Copernicus Environment Monitoring Service

Roadmap for the evolution of Copernicus marine and land services to better serve coastal users

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Content

1 Context

An expert workshop was organized by Mercator Ocean International (MOI) and the European Environment Agency (EEA) in December 2016 as a first step to analyse mid-term (2018-2021) and long term (post 2021) priorities for the evolution of the Copernicus Marine (CMEMS) and Land (CLMS) services to better address user needs in the coastal zone (see Annex 1). This was followed by an open workshop or consultation meeting "Copernicus for Coastal Zone Monitoring and Management" organized by DG GROW with the support of MOI and EEA in July 2017 (see Annex 2).

Following these two workshops, Mercator Ocean International and the European Environment Agency have been invited by DG GROW to continue, as part of their delegation agreement duties, to improve the existing services to better serve coastal users. MOI and EEA were also invited to elaborate, by the end of 2018, a longer-term roadmap for the evolution of their services with respect to the coastal zone.

This document presents the main elements of this roadmap. Main drivers for coastal zone monitoring and forecasting are first summarized (section 2), and are followed by main user requirements regarding the coastal zone (section 3). Main short term (i.e. present delegation agreements, end of 2020 for CLMS, Spring 2021 for CMEMS) evolutions of CMEMS and CLMS relevant for coastal users are described in sections 4 and 5 respectively, while longer term (after the current delegation agreements) evolutions are described in section 6. Main conclusions are given in the final section.

2 Drivers: societal challenges, policies green and blue economy

Coastal zones are more densely populated than the hinterland, exhibit higher rates of population growth and urbanisation, are concentrating economic assets and critical infrastructures, and are supporting green and blue economy. As such, coastal zones are experiencing tremendous socio-economic and environmental changes, which are expected to continue in the future.

Half of the world population is currently living within 60 km of the coast, and three-quarters of all the large cities are situated at the coasts. The growth of coastal population is projected to continue over the coming years: the world population is expected to reach 8.5 billion in 2030 and 9.7 billion in 2050 (United Nations projections, 2015). In Europe, the situation is not different; approximately 40 % of Europe's population lives within 50 km from the coast.

The blue economy largely relies on the coastal ocean; a growing blue economy relies on a healthy ocean. In 2010, the global ocean economy represented USD 1.5 trillion in added value, with a strong contribution from offshore oil and gas, maritime and coastal tourism, ports and maritime equipment, and ocean-based industries employment dominated by fisheries and maritime and coastal tourism (OCDE). In addition to these established activities, emerging ones are projected to grow in the coming decades, including marine aquaculture, ocean renewable energy, marine safety and surveillance (OCDE). By 2030, conservative estimates assess that ocean economy will grow to more than USD 3 trillion (in constant 2010 USD) much of which will rely on coastal tourism, offshore oil and gas and port activities. Marine aquaculture is estimated to grow at an annual rate of 5.7% between 2010 and 2030. At the European scale, coastal regions are tremendously important for the economy. Almost 40 % of the EU's GDP is generated in these maritime regions, and a staggering 75 % of the volume of EU's foreign trade is conducted by sea.

The increasing population pressure on the coastal area urges as well a particular need to shift traditional economic developments along the coast towards a green economy, thus ensuring a better conciliation of the economic activities, in particular in the touristic domain, with the vulnerability of coastal ecosystems, in view of maintaining the added value of ecosystem services.

However, the important role played by our coasts has come at a cost to the environment. Pressure from activities such as shipping, resource extraction, renewable energy and fishing on marine and coastal areas have been felt across most of Europe's coastal regions. This has resulted in habitat loss, pollution and accelerated coastal erosion. Climate change is likely to make coastal zones — and the societies that live in them — more vulnerable. Recent data highlight the continued poor quality of many European coastal waters, with the Baltic Sea being the worst, followed by the North Sea and the Black Sea. The conservation status of Europe's coastal species and habitats is also generally bad or unknown. Only 13 % of the assessments of coastal species made under the Habitats Directive are favourable. Seventy-three percent of the coastal habitat assessments show bad or inadequate conservation status. Coastal tourism has also been a driver and vehicle for economic development in coastal areas: for example, in the Mediterranean area, $224 billion of revenue has been generated in 2011, 40 times higher than in 1970. But the exploitation of coastal zones has also been characterised by negative effects, such as massive urbanisation and accidents. Several research studies provided forecasts on the effects of sea level rise and the areas at risk in Europe as well as its economic cost. For instance, in the absence of further investments in coastal adaptation, the present expected EU annual damage (EAD) due to marine coastal flooding of €1.25 billion is projected to increase by two to three orders of magnitude by the end of the century, ranging between 93 and €961 billion. The current expected annual number of people exposed (EAPE) to coastal flooding of 102,000 in Europe is projected to reach 1.52-3.65 million by the end of the century.

If coastal regions are to continue to power our economies, shelter a rich biodiversity, and remain home to millions of Europeans, we must manage them more carefully. This management must also be conducted in an integrated fashion, balancing the competing interests of human development with the need to ensure healthy and resilient coastal ecosystems.

The growing pressure on the coastal zone, ocean resources and marine spatial planning is expected to continue as a result of projected growth in blue economy, coastal population, and climate change - inducing warming, rising sea levels, acidification and deoxygenation of the oceans. Ocean activities and ocean economy growth cannot follow a business-as-usual scenario over the coming decades and an approach driven by sustainability (e.g. UN Agenda 2020 and its SDGs) must be followed.

The essence is that nowadays coastal zone management experiences a conflict between economic development (growth and jobs) and sustainable environment, and there is a need for bridging knowledge (data/information and methods/tools) and governance (decision-makers at every level) in order to ensure social and ecosystem resilience. This is where Copernicus services play a key role in delivering detailed and long-term information essential for decision makers and downstream services.

The EU has installed a dense network of regulations and directives, with the intention to allow economic prosperity while at the same time improving and maintaining the status and protective functioning of coastal ecosystems in Europe.

The importance and complexity of coastal systems in Europe is also reflected in the wide range of Directives.

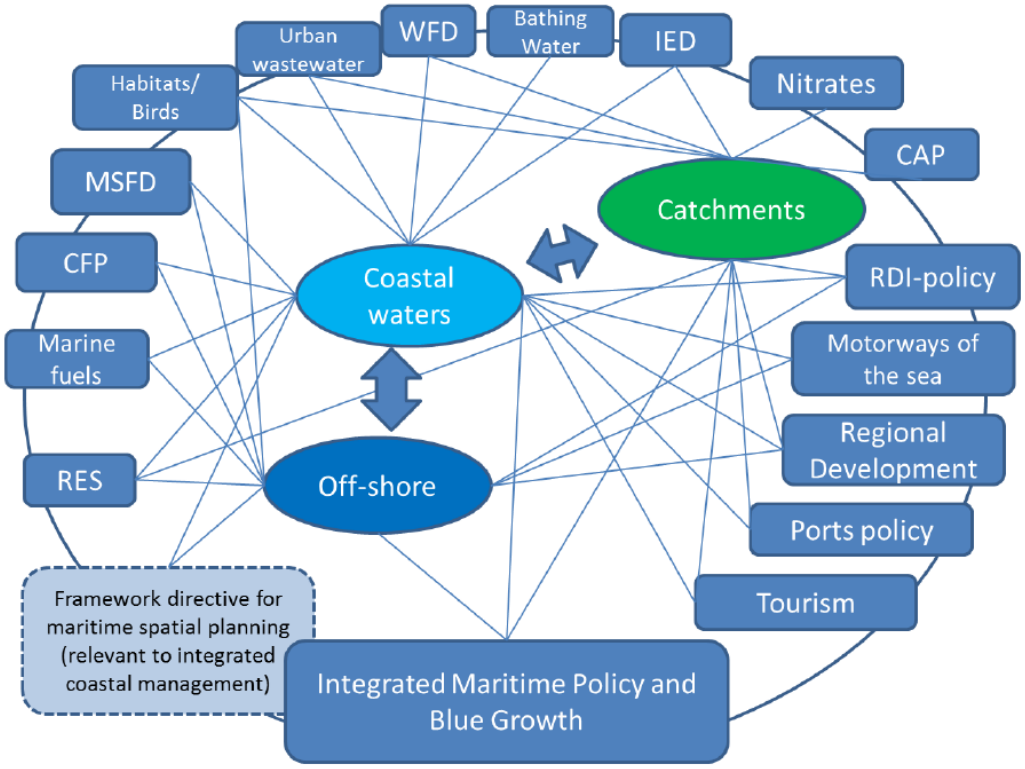

Figure 1: Schematic overview of selected EU policies and policy instruments related to the land-coast-sea nexus

A comprehensive monitoring of coastal zones puts Copernicus Services in front of a set of new challenges. These challenges also reside in the fact that the coast is per definition also the border of the thematic domains of the Land, Marine and other Copernicus Services. The strong mutual interaction and influence between the ocean and the land require from the outset of any activity a cross service approach. A strong cooperation between Copernicus Services is essential as neither CMEMS nor CLMS can alone address the broad and diverse range of requirements in coastal zones.

