    c) Tidal Energy
4. Technology
    a) Underwater autonomous vehicles
    b) Bathymetric surveying and mapping
5. Commerce and trade
    a) Shipping and ship building
    b) Maritime transport
    c) Ports and related services
    d) Tourism
6. Indirect contributions
    a) Carbon sequestration
    b) Coastal protection
    c) Waste disposal
    d) Biodiversity protection

As the concept of Blue Economy evolved and matured over the years, the principle of **Sustainable** Blue Economy was firstly formulated by WWF (WWF, 2015) after a global consultation process. This was followed by a much larger ambitious agenda on 17 Sustainable Development Goals (SDG's) for 2030, formulated and agreed by the members of the United Nations in year 2015 (https://sdgs.un.org/goals, UN 2015a, UN2015b). Among the 17 Goals, ***SDG 14 Life below water***, focusses on the Ocean:

> ***Conserve and sustainably use the oceans, seas and marine resources***
>
> *The ocean drives global systems that make the Earth habitable for humankind. Our rainwater, drinking water, weather, climate, coastlines, much of our food, and even the oxygen in the air we breathe, are all ultimately provided and regulated by the sea.*
>
> *Careful management of this essential global resource is a key feature of a sustainable future. However, at the current time, there is a continuous deterioration of coastal waters owing to pollution, and ocean acidification is having an adversarial effect on the functioning of ecosystems and biodiversity. This is also negatively impacting small scale fisheries.*
>
> *Saving our ocean must remain a priority. Marine biodiversity is critical to the health of people and our planet. Marine protected areas need to be effectively managed and well-resourced, and regulations need to be put in place to reduce overfishing, marine pollution, and ocean acidification.*

Implementing and monitoring this SDG 14 in the Arctic calls for detailed knowledge of the marine environment and thus for a comprehensive and concerted observing and monitoring of the Arctic Ocean physical, biogeochemical and biological state and evolution. This knowledge must be an essential component in all the present and future planning and decision process of Arctic Blue Economy activities. A rapid access to reliable and accurate ocean information is vital in addressing threats to the marine environment, in the development of policies and legislation to protect vulnerable areas of the coasts and open ocean, in understanding climate trends and in forecasting future changes. Likewise, better quality and more easily accessible marine data is a prerequisite for further sustainable economic development. Constant monitoring of the Arctic Ocean observing capacity and existing gaps is a core activity to ensure an optimized, and thus cost efficient, sustained ocean observing system which will require huge investments and a strong partnership between public and private stakeholders.

2. Blue Economy in the Arctic

A major part of the economic activities in the Arctic are related to Blue Economy, with the extraction of marine natural resources being the most important economic sector (ECONOR, 2017). The nations surrounding the Arctic have however, different priorities, cultures or policies, affecting their economies, and consequently the blue economy activities varies from country to country and region to region reflected in varying relative importance of fishery and hunting, shipping, tourism, mineral and energy extraction etc.

Generally, the Arctic economy has changed rapidly over the past few decades primarily due to three main factors and global trends (WWF, 2018): climate change, fast technology developments and evolving global economy demands, which will be elaborated a bit further.

Climate Change in the Arctic

Over past decades several scientific publications and different reports from organisations such as IPCC, AMAP, UNESCO have documented that the Arctic Region is warming at roughly twice the global average rate, with a dramatic reduction in summer sea ice extent as one of the clearest indicators of this trend. Physical and biological processes are being transformed across the entire region, while climate feedback mechanisms in the Arctic's changing atmospheric and oceanic dynamics impact at global scales. This is clearly underlined by some of the key conclusions from the recent IPCC report (Meredith et al, 2019) cited below:

- *The Arctic Ocean have continued to warm in recent years. Over large sectors of the seasonally ice-free Arctic, summer upper mixed layer temperatures increased at around 0.5ºC per decade during 1982–2017, primarily associated with increased absorbed solar radiation accompanying sea ice loss, and the inflow of ocean heat from lower latitude increased since the 2000's*

- *Arctic sea ice extent continues to decline in all months of the year, the strongest reductions in September (very likely –12.8 ± 2.3% per decade; 1979–2018) are unprecedented in at least 1000 years. Arctic sea ice has thinned, concurrent with a shift to younger ice: since 1979, the areal proportion of thick ice at least 5 years old has declined by approximately 90%. Approximately half the observed sea ice loss is attributable to increased atmospheric greenhouse gas concentrations. Changes in Arctic sea ice have potential to influence mid-latitude weather on timescales of weeks to months*

- *Climate-induced changes in seasonal sea ice extent and thickness and ocean stratification are altering marine primary production, with impacts on ecosystems. Changes in the timing, duration and intensity of primary production have occurred with marked regional or local variability. In the Arctic, changes in primary production have affected regional species composition, spatial distribution, and abundance of many marine species, impacting ecosystem structure.*

- *Climate-induced changes in ocean and sea ice, together with human introduction of non-native species, have expanded the range of temperate species and contracted the range of polar fish and ice-associated species. Commercially and ecologically important fish stocks like Atlantic cod, haddock and mackerel have expanded their spatial distributions northwards many hundreds of kilometres, and increased their abundance. In some Arctic areas, such expansions have affected the whole fish community, leading to higher competition and predation on smaller sized fish species, while some commercial fisheries have benefited. These changes are altering biodiversity in the Arctic marine ecosystems.*

- *Shipping activity during the Arctic summer increased over the past two decades in regions for which there is information, concurrent with reductions in sea ice extent. Transit times across the Northern Sea Route have shortened due to lighter ice conditions, and while long-term, pan-Arctic datasets are incomplete, the distance travelled by ships in Arctic Canada nearly tripled during 1990–2015. Greater levels of Arctic ship-based transportation and tourism have socioeconomic and political implications for global trade, northern nations, and economies linked to traditional shipping corridors; they will also exacerbate region specific risks for marine ecosystems and coastal communities if further action to develop and adequately implement regulations does not keep pace with increased shipping.*

- *Future climate-induced changes in the Arctic Ocean, sea ice, snow and permafrost will drive habitat and biome shifts, with associated changes in the ranges and abundance of ecologically important species. Projected shifts will include further habitat contraction and changes in abundance for polar species, including marine mammals, birds, and fish. Projected range expansion of subarctic marine species will increase pressure for high-Arctic species with regionally variable impacts. Continued loss of Arctic multi-year sea ice will affect ice-related and pelagic primary production, with impacts for whole ice-associated, seafloor and open ocean ecosystems.*

- *The projected effects of climate-induced stressors on Arctic marine ecosystems present risks for commercial and subsistence fisheries with implications for regional economies, cultures and the global supply of fish, and shellfish. Future impacts for linked human systems depend on the level of mitigation and especially the responsiveness of precautionary management approaches. Polar regions support several of the world's largest commercial fisheries. Specific impacts on the stocks and economic value will depend on future climate change and on the strategies employed to manage the effects on stocks and ecosystems. Under high emission scenarios current management strategies of some high-value stocks may not sustain current catch levels in the future; this exemplifies the limits to the ability of existing natural resource management frameworks to address ecosystem change. Adaptive management that combines annual measures and within-season provisions informed by assessments of future ecosystem trends reduces the risks of negative climate change impacts on Arctic fisheries.*

Fast technology developments

As the Arctic warms and sea ice is retreating technology is advancing. In order to extend the season of navigability in the Arctic region a number of technological developments are being implemented:

- Icebreakers are becoming larger and more powerful (Fig. 2.1)
- New ships that are not yet intended for Arctic use are nonetheless being designed to meet polar standards to be able go there eventually, especially tourist vessels (Fig. 2.2).
- Satellite observation-based sea ice information are continuously improving with increasing resolution and quality and including guidance on inland routes and position and drift of icebergs.
- Drone technology can assist ships in charting a safe course ice infested water.
- Remotely operated underwater vehicles (ROVs) are used to support mapping activities.

Figure 2.1 Russian icebreaker sailing in the Arctic Ocean. Source: Adobe stock

Huge amounts of money and resources have been invested during last years in Arctic oil and gas exploration, drilling and related technologies in order to be prepared for extraction the large hydrocarbon resources believed to be in the Arctic region. Exploitation of these resources is however still dependent on the elevated costs and the evolution of the global market oil prices, which haven't yet been favourable. Additionally, recent years trends and global agreements focus on the reduction of CO_2 emissions and decreasing of hydrocarbon energy sources will most likely mean that extraction of Arctic oil resources will be reduced, if it will happen at all. Technological development will instead be redirected towards exploitation of renewable energies.

Communication lines is an important technology issue for the Arctic area – communication cables are being laid in Arctic waters and satellite communication is available but bandwidth is still limited and therefore forms a limitation/bottleneck for communication when operating in the Arctic Ocean. This is also a matter of concern for operational data collection and real-time transmission in the Arctic.

Another point of concern from an environmental point of view, is that technological advances have not reached a level where oil spill response technologies can effectively clean up a spill in the ice-covered Arctic waters.

Figure 2.2 Arctic tourism

Evolving global economic demands

The main driver for the technological advances mentioned above are, to a high degree, the pull from the global market and the push for investments. Buch et al., 2021 showed the potential for near future development in three selected business sectors: maritime transport, tourism and fisheries. Other business sectors also face huge potential for growth in the Arctic region in the coming decades due to the rapidly changing climate (Centre for Ocean and the Arctic, 2019) such as:

- **Food production** – in addition to traditional fishery for human consumption, it is possible to utilizing species at lower trophic levels as feed for farmed fish or specialized products for human consumption, optimizing the use of what today is regarded as residual waste products. Aquaculture and bioprospecting can form the basis for high-tech bio/pharmacy industry.

- **Energy** – reduction of CO_2 emissions requires use of energy sources with lower CO_2 emission than oil, like gas, biofuel or renewable energy sources like wind power, solar energy or wave power. The maritime shipping industry is in the process of implementing an energy mix consisting of electrification, hydrogen and biogas, which will be further developed in the coming years.
- **Mining** – deep sea mining and near coastal mining may be possible due to retreating ice in the coming decades.

All these emerging business possibilities in the Arctic require huge investments not only in the individual business sectors themselves, but also in necessary infrastructures like harbours, airfields, security/coastguard, oil-spill combatting, search and rescue facilities, etc. According to WWF (2018) there is a need of investments of the order of 1 trillion USD, and there also seems to exist a great interest in the investor community to engage in the Arctic Blue Economy sector.

