# 2.
# Motivation and international context of ocean forecasting

CHAPTER AUTHORS

**Pierre Bahurel and Enrique Alvarez Fanjul**

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Ocean forecasting took its modern form at the turn of the century, when marine experts on in situ observations, satellite observations, numerical modelling and data assimilation decided to move together towards an integrated approach. Since then, operational oceanography has evolved incredibly fast, fostering communities' engagement, bringing innovations to operations, and structuring new information services for users.

International cooperation was immediately adopted as a natural framework for the development of ocean forecasting, and this is still today an indispensable driving force pulling forward local and national initiatives across continents.

The Global Ocean Data Assimilation Experiment (GODAE), kicked off in 1997 (Bell et al, 2010), played a leading role catalysing the initial steps of this revolution by engaging stakeholders worldwide to build "a global system of observations, communications, modelling and assimilation, that will deliver regular, comprehensive information on the state of the oceans, in a way that will promote and engender wide utility and availability of this resource for maximum benefit to the community". Most of today's ocean forecasting centres were born to respond to this international call and are directly built on principles and methods designed in this framework.

GODAE has indeed established the foundation of an international cooperation for ocean forecasting and one of its first outcomes was to build the scientific and technical "common" required to develop and operate advanced ocean forecasting systems, promoting a cooperation based on openness and inclusiveness, and driven by constant innovation. This worldwide activity is benefitting ocean knowledge and is providing useful tools for decision making actions towards a more sustainable ocean. These motivations and principles are still framing and inspiring today our international cooperation for ocean forecasting.

## 2.1.
## International cooperation for a sustainable ocean

Operational Ocean Forecasting Systems (OOFS) are amongst the main and more powerful tools to build the bridge between marine science and society needs, with a consistent and state-of-the-art digital depiction of the ocean environmental state. It took less than two decades to OOFS to emerge from science, gain realism and operational maturity, and convince users of their value; and this is not by chance if international cooperation was identified from the very first day as a key condition for success, being today the natural playground for the development of the OOFS capacity.

Given its importance in the socio-economic and environmental context, outlined in chapter 1, the role of OOFS is gaining relevance with time, both locally through expert services, and globally through international coordinated actions. This importance is being additionally reinforced by the increasing quality of the forecast services and the international cooperation in data exchange and creation of standards, vital tools for ocean forecasting.

The three pillars of the Global Ocean Observing System strategy (GOOS, 2020) can help to briefly describe this relevance. These are applications, climate, and ocean health:

- **Applications (blue economy):** Ocean forecasting is gaining worldwide relevance in creating applied solutions for final users to contribute to a virtuous blue economy. Both public institutions and private companies are taking active steps to implement the so-called "value chain", that transforms ocean observation into information to be employed by end user applications. This is invigorating economic activities, creating jobs, and providing solutions for environmental problems. Chapter 11 provides detailed insight on this particular and presents several relevant applications. Other outstanding set of examples can be found at [1].

- **Climate:** Climate change is threatening our ocean and, very particularly, our coasts. For example, sea level rise will produce an increase of coastal erosion and inundation events. And the earth climate cannot be explained without a fair understanding of the ocean climate. The study of climate change scenarios with numerical models is our best tool to assess the hazards, one of the key elements of risk analyses, together with vulnerability and exposure. Ocean global reanalyses produced by ocean forecasting centres as reference simulations

1. https://marine.copernicus.eu/services/use-cases

for the past decades are key elements in this domain. These simulations, together with scenario projections, allow us to create climate change impact studies that are the main source of information to design mitigation and adaptation strategies. On shorter time scales, dynamic risk reduction activities are vital for maintaining activities in a changing environment. In this sense, the OOFS will become even more relevant, as the number of extreme events increases. Examples of the ocean climate monitoring by OOFS can be found here, with indicators ([2]) and annual expert reports on the ocean climate ([3]): they are amongst the first OOFS products used by policy makers.

- **Ocean health:** Human activity is impacting ocean health, increasing its temperature and its acidification. This problem is having very visible and dramatic consequences, such as coral bleaching, increments of harmful algal blooms, migration of species and jellyfish proliferation. Ocean forecasting is a key tool to understand the internal dynamics of these processes and, therefore, provide solutions based on knowledge. Additionally, OOFS are providing vital information for strategic action areas to improve sustainability for future generations; food, energy, tourism transport, energy, and seabed mining, as described by the high-level panel for a sustainable ocean economy ([4]). All these activities are benefiting from the accurate forecasts that our present-day systems are providing.