3 User requirements

The diversity of phenomena and user requirements in coastal zones, the complex interactions and mutual influences of the elements in a coastal system, increase also the level of complexity when it comes to its monitoring. For instance, monitoring the dynamics and processes of coastal areas require complementary and consistent information from the land and sea, at high spatial and temporal resolution. Compared to other Copernicus monitoring activities, for coastal zones an unpreceded number and variety of requirements have to be taken into account. Accurate information provided by Copernicus services shall enable the coastal user communities to access reliable and persistent datasets to develop on top of it their own systems and models, which best describe specifics of their areas of interest.

CMEMS and CLMS are user-driven services and user requirements are regularly gathered by Mercator Ocean International, the European Environment Agency, their partners and the European Commission (e.g. questionnaires, workshops, training sessions, user fora). Based on user feedback, a summary of main requirements from Copernicus coastal users is given below.

Policy driven requirements are essential aspects of how and what to monitor. Of particular importance, because of their comprehensive relevance on coastal zones are:

- Water Framework Directive (WFD);
- Marine Strategy Framework Directive (MSFD);
- Habitats and Birds directives;
- Climate and climate change adaptation (mitigation and adaptation);
- Flood directive (including coastal erosion), and
- Integrated Coastal Zone Management (ICZM).

Monitoring the status and pressures on the coastal environment and ecosystems requires:

- Environmental data (ocean, wave, biogeochemistry, sea-ice, atmosphere) with high to very high spatial and temporal resolution, from models and satellite & in-situ observations;
- River inputs (freshwater, sediments, nutrients, waste) (historical, near real time and forecasts;
- Accounting for specific processes relevant for the coastal zone (e.g. river inputs, tides, high frequency ocean processes, harmful algae blooms, eutrophication, extreme sea levels including storm surges);
- Land/sea cover/use status and change mapping;
- Land/sea habitat status, habitat change, species distribution and migration (including invasive species);
- Marine / land pollution (including litter), and nutrient enrichment.

Coastal user communities mainly develop their own systems and models to describe at best specifics of their areas of interest, given that their capacities can be well initialized or forced with accurate information provided by Copernicus services. In addition to the information requested above to monitor the coastal environment, this further requires:

- Provision of boundary conditions and initial conditions (at full resolution and high frequency) for local ocean physical and biogeochemical models.

To monitor land-sea interactions, including coastal erosion, but also for marine energy and operations (e.g. ports, dams), the users demand encompasses:

- Continuous and improved accuracy of land-sea topography as an essential and unanimous requirement, incl. high-resolution bathymetry and digital elevation models;
- Coastline shape and its evolution (coastal erosion/ accretion), sediment transport;
- Monitoring land-sea interactions, including changes in coastal morphology, impacts of marine energy devices and coastal operations (e.g. ports, dams).

For fisheries and aquaculture, users require in addition to high-resolution physical and biogeochemical information:

- Monitoring in real time ocean health and ocean conditions influencing the stock and the production mainly related to the ocean physical environment, water quality and possible pollutions at sea (e.g. harmful algae blooms, oil, land chemical pollutants), monitoring eutrophication, functional types of plankton, plankton biomass, modelling of higher trophic levels (from primary production to fishes).

For activities supporting tourism, users require additionally the monitoring of:

- Bathing water quality monitoring and forecasting;
- Pressures on coastal habitats;
- Urban development / spatial planning (Land and Sea).

Regarding the protective function of coastal zones, more information is needed on:

- Coastline type and coastal erosion/ accretion;
- Extreme sea levels including storm surges;
- Land cover mapping.

Finally, information on the coastal environment is requested on longer time-scales, in particular to better inform coastal managers, local authorities, decision-makers and coastal users:

- Seasonal, decadal predictions and climate change projections of the coastal zone and its ecosystems.

4 Copernicus Marine Service Evolution with respect to the coastal zone

CMEMS and the coastal zone

The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic reference information on the physical state and marine ecosystems for the global ocean and the European regional seas. This capacity currently encompasses the description of the current situation (analysis), the variability at different spatial and temporal scales, the prediction of the situation 10 days ahead (forecast), and the provision of consistent retrospective data records for recent years (reprocessing and reanalysis).

The CMEMS also publishes every year an Ocean State Report. CMEMS Ocean State Reports[1] and associated Ocean Monitoring Indicators[2] rely on the unique capability and expertise that CMEMS gathers in Europe to monitor, assess and report on past and present marine environmental conditions and to analyse and interpret changes and trends of the marine environment.

[1] http://marine.copernicus.eu/science-learning/ocean-state-report/
[2] http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/

The CMEMS provides a sustainable response to European user needs in four areas of benefits: (i) maritime safety, (ii) marine resources, (iii) weather, seasonal forecast and climate and (iv) coastal and marine environment.

As a European *core* service, CMEMS focuses on activities best performed at European level to support with essential products and services the downstream development of expert services. The coastal monitoring services, operated by Member States or private groups, form an important and strategic group of users of the CMEMS. The overall value chain is designed to enhance the socio-economic value of CMEMS by contributing to the implementation of environmental policies implementation and the sustainable use of marine resources in the coastal domain.

The CMEMS is therefore already providing information targeting the coastal environment[3] driven by:

- EU policies related to the coastal ocean: Integrated maritime policy (IMP), maritime spatial planning (MSP), marine strategy framework directive (MFSD), water framework directive (WFD), common fishery policy (CFP).
- Societal and blue economy needs: maritime transport, marine safety, aquaculture, fishery, marine renewable energy, water quality, coastal hazards, coastal zone management.

CMEMS value is related to operational mapping for real-time support, but also understanding and adapting to change, including that arising from human activities (e.g. climate change).

Amongst the different products of the CMEMS portfolio, products especially relevant for monitoring the coastal environment and for coastal users include:

- In situ observations in the coastal marine zone,
- High-resolution satellite L3/L4 products, including for the coastal zone (e.g. SST, ocean colour…)
- Reanalyses, near-real time analysis, forecasts of the ocean circulation and state, waves, sea-ice, and biogeochemistry conditions, at global scale and over European seas.

The service architecture of CMEMS relies on a pan-European network of production centres, which is particularly suitable to capture the diversity of skills and geographical situations:

- Eight centres are specialized in observations: these Thematic Assembly Centres (TACs) are gathering observational data and generating elaborated products, e.g. multi-sensor data products, derived from these observations. CMEMS operates today six “satellite” TACs organized by ocean variables (sea surface topography, ocean colour, sea surface temperature, sea ice, winds and waves), one “in-situ” TAC (focussed on at-sea measurements) and one multi-observation TAC
- Seven centres are specialized in modelling/assimilation: these Monitoring and Forecasting Centres (MFCs) are distributed according to the covered marine area (Global Ocean, Arctic Ocean, Baltic Sea, Northwest European Shelf, North Atlantic Iberia-Biscay-Ireland area, Mediterranean Sea and Black Sea), and generating model-based products (forecasts, hindcasts and reanalyses) both for physics and biogeochemistry.