However, the climate change itself combined with the related increase in emerging Blue Economy activities puts severe pressure and threats on existing professions such as hunting and also on the traditional life and culture of indigenous people and particularly on the vulnerable Arctic ecosystem. A responsible and sustainable development of the Arctic Blue Economy has therefore come very high on the agenda for the nations surrounding the Arctic. It is clearly stated that there is an urgent need to call for a more coherent, integrated, fair and science-based approach to manage the economic development of the Arctic Ocean balancing, on one side the desire to improve economic profit, human living standards and wellbeing, and on the other side the imperative to sustain ecosystem health and the preservation of the environment.

Such a science-based management approach must build on accurate and detailed information on the status of the Arctic environment and the ecosystem; but at present the knowledge and understanding of the functioning of the physical environment of the Arctic Region is rather limited: critical physical processes are poorly understood, ecosystems remain unstudied and undiscovered, and indigenous voices go generally unheard. This lack of knowledge makes it impossible to detect, predict or manage the interrelated physical, biological and social impacts of climate change whereby sustainable development strategies are almost impossible to implement.

An increased knowledge and understanding of the Arctic Ocean environment and ecosystem and subsequent monitoring and management of the same must built on a coordinated and sustained Arctic Ocean Observation System including both remote and in situ observations, because:

You cannot manage what you do not observe

3. Ocean observations

In order to design an adequate and well-integrated ocean observing and monitoring strategy for the Arctic Ocean, it is necessary firstly to define the observing objectives. Ocean observing objectives should address one or more societal relevant needs and societal benefit areas, which requires a prior consultation with all relevant user and stakeholder groups, Fig.3.1

Fig.3.1 Type of users ranging from industry to private citizens, from governments to non-governmental organisations. Source: DeYoung et al, 2019

Examples of marine products and services that could be requested by these user groups are cited below (related with the Blue Economy activities):

- **Marine Transportation and Shipping:** Forecasts of extreme wave events, hurricanes and storm tracks, forecasts of ocean currents, sea-ice monitoring and iceberg tracking, oil spill and pollutant dispersals, and the locations of whales and other protected species, with advisories to modify ship routes or decrease speeds to avoid collisions.
- **Food Security:** Helping to achieve global food security, maximizing the sustainable food benefit that we can extract from the ocean now and in the future, by supporting sustainable fisheries and mariculture operations and management.
- **Biodiversity and Ecosystem Sustainability:** Understanding changes in biodiversity and ecosystems to determine impacts on natural capital and ecosystem services and

ensure our ocean resources can support human nutritional, recreational, and health needs. This includes monitoring the present abundance and distribution of organisms and improved forecasting of events which impact recreational and commercial use of the ocean.
- **Disaster Resilience:** Storm surge, hurricane and tsunami warnings are provided with enough advanced notice and precision to support successful emergency response.
- **Climate Change:** Research that includes climate change indicators including measurements of ocean heat and circulation providing regional sea level monitoring, ocean circulation changes and climate feedbacks, and changes that affect ocean life, such as regional pH and oxygen levels.
- **Ocean System Science:** Research that allows discovery of new processes and phenomena of the ocean system, supports embedded process observations, enables the development and validation of ocean system models and supports innovation in ocean state assessment and prediction.

User needs may evolve along with changing citizens' concerns, policies, industry priorities, and ocean state, as well as the feasibility of new measurements enhanced by observing technological improvements. Thus, all individual components of an Arctic Ocean observing system must constantly work with end-users to refine evolving high-level requirements and to optimise the information access, delivery methods, and ocean observing technologies to ensure that the users are receiving useful timely quality information.

When the observing objectives for an Arctic Ocean Observation System has matured out of the user consultations, it is for the observing community to identify the relevant phenomena to observe. The phenomena assist in identifying which variables to measure as well as determining the relevant time and space scales over which the observing is to be executed, data quality and timeliness of data delivery. From the combination of phenomena and variables, the set of suitable observing platforms and sensors emerge. This "selection" is, *per-se*, a predefined process because observing platform have only limited/known time/space/sensor potential.

The Arctic Ocean environment is vast, remote, and harsh, and the cost involved in its observation are very high. There is, therefore a strong need to avoid duplication of efforts, across observing platforms and networks, and to adopt common standards for data collection and dissemination to maximize the utility of data. To address these concerns, the "Framework for Ocean Observing" (UNESCO 2012) recommended to approach ocean observations with a focus on **Essential Ocean Variables** (EOV's), ensuring assessments that cut across platforms and recommend the best, most cost-effective plan to provide an optimal global view for each EOV.

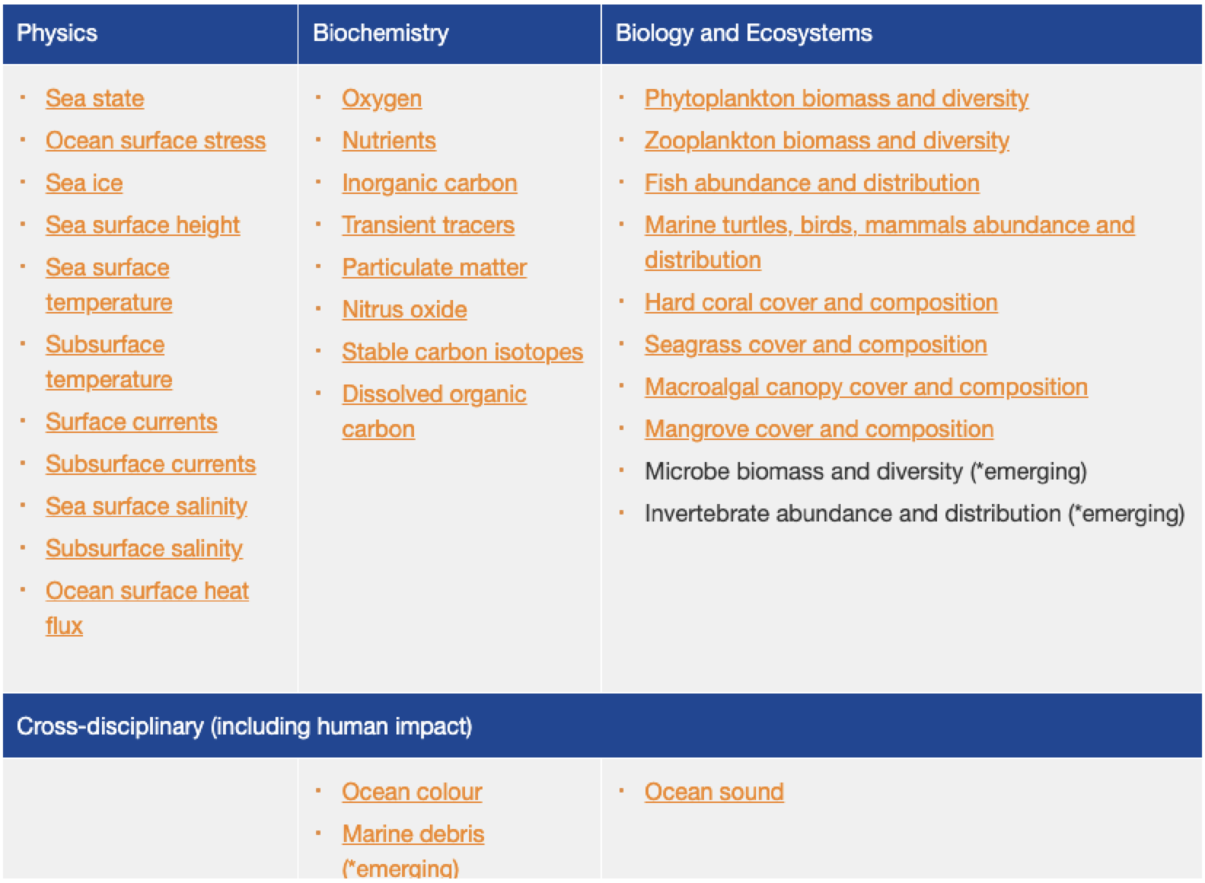
Essential Ocean Variables are identified by the Global Ocean Observing System (GOOS) Expert Panels, based on the following criteria:
- **Relevance:** The variable is effective in addressing the overall GOOS Themes – Climate, Operational Ocean Services, and Ocean Health.

- **Feasibility:** Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

When EOVs are identified, a series of recommendations are created and disseminated by the Expert Panels, including what measurements are to be made, various observing options, and data management practices. Table 3.1 displays the GOOS EOVs defined by the different GOOS expert panels.

Table 3.1. GOOS list of Essential Ocean Variables

Source: https://www.goosocean.org/index.php?option=com_content&view=article&layout=edit&id=283&Itemid=441



Physics	Biochemistry	Biology and Ecosystems
· Sea state · Ocean surface stress · Sea ice · Sea surface height · Sea surface temperature · Subsurface temperature · Surface currents · Subsurface currents · Sea surface salinity · Subsurface salinity · Ocean surface heat flux	· Oxygen · Nutrients · Inorganic carbon · Transient tracers · Particulate matter · Nitrus oxide · Stable carbon isotopes · Dissolved organic carbon	· Phytoplankton biomass and diversity · Zooplankton biomass and diversity · Fish abundance and distribution · Marine turtles, birds, mammals abundance and distribution · Hard coral cover and composition · Seagrass cover and composition · Macroalgal canopy cover and composition · Mangrove cover and composition · Microbe biomass and diversity (*emerging) · Invertebrate abundance and distribution (*emerging)
Cross-disciplinary (including human impact)		
	· Ocean colour · Marine debris (*emerging)	· Ocean sound

The INTAROS project has detailed the ocean phenomenon's important to be observed in the Arctic Ocean (Buch et al., 2017), whereby the relevant EOV's were identified, which constitute a subset of the EOV's listed in Table 3.1. The requirements – spatiotemporal resolution, quality and timeliness - for these EOV's has been quantified by the INTAROS ocean group (Buch et al, 2021) using the requirement database established by Copernicus In Situ Coordination Team as a guide and source of information. Table 3.2 shows requirements for EOV's relevant to observe in the Arctic Ocean.

