IMMERSE

Deliverable D2.1

Roadmap for implementation of IMMERSE outcomes within the CMEMS systems

V1.0

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Versions of the document

Version	Date	Description	Author
1.0	09/04/2019	Creation First draft	Y. Drillet

Applicable and Reference Documents

Version	Ref/link	Title	Date
V4	CMEMS STAC (2017). Available online	Copernicus Marine Environment Monitoring Service (CMEMS) Evolution Strategy : R&D priorities	Nov 2018
V1	Mercator Ocean (2016). Document prepared with the support of the CMEMS Science and Technology Advisory Committee (STAC). Available online	CMEMS High-level Service Evolution Strategy	Sept 2016
V1	Mercator Ocean International, European Environment Agency. Internal report	Roadmap for the evolution of Copernicus marine and land services to better serve coastal users	Dec 2018
	J. Le Sommer et al.	Proposal Improving Models for Marine EnviRonment SErvices (IMMERSE)	March 2018
	Le Traon PY et al. Front. Mar. Sci. 6:234. doi: 10.3389/fmars.2019.00234	From Observation to Information and Users: The Copernicus Marine Service Perspective.	2019

V2	NEMO consortium. Online internal report.	NEMO development strategy V2 : 2018-2022	2017

Glossary and Abbreviations

CMEMS	Copernicus Marine Environment Monitoring Service
MFC	Monitoring and Forecasting Center
TAC	Thematic and Assembly Center

1. Introduction and context

The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic reference information on the physical and biogeochemical ocean and sea-ice state for the global ocean and the European regional seas. CMEMS serves a wide range of users (more than 15,000 users are now registered to the service) and applications. Observations are a fundamental pillar of the CMEMS value-added chain that goes from observation to information and users. Observations are used by CMEMS Thematic Assembly Centres (TACs) to derive high-level data products and by CMEMS Monitoring and Forecasting Centres (MFCs) to validate and constrain their global and regional ocean analysis and forecasting systems. The main objectives of CMEMS are also reminded in the recent paper “From Observation to Information and Users : The Copernicus Marine Service perspective” by Le Traon et al, 2019. Other reference documents defining the CMEMS strategy in terms of high level evolution for the service (Mercator Ocean, 2016) and about R&D priorities (STAC, 2018) haves been published and are available online.

The organisation of CMEMS during 2018-2021 is described in Figure 1. Two main activities concern on the hand the Production & Service, and on the other hand the Evolution including scientific evolution, outreach and users uptake. The IMMERSE project will provide evolution and improvements to the MFC production centers (see Figure 2 for the definition of the seven MFC domains)and it will contribute to CMEMS long-term development, as described on Figure 3. Tier 1 R&D activities (~1 year) are mainly performed by the Production Centers, which integrate new developments in the next version of their systems. Tier 2 (~2-3 years) R&D activities are performed by the Production Centers and with contributions by external projects and partnerships mainly in the framework of the Service Evolution open calls. Tier 3 (3 to 10 years) R&D activities correspond to long-term developments, performed for instance in the framework of H2020 projects, which is the case for the IMMERSE project.

This document is the roadmap for the implementation of IMMERSE outcomes within the CMEMS systems. The roadmap is organised as follows. Section 2 describes the current status of the CMEMS

systems Section 3 describes the main system evolutions planned in the production centers. Section 4 describes expected improvements for these systems based on IMMERSE developments and section 5 describes how IMMERSE developments will be integrated in CMEMS systems. The first version of the present roadmap, written during the first year of the project, will be updated every year taking into account advancements of the IMMERSE developments and evolution of the CMEMS systems. Interactions with the leaders of each MFC production centers will be organised to integrate regular updates of the development plan and roadmap in the framework of the Production Centers formal Specification and Design Reviews (proposed evolutions by CMEMS production centers for year+1 and year+2) organised by CMEMS.