The ocean dynamics is of course not limited by our national boundaries, so international cooperation is necessary when dealing with ocean forecasting. But the other reason for imposing international cooperation to ocean forecasting centres, as a mandatory framework for action, is the need to build a strong community voice supporting the policy effort towards a sustainable ocean. With the Ocean relevance increasingly present on international political agendas (see the UN Agenda 2030, the EU Green Deal, and many other initiatives), knowledge derived from OOFS is today essential, and the only way to achieve this is by action on a global framework. Even when OOFS implementation and ocean applications are local, they contribute to a global challenge. On the local scale they bridge the gap between ocean observations and applications and are active players of a prosperous Blue Economy. But their impact is global, by supporting assessment studies and contributing to an improved local sustainability policy that impacts, at the end, the global ocean.

Due to the previous reasons, the international structuration of the OOFS community is an essential condition for a sustainable development of the ocean. Ocean Forecasting is now a recognized player of international ocean governance fora such as the UN ocean initiatives where ocean policies are discussed. Remarkably, ocean forecasting has been identified by the UN as a key contributor for its 14$^{th}$ sustainable development goal "life below water".

## 2.2. International cooperation to build our "common"

All ocean forecasting systems have in common their dependence on reliable ocean observations and state-of-the-art ocean modelling components, together with the human expertise and operational processes to design, develop and operate such systems. Marine services based on OOFS are consequently critically dependent on the considerable investments required to develop upstream research for capacity building and large infrastructures such as satellites, marine observation networks and super-computers. Such massive investments are not affordable at the scale of one entity or one nation, and international cooperation is the only framework able to ensure a sustainable effort in this matter and build this indispensable framework for the OOFS worldwide community.

The "butterfly diagram" (Figure 2.1) illustrates the position of ocean forecasting in the overall value chain, bridging ocean observations with end-users (Bahurel et al., 2010). Ocean forecasting is present on the two steps signed with gears on the figure. On one hand, at the so-called "core services", where its mission consists in integrating the richness and variety of ocean observations to build a state-of-the-art description of the ocean environment, multi-variable, consistent in space and time, reliable, and immediately action-

2. https://marine.copernicus.eu/access-data/ocean-monitoring-indicators
3. https://marine.copernicus.eu/access-data/ocean-state-report
4. https://www.oceanpanel.org/

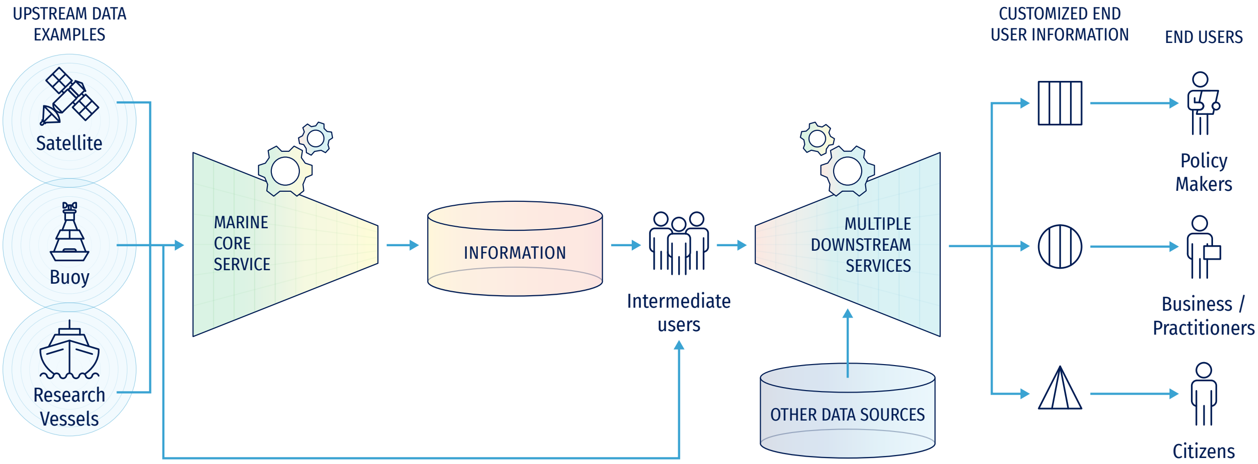


**Figure 2.1.** From observation to end user services: the ocean value chain.

able by expert services in their own fields of expertise. On a second step, intermediate users can use this freely available description to enrich the data via model downscaling and, finally, generate tailored information and indicators for decision making. This is done via a large variety of downstream services, such as storm surge forecast warning systems or water quality monitoring services.