Table 3.2 Requirements for Essential Ocean Variables relevant for the Arctic Ocean. (Buch et al, 2021)

Name	**Uncertainty**	**Update Frequency**	**Timeliness**	**Horizontal resolution**	**Vertical resolution**
Sea Surface Salinity	Threshold: 0,3psu Breakthrough: 0,1psu Goal: 0,05psu	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	
Subsurface salinity	Threshold: 0,1psu Breakthrough: 0,07psu Goal: 0,05psu	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	Threshold: 10m Breakthrough: 5m Goal: 1m
Sea surface Temperature	Threshold: 0,1K Breakthrough: 0,05K Goal: 0,05K	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2 d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	
Subsurface temperature	Threshold: 1k Breakthrough: 0,5k Goal: 0,1k	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2 d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	Threshold: 10m Breakthrough: 5m Goal: 1m
Surface currents	Threshold: 5cm/s Breakthrough: 2cm/s Goal: 1cm/s	Threshold: 7d Breakthrough: 5d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	
Subsurface currents	Threshold: 5cm/s Breakthrough: 2cm/s Goal: 1cm/s	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400 km Goal: 300km	Threshold: 100m Breakthrough: 50m Goal: 10 m
Sea level	Threshold: 0,05m Breakthrough: 0,02m Goal: 0,01m	Threshold: 1h Breakthrough: 30min Goal: 10min	Threshold: 1h Breakthrough: 10 min Goal: 2min	Threshold: 200km Breakthrough: 50km Goal: 10km	
Sea state	Threshold: 0,25m Breakthrough: 0,25m Goal: 0,1m	Threshold: 7 d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	
Sea Ice Cover	Threshold: 15% Breakthrough: 10% Goal: 5%	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	
Sea Ice drift	Threshold: 2km/d Breakthrough: 0,5 km/d Goal: 0,1 km/d	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500 km Breakthrough: 400 km Goal: 300 km	
Sea Ice thickness	Threshold: 40% Breakthrough: 20% Goal: 5%	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 3d Breakthrough: 2d Goal: 1d	Threshold: 500 km Breakthrough: 400km Goal: 300km	
Nutrients	Threshold: 25% Breakthrough: 10% Goal: 10%	Threshold: 90d Breakthrough: 30d Goal: 7d	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 500km Breakthrough: 400 km Goal: 300 km	Threshold: 10m Breakthrough: 5m Goal: 1m
Oxygen	Threshold: 25% Breakthrough: 10% Goal: 10%	Threshold: 90d Breakthrough: 30d Goal: 7d	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 500km Breakthrough: 400km Goal: 300km	Threshold: 10m Breakthrough: 5m Goal: 1m
Chlorophyll	Threshold: 30% Breakthrough: 10% Goal: 5%	Threshold: 90d Breakthrough: 30d Goal: 7d	Threshold: 7d Breakthrough: 3d Goal: 1 d	Threshold: 500 km Breakthrough: 400 km Goal: 300 km	Threshold: 10m Breakthrough: 5m Goal: 1m
Inorganic carbon (DIC, TA, pCO2, pH)	Threshold: 30% Breakthrough: 10% Goal: 5%	Threshold: 90 d Breakthrough: 30 d Goal: 7d	Threshold: 7d Breakthrough: 3d Goal: 1d	Threshold: 500 km Breakthrough: 400 km Goal: 300 km	Threshold: 10m Breakthrough: 5m Goal: 1m
Bathymetry	Threshold: 1m Breakthrough: 0,5m Goal: 0,1m	Threshold: 10y Breakthrough: 5y Goal: 1y	Threshold: 1y Breakthrough: 1y Goal: 1y	Threshold: 100km Breakthrough: 50 km Goal: 2km	Threshold: 10 m Breakthrough: 5m Goal: 1m
Greenland Ice Sheet Mass Change		Threshold: 5y Breakthrough: 1y Goal: 1m	Threshold: 1y Breakthrough: 6m Goal: 3m	Threshold: 8 areas Breakthrough: each terminal glacier Goal: each terminal glacier	
River Discharge	Threshold: 25% Breakthrough: 10% Goal: 5%	Threshold: 7d Breakthrough: 1d Goal: 6h	Threshold: 7d Breakthrough: 1d Goal: 6h	Threshold: 10km Breakthrough: each hydrological basin Goal: each hydrological basin	

A set of well-defined requirements will assist the design of an ocean observing in two ways:

- By comparing the existing observation system to the requirements, the gaps are identified.
- Form the basis for a calculation of the costs of establishing and maintaining the optimal observing system.

The INTAROS project and the Copernicus In Situ Coordination Group (Ludwigsen et al, 2018; Buch et al, 2019) have recently monitored the status of the Arctic Ocean observing activities and some key findings were identified:

- The Arctic Ocean is generally undersampled in particular the central part,
- Most observations are funded via time-limited national and EU research funds meeting national priorities and therefore lack international coordination,
- Far from all data are freely available in a timely manner due to insufficient communication facilities and/or data management structures, national or institutional data policies, scientific publication etc.

In order to address all the needs and requirements for timely information on the state of the Arctic Ocean articulated by various user groups, it is important to establish a multi-disciplinary, efficient, integrated, fit-for purpose and sustained observing system for the whole Arctic Ocean. It is important to stress that uninterrupted multi-decadal observations are crucial to understand the Arctic Ocean system as a whole and its long-term evolution in order to correctly manage the ocean's resources on which human lives and economies depend. The short-term funding cycles characterizing the present Arctic Ocean observing (primarily based on short-term research funds), challenges the continuity of measurements over the long term, and makes the funding of a new generation of the workforce, technology development, and the research fleet vulnerable.

Ocean observations are extremely costly, which makes it mandatory to seek for intelligent, cost-efficient design and implementation solutions to minimize costs, which includes:

- Strong international coordination to ensure that data requirement for various user groups are merged into one multipurpose system to avoid duplication of effort and minimizing maintenance costs i.e., follow the philosophy ***“measure once use multiple times***”. This will require establishment of a clear governance structure with well-defined responsibilities and tasks - such a structure will most likely be a demand to obtain the required long-term sustained funding.
- The dominating costs of an ocean observing system are the operational expenditure especially for observation systems that involves ship-time and particularly in the

remote, harsh and ice-covered Arctic. Focussing on multidisciplinary, multiplatform solutions together with a coordinated use of ship facilities can help reduce costs.

- Innovative cost-effective observing technology and data communication solutions for Arctic observations securing continuous NRT data flow from this harsh environment also during wintertime must continuously be pursued.

An efficient ocean observation system needs to be accompanied of open data policies and effective data management – which makes data available to users on a free and unrestricted basis. There is a global recognition that open data access encourages wide use of data, and the development of new data products. Data and associated metadata management that enables access, use and interpretation of data and products must be based in the well-established FAIR (Findable, Accessible, Interoperable and Reusable) guiding principles.

The current existing data management landscape is complex, having different specific data management infrastructures for specific data types, which can cause delayed and duplicate data receipts, missing data and metadata, and undocumented data processing procedures. Streamlined, modern data management structures are required: they can simplify, automate, and make more efficient the flow of data. This would support routine data exchanges within and between observation networks, and user-friendly tools for data/products discovery, viewing and access. Community standards are the foundation for interoperability.

A better coordination of all existing national and international efforts for data management and communication is highly required. Europe has over the past decades invested huge resources in building marine data management facilities and infrastructures (e.g. EMODnet, CMEMS INSTAC, SeaDataNet), which represents a good basis for further developments without the necessity of duplicating efforts or building new infrastructures.

4. Benefits of ocean observations: the value chain

Prior to exploring the economic potential of ocean observation data, products and services, it is important to present an overview of the value chains of ocean observations. The value chain of ocean observations maps the relationships between the observations, the produced data, the data processing, the generation of products and services, and finally the usage of products and services by different intermediate or end-users. The demand of these communities of users forms the basis for a socio-economic evaluation of ocean observations.

4.1. Understanding value chains in ocean observations

Mapping out relationships between ocean observations, related products and services and the user communities is essential for identifying and quantifying their benefits. However, value chains of ocean observations are complex due to a wide variety of data producing entities, different ways of processing, and wide variety of user disciplines or purposes. Understanding all of them requires a multidisciplinary approach, which entails difficulties of its own, e.g., finding a common language between ocean scientists and other user groups (NOAA, 2018). At present, the required detailed information necessary to build accurate and complete value chains accurately is still scarce. A short overview is presented here to have a basis for the analysis.

A generic schematic of a value chain is provided in Figure 4.1. Global, regional and national ocean observation systems collect data for ocean research and technology innovations. The data is then processed, i.e., edited, published on open data platforms, used for modelling, etc., and fed into different products and services.

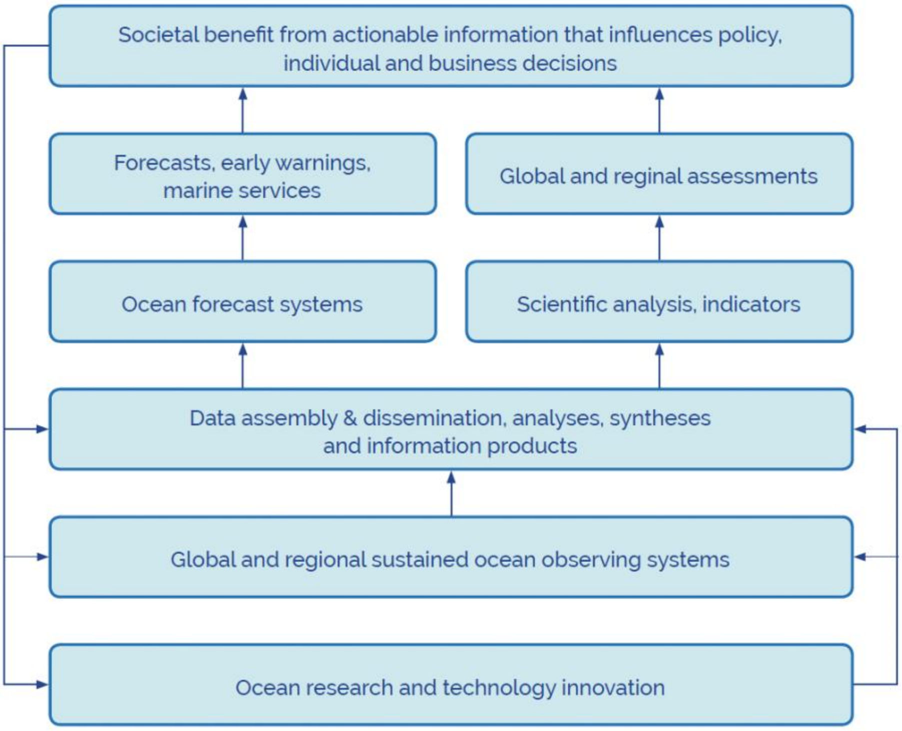


Fig 4.1 Blue Value Chain
(Adapted from G7 Ocean Expert Group Think Piece May 2016)

