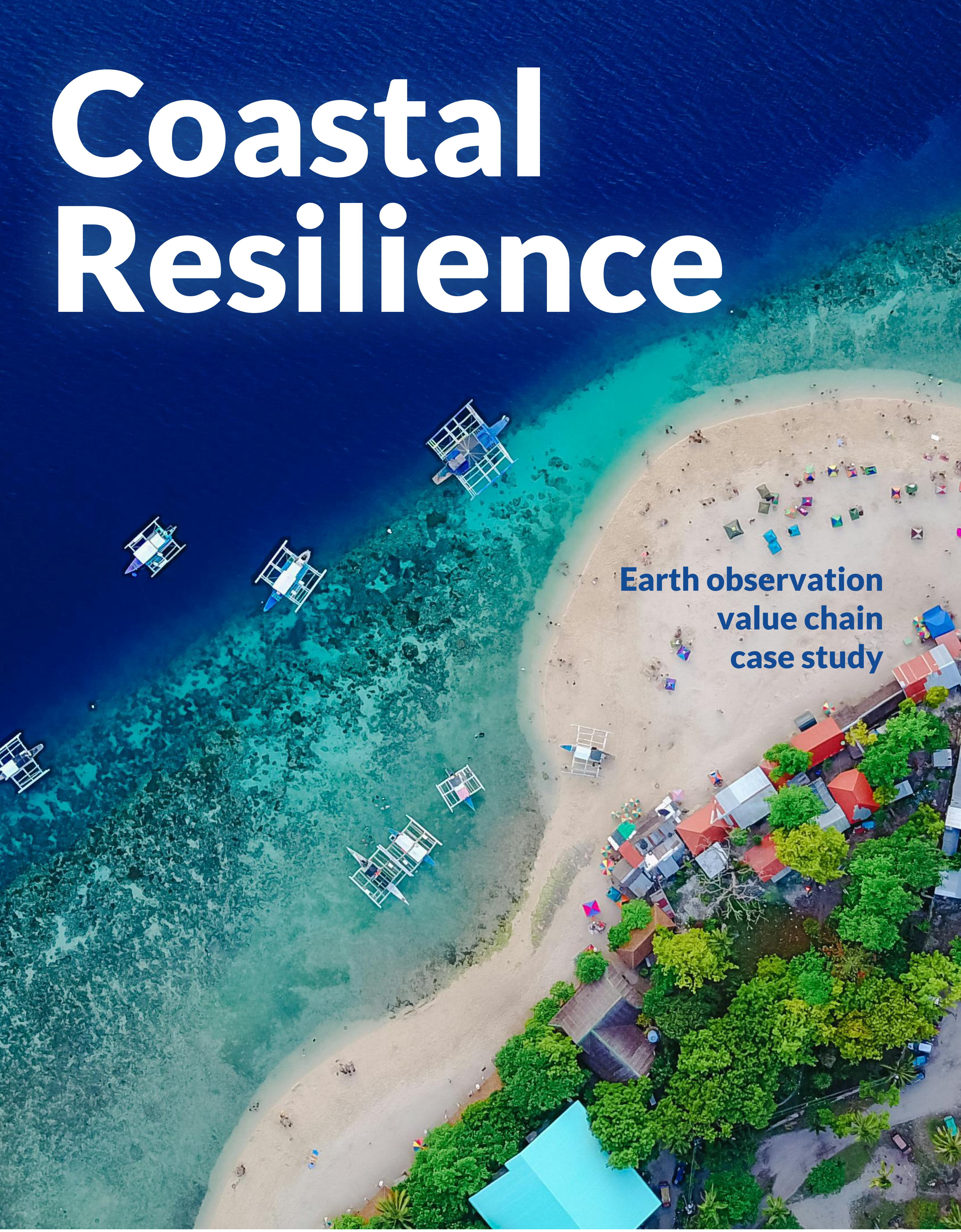
Coastal Resilience



Earth observation value chain case study

Funded by the European Union

EU4Ocean obs

Implemented by

MERCATOR OCEAN INTERNATIONAL

Sept 2024

www.eu4oceanobs.eu/use-cases

Description

Coastal zones are highly dynamic regions where the land and the ocean meet. They host unique ecosystems supporting not only marine life and coastal communities, but the entire planet. Coasts are a source of food, economic and biological value, and important social and cultural services to society.

Exposed to a range of natural hazards such as erosion and flooding, due to sea level variations, coasts are also under immense anthropogenic pressure. It is estimated that more than one third **- 2.75 billion people -** of the world's population lives within 100 km of the coast, making coastlines on average three times more populated than the rest of the world. Intense urbanisation, pollution and overexploitation of resources are changing the natural balance of coastal zones, reducing resilience in these environments and impacting marine life. Human-induced global warming is rising sea levels at an accelerated rate, increasing the coastal population's vulnerability to more frequent extreme weather events, waves and flooding. As coastal communities are expected to grow, as a response to the world's population growth, coastal resilience is paramount to safeguard people's lives and the conservation of marine and coastal ecosystems.

This use case presents how Earth observation and derived information and applications are advancing coastal resilience in the face of coastal hazards. The document also provides concrete examples of how the European Union is contributing to the monitoring and forecasting of coastal zones, and the provision of free and open access data and information, supporting mitigation and adaptation measures to protect people and ecosystems, and build coastal resilience in Europe and beyond.

What is coastal resilience and why is it important?

Coastal resilience is the capacity of a social community or environment to cope with natural or anthropogenic pressures, and recover from hazards such as erosion, sea level rise, pollution and coastal flooding and inundation.

According to the United Nations, over 3 billion people depend on marine and coastal resources for their subsistence. Highly populated and intensively exploited areas, coastal zones are also under immense pressure from human activity. The over-exploitation of marine resources and human-induced global warming are damaging coastal zones, marine life and intensifying hazards at the coast.

For naturally exposed, economically dependent and risk-prone populations, especially those living in low-lying areas – below 10m above the average sea level – coastal resilience is vital. Thus, reducing coastal vulnerability and building resilience by **preventing**, **mitigating** and **adapting** to coastal hazards is of utmost importance. These three foundational measures help to reduce the risk of health and safety issues, population displacement, infrastructure damage, economic losses and the exposure of coastal zones and communities to storms and extreme weather events.

10 cm

is the global mean sea level rise in the past 30 years. In the last 10 years sea level has risen at a rate twice as fast.

At least 600 million

people live in coastal zones at 10 m or less above the average sea level. This number is expected to double by 2060.