The left wing of this butterfly (Marine Core Service) also illustrates the OOFS 'common' – i.e., the assets developed through international cooperation and shared by the OOFS community as a common good – that the GODAE initiative has invented two decades ago, and that international cooperation has developed through different channels.

This OOFS 'common' includes:

- **Data:** Ocean observations measured from space by satellites, and in situ by vessels and autonomous networks as well as different forcings or coupling with atmosphere and river run-off required to run OOFS systems. International cooperation has not only organised and simplified the access to these data worldwide, but also has strengthened the voice of the OOFS community for a sustained observation effort.

- **Tools:** Operational tools used to generate a reliable 4-dimensional description of the ocean environment and operate ocean forecasting systems include models, data assimilation systems and product generation software. Full-fledge integrated systems and their parameterization are specific to their purpose, location, and operating team but they are composed of individual bricks (e.g., NEMO -Nucleus for European Modelling of the Ocean- modelling tool) that are frequently shared to feed the OOFS common.

- **Standards:** data sharing or product validation are driven by expert processes and standards to reach efficiency to interoperability. One of the best examples is the adoption of common data formats to facilitate exchanges. The international community work started with GODAE in the field of product validation with the definition of common protocols ("metrics") now widely adopted by OOF centres worldwide.

- **Products:** together with input data entering OOFS, the output products generated by these systems (ocean forecasts, ocean simulations, ocean indicators, …) are widely shared to feed a common set, facilitating intercomparison and individual systems improvements.

- **Know-how:** the outcomes of research undertaken by scientists in the OOFS fields are of course a key asset for the community worldwide, and the scientific community has proposed in this matter fruitful models of cooperation; this common knowledge has been extending its scope with the development of OOFS through the sharing of best practices in the domain of system operations, market development and user uptake.

This is at the heart of international cooperation and its content is in constant evolution. It reveals the strength and the dynamism of the OOFS community: we are prepared to see in the coming years a bloom of innovation to support OOFS development in the coastal zones, marine biodiversity, polar areas, climate adaptation, all integrated in the new paradigm offered by digital twinning.

## 2.3. International cooperation to foster openness and inclusiveness

The principle of openness – free and open sharing of data, exchange of knowledge, interdisciplinary cooperation – and the unwavering ambition to generate at every moment the best possible information to improve our knowledge on the ocean and contribute to a sustainable development are fundamentals in this approach. This principle is a cornerstone of international cooperation and has been a key factor of success of the development of ocean forecasting.

One of the most structuring elements has been the adoption of open & free data policy amongst our community. As previously mentioned, data sharing is a vital need to have a predicted ocean. The Resolution 40 of the World Meteorological Organization related to the exchange of meteorological data was the first model identified by weather oceanographers. Afterwards, the scope has been extended by several international initiatives developed to promote data exchange and systems interoperability at a wider scale, facilitating interdisciplinary approaches. For example, the INSPIRE Directive aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies and activities which may have an impact on the environment ([5]).

This European Spatial Data Infrastructure is enabling the sharing of environmental spatial information among public sector organisations, facilitating its public access across Europe, and assisting in policymaking across boundaries. Beyond its simplicity for implementation (open sharing means less energy spent in control and more in value creation), openness is a key condition for inclusiveness. Being inclusive is identified as particularly important in the field of modern oceanography where stakeholders, motivations and situations are particularly diverse and rich. The Copernicus Marine service in Europe has shown the strength of a state-of-the-art operational service implemented by hundreds of experts and teams, distributed throughout Europe, coming from public and private sectors, from operational and research organisations, from different countries, from diverse cultures and relations to the ocean. Openness facilitates inclusiveness and enables diversity, bringing together the best skills and fostering capacity building. This principle of inclusiveness is particularly important to successfully manage the seamless integration of coastal centres in the OOFS framework, where – here again – the first priority will be to build a worldwide capacity open and benefitting to all.