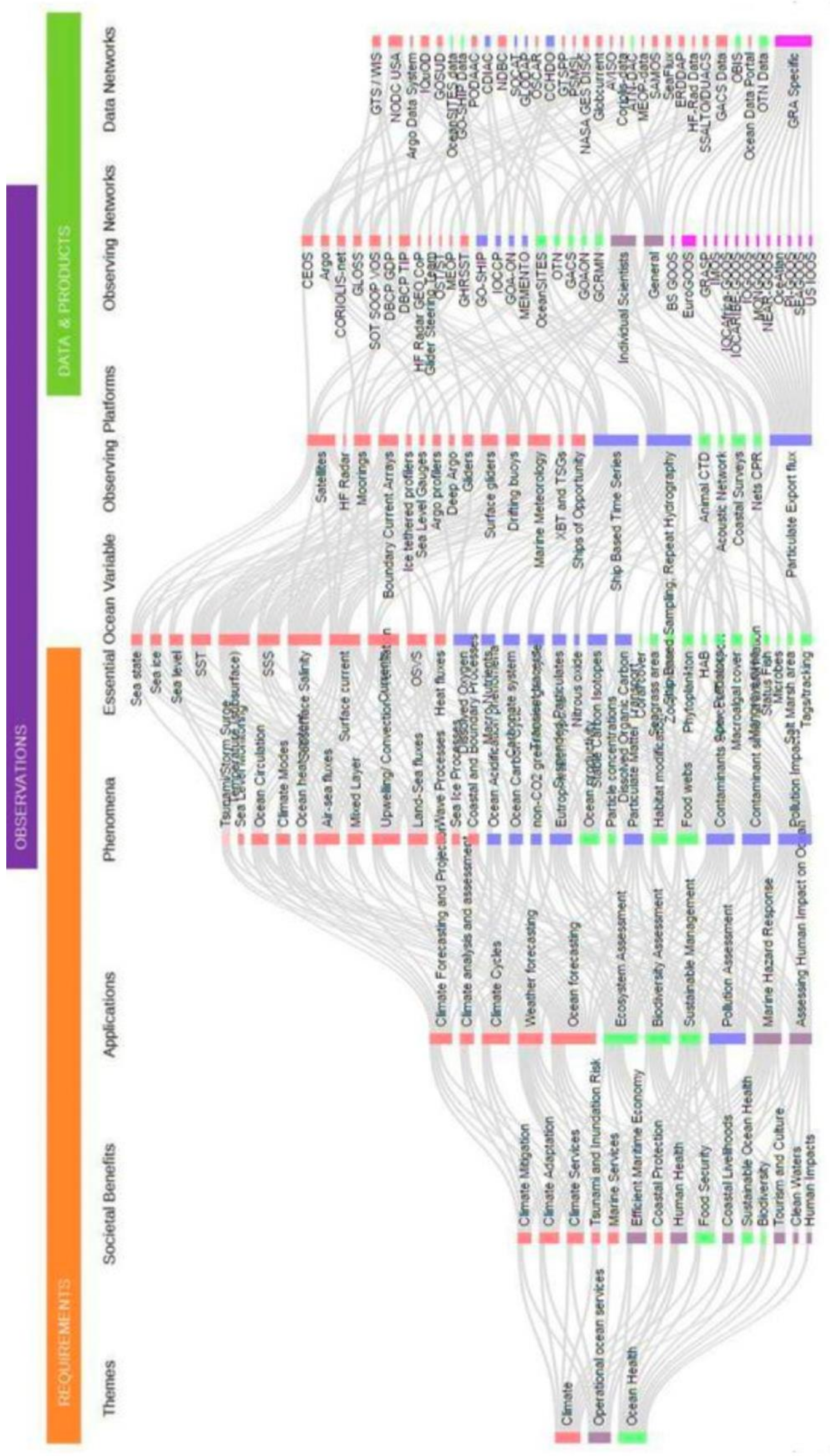


Figure 4.2 Overview of value chains of ocean observations provided by GOOS

In the schematic value chain (Fig. 4.1) two categories of products and services are considered. The first category includes forecasts, early warning systems and marine services (left branch in Fig 4.2). Products and services of this category usually have a short- to mid-term perspective and a relatively clearly defined scope of application. Examples of these are operational oceanography services like real-time forecasts of sea state, currents or sea ice concentrations.

The second category of products and services considers global and regional assessments of ocean dynamics and climate change (right branch in Fig. 4.1). These products usually have a long-term perspective and are normally used by government bodies to define long-term policies or strategies.

Both categories of products and services generate either economic or social (public) benefits. However, the assessment of these benefits requires much more detailed information on the value chains of ocean observations.

GOOS has developed a more detailed overview of value chains of ocean observations (see Figure 4.2). It clearly shows the complexity and interconnectedness of the individual value chains, which poses a huge challenge to the valuation of ocean observations. Observing platforms and networks (right part of Figure 4.2) gather data to provide information on EOVs (middle column of Figure 4.2). The EOVs are used to explain, model und examine a variety of ocean phenomena. Findings from that research feed into applications that generate benefits (left part of Figure 4.2).

Both examples of value chains do not explicitly yet include the end-user communities, which are the link between products and services and the benefits. A better monitoring of the data flow, i.e., from source to product or service to user and purpose, is necessary. It could be helpful to conduct regularly updated surveys among user groups to get a better understanding of the data flow.

Figure 4.3 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., 2009). In the final step, the data is integrated, validated and analysed to develop user-friendly applications.

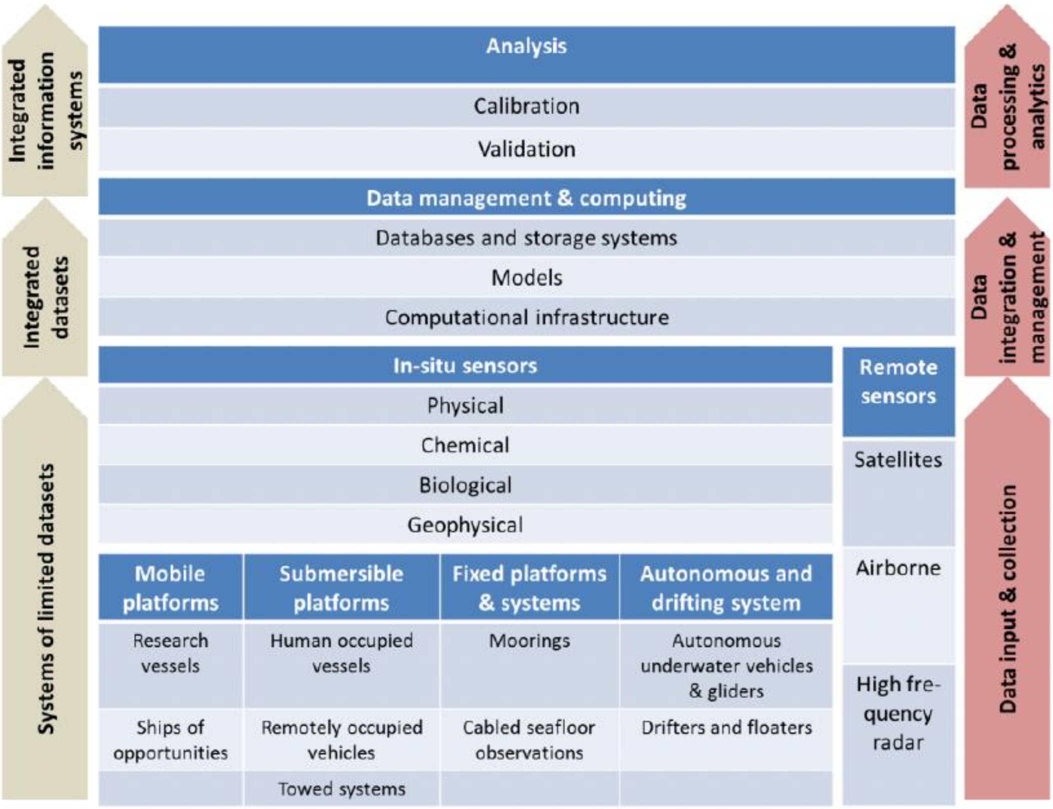


Figure 4.3. Steps involved in data assembly, dissemination and analysis
Source: EU Com (2013)

Much has improved over the past 15 years regarding infrastructure and the necessary consensus on common standards on issues such as data formats, real-time or delayed mode, quality control, and data distribution.

4.2. The communities of users and stakeholders

Although, the diversity of ocean observations' users keeps growing, they can according to Rayner et al, 2019 be divided into four main groups:

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

The operational user community includes the intermediary users and end-users of real-time ocean information's, products and services in support of strategic decision making and operational planning - optimized planning and decision-making translates into different kinds of benefits. Depending on the type of operational user, these can be, for example, commercial benefits such as cost savings or increased revenues, or reduction of risks associated to marine operations. The intermediate users can be private for-profit companies (consultancies, etc) that use the marine information for their business scheme to provide services to end-users.

Policy end-users rely on ocean data and information to help inform the drafting of effective legislation to ensure safety of life or property, protection of the environment, or regulation of the use of ocean space and ocean resources. Ocean data and information are further needed to monitor the compliance with the resulting legislation e.g., EU's Marine Strategy Framework Directive, Water Framework Directive or the Marine Spatial Planning. Ocean data and information also deliver benefits in terms of measuring policy effectiveness and performance, for example, determining the effectiveness of a policy to reduce concentrations of harmful pollutants requires long-term monitoring to determine whether the policy is achieving or not this goal.

The public at large, being an end-user of ocean data and information, is an important stakeholder in the blue economy. Activities such as surfing, sailing, diving, sport fishing, or general coastal tourism are all significant ocean economic activities. Those engaged in these recreational and leisure activities increasingly make use of open access and commercial ocean data and information products. In the Arctic the increasing cruise tourism is a good example.

The scientific user community includes academia, institutions, organizations and projects that focus on scientific research. The role of the scientific community is twofold when it comes to ocean observations. Science is not only a user but more importantly also the main producer of ocean observations. Scientific interest initiates ocean observation and defines which and how data are collected - the scientific community highly motivates the development of suitable and efficient measure instruments reaching from individual sensors to complex observing systems.

Scientists develop, as users of ocean observations, data management and analysis techniques to derive insights on the ocean functioning and its dynamics. These insights contribute to society's knowledge pool and are used to develop, for example, forecasts, assessments and recommendations for decision-makers. Science lays the groundwork for any use of ocean observations. Therefore, it is essential for a thoughtful and sustainable use of the ocean.

Ocean observations are only one asset provided by ocean science (UNESCO-IOC, 2017). Thus, an estimate of the value of ocean observations does not capture the total value of ocean science. The contribution of ocean science to society is crucial for a sustainable life on Earth, especially with respect to climate change. Associated benefits in the short-, mid- and long-run need to be considered for a holistic quantification of ocean science's value to society.

One way to measure the scientific output is to consider scientific publications. Another type of scientific output are open data platforms where edited and (to some extent) processed ocean observations are made publicly available. These platforms are used to share data within the scientific community and to promote synergy effects). They also enable operational users to use the data and therefore benefit from ocean observations. In addition to the data, operational users also benefit from technological development spill-overs.