[3] We use here a broad “marine” definition of the coastal ocean, i.e. the interface between the deep ocean and continents where specific coastal ocean processes such as the interface/coupling with land (e.g. river inputs), tides and high frequency effects dominate the ocean dynamics.

- A Central Information System (CIS), with a manned service desk relying on a network of technical & marine experts supports users, proposes for users a unique facility for searching, viewing and downloading products and information.

This distributed architecture, designed to facilitate the involvement of highly-skilled experts in each thematic and geographical area, is particularly favourable to foster innovation for coastal needs.

New products and services to better serve marine coastal zone users

During 2018-2021 CMEMS products will evolve to better serve marine coastal zone users. These evolutions include:

i) New products based on coastal zone observations, such as surface currents delivered by high-frequency radars along the European coasts.

Ocean surface currents observed by high-frequency radars (HFR) along the EU coasts will be progressively integrated in CMEMS's catalogue during the period 2018 to 2021 following the recommendations from the CMEMS Service Evolution funded R&D project INCREASE. Products will include radial velocities, total velocities, in near-real time and as reprocessed observations.

ii) Increased resolution and improved algorithms to better process observations in the coastal zone.

Thematic Assembly Centres (TACs) will improve their algorithms to better process data in the coastal zone. For instance, sea level observed by satellite altimetry will be processed starting from full rate altimetry (20 Hz) and higher resolution along-track observation will be provided (5 Hz, corresponding to 1 km, instead of 1 Hz) with an improved editing of observations, especially beneficial in the coastal zone. Sea level data will also be provided together with their associated geophysical corrections that are interesting / useful in the coastal zone: barotropic tides, stationary internal tides, barotropic response of the sea level to atmospheric wind and pressure forcing (relevant for storm surges, including the so-called inverse barometer effect), non-along-track-filtered data. This should notably facilitate the assimilation of sea level satellite observations in coastal ocean models. Mean sea surface and mean dynamic topography products will also be used, with an expected reduction of errors especially in the coastal zone. Observations provided by new missions such as Sentinel 3b will be included in CMEMS's catalogue.

Algorithms have been developed to retrieve wave parameters from SAR Sentinel-1a Sentinel-1b data in TOPS Mode. Resulting CMEMS products will have a targeted resolution of 10 km x 10 km and will provide L3 full wave directional spectra information in the coastal ocean (with visible effects from shoaling /refraction).

Regarding satellite observations of ocean colour, the approach for identification of case 1 (open ocean)/case 2 (coastal ocean) waters will be updated. Chlorophyll algorithms for case 2 waters (coastal) and for optically complex waters (particularly Baltic and Black seas) will evolve for improved coastal ocean colour products over European regional seas. In addition, ocean colour products based on OLCI/Sentinel-3a and 3b observations will be delivered at full resolution (300 m) for European coastal areas. Based on the Highroc FP7 project (see below) outcomes and recommendations, new high resolution coastal ocean colour products based on Sentinel 2, Sentinel 3 and MSG data will also be developed and included in the CMEMS catalogue.

iii) Improved interfaces with EMODnet / bathymetry.

Effective cooperation agreements between CMEMS and EMODnet dealing with the collection and sharing of physical and biogeochemical data in the European seas are now in place. During CMEMS

Phase-II, they should be extended to new products. High resolution bathymetric products developed by EMODnet could thus be made available to CMEMS coastal users.

iv) Upgrade of numerical ocean models used to produce ocean forecasts and reanalyses.

Products based on ocean numerical models (including their physical, biogeochemical and wave components) will be more suited for coastal ocean users during the 2018-2021 period thanks to different evolutions.

First, ocean models will include a more complete representation of ocean processes and information on finer spatial scales. The resolution of the models will be increased, both in the horizontal and in the vertical, to e.g. better resolve small scale processes and the topography in critical areas. The increase in resolution will also enable models to better represent dynamics captured by existing and future Earth Observation platforms (e.g. high resolution sea surface temperature, swath altimetry) that might also be assimilated in coastal models, leading to more consistency between CMEMS and coastal models. During the 2018-2021 period, wetting and drying will start to be included in CMEMS models to improve tides and sea level forecasts. By 2021[4], all CMEMS physical ocean models will include tides and atmospheric surface pressure forcing. Wave-ocean interactions will be increasingly represented in the wave and physical ocean models during 2018-2021 (inclusion of the effect of ocean currents and sea level on waves, inclusion of the Stokes-Coriolis force, sea-state dependent momentum and energy fluxes in the ocean circulation model). These evolutions will allow a better representation of coastal sea level, ocean and coastal circulation and wave climates. As atmospheric surges, tides and waves are processes of interest for the coastal community, including them in CMEMS models will improve the forcing of coastal models using CMEMS regional models as boundary conditions.

A second evolution of Monitoring Forecasting Centres (MFCs) ocean numerical models that will be beneficial for coastal users concerns an improved representation of river inputs of freshwater and nutrients. Most models will improve their river inputs, although through different actions. When possible, models will include inputs from more rivers (e.g. going from 7 to 39 rivers for the Mediterranean Sea), move away from climatological values for the mass and nutrients fluxes to use high-frequency interannual river runoffs. Ocean-river coupling will be developed for the main rivers flowing into the Mediterranean Sea and Black Sea through an estuarine box model, to provide more realistic values of river discharge and salinity at the river mouth. Yet, actions will still be required after 2021 to further improve river runoffs (mass flux, nutrients, suspended matter) in a coordinated and homogenized way in CMEMS (see annex 3).

Finally, products should be delivered at higher-frequency to better force coastal models (up to hourly fields). Specific products should be developed to better serve downstream coastal services (e.g. providing full resolution and high frequency boundary conditions on prescribed boundaries).

v) Better service towards coastal users and applications

Among its main tasks, Mercator Ocean International has to maintain the open and continuous dialogue already existing with CMEMS users to collect their requirements and to support them in the use of the service. New services are planned as continuous evolution to better answer user needs. Of interest for the coastal marine areas we will have:

[4] IBI and NWS CMEMS regional MFCs already include tides. By the end of 2018, a new 1/12° hourly global surface current product (SMOC) will be provided to CMEMS users. SMOC will include surface and wave (Stokes drift) currents from the GLO MFC operational systems and hourly tidal currents from FES2014 tidal model.

- A MSFD portfolio using and highlighting CMEMS products and applications that contribute to provide answers to this EU Directive
- Additional download formats thus opening product access to additional communities (netcdf, grib, shapefile…)
- Links between the different Copernicus catalogues especially the Marine and the Land ones as well as links between the CMEMS catalogue and the EMODnet one.

R&D activities to improve CMEMS products and the coupling with coastal users

R&D activities needed for the short/mid-term evolution of CMEMS are funded directly through CMEMS (Service Evolution R&D projects). These R&D activities provide support for cutting-edge R&D activities required to ensure the scientific evolution of CMEMS, including its coastal dimension, and to better meet needs from coastal users. They include the development of new tools to better interface CMEMS regional models to coastal local models, improved river-ocean coupling, improved modelling of large wave events, and improved data assimilation of sea level in coastal zones. R&D activities needed for the long-term evolution of CMEMS are also promoted in the framework of external projects and programmes, such as H2020. External projects relevant for CMEMS and its downstream services with respect to the coastal zone deal with improved resolution in models and satellite observations and improved interfaces with coastal models, the development of user-relevant service platforms for coastal water based on Earth Observations, coordination of in-situ observatories for an improved coastal monitoring and forecasting.

A description of projects targeting coastal users that are funded by CMEMS to prepare its long-term evolution, or that are external to (e.g. H2020) but monitored by CMEMS is given in Annex 3.

Developing the uptake of CMEMS products by coastal users

CMEMS User Uptake activities are set up to open CMEMS to new communities, to improve CMEMS users' loyalty and to foster the service uptake by new users and the development of private and public downstream services. The objective is to promote existing CMEMS downstream services and to develop new ones in attracting new user communities.