Around 3 billion

people depend on marine and coastal resources for their livelihoods.

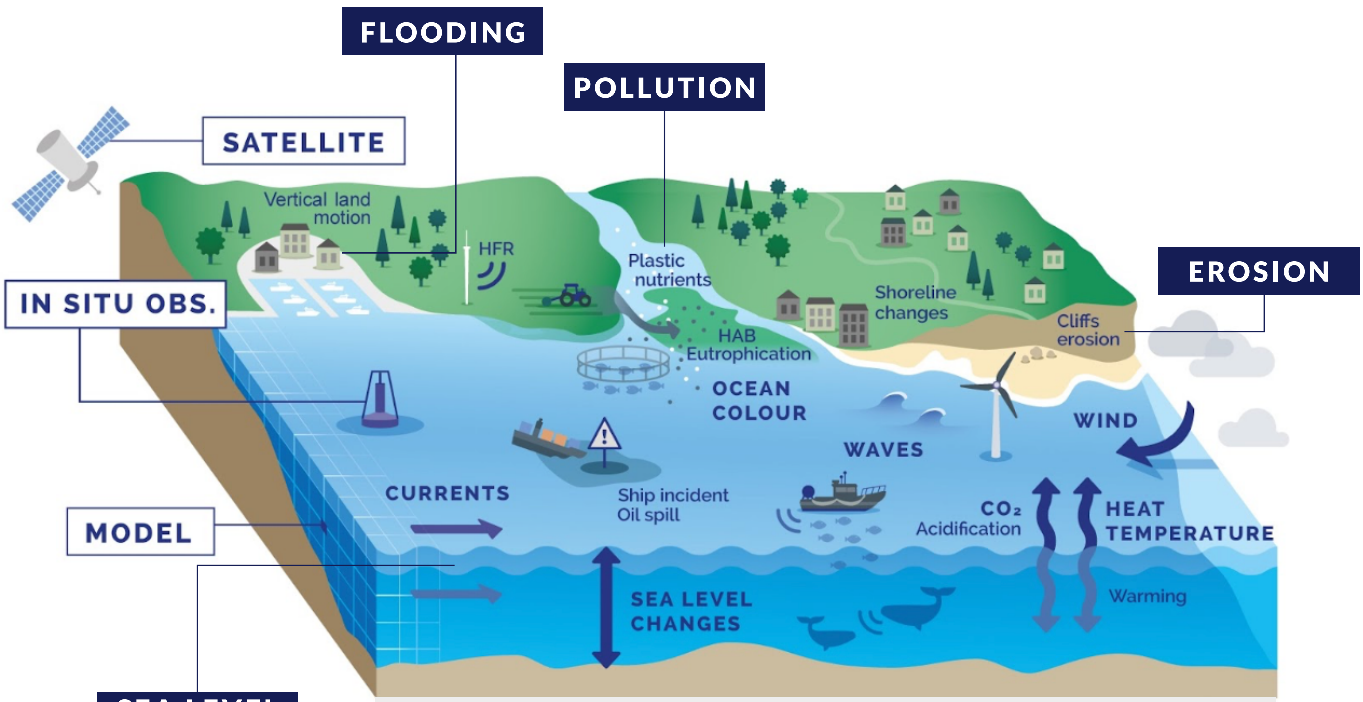


Figure 1:
Natural and anthropogenic pressures on coastal zones. Adapted from Melet et. al 2020. Sea level changes, flooding, pollution and coastal erosion are some of the coastal hazards considered in this case study.

Why do we need Earth observation-based information and services to safeguard against coastal hazards?

The coastal zone is a dynamic region encompassing both marine and land environments. Due to its changing nature (tides, sediment erosion and deposition, shoreline changes) coasts are challenging regions to study, varying between marine and terrestrial features.

Earth observation, through satellite, airborne sensors or direct in-situ measurements allow an assessment at different scales in space and in time. Today, we rely on observations of atmospheric and oceanographic conditions, which are collected at global scale and used in the development of weather forecasting and maritime security systems. Monitoring services help to understand the state of the ocean and coasts over time and anticipate hazards on a short and long term. The creation of forecasts (predictions) up to ten days based on present conditions, allow the detection of, for example, nutrient pollution and the occurrence and intensity of storms. These forecasts can be integrated into early warning systems, useful to put in place adequate preventive and emergency measures for local authorities, search and rescue services, fisheries' management and other economic coastal activities. Monintoirng the coastline also helps to understand natural long-term processes such as coastal erosion and sedimentation, and anticipate integrated coastal zone management plans.

In constant evolution, Earth observation (mainly through remote sensing techniques) offers the capacity to observe coastal zones globally and at large time scales. Earth observation-based information can provide essential support to mitigation and adaptation measures and contribute to minimising impacts on coastal communities and the environment.

'Observations are fundamental to improve the accuracy of monitoring and forecasting systems. These systems help understanding short and long-term changes in coastal zones, anticipate future conditions, reduce the vulnerability and exposure of coastal populations to hazards and inform long term mitigation and adaptation strategies.'

Figure 2:
Large waves caused by Storm Eunice cashed over sea defences in Porthcawl, Wales, February 2022. Photo credit: Jacob King

Coastal hazards (both naturally occurring or caused by human activities) such as sea level rise, flooding, erosion and pollution have an impact on coastal communities and ecosystems. Below are a few examples of the environmental and socioeconomic impacts brought by the above mentioned coastal hazards.