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

Different applications require different data, products and services. For example, the maritime shipping sector in the Arctic relies traditionally on weather, sea ice and sea state observations and forecasts. New climate change phenomena like increasing melting of sea ice or sea level rise raise the demand for information on sea ice cover and concentration, batyhymetry or tides. In the offshore oil and gas production, different activities such as location choice, environmental impact studies, engineering design and set-up, production and decommissioning require different marine products and services including wind, wave, current and bathymetric information (Calverley, 2018). Emerging industries like the marine renewable energy production need new types of products and services with information on salinity gradients, resource and temperature evaluation in addition to information on wave, wind and currents (Gruet, 2018). In some cases, experiences from used products and services can be transferred from one industry to another. The offshore aquaculture sector could benefit from lessons learned in the offshore oil and gas industry with respect to engineering design and marine construction (Rayner, 2018).

Even though users of ocean observations and corresponding applications are rather well-known, there is only little information about the use of publicly available ocean observations by those users. A few studies based on surveys provide some insights – OECD has recently (OECD, 2021) published the results of a survey performed in the United Kingdom. Fig 4.4 shows the use of ocean data among a range of users.

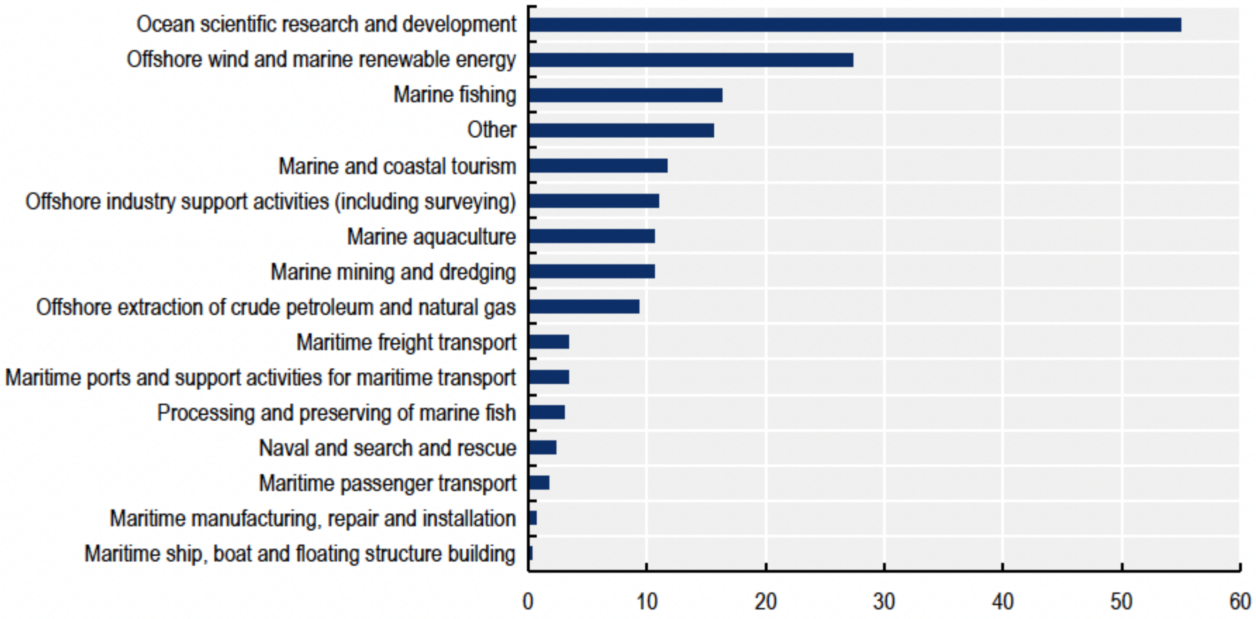


Figure 4.4 Public marine data are used across a range of industries, including several such as offshore wind and marine renewable energy that are burgeoning ocean economic activities. Source: OECD, 2021
(Count of industries selected by respondents weighted by the importance of each industry in the respondents' overall activities)

The type of data that is accessed by the responding users is shown in Fig.4.5

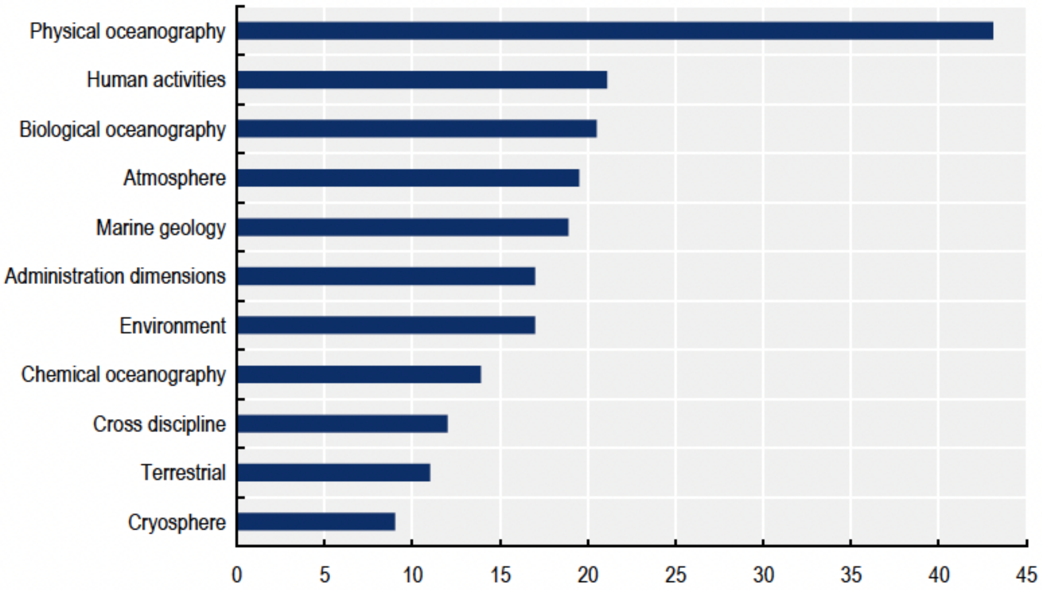


Figure 4.5 Data types accessed by users. Source: OECD,2021

4.3.The communities of data providers

Data providers (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 due to commercial or scientific reason. Fortunately, there have over the past couple decades been a tendency towards open and free exchange of data - including real-time data. EU has highly supported this trend via two programmes:

The Copernicus Marine Environment Monitoring Service (CMEMS) - provides regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas including the Arctic Ocean. The observations and forecasts produced by the service support all marine applications, including:

- Marine safety;
- Marine resources;
- Coastal and marine environment;
- Weather, seasonal forecasting and climate.

For instance, the provision of data on currents, winds and sea ice help to improve ship routing services, offshore operations or search and rescue operations, thus contributing to marine safety. The service also contributes to the protection and the sustainable management of living marine resources in particular for aquaculture, sustainable fisheries management or regional fishery organisations decision-making process. Physical and marine biogeochemical components are useful for water quality monitoring and pollution control. Sea level rise is a key indicator of climate change and helps to assess coastal erosion. Sea surface temperature elevation has direct consequences on marine ecosystems and the occurrence of tropical cyclones.

As a result, the service supports a wide range of coastal and marine environment applications. Many of the data delivered by the service (e.g., temperature, salinity, sea level, currents, wind and sea ice) also play a crucial role in the domain of weather, climate and seasonal forecasting**.** The products delivered by the CMEMS are provided free of charge to registered users. These products encompass a description of the current situation (Analysis), the variability at different spatial and temporal scales, the prediction of the situation a few days ahead (Forecast), and the provision of consistent retrospective data records for recent years (Re-analysis).

CMEMS has a portfolio of 38 products for the Arctic Ocean – Fig 4.6 and 4.7 provides an overview of users to these products and their engagement/contribution to the above mentioned four CMEMS areas of benefit.

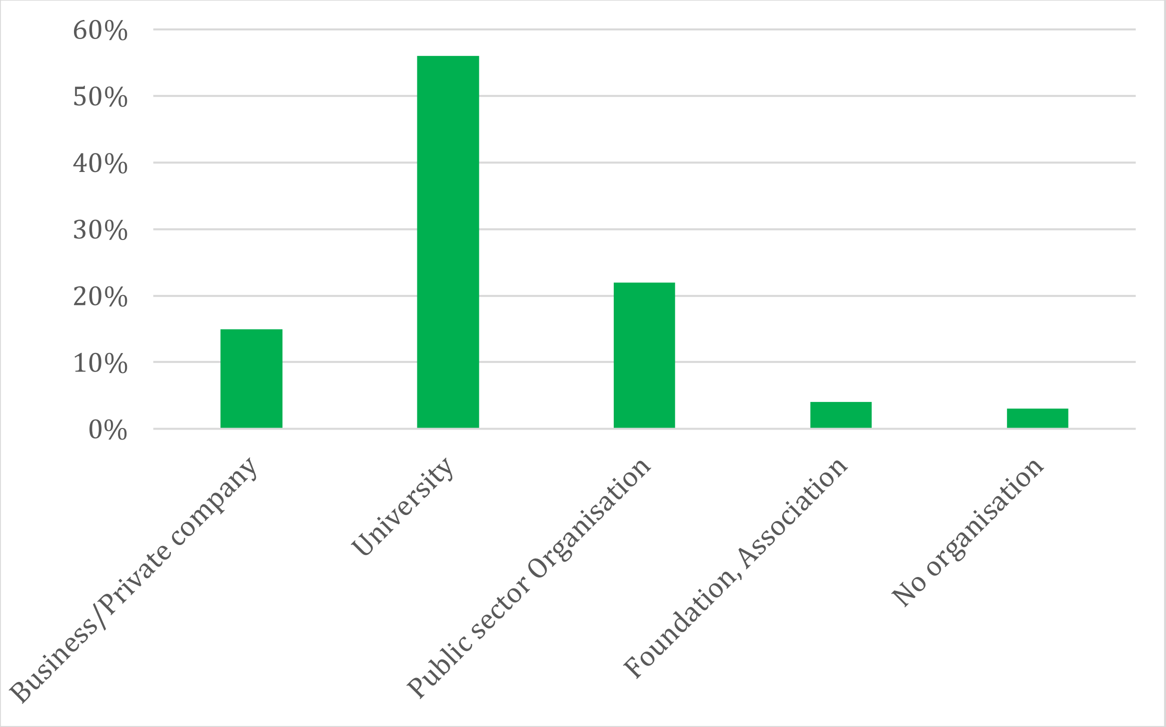


Figure 4.6. Organisation types using CMEMS Arctic products and services (Jan2020-Sep2021)
Source: CMEMS Helpdesk