This User Uptake component supports CMEMS in all its operations and evolutions and takes the shape of several successive contracts. A first round of CMEMS User Uptake contracts started on March 2017 and will end on September 2018. The 17 selected contracts focus on demonstrations of operational and coastal downstream CMEMS services including those linked to EU Marine Strategy Framework Directive (MSFD). A second batch of CMEMS User Uptake contracts started on May 2018 and will end on November 2019. The 10 selected contracts focus on new demonstrations of operational and coastal downstream CMEMS services in areas not enough covered by the previous call for tender.

These two series of User Uptake contracts focus on coastal areas in order to demonstrate users' applications on all the coastal CMEMS geographical regions. The areas of benefits concerned are water quality, eutrophication, tourism activities, coastal oceanic and weather forecasts, fisheries and aquaculture, marine energy and marine litter. All demonstrations are accessible from CMEMS web portal in the "Use Case" section.

New services from the Eumetsat/ECMWF/MOI DIAS platform

WEkEO is the EU Copernicus DIAS reference service for environmental data, virtual environment and skilled user support. EUMETSAT, ECMWF and Mercator Ocean International have joined their experience and skills to build up WEkEO in a stepwise approach, minimizing the risks, capitalizing on user feedback, and strongly involving the industry through procurement. The WEkEO Copernicus DIAS service will allow users to discover, search and access all Copernicus data and information (Sentinels, Services). Cloud-based processing capabilities will be provided so that users can develop and execute their own applications.

In the short term (2018-2021), coastal users will be able to find i) all needed data for their coastal applications (Level 1&2 high resolution data from Sentinel 1, 2 and 3, Copernicus Land & Marine & Climate monitoring service products), ii) an advanced visualisation tool to map and overlap the latter (e.g high resolution S1 or S2 observations with Copernicus Marine Service ocean forecasts), iii) numerical tools, iv) virtual machine (to transform products) (e.g. applying their own algorithms for the L2 processing of Sentinel data), and finally v) a Market Place to promote for the results and achievements of such applications.

5 Copernicus Land service evolution with respect to the coastal zone

The Copernicus Land Monitoring Service (CLMS) has been jointly implemented by the European Environment Agency (EEA) and the Joint Research Centre (JRC)[5] since 2011. CLMS provides geographical information on land cover/use to a broad range of users in the field of environmental terrestrial applications. This includes land cover, land use status and change information as well as their key characteristics, vegetation state, water cycle and earth surface energy variables.

CLMS products (see table below) are divided into 5 categories: 1/Systematic biophysical Monitoring, 2/Land Cover & Land Use mapping, 3/Thematic hotspot mapping, 4/Reference data and imagery and 5/Ground Motion Service

These categories enable applications to be developed in a wide range of areas. These include: spatial and urban planning, forest management, water management, agriculture & food security, nature conservation and restoration, ecosystem accounting, mitigation to climate change.

The products and services (and their priorities) are continually evolving and their creation and development are defined in consultation with stakeholder communities, amongst other via the EEA's Eionet network, as well as including advice from the Copernicus User Forum. The priorities are set by the European Commission and EU Member States and participating countries within the Copernicus Committee. The European Environment Agency (EEA) also works in cooperation with other Copernicus Services, such as Copernicus Marine Environment Monitoring and Copernicus Emergency Management, to create new products.

[5] Responsible for the implementation of CLMS Global Land: https://land.copernicus.eu/global/

Portfolio category	Product name	Individual products (*italic: on-going production or planned*)
Systematic Biophysical Monitoring (low level products, continuous automatic processing)	High resolution Snow and Ice	*Fractional Snow Cover (FSC)* *Wet Snow Extent* *Permanent Snow Line* *River/Lake Ice*
	High Resolution Phenology	*Various phenological indicators and seasonal trajectories*
Land Cover & Land Use Mapping (3 or 6 years cycles, high level products, high level of manual work)	Corine Land Cover (CLC)	Land Cover & Land Use status and change
	Corine Land Cover plus (CLC+)	*CLC-backbone* *CLC-core* *CLC+ instance*
	High Resolution Layers	Imperviousness Forest Grassland Wetness & Water Small Woody Features
Thematic Hotspot Mapping (6 years cycle, high level products, high level of manual work)	Urban Atlas	Land Cover & Land Use status and change
	Riparian Zones	Land Cover & Land Use status and change
	Natura 2000	Land Cover & Land Use status and change
	Coastal Zones[6]	*Land Cover & Land Use status and change*
Reference Data and imagery	EU-DEM	EU-DEM Slope Aspect Hillshade
	EU-Hydro	Rivers (centreline and outline) Inland waters Coastline/Baseline Drainage network
	European Image Mosaics	Very High Resolution (VHR) High Resolution (HR)
	Global Image Mosaic	High Resolution (HR)
Ground Motion Service	*In planning*	

Table 1: Overview of CLMS products[7]

Already now, coastal users can benefit from CLMS datasets. From the currently existing datasets, the following products seem to be of particular relevance:

- High resolution Snow and Ice (wall-to-wall product; relevant for floods (in preparation));
- High Resolution Phenology (wall-to-wall product; plant phenology (in preparation));
- Corine Land Cover (cyclic every 6 years, wall-to-wall LCLU mapping since 1990, low spatial resolution);
- High Resolution Layers (cyclic every 3 years, wall-to-wall mapping of: Wetness & Water, Imperviousness, Forest, Grassland);

[6] The Coastal Zones LCLU is part of the upcoming products included in this roadmap document.
[7] https://land.copernicus.eu/product-portfolio/overview

- Thematic hotspot mapping (cyclic every 6 years, very high resolution mapping of: Urban Atlas, and Natura2000 areas with partial coverage of coastal zones and Riparian Zones with spatially explicit LCLU information on the entire Pan European river system;
- EU-DEM (wall-to-wall basic morphology parameter); and
- EU-Hydro (Pan European topological coast-, river- and lake-delineation, drainage network).

Coastal zones monitoring in the current delegation agreement of CLMS

On the short-term CLMS is already actively working on the enhancement of Copernicus coastal zones monitoring capabilities. Within the current delegation agreement, the focus is on the implementation of a Land Cover Land Use (LCLU) monitoring system capable of tracking trends and dynamics in coastal landscapes. LCLU mapping is proven to be a highly effective instrument for the monitoring of status and trends within a landscape.

Currently existing CLMS products do either not sufficiently cover coastal zones (i.e. existing thematic hotspot mapping) or they cover it with an insufficient spatial (i.e. CLC) or thematic (i.e. High Resolution Layers) level of detail. Therefore, a dedicated LCLU mapping product as part of the 'thematic hotspot mapping' is implemented. The area to be mapped as coastal zone is approximated by a 10 km landwards buffer from the coastline. In analogy with other *thematic hotspot mapping* products the planned coastal zones product is based on VHR satellite imagery[8]. In addition, thanks to a tailored nomenclature with approximately 65 LCLU classes addressing specifically coastal zones, a minimum mapping unit of 0.5 ha and a minimum mapping width of 10 m, it will be capable of reflecting also small landscape characteristics with a high level of detail. If sufficient satellite data is available for the reference year 2012, the first LCLU status map will be produced for 2012, change and status updates will be mapped in a 6-year cycle. For the final LCLU product, two status maps (2012 and 2018), and a 2012-2018 change map with an area of more than 670.000 km^2 each are foreseen. A special attention is given to the integration of existing CLMS products. Whenever possible more basic dataset from *Systematic Biophysical Monitoring* and *Land Cover Land use mapping* (in particular HRL) are used for the characterisation of landscape units. This allows maximising synergies and comparability within CLMS products. Furthermore, the high level of detail in the nomenclature requires available in situ data to be addressed on top of the VHR image data.

The tender for coastal zones LCLU mapping will be published before the end of 2018. The implementation phase is expected to end by the end of 2020. The involvement of national authorities is of particular importance and is therefore, explicitly foreseen over the entire implementation phase.

Beside the implementation of a LCLU monitoring system, the evolution toward a more comprehensive Coastal Zone monitoring system is prepared. LCLU mapping is an efficient tool for monitoring LCLU dynamics but coastal zones are typically also characterised by highly dynamic processes, which are not well represented by such datasets. Typically, such processes are related to water, a central element also in coastal zones.