## 2.4. International frameworks to support OOFS development

Amongst the United Nations framework, the Intergovernmental Oceanographic Commission (IOC) of UNESCO is critically instrumental to build the world ocean 'basic infrastructure', i.e., observations, data management, and forecasting. Within IOC, the Global Ocean Observing System (GOOS) program is a key element of this community effort, and a powerful instrument to structure expert cooperation in the different related thematic areas (e.g., from physics to biology) and the different regions through the GOOS Regional Alliances. In this frame, the Expert Team on Operational Ocean Forecasting Systems (see below) is fully devoted to ocean forecasting. The IOC International Oceanographic Data and information Exchange (IODE) program complements this effort, with special focus on the setting of ocean data information system.

Beyond IOC-UNESCO, the other GOOS sponsors – World Meteorological Organization (WMO), UN Environment Program (UNEP) and the International Science Council (ISC) – are all active players in this area. WMO offers a solid model of organisation, set for weather forecasting, where the management of basic infrastructures on one hand – see for instance the WMO Global Data Processing and Forecasting System (GDPFS) that coordinates Member capacities to prepare and make meteorological analyses and forecast products – and the management of weather services on the other, can inspire the world ocean community and propose immediate hooks to develop ocean/weather synergies, as it is already

5. https://inspire.ec.europa.eu/

the case for observations. The marine component of Global Environment Monitoring System (GEMS Ocean) of UNEP is another example where ocean prediction information is identified as a key source of information. As an illustration, we can observe how the World Environment Situation Room – which is an environmental dashboard operated by UNEP for its Member States – includes in its Ocean/ SDG14 section operational ocean prediction products.

It is in this framework where the ETOOFS (Expert Team on Operational Ocean Forecasting Systems) action takes place: hosted by IOC and co-sponsored as GOOS by IOC, WMO, UNEP and ISC, this body brings together experts representing each continent, highly motivated to share and improve their experience and skills to help developing countries build their national centres for operational oceanography. ETOOFS enables worldwide use of timely and reliable ocean forecasts for applications in national security, environmental protection, and the maritime economy. It is a vital operational link between observing networks and marine services.

Amongst others, the following ETOOFS activities are to be highlighted:

- Manage and maintain guide, scope and requirement documents for countries providing ocean forecasting services.
- Manage and maintain an overview of active operational ocean forecasting systems.
- Manage and promote the adoption of an international standard to support interoperability and common formatting of ocean forecast products and services.
- Guide and initiate actions contributing to improving operational ocean prediction system efficiency, fidelity and service quality.
- Promote and facilitate support for, and development of, operational and forecasting systems and their adoption in the wider community.
- Provide advice on operational ocean forecasting systems related matters and prepare submissions on the requirements of operational ocean forecasting systems operated by countries to other international groups.

Multilateral initiatives such as the G7 Future of Seas and Ocean Initiative ([6]) or the Blue Planet component of the international GEO (Group on Earth Observations) program ([7]) are other relevant frameworks where the value of OOFS is progressively recognized and further developed. We observe for instance how the priorities set by the G7 FSOI (Future of the Seas and Oceans Initiative) on digital oceanography (amongst others) and by GEO Blue Planet on marine applications are dependent on ocean prediction.

It is also important to mention the tremendous contribution of large organisations such as the European Commission in Europe, which, in the frame of its space program Copernicus, has created and supports a unique Copernicus Marine forecasting service (Le Traon et al., 2017) organisation ([8]). This European-made service follows the international cooperation principles presented above, with a global impact as the first driver, and was the key to design, build and operate a "core" service following common good principles, and to implement a full open data policy and an inclusive service organisation across Europe. The link with the other continents – America, Asia, Australia, Africa – is at the heart of Copernicus Marine. Similarly, we can observe how the African Union has encouraged structuring initiatives for a prosperous Blue Economy across the African continent with IOC, with GEO and other programs where ocean forecasting is instrumental. The workshop organised by ETOOFS in the preparation phase of the present guide has shown a remarkable demand on all continents for a reinforced community approach and OOFS capacity development worldwide.