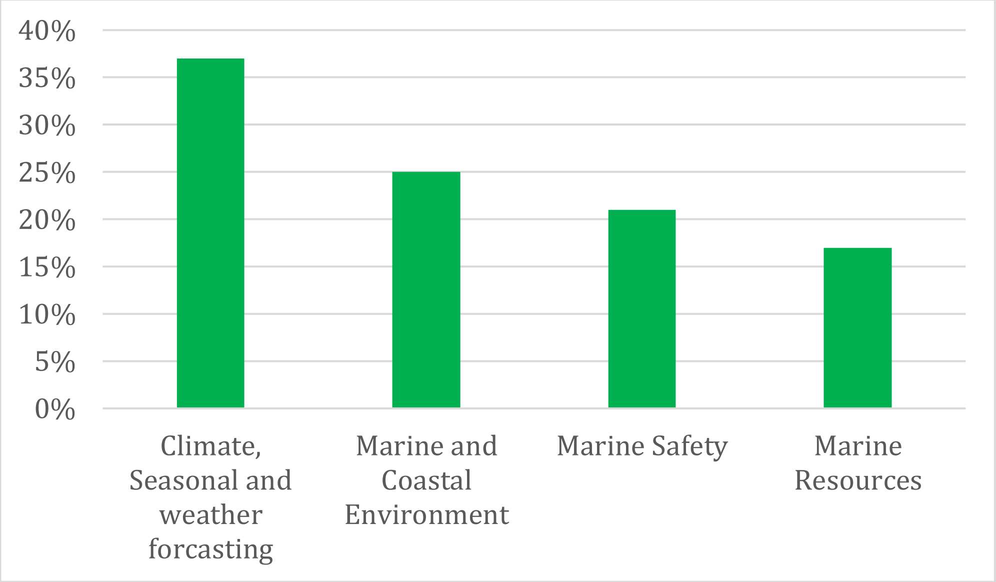


Figure 4.7 Area of Benefits of CMEMS Arctic products and services (Jan2020-Sep2021)
Source: *CMEMS Helpdesk*

The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy. These organisations work together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products.

This "collect once and use many times" philosophy benefits all marine data users, including policy makers, scientists, private industry and the public. It has been estimated that such an integrated marine data policy will save at least one billion Euros per year, as well as opening up new opportunities for innovation and growth.

EMODnet provides access to European marine data across seven discipline-based themes:

- Bathymetry
- Biology
- Chemistry
- Geology
- Human activities
- Physics
- Seabed habitats

For each of these themes, EMODnet has created a gateway - supplemented with a data ingestion- and central gateway - to a range of data archives managed by local, national, regional and international organisations. Through these gateways, users have access to standardized observations, data quality indicators and processed data products, such as basin-scale maps. These data products are free to access and use. Fig 4.8 shows the volume of downloads from the EMODNET data portals in 2020.

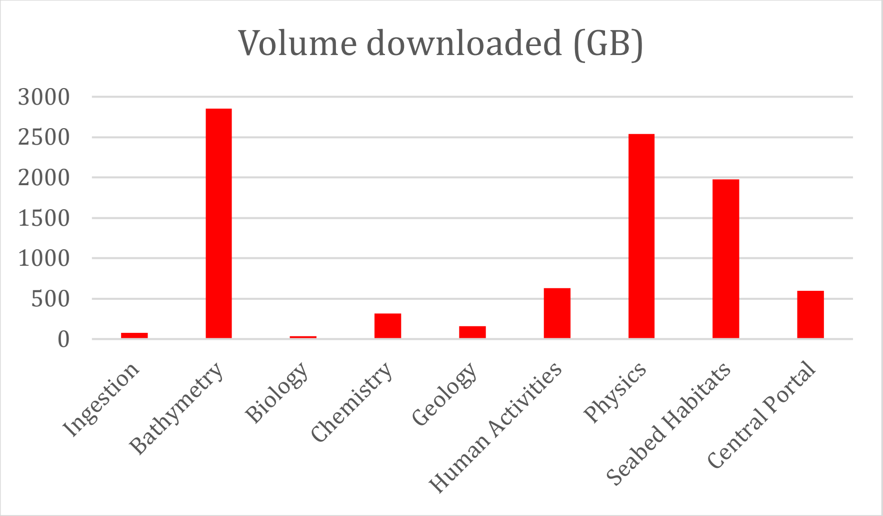


Figure 4.8 Volume of downloads from users of EMODnet portals in 2020
Source: EMODnet, pers. Comm.

In 2020 EMODnet put special focus on the Arctic by – in close cooperation with CMEMS In Situ Thematic Assembly Center (INSTAC) and EuroGOOS - establishing a special **Arctic Marine Data Portal**[4] for physical oceanographic data, which will form the basis for a future distribution of Arctic Ocean observations. To further develop this portal, EMODnet will have to interact with additional Arctic data providers to harvest metadata and provide links to data held by major projects (e.g., INTAROS (iAOS Portal), Arctic PASSION (SAON data portal)) and initiatives (e.g., GEOSS (GEOSS Portal)).

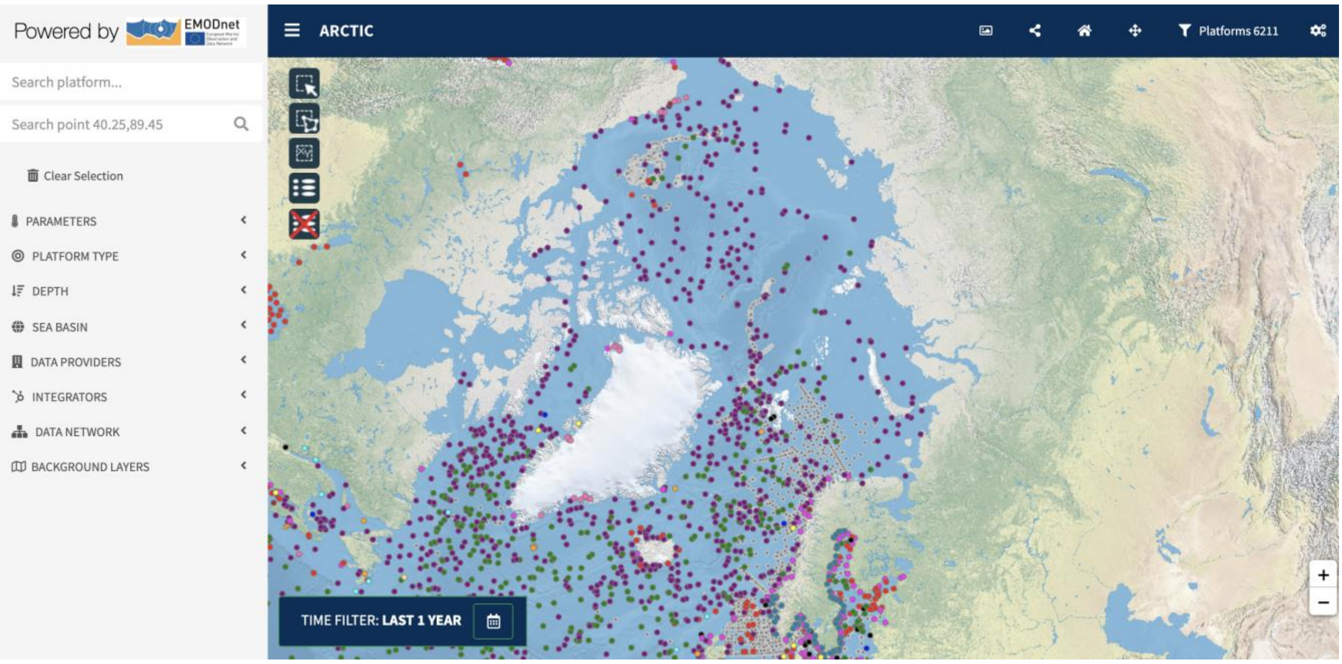


Figure 4.9 Observations in the Arctic Ocean from November 2020-October 2021 available in Arctic Marine Data Portal. Source: https://arctic.emodnet-physics.eu/

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[4] https://arctic.emodnet-physics.eu/

5. Cost-benefit analysis

Assessing the value and quantifying the cost-benefit of ocean observations has been of interest to the ocean observing community for several decades. The main driver behind valuing ocean observations is the need of decision-makers to justify investments in ocean observing infrastructures. Typically, a cost-benefit-analysis is envisioned to support this decision-making. In a cost-benefit-analysis estimates of the value of ocean observations (i.e., the benefits associated with the use of ocean observations) are compared to the costs associated with the corresponding observing system. If benefits exceed costs the investment is considered worthwhile.

A cost-benefit-analysis for ocean observations in the Arctic Ocean has not been withing the scope of INTAROS, so this chapter relies heavily on work performed by OECD (OECD, 2018a,b) and work done in the H2020 AtlantOS project.

5.1. Costs

Costs associated with ocean observation include capital costs for the initial set-up of technological equipment and infrastructure (e.g. vessels, buoys, gliders, floaters, sensors) and running costs for maintaining the technological equipment and infrastructure, and harvesting and processing of gathered data. Cost information is available to a greater extent than information on benefits of ocean observations. Usually prices for technological equipment, labour costs for skilled personnel, etc. are known, which allows a more accurate estimation of costs.

However, estimating costs, their distribution over different areas of a project (e.g., installation, maintenance, professional staff) and their development over time is challenging. The AtlantOS project tried to estimate the costs of the existing Atlantic Ocean Observation System (Reilly et al, 2018). Their cost analysis was a first step to develop a consistent cost accounting framework for ocean observing networks. The financial figures gathered provided an indication of the level of funding required to operate a basin-scale Atlantic Ocean observing network.

The analysis, however, identified a number of limitations with the financial data gathered for each network. In many cases, the level of detailed cost information provided – capital investments as well as annual operational costs – depended on the maturity of the network. It was therefore impossible to estimate the expenditure of all ocean observing networks in the Atlantic domain and more work is required to achieve a fully comprehensive overview.

Reilly et al, (2018) concluded that the cost accounting process needs refinement and standardisation across the networks. A common approach could involve the classification of costs into capital and operational expenditure - this would help inform national policy discussions and reports regarding the allocation of funding for ocean observing networks. For this to occur, it is recommended that institutes in all countries collaboratively work together to collect data on investments in ocean observations. Increased cooperation and integration between the networks would help to provide assessments that are more accurate.