The first step in preparing CLMS for the monitoring of such high dynamic phenomena is the improvements related to the EU-Hydro dataset. This dataset is characterised by a spatial delineation of the coast, lakes and rivers including topological relationships required for hydrological

[8] https://spacedata.copernicus.eu/documents/12833/14545/DAP_Document_V2.4

applications. EU-Hydro is expected to become the harmonised reference dataset for hydrological applications at pan-European level. The EU-Hydro release based on the public beta version (available since June 2016) is expected to be published in quarter 1 of 2019. A currently active framework contract covers activities that aim at improving and correcting topological and geometric information and also to add information related to the longitudinal connectivity (damns and artificial barriers). With the guidance of the Water and Marine group at the EEA, which is responsible WFD's related reporting activities at the EEA, CLMS is also working on a full integration of ECRINS[9] capabilities into EU-Hydro which will consolidate and facilitate reporting related to the WFD.

6 Long-term Copernicus Marine and Land Service evolutions

The work carried out with users and experts of the coastal domain together with the CMEMS and CLMS implementation teams confirmed the value of a two-fold approach:

1. capitalize on the strengths of the existing Copernicus Marine and Copernicus Land Services to meet marine and land specificities, but foster a coordinated approach in the implementation based on a common knowledge of the user environment.
2. identify key areas where a joint approach is directly needed to improve the service value for users and lower the artificial barrier splitting coastal communities, build coordinated action plans to explore new innovation service areas.

6.1 A coordinated approach for service implementation

In addition to continuing delivering and improving products describing marine and land environments, including their coastal interfaces, the long-term evolution of the Marine and Land Copernicus Services (i.e. post current delegation agreements) should focus on coordinated cross-service activities serving the scope of a more comprehensive coastal monitoring.

Different areas of action are identified were a consistent approach can foster the overall efficiency of the two services implementation in this domain, and build an integrated knowledge base regarding the coastal area. Mercator Ocean and EEA could take actions to this end in the following fields:

- *the monitoring of user requirements and feedbacks* to drive short-term adaptation of the services but also long-term evolutions requiring investigations and developments;
- *the organization of Copernicus events, workshops and training* to gather all coastal stakeholders as one community, regardless of land or marine distinctions;
- *the assessment of marine & land services requirements for observations and for research priorities in the coastal area,* to contribute to the overall requirement for infrastructures and research investment required by Copernicus;
- *the assessment of the services impact* in the environmental policies and business areas, to contribute to the overall monitoring of the Copernicus value for a sustainable development;
- *the planning and reporting to the Copernicus program governance* on marine and land services in a common form to help EC and Member States taking decisions with a consolidated view for the coastal area.

[9] https://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network

6.2 A coordinated approach for improving the service offer to user

Copernicus Marine and Land services aim at making the best use of existing and future Copernicus EO observations. This will require a significant evolution of Copernicus Marine and Land core monitoring services and a strengthening of the links with downstream coastal monitoring activities organized both in the public (member states) and private sectors. Several elements require to be jointly organized as their relevance reaches outside the boundary of current individual Copernicus Services.

The priorities in the long-term evolution of Copernicus Marine and Land Services as requested by coastal users and policy purposes are presented below.

6.2.1 Characterization of coastal zones

A better characterization of the coastal zones is needed notably to assess their vulnerability and for a sustainable use of the coastal ocean and its resources. Improved services would focus on:

- A better characterization of the coastal zone bathymetry and topography, through e.g. satellite image processing, digital elevation models. This is particularly needed for coastal flooding risk and vulnerability assessment and consequently also for activities related to coastal protection.
- A better characterization of the coastline position and dynamics, including erosion and accretion phenomena. This also relies on the provision of information on relevant marine and land processes causing pressures on the coastal environment (e.g. waves, sea level changes, coastal land cover and use, …).
- A better characterization of land cover land use dynamics and habitat information, by establishing data enrichment processes (such as key ecosystem attribute information) and the transition towards the EAGLE data model which will allow for a better data integration. To be highlighted is the probable availability of the product codenames CLC+[10]. CLC+ will bring the Corine Land Cover typical wall-to-wall coarse LCLU mapping into the domain of the 1 ha grid cell LCLU mapping implemented all over EEA39, thus including coastal zones. CLC+ relies on the EAGLE concept, which is by design intended for a high level of inter-product flexibility. CLC+ is planned to become fully operational as of 2021, and from then onwards will be in a position to be used as baseline LCLU map which by a thematic enrichment can address specific needs of coastal zones.

6.2.2. Modelling and forecasting of the coastal zone

- **Global and Regional European Seas:**

  CMEMS will continue delivering a marine service based on state-of-the-art, high spatial resolution, integrated and more coupled blue-green-white ocean monitoring and forecasting capacity. CMEMS products will allow a better characterization of coastal ocean marine conditions including ocean circulation, physical state (e.g. temperature, salinity), currents, waves, winds, sea-ice, and biogeochemistry (e.g. phytoplankton, nutrients, chlorophyll, oxygen, carbon). CMEMS' target is to meet the "marine biology" demand and (for that reason) reach the level of excellence that CMEMS has now for the "marine physics" at the end of the next MFF period: to be able to better support environmental policies (MSFD),

[10] https://land.copernicus.eu/user-corner/technical-library/copy3_of_technical-library#clc-

sustainable development goals (e.g. SDG 14), fisheries and aquaculture management and living marine resources protection.

Several R&D projects (Annex 3) are preparing evolutions on these aspects, including: preparing higher-resolution systems, improved coupling effects between ocean-sea-ice-atmosphere-waves, improved representation of processes of importance for coastal zones, improved satellite data processing in the coastal zones, forecasting large wave events, providing better information on phytoplankton functional types, on low and mid trophic levels needed to bridge the gap to go towards relevant information on high trophic levels (fishes).

- **Interfacing with coastal models / nesting:**

  The monitoring and forecasting of coastal zones could also be improved through a convincing EU leverage by encouraging co-production between member state services and Copernicus Services. This requires a significant evolution of the Copernicus core European services to build coastal monitoring activities based on Copernicus Services' existing products and local coastal monitoring systems; to make the best use of existing and future Copernicus satellite observations; and to strengthen the links with downstream coastal-monitoring activities organized by both the public (member states) and private sectors.

  The "one-way" vision of a core service delivering information to downstream users without feedback to upstream providers has a number of limitations since the coastal strip should also be considered as an "active" boundary layer that influences the open ocean region connected to coastal areas. Scientifically, interactions between land, littoral, shelf, regional and abyssal seas are still a major unknown, poorly characterized and modelled.

  Regarding ocean models, it is therefore needed to develop CMEMS in such a way as to enable more efficient interfacing with a large variety of coastal systems describing the physical and biogeochemical coastal ocean states and ecosystems. Future operational circulation models implemented in the open ocean in CMEMS should enable more flexible coupling with a variety of model codes and regional configurations, specifically customized for coastal dynamics and benefiting from user experience and practices. Including users interface with near-shore, estuary and hydrological models, or unstructured grid models in areas that require very high resolution with good representation of topographic features.

6.2.3 River monitoring and forecasting

River discharges are at the land-marine boundary affecting marine coastal zone in various ways (salinity, circulation, sea level, biology, water quality, etc.). A better monitoring and forecasting of major EU rivers and production of validated river discharges for freshwater input, nutrient loading, particulate and dissolved matter is an essential evolution for the Copernicus Services. An extension of the product could be defined in that regard, based on the formalism of existing or emerging modelling frameworks. This could include:

- Near real time observation and characterization of EU rivers based on in situ observations and satellite observations (Sentinel missions):
  - CLMS already maintains and improves the EU-Hydro dataset. EU-Hydro maps all pan-European rivers mapped based on VHR 2012 imagery. EU-Hydro contains the topological relationships of the water network necessary for water flow modelling.

Based on EU-Hydro, the thematic hotspot mapping product Riparian Zones[11] maps the LCLU accompanying European rivers up to Strahler level 2[12]. The distribution and quantification of LCLU can be used to assess pollution and flooding parameters. The next needed step would be the integration of harmonised in-situ data and satellite information to feed flooding and fresh and marine water quality forecasting models (see next point).