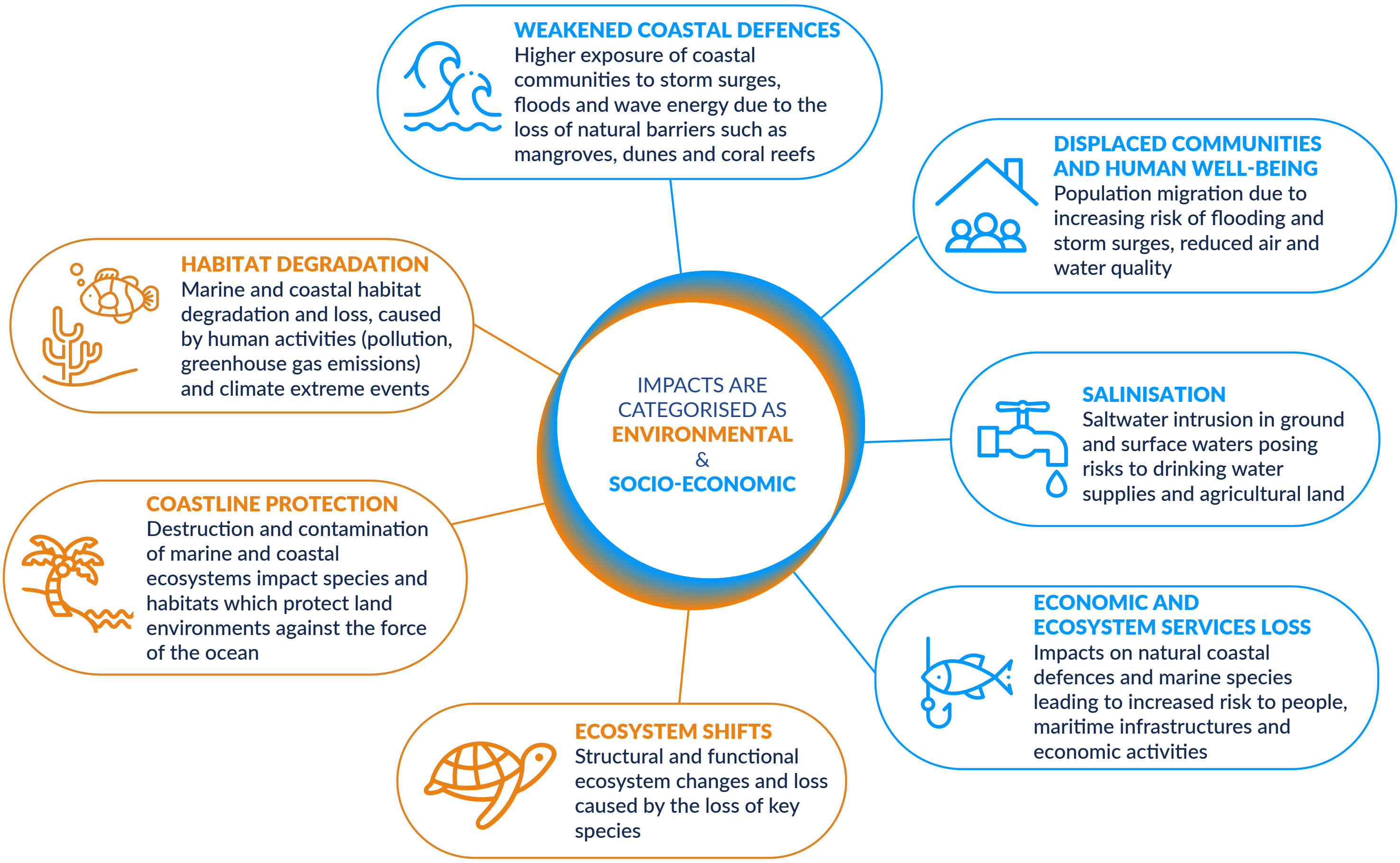


Figure 3: *Environmental and socio-economic impacts related to coastal hazards*

The ocean observing value chain and how it supports coastal resilience

Observations are necessary to accurately monitor coastal regions and assess how the different human and climate pressures are impacting marine and coastal ecosystems. In-situ measurements collect "on-site" data at a specific moment in time. These are essential to calibrate remote sensing observations (e.g. satellite-based) and evaluate the accuracy of mathematical representations (numerical models) of the marine and coastal environment. Together, observations and numerical modelling are the foundation of operational monitoring and forecasting systems.

In-situ and airborne coastal and marine data

In-situ observations of the coastal and marine environment include observing a wide range of physical, chemical and biological parameters. Autonomous instruments such as tide gauges, coastal moorings, drifting buoys, and profiling floats and gliders collect information on sea level, currents, waves, sediment, nutrients, dissolved oxygen, pH and phytoplankton concentration. The biological component is often and mainly assessed through water and species sampling to study plankton types, invasive species presence, biodiversity richness, fish distribution and other ecological information.

Social surveys may also be performed to understand people's sense of risk towards a problem, their willingness to relocate in case of threat, what their take on the issue is and what they would do to mitigate and adapt to the changes.

Satellite observations

Satellites observe the Earth from space at different time and space resolution capacities. There are two types of satellite techniques: **active** and **passive**. Active (or radar) techniques send pulses towards the Earth and measure the signal received after its reflection at the sea surface. An example of active satellites are altimeters, which have been groundbreaking in sea level monitoring. Passive satellites, on the other hand, measure the natural radiation emitted from the sea or reflected solar radiation. For example, water, sediment, vegetation and artificial objects are detected by the satellite optics as all these elements reflect sunlight at a visible wavelength.

Satellites collect information on physical and chemical parameters such as sea surface temperature, sea level, chlorophyll-a concentration, significant wave height and sea-ice parameters, which complement in-situ data, and help the development and evaluation of numerical models of the complex marine-coastal environment. Although highly successful for the open ocean, observations of the coastal zone natural processes are still a challenge, as observing the coastal zone requires frequent (e.g. hourly) and very high resolution observations, and the land-ocean transition poses specific challenges for satellite observations.