The annual expenses of the Atlantic Ocean observation system as estimated by Reilly et al, (2018) are given I Table 5.1

Network	Maturity level (status)	Annual CAPEX (€)	Annual OPEX (€)	Total Annual Running Cost (€)
GO-SHIP	Mature	N/A	N/A	3,766,568
SOOP - European FerryBox	Pilot	1,875,066	1,538,993	3,414,059*
Continuous Plankton Recorder	Mature	N/A	N/A	2,076,652*
Argo	Mature	7,918,810	672,120	8,590,930
OceanSITES	Mature	2,754,000	910,000	3,664,000
Glider	Pilot	N/A	N/A	4,500,000*
PIRATA	Mature	1,200,000	5,107,100	6,307,100
Surface Drifter	Mature	804,300	332,751	1,137,051
Ocean Tracking Network	Pilot	N/A	N/A	2,466,032
Total				**34,762,992**

*Personnel cost included

Where OPEX = Operating Expenditure and CAPEX = Capital Expenditure; N/A = Not Available

Table 5.1 Estimated annual running costs of Atlantic Ocean observing networks. (Source: (Reilly et al., 2018)

Personal costs were estimated to amount to additional **€10.297.500 per year**.

The estimated percentage financial sponsorship of the networks in terms of Government, Research Project and Private funding is shown in Table 5.2. According to Reilly et al., 2018 the percentages provided in Table 5.2 are merely an initial indication of the sponsorship contribution and further details is required to gain a more accurate assessment of how the networks are funded.

Network	Government	Research Projects	Private Parties
GO-SHIP	87	13	0
SOOP - European FerryBox	N/A	N/A	N/A
CPR	35	65	N/A*
Argo	25	75	0
OceanSITES	90	10	0
Glider	N/A	N/A	N/A
PIRATA	100	0	0
Surface Drifter	95	5	0
Ocean Tracking Network	N/A	N/A	N/A

*The Private percentage funding contribution for the CPR network is currently unavailable as the “in-kind” contribution in terms of ship-time is unknown. This is likely a significant percentage of the overall cost to run the network.

Where N/A - Not Available.

Table 5.2 Estimated percentage contribution by sponsors to each network. Source: Reilly et al, 2018

According to this analysis the Atlantic Ocean observing system costs around 45 mill. Euros/year, but this number is only part of the truth since national monitoring programmes (environment, fishery, hydrography, geology, storm surge), coastal observatories, national research projects etc. was not included, so the total cost of the Atlantic Ocean observing system may well be close to 100 mill. Euro per year.

The expenditure of the Atlantic Ocean Observation System cannot be taken as an indicator for the cost of the existing Arctic Ocean Observation System, since the Arctic Ocean is severely undersampled compared to the Atlantic Ocean; but the analysis performed by Reilly et al, 2018 including the identified shortcomings can be used as a template for cost calculation in the planning and design of a future Arctic Ocean Observation System. It must in this context, however be remembered that the harsh Arctic environment put special demands on the observing and communication technology and ships.

5.2. Benefits

Quantitative information on the value of ocean observations is very limited or not available. Determining the value of ocean observations is often based on the concept of value of information i.e., the use of data generated products and services leads to improved information about the ocean state, benefitting both society and the commercial/blue economy sector.

According to Liebender et al., 2016:

- *Societal benefits of ocean observation include a better understanding of the changes in marine ecosystems (UN, 2015a) and the current health of the oceans. 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, sea ice reduction and sea level rise.*

- *Blue economy benefits are the result of improved decisions for commercial operations. For example, operational maritime industries are able to prepare for risks and adapt to changed environmental conditions through the use of support tools, such as ocean forecasts on currents, waves, sea ice distribution etc. which supports the blue economy sector in gaining higher productivity results, improved economic performance and better security for ships, cargo and crew.*

- *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 blue economy sector.*

There are a variety of benefits derived from the use of ocean observations (OECD, 2018a), see Table 5.3.

Benefits	Description
Cost avoidance	includes avoided costs and loss reduction, due to e.g. appropriate preparations that prevent storm damages
Cost savings	includes decreases in costs due to savings or reduction and social cost savings
Defence	includes the improved readiness of public defence
Employment	includes increases in employment
Increased consumer surplus	includes increases in consumer surplus
Increase in GDP	includes increases in GDP
Increased producer surplus	includes increases in producer surplus
Increased revenues	includes revenues, tourism expenditures, dollar value of exports and production value
Improved business management	includes increases in efficiency or productivity that are not captured by increased revenues or cost savings
Improved environmental management	includes increased efficiency in management decision-making regarding environmental management and protection
Improved forecasting	includes the reduction of risk and uncertainty, improved planning security, early warning systems and predictions of currents, waves, and weather and other ocean related phenomena
Lives saved	includes additional lives saved
Research benefits	includes benefits from collaboration of research institutions and joint data collection
Social welfare gains	includes gains in social welfare
Value added	includes increases in value added

Table 5.3 Categories of benefits. Source: OECD, 2018a

These 15 different benefit categories in table 5.3 can broadly be categorised in three families of benefits (OECD, 2018a):

- ***Direct economic benefits*** *are generated through the use of products developed using ocean observations (e.g., commercialisation of ocean and weather forecasts valued through the revenue generated by companies selling forecasts). This category is relatively straightforward, but the economic data needed to conduct the assessment are generally quite scarce. Commercial revenues from selling products or services based on ocean observations are not mentioned in the literature reviewed.*

- ***Indirect economic benefits*** *are accrued through the wider economic activity enabled by products or services (e.g., better ship routes as a result of accurate weather and ocean forecasts, valued, for example, by reduced fuel costs as a result of avoiding bad weather). The indirect economic benefits follow gains in efficiency or productivity from using improved ocean observations. This category is the most represented in the literature with costs savings (30%), cost avoidance (15%) and increased revenues (14%), as the three most frequent types of benefits cited in the studies.*

- ***Social benefits*** *are received by society in general in ways that are often difficult to identify and quantify precisely (e.g. improved environmental management or better understanding of the impacts of climate change valued for example by estimations of the avoided costs associated with mitigating climate change). The most frequent types of social benefits are improved environmental management (10%), lives saved (7%) and improved forecasting (6%).*

The relative frequencies of indirect and social benefits are provided in figure 5.1 based on 303 observations (note that more than one type of benefit per assessment is possible). Note that Macro-economic figures, such as value-added, increase in Gross Domestic Product (GDP) and employment are rare, in the reviewed assessments. Main public-related benefits include improved environmental management, lives saved and improved forecasting.

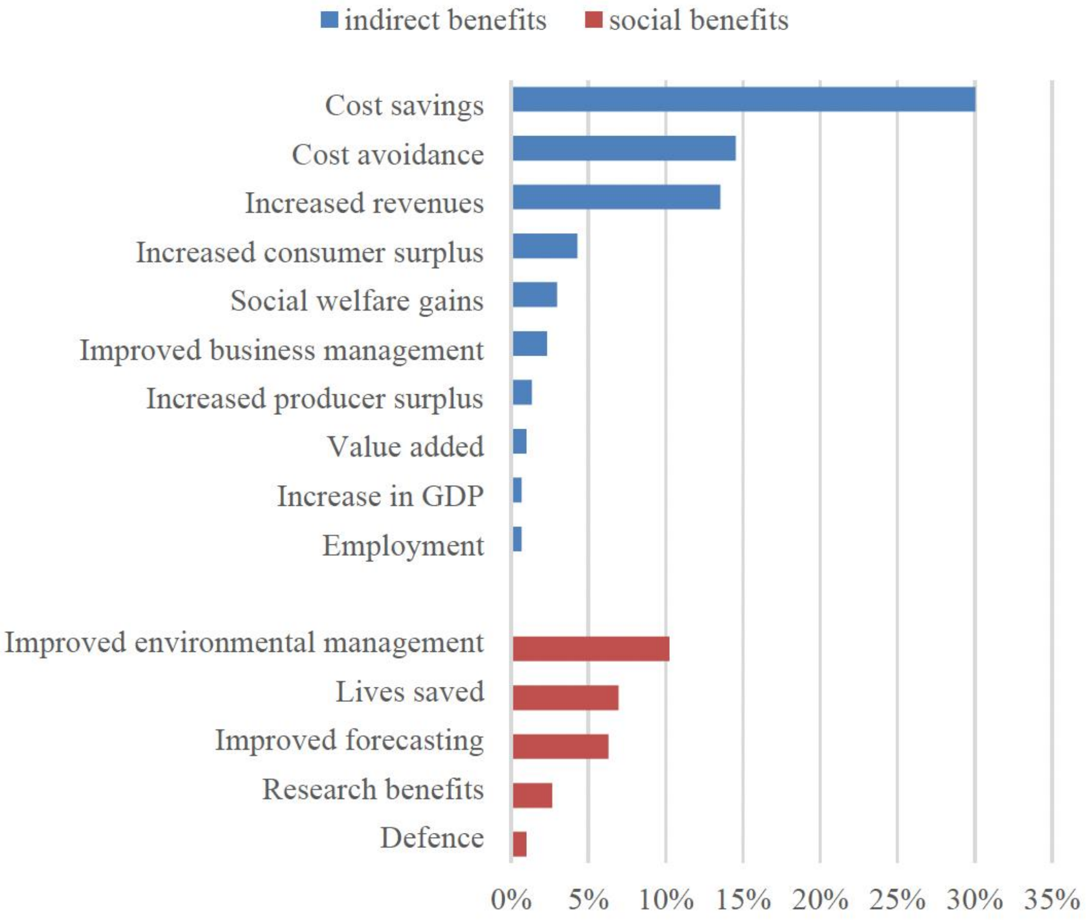

Figure 5.1. Types of benefits identified in the literature(more than one type of benefits per assessment is possible**).** Source: OECD, 2018a

Quantification of indirect benefits are better assessed than social benefits (see figure 5.2). Indirect benefits tend to be generated by commercial user domains, for whom a better understanding, appropriate data and methodologies are available and allow a better quantification of benefits.

Social benefits tend to be qualitatively described rather than quantified (see figure 5.2). Most of the social benefits are generated by public user domains, that are likely to lack appropriate data and methods to quantify benefits. Benefits in terms of lifes saved are an exception. Monetary estimates for lives saved can be derived by applying statistical values of life (OECD, 2018b).

The benefits with the highest share of quantitative assessments (100%) are macro-economic measures, e.g., GDP, employment, value-added, consumer and producer surplus. Increased revenues and cost savings are also quantified in the majority of assessments (85% and 65%, respectively).

Benefits with less than 50% of quantitative assessments are improved environmental management (45%), improved business management (43%), defence (33%), improved forecasting (21%) and research benefits (13%).