- Modelling and forecasting of rivers (Europe and Global)
    - A better representation of the marine-land boundary through ocean-estuary-river coupling has been initiated in CMEMS through actions from the production centres and through funding of R&D projects (Annex 3). However, a more advanced framework is needed to meet CMEMS requirements regarding ocean-river coupling. A homogenized and more unified approach is indeed needed for CMEMS production centres, with the monitoring of major EU rivers and the production of validated river discharges in near-real time and over the last decades for the freshwater mass input, nutrient loading, and particulate and dissolved matter. A homogenised river forcing or ocean-river coupling approach for global, regional and coastal models is also targeted.

This extension should become a typical case of cooperation involving the Copernicus Marine monitoring and the Land monitoring Service and in interaction with the Copernicus Emergency Management Service and its European and Global Flood Awareness Systems (EFAS & GloFAS).

6.2.4 Climate change and coastal vulnerability

Assessing climate change impacts on the coastal environment and its vulnerability (including in the rapidly changing Arctic Ocean) emerges as a strong need for an effective management and planning of the coastal zone (e.g. sea level rise, flooding, coastal erosion, habitat changes, pollution and infrastructure risks, mitigation/adaptation strategies, protective functioning) and its resources (e.g. fisheries, aquaculture and aggregate extraction/ dredging).

New capabilities for seasonal to long-term (multi-decadal to centennial) projections of the ocean state and of marine ecosystems at regional to coastal scales could be developed by building on CMEMS systems and transforming the high level of CMEMS' ocean expertise into a strong assessment capability on the ocean's climate both for physics (e.g. sea level rise, warming, sea ice shrinking) and chemistry (deoxygenation, acidification). This includes the monitoring of the essential role of the oceans on the carbon cycle. This activity shall be conducted in close collaboration with the Climate Service to foster cross-fertilization between both Copernicus services.

The systems developed in CMEMS offer high resolution and a consistent dynamic framework in terms of forcing and representation of processes, with for instance the ocean model including tides and surface atmospheric pressure forcing, ocean-wave coupled systems). CMEMS regional systems could improve at regional/coastal scales the state-of-the-art ocean projections as provided by coarse resolution CMIP models and C3S. CMEMS could build upon its operational oceanography systems and services to develop its capability to provide information on the long-term evolution of the ocean physical and biogeochemical state at regional to coastal scales and at higher resolution than currently available projections. This should be carried out in close interaction with the C3S.

[11] https://land.copernicus.eu/local/riparian-zones
[12] https://en.wikipedia.org/wiki/Strahler_number

Projections of biogeochemical variables could feed projections of higher trophic levels (e.g. through the use of models being developed as part of CMEMS funded R&D projects) for applications related to marine ecosystems. The latter are also being impacted by climate change with for instance decreased ocean productivity, changes in current patterns and habitats, migration pathways, altered food web dynamics, and shifting species distributions.

Monitoring and forecasting of climate change impacts on land are of vital importance for coastal areas. On one side the exact knowledge and the projection of threats in long-term scenarios, such as sea level rise and storm surges, need to be continuously monitored and forecasted, on the other side, in order to assess the impact, primarily affected land areas need to be specifically characterised. Such knowledge is essential for any short and long-term planning activities in coastal areas and essential to mitigate on time risks on infrastructure and land habitats, and their protective functioning. The characterisation of the coastal interface also needs to be addressed from the perspective of coastal vulnerability. This mainly includes the characterisation of the coastal frontage (land and marine), coastal erosion and accumulation activities, assessment of protective functioning of the landscape (natural and anthropogenic) and anthropogenic infrastructure.

6.2.5 DIAS evolution

In Copernicus 2.0, there will be a full integration of land, marine, atmosphere and climate service portfolios together with other initiatives (such as EMODnet) into advanced cloud facilities. Cloud based virtual machines on scalable high performance processing and storing capabilities could for example allow coastal users to run their own processes and simulations without the need to gather data from different location or invest in costly hardware infrastructure.

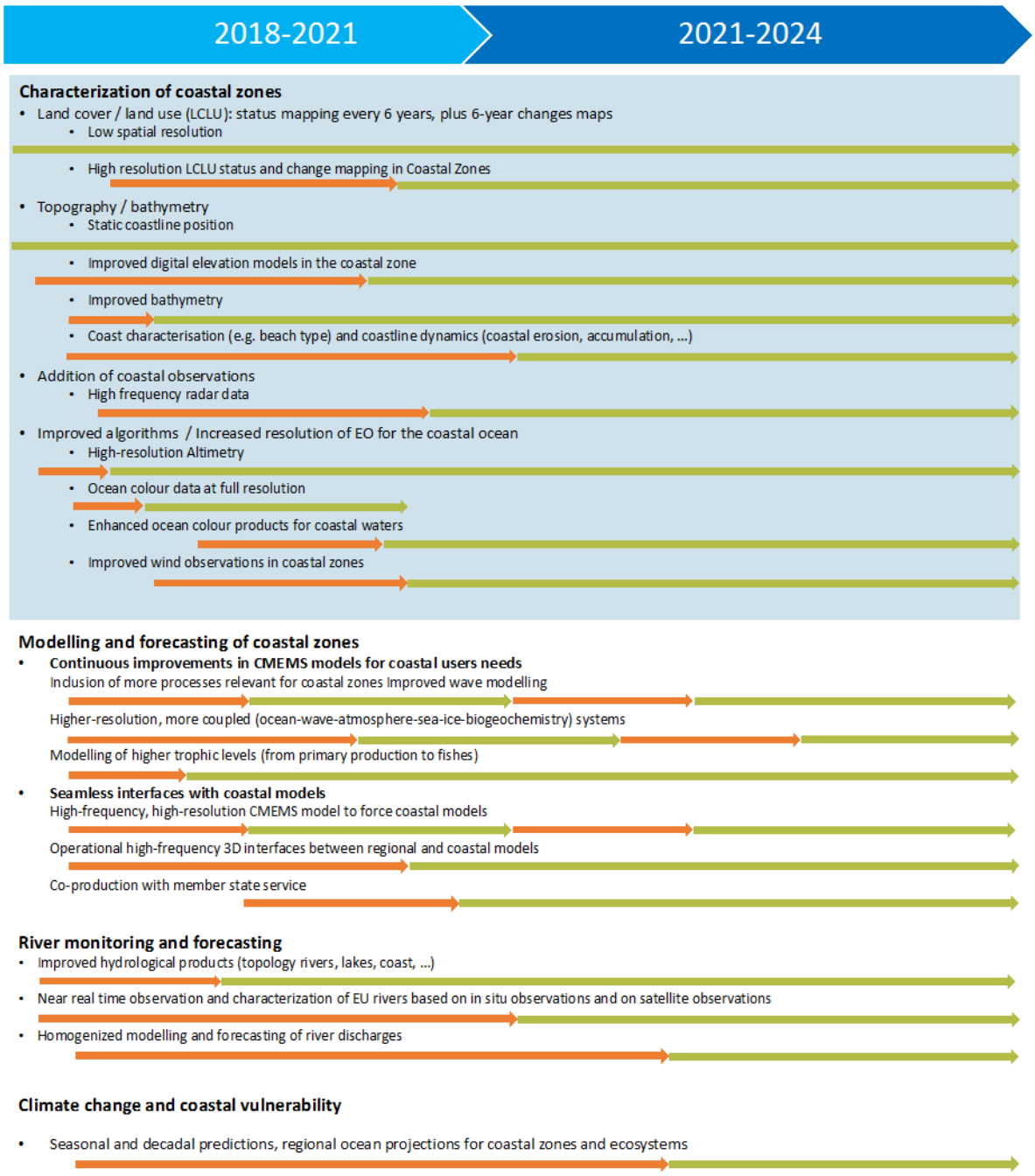

Figure 2: Graphical roadmap for the evolution of Copernicus marine and land services to better serve coastal users. The orange arrows denote a preparatory / pre-operational phase, while green arrows denote an operational phase. Timelines are indicative. Some activities should be developed in collaboration with other Copernicus Services.