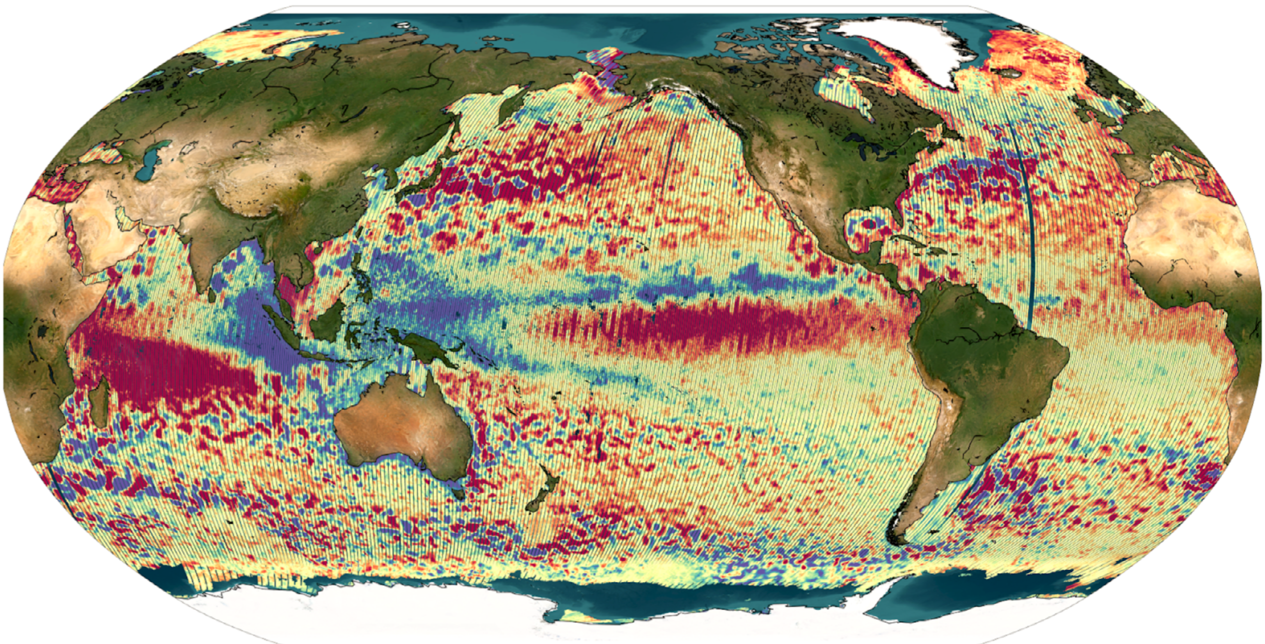


Figure 4 : *Sea surface height anomalies is one of the parameters used to assess global average sea level. It shows the sea surface level according to the average value obtained over a thirty year-long period. SWOT satellite imagery from January 2024.*
Credit: CNES,CLS

Modelling and forecasting

Numerical models, multi-dimensional mathematical representations of the ocean, are used to describe the state of the marine and coastal environments. Satellite and in-situ observations are integrated into numerical models to improve its accuracy - make it as close to reality as possible - and allow the prediction of conditions in a certain point in space and time.

Numerical modelling allows the representation of:

- **present conditions** (analysis and nowcast),
- decade-long periods into the **past** (reanalysis, hindcast)
- a prediction of short-term **future** conditions (up to 10 days forecast).

Modelling and forecasting systems are powerful tools when studying areas such as the quickly-evolving and complex environment of the coastal zone, allowing the understanding of natural coastal processes, drawing future scenarios and reducing coastal communities' vulnerability to coastal hazards. Forecasting is at the core of early warning systems used as an adaptation measure against coastal hazards.

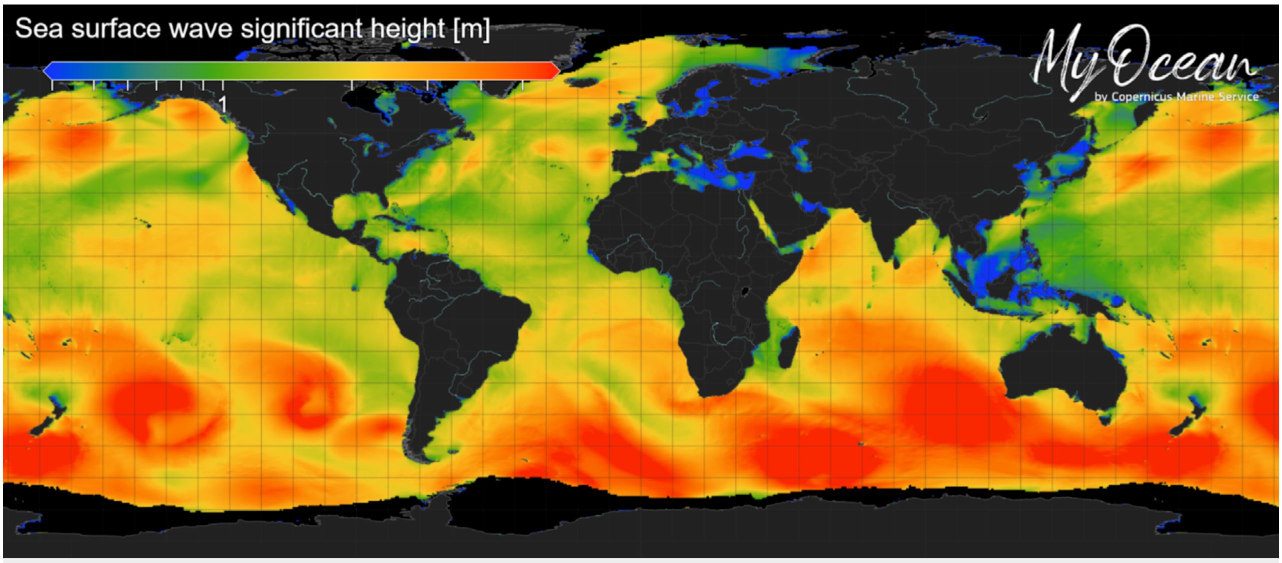


Figure 5: *Sea surface wave significant height (m) forecast product for 1 June 2024. Product is visualised using the tool MyOceanPro.* Credit: Copernicus Marine Service.

Data and information access

Both observations, analysis and forecasts can be processed into ready-to-use products and applied into different sectors such as research, maritime navigation, aquaculture, coastal zone management and evidence-based policy-making. The applications are vast and include, the creation of early warning systems for storms and floods and water quality bulletins. There are several monitoring and forecasting services and platforms which provide free access to open source data, information and tools dedicated to the marine and coastal environment. An example is the European Union's Earth Observation programme Copernicus, dedicated to the collection, analysis and distribution of environmental data in support of citizens.