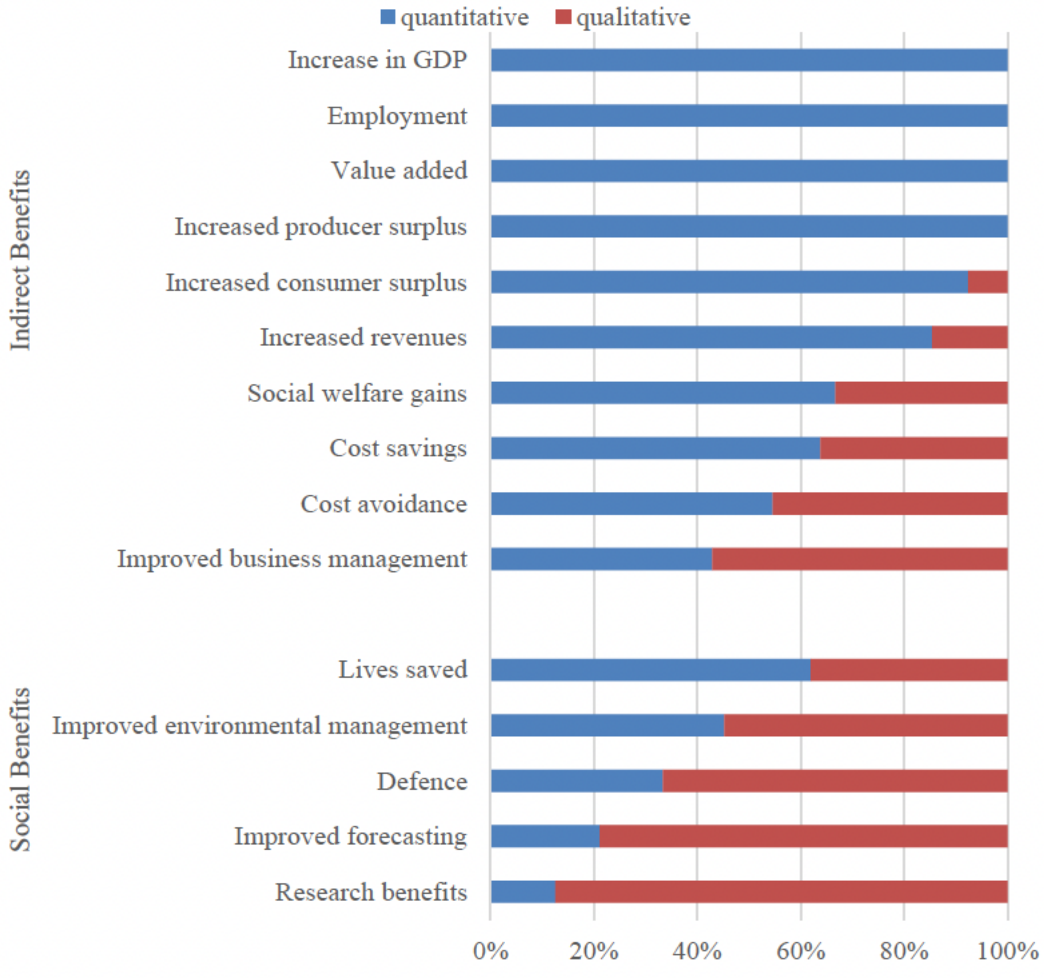

Figure 5.2 Quantitative vs. qualitative assessments by type of benefits. Source: OECD, 2018

Although ocean observations play an important role for a variety of scientific and operational user domains, putting a value on ocean observations remains very challenging especially when non-market goods and intangible benefits are included. The choice of the proper methodology for valuing ocean observations is not universal but context-specific. Several factors determine the selection of a suitable methodology including the objectives of the study, the timing of the study (i.e. *ex ante* vs. *ex post* consideration), the nature of benefits (i.e. expected vs. known), the available assessment expertise, provided resources and the quality of primary data sources.

Although scientific knowledge is used for a variety of purposes (e.g., decision-making in the private or governmental sectors, or as public information) it is difficult to capture the socio-economic impacts of scientific knowledge in monetary terms. Attempts to quantify ocean observations focus on specific applications by operational users. In some cases, it is possible to quantify the value of ocean observation, as for example valuing improved sea state forecasts for a commercial shipping company. However, there are also cases where the quantification is very challenging or even impossible, as for example valuing improved biodiversity information for environmental management. Another important aspect is that it is difficult to anticipate which data might not be considered valuable today, but might be required in the future. Therefore, it should be kept in mind that approaches to valuing ocean observations are prone to uncertainties and might underestimate the actual value of the scientific contribution.

A thorough assessment of the value of ocean observations would require further efforts in identifying and understanding the different user communities, their use of ocean observations and the associated benefits, based on common standards for the evaluation process. Quantifying socio-economic benefits will bring a strong argument – in addition to the scientific benefits – for the sustainability and improvement of ocean observations.

OECD (OECD, 2018a) recommends to follow three pragmatic steps in such a future approach for a cost-benefit analysis:

- ***Tracking the users and mapping value chains***
    - *Increased efforts among providers of ocean observations data to track user groups, their downloads and use of the data would help identify associated marketable and social values. This would involve improved identification and mapping of end-users, whether they are scientific or operational users.*
    - *Surveys of end-users of ocean observations could be a useful tool to gather characterisations of users, the products and services they require and the benefits they realise by using ocean observation. These surveys could be conducted in cooperation with open data platforms, such as CMEMS and EMODnet in Europe, NOAA in USA or AODN in Australia, with their user base as the target group.*
    - *A more thorough and detailed analysis of dedicated value chains for some of the main products and services derived from ocean observations could also contribute to reveal a more robust valuation of socio-economic benefits. There are very useful efforts underway at national and international levels (e.g., NOAA studies, GOOS), but there are still some overlooked sectors. Convening an international expert meeting specifically on lessons learned on user groups at different levels of value chains would be very useful for the ocean observing community.*

- ***Advancing on methodologies***
    - *The studies differ considerably in spatial and temporal scope, methodology used and user domain considered. The ocean observation community would benefit from international standards or guidelines for the valuation of ocean observations. This would simplify the comparison of different studies and allow the aggregation of results.*
    - *A holistic socio-economic valuation of ocean observations needs to account for marine environment and ecosystems, but is still challenging even though tools and methodologies developed. As long as the current value of the environment and ecosystems is unknown, assessing the impact of improved ocean observations will hardly be possible.*
    - *There are several general challenges, when assessing the benefits of ocean observations, e.g. the public good character of many ocean observations, complex value chains and taking stock of a variety of stakeholders. The comparison of individual studies' results can be complicated by varying temporal, sectoral, and spatial scales applied in the assessments. Still, improvements in methodologies can be made. The weather and the environment policy communities have both tested and paved the way for useful and proven value of information techniques applicable to ocean observations.*
- ***Expanding the international knowledge base***
    - *The OECD, 2018a analysis can serve as a starting point for sharing the international knowledge base with the community. Expanding the known literature and making it ever more inclusive would constitute a natural next step, since based on discussions with different stakeholders, more substance could be included.*
    - *This would involve an even more international coverage (e.g., considering recent studies from Asia and Latin America) and the inclusion of further work on the valuation of social benefits.*
    - *There is a real potential to improve the knowledge base on the value of ocean observations, with the objective to provide more robust evidence-based information to decision-makers.*

It is therefore recommended that the management of the future Arctic Ocean Observation System works closely with experts from OECD on the establishment of a robust cost-benefit analysis methodology for the Arctic Ocean.

6. Summary and conclusions

Climate change, fast technology developments and increasing demands from global economy have, over the last decades, opened the space for a rapid development of Blue Economy in the Arctic region. Development of this economical potential requires huge investments in individual business sectors themselves as well as in supporting infrastructures – in the order of 1 trillion USD (WWF, 2018) – and the investor community seems to be highly interested and ready to invest in Arctic Blue Economy.

Growing Blue Economy in the Arctic puts, however, severe stress and threats on the vulnerable Arctic environment, on traditional Arctic professions related with the sea and on traditional life and culture of indigenous people living in the Arctic. Initiatives towards a responsible and sustainable development of Arctic Blue Economy are therefore high on the agenda among the community of nations surrounding the Arctic. This fact calls for a science-based approach to manage the economic development balancing the desire to improve economic profit, human living conditions and wellbeing with the imperative to sustain ecosystem health and preserve Arctic environment. Mandatory for this approach is a good knowledge and understanding of the functioning of the Arctic Ocean environment and ecosystem, which requires a well-coordinated, integrated, sustained fit-for-purpose Arctic Ocean Observing System - “***You cannot manage what you do not observe”.***

The design of an Arctic Ocean Observation System should follow the concept outlined in the “Framework for Ocean Observations” (UNESCO, 2012), which includes a suite of logical steps:

1. Map user requirements for information, products and services
2. Identify the ocean phenomena associated with the observing objectives that are linked to user requirements
3. Identify the Essential Ocean variables associated with observing objectives.
4. Quantify the observation requirements – spatiotemporal resolution, quality and timelines
5. Compare information on the existing observation system with user requirements (point 1) and observation requirements (point 4) to identify gaps
6. Design an optimised observing system building on what exist, using up-to-date but well-proven technology incl. real-time data communication and data management

Implementing these six steps for the Arctic Ocean requires a strong international coordination and governance structure to ensure:

- Continuous dialog with relevant user and stakeholder communities on their request for information, products and services
- Long-term sustained funding
- Adjustments of evolving observing requirements when appropriate
- Development of new observing technologies
- Data centres apply the FAIR principle.

An important component of design and implementation of an Arctic Ocean Observing System is assessment of the economic value and cost-benefit analysis of the system i.e., justify that the benefit exceed the costs.

Ocean Observing cost includes capital costs for the initial set-up of the observing system (instruments, ship time) and running costs for maintaining the observing system incl. harvesting, processing and sharing of the data. The cost calculation therefore seems fairly straightforward since all expenses of all components should be available. However, experience from the AtlantOS project (Reilly et al, 2018) pointed to a number of limitations on the financial data gathering. It was therefore concluded that the cost accounting process still needs further refinement and standardisation of methodologies.

Information on the value and benefits of ocean observations is of great interest but generally very limited. OECD has in recent years, in cooperation with various ocean observing communities, started to address this issue in order to establish ways to quantify the value of ocean observations. They have identified a number of benefit categories that can be grouped in three main benefit areas (OECD, 2018a):

- *Direct economic benefits*
- *Indirect economic benefits*
- *Social benefits*

The direct and indirect economic benefits are better quantified than social benefits, which tend to be more qualitatively described.

For future development of valuing ocean observations and a cost-benefit analysis, the OECD (OECD, 2018a) recommends to follow three pragmatic steps:

- *Tracking the users and user groups and mapping the observations value chain;*
- *Advancing on common and agreed methodologies of valuation;*
- *Expanding the international knowledge base*

It is therefore recommended that the management of the future Arctic Ocean Observation System works closely with experts from OECD on the establishment of a robust cost-benefit analysis methodology for the Arctic Ocean.

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