7 Conclusion

The roadmap provides an overview of the possible short-term / long-term evolution of the Copernicus Marine and Land Monitoring Services to better answer coastal user needs.

The work carried out shows that the Marine and Land services successfully set up by the Copernicus programme in this first phase are solid assets to address present/future user needs for coastal zone monitoring. Two lines of actions are identified for the future:

- continue improving regularly the two services in their respective areas to keep them state-of-the-art but develop best practices exchanges at the level of the two entrusted entities and build a common knowledge base regarding Copernicus and the coastal zone.
- undertake a series of scope centred, cross Copernicus service actions, to improve monitoring and service capabilities in the coastal domain, characterizing the area, modelling and forecasting its environment, integrating river information, assessing the vulnerability to climate change, and improving the integrated access to data and information.

Short-term evolutions are already planned and will be progressively implemented by the two services in interaction with the user community and taking into account the delineation between the core and downstream services.

For the long-term evolution, cross-service coordination seems to be the essential attribute to achieve a comprehensive monitoring of coastal zones. Initial proposals need to be discussed with the EC, member states and the user community. Their implementation will depend on the long-term evolution of the Copernicus programme and its services for the next MFF.

8 Annex 1: main recommendations from the expert workshop

Improving the monitoring and forecasting of coastal zones building on Copernicus Marine and Land services and making the best use of existing and future Copernicus satellite observations is both needed and feasible. This requires both a significant evolution of Copernicus Marine and Land core European services and a strengthening of the links with downstream coastal monitoring activities organized both in the public (member states) and private sectors. The workshop identified several important gaps or areas of improvements. A series of short-term/mid-term actions and recommendations were identified. They take into account the necessary delineation between core and downstream activities. This is detailed in the syntheses of each of the five discussion topics in the workshop report's Annexes 2, 3, 4, 5 and 6. The main recommendations can be summarized as follows:

- Better processing (i.e. specific algorithms) of satellite observations is required to improve the quality of coastal products. This could be organized as part of the evolution of CLMS and CMEMS from 2018 onwards. This applies, in particular, for CMEMS to ocean colour products in the coastal zone (Sentinel 3 and Sentinel 2, MSG/SEVERI).
- New satellite products to better characterize the state of the coastal zone (e.g. coastline, coastal erosion) and its evolution (e.g. on seasonal to annual basis) should be proposed.
- Improved Digital Elevation Models (DEM) and Bathymetries are basic core requirements for the coastal zone.
- New satellite data/products are also required for the Regional Seas Conventions (e.g. Barcelona Convention/Mediterranean). Many neighbourhood policies, the MSFD and MSP Directives rely on the availability of such data.
- Based on an analysis of existing capabilities and requirements from other Copernicus services (in addition of CMEMS and CLMS) (e.g. emergency, C3S), the need to extend the marine and land service activities to the monitoring and forecasting of all major EU rivers (river outflows, nutrient and sediment loading) should be analysed. By extension other linkages between land related and sea related parameters should be explored.
- Similarly, the monitoring, short and long-term prediction of sea level close to the coasts should be improved. This is required for a wide range of applications (flooding, coastal erosion, coastal zone management).
- Stronger interfaces between CMEMS and downstream coastal marine monitoring systems should be developed. This includes harmonization and standardization issues (e.g. formats, quality assessment methods, documentation, data distribution) and of the use of consistent and improved bathymetry, atmospheric forcing and river inputs.
- Pilot studies should be conducted for representative sub-regional/local coastal areas spanning the relevant fields (physical, biological) of the coastal marine environment (cf CMEMS User Uptake activities).
- Links/interfaces with EMODnet portals and activities (e.g. bathymetry, seabed habitats, chemistry) should be reinforced.

- Products from national/member states coastal monitoring systems could be made available through CMEMS, CLMS or Copernicus (e.g. DIAS) data portals (coproduction EU & Member States).
- Copernicus could include in the longer run core/common/generic coastal activities to support the development of coastal downstream services and strong operational interfaces with the Copernicus Marine and Land services (e.g. short-term/mid-term R&D on modelling, data assimilation and coupling, satellite observations and products from Sentinels, in-situ data gathering and processing).
- Capacity building and development of best practices are also very important for the coastal zone monitoring activities developed by member states and local authorities. This is an area where a European approach would be beneficial.

9 Annex 2: Open workshop – conclusion

The concluding remarks were given by Hugo Zunker (DG GROW Copernicus Unit) who started his intervention by acknowledging the relevance of the coastal management and monitoring topic and the large user community linked to it. He then stated that the European Commission does not foresee the creation of a new stand-alone service focused on coastal. The idea is to build on Copernicus data and service information already available or which will be available in the short to medium-term. DG GROW will carefully consider the boundary layer and interface between the core services and the downstream actors when deciding upon future coastal products, when the aim of fostering and supporting the downstream ecosystem. Moreover, the European Commission encourages a structured and sustained dialogue amongst CLMS and CMEMS, and positively welcome the proposed adaptation of current products presented during the event.

For what concerns the practical next steps, Mercator Ocean International and the European Environment Agency are invited to continue, as part of their delegation agreement duties, to improve the existing services to better serve coastal users. This user driven service evolution should take into account some of the initial short-term recommendations of this workshop, keeping in mind the delineation between the core services and the downstream actors.

MOI and EEA are also invited to elaborate a longer-term roadmap, which would build on the conclusions of this workshop and the subsequent interaction of the Entrusted Entities with the coastal user community, while keeping the downstream players in the loop. The roadmap could include, in particular, the development of tailored tools aimed at facilitating the coastal users in accessing the relevant data and/or information from the different Copernicus services (if applicable), taking into account the intrinsic cross-cutting nature of the coastal application domain.

10 Annex 3: Coastal Zones monitoring R&D activities

R&D activities needed for the long-term evolution of Coastal Zones monitoring are promoted in the framework of external projects. CMEMS and CLMS will notably monitor projects relevant for Coastal Zones to identify scientific and technical developments that could be taken up improve its products in coastal areas and for coastal users.

The following past or on-going FP7, H2020 or INTERREG R&D projects are beneficial for the evolution of CMEMS, CLMS and its downstream services with respect to the coastal zone. They deal with:

- Improved resolution and improved interfaces with coastal models
    - CEASELESS H2020 (2017-2019) (Copernicus Evolution and Applications with Sentinel Enhancements and Land Effluents for Shores and Seas) aims to achieve a high-grade analysis of coastal sea dynamics based on 1/ superior level of information provided by Sentinel combined with in-situ coastal observations and 2/ greater wealth of processes in metocean models that consider explicitly the land boundary condition (including, thus, the linkage to the emerged coast). This will support an enhancement of the Copernicus coastal dimension that is timely and commensurate with the challenges faced by vulnerable coastal systems, contributing to create a weather-smart society and a variety of weather-based services.
    - IMMERSE H2020 (2019-2022) (Copernicus Evolution – new generation of Copernicus Marine Service models). The overarching goal of IMMERSE is to ensure that the CMEMS has continued access to world-class marine modelling tools for its next generation systems. IMMERSE will address the following objectives: 1/ develop a new, efficient, stable and scalable NEMO reference code with improved performances adapted to exploit future HPC technologies, 2/ develop NEMO for the challenges of delivering ocean state estimates and forecasts describing ocean dynamics and biogeochemistry at kilometric scale, 3/ prepare the exploitation of the next generation of high resolution observing networks within CMEMS systems and in detailed, downstream modelling systems, 4/ develop a flexible and generic software tools series for interfacing CMEMS observation and model-based products and detailed, downstream modelling systems, 5/ provide proven model code and software tools with assessments suitable for rapid deployment in CMEMS.
- Development of user-relevant service platforms for coastal water based on Earth Observation (EO)
    - CORESYF H2020 (2016-2018): supports coastal research applications using EO data. Applications include: bathymetry determination (from SAR Images and optical sensors), benthic habitat classification and water quality (from optical sensors), vessel and oil spill detection, time-series processing for hyper-temporal optical data analysis, improved ocean coastal altimetry.
    - COASTOBS H2020 (2018-2020): Near-real time monitoring, early warning, environmental reporting and analysis of coastal water quality. Products include standard coastal water quality products (Chlorophyll-a, total suspended matter, turbidity, SST). A number of innovative products will be advanced from research to operational status within the project with a focus on the marine biology (e.g. algae, phytoplankton size classes and primary production). Another innovative aspect will be the definition and implementation of higher-level products such as aggregated products and indicators that match the users' information needs (e.g. HAB forecasts, shellfish culture potential).
- In-situ observations
    - JERICO-NEXT H2020 (2015-2019): Aims at improving and innovating the cooperation in coastal observatories in Europe by implementing the coastal part of a European Ocean Observing System.