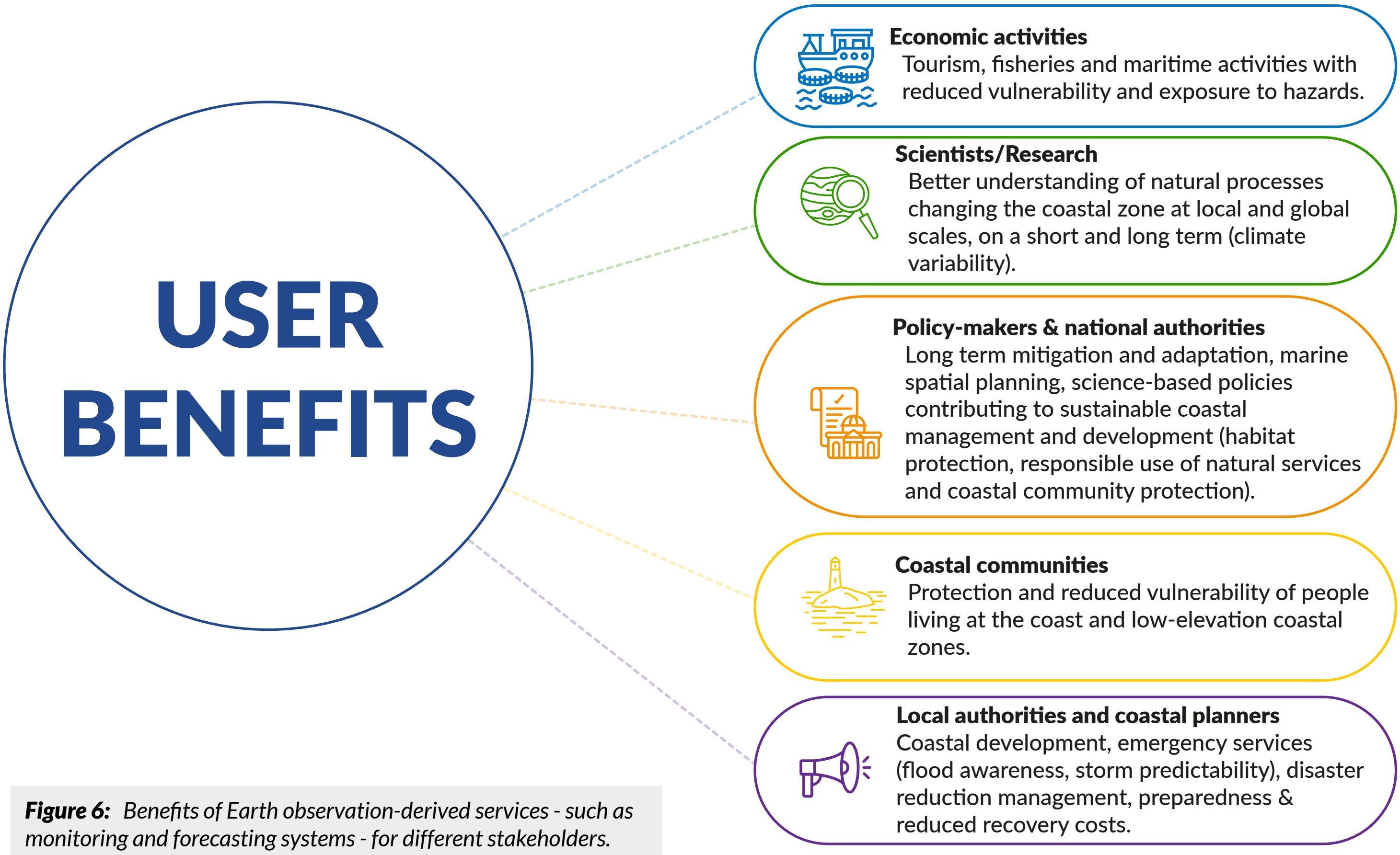


Figure 6: *Benefits of Earth observation-derived services - such as monitoring and forecasting systems - for different stakeholders.*

EU efforts supporting coastal resilience

The European Union's (EU) commitment to improve coastal resilience is underpinned by legislation targeting marine and coastal waters, biodiversity and climate.

- **Integrated Marine Policy** : provides an harmonised approach to maritime issues by strengthening the link between different policy areas. Includes five cross-cutting policies - blue growth, marine data and knowledge, maritime spatial planning, integrated maritime surveillance and sea basin strategies.
- **European Green Deal** : is the EU's strategy to reach climate neutrality by 2050. It covers (among others) strategies on biodiversity, greenhouse gas emissions reduction and adaptation to climate change.
- **European Climate Law** : climate goals integrated in the EU Green Deal set as law. Targets include a reduction of 55% in greenhouse gas emissions by 2030 and net-zero emissions by 2050.
- **Marine Strategy Framework Directive** : focuses on the protection of marine ecosystems and biodiversity by helping EU countries achieve good environmental status.
- **Floods Directive** : European law which requires EU countries to assess all areas where significant floods can occur, map flood extent, assets and humans at risk in these areas, and take adequate measures to reduce flood risk.
- **Water Framework Directive** : requires the protection of water bodies in order to achieve good status for Europe's rivers, lakes and groundwater.
- **Bathing Water Directive** : this law requires EU countries to monitor and assess surface bathing water. Besides demanding continuous monitoring, it also ensures information on the state of the bathing water is given to the public during bathing season.
- **Nature Restauration Law** : calls for member states to restore at least 30% of habitats from poor to good condition. Covered habitats include forests, grasslands, wetlands, rivers, lakes and coral beds.
- **Zero Pollution Action Plan** : pledge for air, water and soil pollution to be reduced to non-harmful levels by 2050. By 2030, some of the goals include improving water quality by reducing waste, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%).

Marine research and data infrastructures and services

The EU has put in place and supported the creation of services providing timely data and information to respond to different needs of the coastal sector.

Copernicus (copernicus.eu)
The EU's Earth observation programme monitoring the environment and providing free and open source data and information on six thematics: marine, land, atmosphere, climate change, emergency and security.

Copernicus Marine Service (marine.copernicus.eu)
Provides access to data on the physical and biogeochemical features of the ocean, essential ocean variables and monitoring indicators. The service is working on improving the coastal product offer through research and innovation projects. Recently added products include the high resolution (1 km) daily sea surface wind from satellite measurements for all regional seas and a storm-derived wind product which will be delivered throughout the duration of very-high-winds caused by storms.
The National Collaboration Programme of the Copernicus Marine Service has initiated a EU Coastal Monitoring Pilot Demonstrations call for tender to develop national level pilot exemplary use cases of coastal downscaling monitoring activities that support the implementation of EU Environmental Directives in member states.

Copernicus Land Monitoring Service (land.copernicus.eu)
Includes products on the Land Cover and Land Use in the coastal zone capturing landscape dynamics at high horizontal resolution over all EU coastal territory.

Emergency Monitoring Service (emergency.copernicus.eu)
Provides population Exposure Mapping, Rapid Mapping in case of hazard and a Flood Awareness System (EFAS) jointly developed by the European Commission and the European Centre for Medium Range Weather Forecasts (ECMWF) as part of a monitoring and early warning measure.

Copernicus Atmosphere (atmosphere.copernicus.eu) & Climate Change Monitoring Services (climate.copernicus.eu)
Provide present and past data on greenhouse gases emissions, air quality and changes happening in the climate systems.