OceanPredict ([9]), which descends directly from the initial GODAE initiative, is the best international framework to develop science & technology initiatives in the field of ocean forecasting. At a scientific level, the modelling community is indeed self-organised thanks to it. This is a team dedicated to work with the Global Ocean Observing System (GOOS) and associated groups to co-design and co-develop the ocean observing and forecasting system of the future, with the aim of delivering the essential information needed for safety, wellbeing, and prosperity. OceanPredict is a vigorous and strong international coordination mechanism to build the ocean prediction capacity of the future. This will be achieved thanks to the improvement of the science, capacity, efficacy, use, and impact of ocean prediction systems, contributing to a seamless ocean information value-chain, from observations to end users, for economic and societal benefit.

Finally, the launch by IOC-UNESCO of a "UN Decade of Ocean Science for Sustainable Development" is an excellent opportunity to do more, reinforce international cooperation and enrich our community and knowledge in the field of ocean prediction. The relevance of ocean forecasting systems will be even larger in the future, with more reliable

6. https://www.g7fsoi.org/
7. https://geoblueplanet.org/
8. https://marine.copernicus.eu/
9. https://oceanpredict.org/

and interoperable services, able to serve a wider range of final users. In this process, the activities of the UN Decade of Ocean Science will be of paramount importance (UNESCO-IOC, 2021). Under the vision "the science we need for the ocean we want", the Ocean Decade will implement transformative ocean science solutions for sustainable development. The following outcomes describe "the Ocean We Want, which is the aim and final target of this initiative:

- A clean ocean where sources of pollution are identified and reduced or removed.
- A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed.
- A productive ocean supporting sustainable food supply and a sustainable ocean economy.
- A predicted ocean where society understands and can respond to changing ocean conditions.
- A safe ocean where life and livelihoods are protected from ocean-related hazards.
- An accessible ocean with open and equitable access to data, information, technology, and innovation.
- An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development.

As a part of the Decade activities, Mercator Ocean International will implement a Decade Collaborative Center for Ocean Prediction (OceanPrediction DCC). This initiative will provide: i) a global forum to focus and optimise the efforts of individual Decade programmes on achieving the collective goals of the Decade, ii) a communication and collaboration hub that brings together Decade programmes with ocean prediction activities, institutes, and organisations outside of the Decade, and iii) the global technical and organisational structure required to establish a pilot for a Global Ocean Data Processing, Modelling, and Forecasting System building on the innovations generated by Decade programmes – such as CoastPredict, Foresea or DITTO (Digital Twins of the Ocean) to name a few – and other national, regional, international and intergovernmental partners.

## 2.5. An international community of Operational Ocean Forecasting Systems ready for the next steps

The OceanPredict website describes a first series of ocean forecasting systems, projects and centres, illustrating the worldwide dynamism of this scientific and operational domain: they are BlueLink in Australia, Concepts in Canada, ECCO, Hycom and NCEP in the United States, ECMWF and the Met Office in the United Kingdom, INCOIS in India, Mercator Ocean International in France, CMCC (Centro Euro Mediterraneo sui Cambiamenti Climatici) in Italy, MOVE/MRI in Japan, NMEFC (National Marine Environmental Forecasting Center) in China, REMO in Brazil and the NERSC (Nansen Environmental and Remote Sensing Center) in Norway: they have in common their global and basin-scale geographical extensions and also their international visibility. But how many other OOFS could we map all over the world? What about SAMOA (Sistemas de Apoyo Meteorológico y Oceanográfico de las Autoridades Portuarias) in Spain (Alvarez Fanjul et al., 2018)? How many of them are in the Pacific or along the African coast? In the Mediterranean only, and for the currents only, we can find 32 different forecasting systems according to the MonGOOS webpage ([10]): they can be local, they can have different purposes, missions or maturities but they are exemplary of the richness and readiness of the OOFS community worldwide. It is time for us all to structure further this talented community and make it visible. The new international momentum offered by the UN Decade of Ocean Science on one hand and the technological breaks proposed by the integration of digital twining is a real chance. Ocean prediction centres are ready for a new step in this digital oceanography, and they are well prepared: committed for a sustainable ocean, for a state-of-the-art common set of assets nourished by all and benefitting to all, and for an open and inclusive approach.

10. http://www.mongoos.eu/

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