- MYCOAST INTERREG (2017-2021). MYCOAST aims to build a coordinated Atlantic Coastal Operational Observatory in the Atlantic area targeted towards the improvement of coastal monitoring and forecasting tools to support threat and emergency response. MyCoast will allow deploying and capitalizing innovative and standardized tools in the risk management systems applied mainly to (i) extreme weather events leading to flooding, (ii) maritime safety and (iii) coastal pollution.
- MONOCLE H2020: Developing essential research and technology to lower the cost of acquisition, maintenance, and regular deployment of in situ sensors. The MONOCLE sensor system will establish firm links between operational Earth Observation (EO) and essential environmental monitoring in inland and transitional water bodies. These aquatic ecosystems, which are particularly vulnerable to direct human impacts, represent areas of the weakest performance in current EO capability, despite the major technological advances in recent decades. At the same time, these areas are of great economic importance and are crucial to sustainable food, energy, and clean water supply.

- High resolution ocean colour products
  - HIGHROC FP7 (2013 – 2017). The project aimed at providing coastal water products and services by integrating information from typical medium-resolution (MR) ocean colour sensors, such as MODIS or OLCI, with high spatial resolution (HR) sensors e.g. OLI on Landsat 8 or MSI on Sentinel 2. Improvements in temporal resolution were also offered with MSG-SEVIRI. The HIGHROC partners developed three service chains to process and deliver products to their users: 1/ a Sentinel 3 processing chain that delivered products from typical Ocean Colour sensors (MODIS, VIIRS, OLCI) as well as the multi-temporal and multi-spatial synergy products, 2/ a Sentinel 2 processing chain that provided processed products from Landsat 8-OLI and Sentinel 2-MSI and 3/ a GEO processing chain that generated high temporal resolution products from MSG-SEVIRI. Some of the services demonstrated as part of HIGHROC could be transferred in CMEMS portfolio (see previous section).

- Rural and Urban development along the coast
  - CUTLER H2020: Harvest the rich basis of data offered by the existing infrastructures for sensing the environment, the society and the economic activity, to build the data mining and visualization tools for extracting actionable knowledge out of these data, and to use these tools for supporting a platform on policy design, implementation and evaluation that will be filtered through the lens of urban resilience.
  - COASTAL H2020: The goal of the COASTAL project is to formulate and evaluate business solutions and policy recommendations aimed at improving the coastal-rural synergy to foster rural and coastal development while preserving the environment. Rural development in the EU is increasingly affected by changing market developments, decreasing population densities, urban sprawl, lack of employment, desertification and other environmental, economic and social pressures. On the other hand, coastal areas provide interesting business opportunities but are also influenced by economic activities in the hinterland.

    Multi-Actor Approaches will be combined with System Dynamics to analyse the environmental, economic, and social interactions of rural and coastal areas in a holistic manner. The underlying feedback structures governing the dynamics, vulnerabilities,

limitations, and business opportunities of the land-sea system will be identified and analysed, taking into consideration the regulatory frameworks, stakeholder priorities and social-economic conditions at the local, regional and macro-regional scale levels. Multi-Actor Labs using qualitative and quantitative tools will be set up to support the co-creation exchanges between scientific experts, stakeholders, business entrepreneurs, sector- and administrative representatives.

- Downstream Applications

  - CyanoAlert Horizon 2020 will be a global service for environmental authorities and the commercial sector, concerned by health risks and quality of water resources. The project makes use of the wealth of information provided by Copernicus to deliver a fully automated application for assessing toxin-producing cyanobacteria blooms in water resources globally. The service foresees a dual system that provides user-specific information for monitoring and reporting purposes to paying customers, and a free and open information service for the general public. The service will be implemented through a collaboration between European SMEs, and with pilot users in the government and commercial sector. Through establishing a supply chain for the information products and integrating these into customer's workflows, the project seeks to create a sustainable business within three years following the period of project funding.

  - EOMORES H2020 will develop reliable, sustainable and fully-automated services for water quality monitoring, combining satellite data, on-site measurements, and ecological modelling. These three sources can be flexibly combined into higher-level products designed to fit your operational environment.

    Services will conform with INSPIRE, Open Geospatial Consortium (OGC) and International Organisation for Standardization (ISO) standards, especially Web Coverage Service (WCS) for mapped products and Sensor Observation Service (SOS) for time series of in situ measurements. EOMORES products will be stringently validated to assure high levels of accuracy and quality.

  - SPACE-0 H2020 (Space Assisted Water Quality Forecasting Platform for Optimized Decision Making in Water Supply Services) integrates state-of-the-art satellite technology and in-situ monitoring with advanced hydrological, water quality models and ICT tools, into a powerful decision support system. This generates real-time, short- to medium-term forecasting of water flows and quality data in reservoirs, used to optimise water treatment plant operations and establish a complete service line from science to the water business sector.

In addition to the above external projects, CMEMS is directly funding R&D projects to provide support for cutting-edge R&D activities required to ensure the scientific evolution of CMEMS, including to better meet needs from coastal users. The user requirements in terms of both quantitative information (e.g. variable types, geographic coverage and resolution) and scientific quality of CMEMS products are the main drivers of these R&D activities. Outcomes of the ongoing CMEMS Service Evolution R&D projects (over 2018-2020) should impact CMEMS products in 2021, with several projects targeting coastal users:

- [CURAE] Development of a new set of downscaling and coupling tools which, based on present CMEMS products, will open a range of coastal applications and contribute to enhance the coastal dimension in CMEMS. The core of the project is the incorporation of the

coastal fringe as an active boundary layer, interacting bi-directionally with the shelf sea and including the continental discharge in terms of water, sediment and nutrient fluxes. To prove the feasibility of this approach two coastal pilots have been selected that feature river and irrigation discharges, dredging and their interactions. The selected sites also represent two contrasting environments and two different numerical approaches for downscaling so that the derived conclusions and tools should be generic enough and of direct value for a CMEMS extension towards the coast.

- [LAMBDA] Improved characterisation of the land-marine boundary conditions and CMEMS ocean models in coastal areas through the coupling of a watershed numerical model with CMEMS regional ocean models. This could improve the representation of river discharge in CMEMS model. Developments are focused on the European Atlantic coasts (do not cover the Mediterranean, Black, and Baltic Seas).
- [BRONCO] Improved ocean reanalyses through more realistic river freshwater input, and improved consistency of the atmospheric (ERA5) and river runoff (based on GLOFAS) forcing.
- [LATEMAR] Improved modelling of large wave events during marine storms. This could lead to an upgrade of CMEMS wave forecasting systems, and to an extension of CMEMS's products catalogue with information on large waves. Developments are focused on the Mediterranean Sea.
- [COMBAT] Improved assimilation of sea level data in the coastal zone. Altimetry derived Mean Dynamic Topography (MDT) can be assimilated in ocean modelling systems to estimate more precisely sea surface in the simulations. Yet, global mean dynamic topography estimates show large uncertainties in the coastal areas. Development will be performed to take advantage of a coastal high-frequency radar system to be used, together with in situ and other remote sensing data, as an input in the MDT computation, for improving its precision in the coastal strip. Necessary elements for ensuring an effective assimilation of this coastal MDT and the corresponding Absolute Dynamic Topography in numerical models will be designed.