The Copernicus Coastal Hub (coastal.hub.copernicus.eu)
Provides a centralised access to all six Copernicus services' data and products related to European Coastal Zones. The hub also shares use cases where Copernicus data has been used to tackle coastal issues such as pollution, coastal erosion and marine protected areas management. For data visualisation, the Coastal hub includes the Data Viewer displaying the Land Use/Land Cover classification and the EU-Hydro network with inland and coastal waters classification.

Copernicus

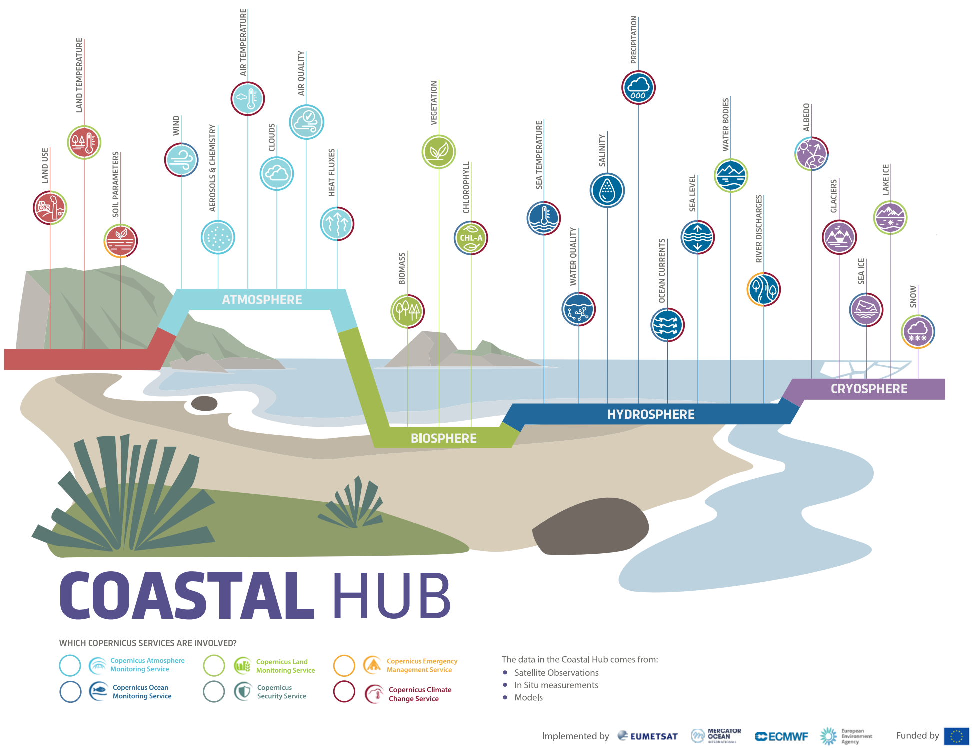


Figure 7: *Coastal-Hub product offer in a nutshell including products from all six Copernicus Services.*
Source: Coastal Hub. European Commission.

European Marine Observation and Data Network (EMODnet)
Is an in-situ marine data service providing information on bathymetry, geology, physics, chemistry, biology, seabed habitats and human activities. EMODnet hosts the European Atlas of the Seas, a web-based platform with statistical data on Europe's seas and coasts such as coastal regions geography and statistics, renewable energy and maritime resources, fishing stocks, quotas and catches, and European fishing fleet.

European Environment Information and Observation Network (EIONET)
A partnership network of the European Environment Agency (EEA), and its 38 members and contributing countries, providing data on the state of the environment.

Marine Information System for Europe (WISE-Marine)
Provides data and information on the state of Europe's seas, on the pressures affecting them, and on the measures being taken to preserve the marine environment.

Joint European Research Infrastructure of Coastal Observatories (JERICO-RI)
Standing for Joint European Research Infrastructure of Coastal Observatories - Research Infrastructure, aims at strengthening the European network of coastal observatories and providing operational service for the delivery of marine and coastal environmental data and information.

European Marine Biological Resource Centre (EMBRC)
Enables access to services, facilities, and technology platforms in more than 70 marine stations in 9 European countries in support of robust, cost-effective and efficient marine research.

Marine Biodiversity Observation Network (MBON)
Dedicated to data and knowledge exchange with the goal to better monitor changes in biodiversity in the ocean. They focus on sharing protocols, methods and data systems in order to obtain optimal processes of marine and coastal biodiversity measurements globally.

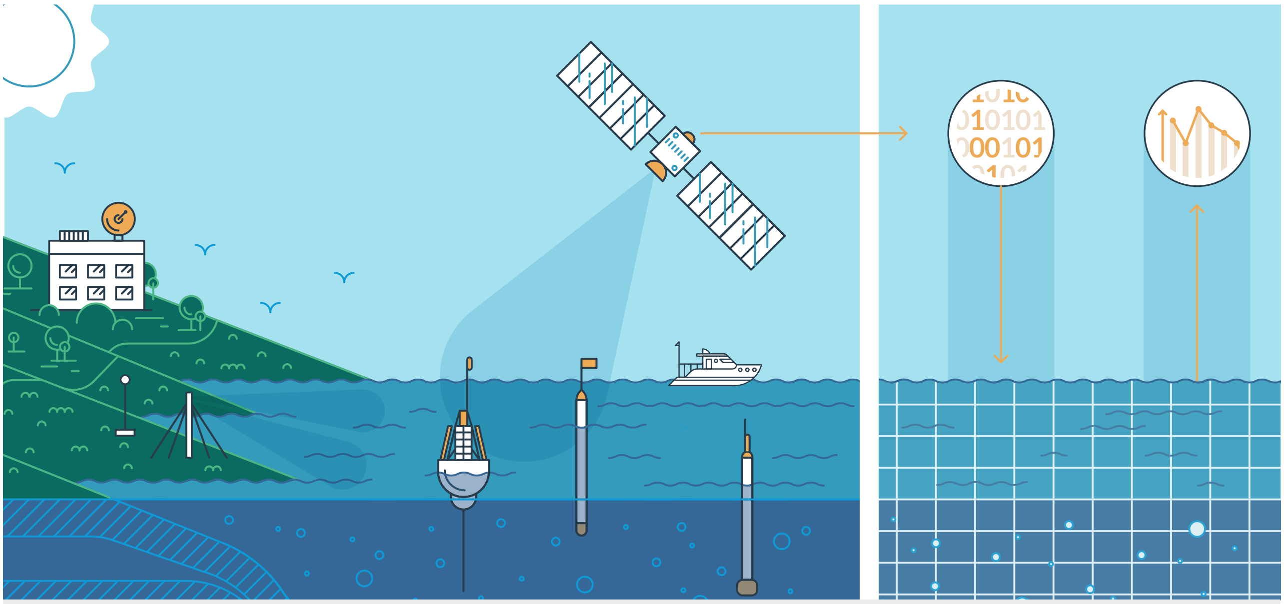


Figure 8: *In-situ and satellite observations are integrated into numerical models describing the ocean and the atmosphere to create a multi-dimensional view of the marine and coastal environments.* Source: Copernicus Marine Service

Research and innovation projects

The EU supports initiatives working towards sustainable research and development for the coastal and marine sectors. Below are some of the projects funded under the Horizon 2020 and Horizon Europe research and innovation programmes:

Forecasting and Observing the Open-to-Coastal Ocean for Copernicus Users (FOCCUS)
The project's main aim is to provide high-quality, trusted marine knowledge for evidence-based management, sustainable blue economy transition, and climate resilience in European coastal areas. This project is part of a parallel service evolution initiative for the Copernicus Marine Service.

Collaborative Land-Sea Integrated Platform (Coastal)
The aims at improving coastal and rural synergies by developing an online platform for knowledge exchange about land-sea collaborations, showing concrete examples and tools, and works on participating in coastal-rural planning using case studies in a few EU countries.

Coastal Climate Core Services (COCLICO)
Focuses on improving decision-making on coastal risk management and, specifically, on adaptation to sea level rise. To support this goal, an open-source information platform with current and future coastal risks is being developed.

Adapt4Coast Cluster
A collaboration of four EU-funded projects (CoCliCo, REST-COAST, and SCORE and Protect) dedicated to bolstering climate resilience in European coastal areas and cities. It involves implementing an integrated solution that combines smart technologies and nature-based solutions.

European Coastal Awareness System (ECFAS)
The was a proof-of-concept project lasting between 2021 and 2022 with the aim of creating a coastal flood awareness system to be integrated in the Copernicus Emergency Monitoring Service.

European Digital Twin Ocean (EU DTO)
Is building a virtual representation of the marine and coastal environments around the globe, providing knowledge and understanding of the past and present state of the ocean and trustable predictions of its future behaviour. A key project under this initiative is EDITO-Model Lab, working to develop the next generation of ocean numerical models and what if scenarios on specific applications including using nature based solutions against coastal hazards.

PREP4 Blue (link)
Aims at creating and implementing foundations for research and innovation projects working under the EU mission Restore our Ocean and Waters by 2030. The project will create tools, guidelines, methodologies and recommendations in support of the activities of the several projects funded for this specific Mission.

FORCOAST (link)
provides information services on water quality and met-ocean variables for the coastal zone and nearshore, responding to specific needs in the fisheries and aquaculture sectors.

Blue Mission Banos (link), Blue Mission AA (link) and Blue Mission Med (link)
Blue Mission includes three projects focusing on implementing the mission Restore our Ocean and Waters by 2030 in the Baltic and North Sea, in the Atlantic and Arctic and in the Mediterranean Sea.

Ecosystem-Based Governance with Danube Lighthouse Living Lab For Sustainable Innovation Processes (EcoDaLLi)
This project seeks to centralise Danube governance structures for ecological restoration, protection and conservation of the Danube basin and its delta. The project expects to reach this goal by fostering a stronger innovation ecosystem within a well-connected Living Lab system.

Large Scale Integrated Sea-level and Coastal Assessment Tool (LISCOAST)
A coastal flood impact assessment tool considering projections of coastal hazards and exposure and vulnerability in coastal areas considering climate change impacts such as storm surges and extreme sea level.

Land Sea Interface- Let's Observe Together! (LandSeaLot)
A four-year project applying novel approaches to bring together the land-sea interface area observation communities to co-design and develop a robust observation of the land-sea interface area.

EU supported & led initiatives, partnerships and working groups

As important as it is to collect, analyse and distribute data and information, it is equally important to create consensus on best practices and resource optimisation between the different communities of users, authorities and governance bodies. Below are a few working groups and programmes working towards strengthening collaborations and improving observations and monitoring systems across marine and coastal environments.

European Marine Board Coastal Resilience working group
focuses on the resilience of coasts from a holistic perspective including natural sciences (ecological, hydrological, chemical, physical, geological, etc.), ecosystem service provision, and links to socio-economic and governance systemwas

All-Atlantic Ocean Research and Innovation Alliance (AAORIA)
As one of its Action Areas, works to increase understanding of the relationship between the ocean and climate and developing outcome-oriented science for mitigating and adapting to the consequences of climate change, particularly for the benefit of increasing resilience of coastal communities.

GEO Blue Planet - Coastal Geomorphology Working Group (link)
The ocean and coastal arm of the Group On Earth Observations. It gathers a vast community of ocean and coastal actors - scientists, organisations, national institutions and government agencies - seeking to strengthen and create links among the international community of data producers and decision makers, build capacities and improve science based policy-making. GEO Blue Planet's activities cover several coastal themes including coastal hazards (shoreline changes, flooding, plastic pollution, eutrophication) and adaptation to climate change.

CoastPredict (link)
Co-designed with the Global Ocean Observing System (GOOS), Coast Predict is a UN Ocean Decade programme working towards creating an integrated coastal ocean observing and forecasting system global framework.

EuroGOOS - Coastal Working Group (link)
The European component of the Global Ocean Observing System (IOC UNESCO), EuroGOOS, has as its main goals to establish corporations and promote ocean observations for societal benefits. The coastal working group works towards ensuring the ocean and coastal observing value chain fits user needs, operates in a sustainable way and identifies future steps to continue to respond to societal and environmental needs.

UN Decade Collaborative Centre on Coastal Resilience
The UN Decade of Ocean Science for Sustainable Development (Ocean Decade) challenge 6 aims at enhancing multi-hazard early warning services and design adaptation planning strategies for vulnerable coastal areas. The collaborative centre for Coastal Resilience will focus on strengthening the connection between new science and technology developed in the Ocean Decade and coastal stakeholders, implementing innovative co-design practices for coastal resilience.

Earth observation value chain for coastal resilience

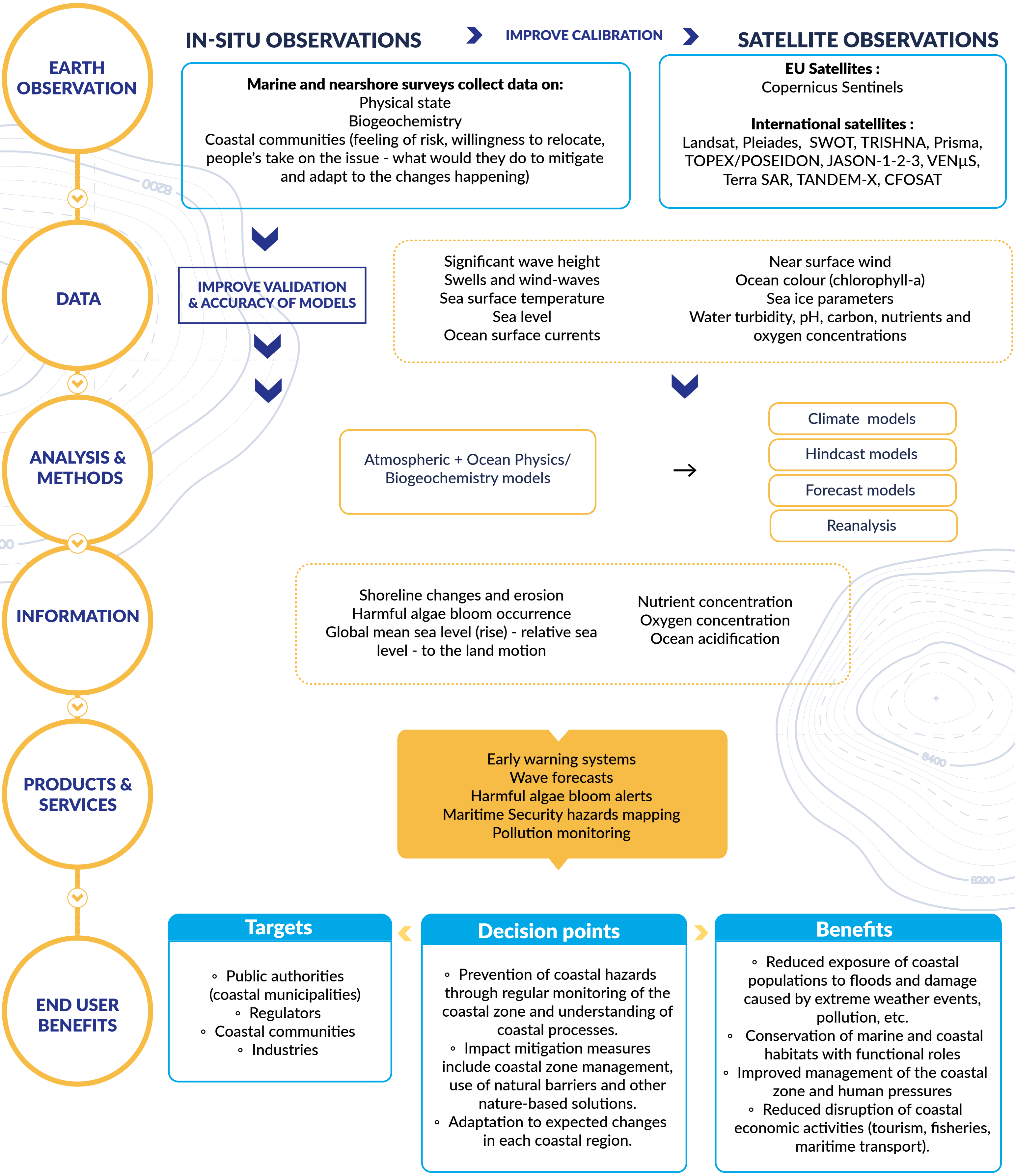


Figure 10: *Earth observation-based monitoring and forecasting value chain to support coastal resilience.*

Gaps & limitations in coastal observations and monitoring services

Limited satellite accuracy:
Satellites provide a global vision of coastal zones. Some satellites also allow the coverage of climate scales, as it looks at large areas of the globe for long time periods. However due to its distance from Earth and difficulty in observing the last kilometres off the coast (~20km) studying ocean-land transition in detail is still a challenge.

In-situ measurements' high costs and limited spatial coverage:
Although highly accurate, monitoring coastal zones through local surveys over long time periods is resource consuming and logistically difficult to maintain at a global scale.

In-situ observation bias :
There is a clear bias regarding in-situ measurements around the globe caused mainly by different economic capacities.

Data gaps limit accuracy and efficiency of monitoring and forecasting systems:
To improve accuracy and performance of monitoring and forecasting services, more and better in-situ and satellite observations are needed.

Recommendations to improve coastal monitoring and forecasting

Improved satellite accuracy:
Satellite data with higher precision can be a significant improvement when predicting long-term changes such as regional sea level variations.

Higher spatial resolution and multi-band satellites :
The coastal zone is exposed to natural processes and changes happening at centimetre and metre level. Hence, higher spatial resolution imagery is needed to enable the screening of the coastal zone at such fine scale. A higher capacity to capture rapid evolutions and provide information on wave propagation, drifting objects or harmful algal blooms would also be an important improvement.

Joint observations:
Simultaneous observation of different variables to better characterise processes influenced by several factors. For instance, ocean circulation, which impacts heat and nutrient transport, can be studied through surface currents and wave energy and height, but these are not the only influencing parameters in ocean motions. Satellites with wider swath (sensor structure which captures the signal in radar and altimeter active satellites) can help measure different parameters together as it provides a wider spatial coverage.

Holistic approach :
The coastal zone is extremely dynamic and encompasses the marine and the land environment, as well as atmospheric and oceanographic processes. A system able to combine data on all these different environments, current pressures, human economic activities, and available information from the already operational European platforms would be useful to better visualise the coastal environment and what to expect in the future.

Expand the use of earth observations :
By making sure end users such as local authorities, risk managers and decision-makers have access to coastal products and services and that it is understood (by perhaps creating a general audience of their content in order to better decide on measures.

Homogenised system across the coastal zone :
Strengthen collaborations across the coastal zone communities of researchers, local authorities, engineers and local inhabitants in order to facilitate the understanding of coastal processes, changes and the foreseen actions, policy and decision-making.

Acknowledgements
This use case was written by independent consultant Andreia Carvalho under the guidance of Lillian Diarra and Audrey Hasson from the EU4OceanObs team and with contributions from several experts in Earth observation notably Erwin Bergsma (CNES) and Pierre-Yves Le Traon (Mercator Ocean International). Design by Philippe Amouyal. For more EU4OceanObs use cases: https://www.eu4oceanobs.eu/use-cases/

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