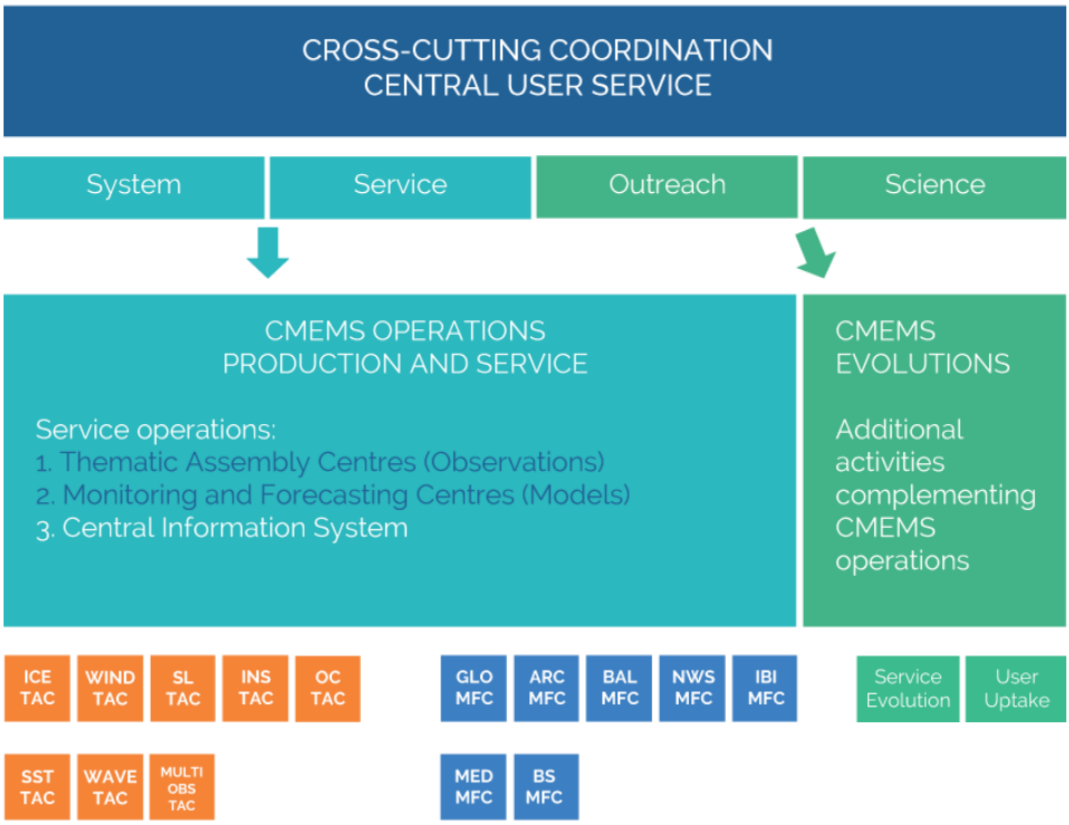

Figure 1 : Schematic view of the CMEMS organisation including coordination, production and cross cuttings activities. The IMMERSE project will provide development and improvements that will be included in the MFC systems.

Figure 2 : Domains of CMEMS Monitoring and Forecasting Centers.

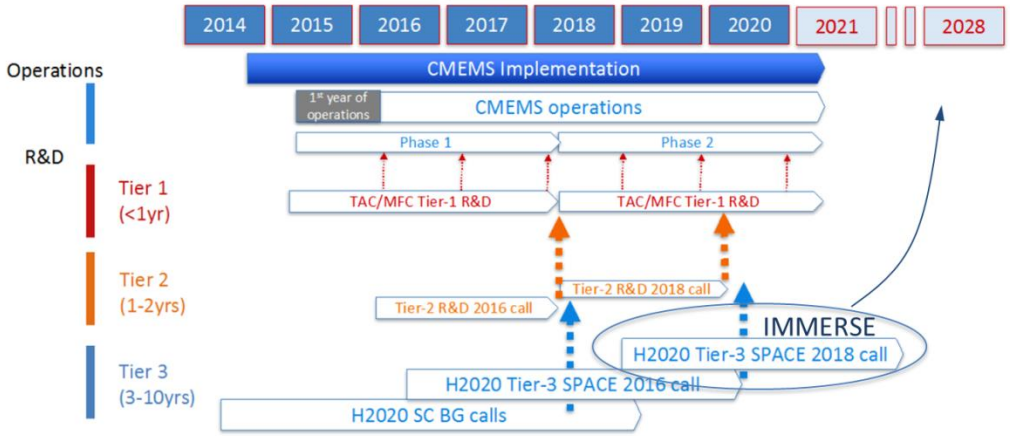

Figure 3 : Planning from the beginning of CMEMS to the next Copernicus phase (to start in 2021).

2. Current Status of CMEMS operational systems

A full description of the systems operated in the framework of CMEMS is available on the web site (http://marine.copernicus.eu/). For each available product (real time or reanalysis) a Quality Information Document (QUID) is provided giving information on the main characteristics of the system and information on the quality of the available variables comparing analysis and forecast to observations. The Figure 4 summarises information on the systems developed and operated in each MFC production centre. Most of the centres developed their systems with the NEMO code that create the strong link with the IMMERSE project. Usage of NEMO model differs from a production center to an other taking into account specificity of the area in term of physics and important processes occuring in the area. An important constraint is related to the high performance computing resources which is an important topic address in IMMERSE project. The current resolution of the forecasting systems are from 1/12° for the global system to 1/60° for the North West Shelf area, the resolution is currently lower for the reanalysis systems (from ¼° to 1/16°). Model resolution is in agreement with the available satellite observations (especially the sea level anomaly) and allows to constrain thanks to data assimilation meso scale features as ocean eddies and fronts. Main differences in term of numerical scheme or parameterisation between the available systems using NEMO are :

- Simulation of **tides** especially in the tidal seas as the Gulf of Biscay, the Channel and the North Sea.
- Higher **vertical** resolution or σ vertical coordinates to improve the circulation on the shelf as for North West Shelf area or mixing and intermediate or deep water formation which is important process in the Mediterranean Sea.
- Vertical **mixing** scheme can also differ from one system to another using TKE or GLS formulation
- **Atmospheric** forcing is most of the time based on ECMWF atmospheric forecast or reanalysis but there is also differences on the formulation/parameterisation to compute atmospheric fluxes, high resolution regional systems can used higher resolution regional atmospheric forecast (for example in the baltic) and one global system is already coupled to an atmospheric model to provide real time forecast.

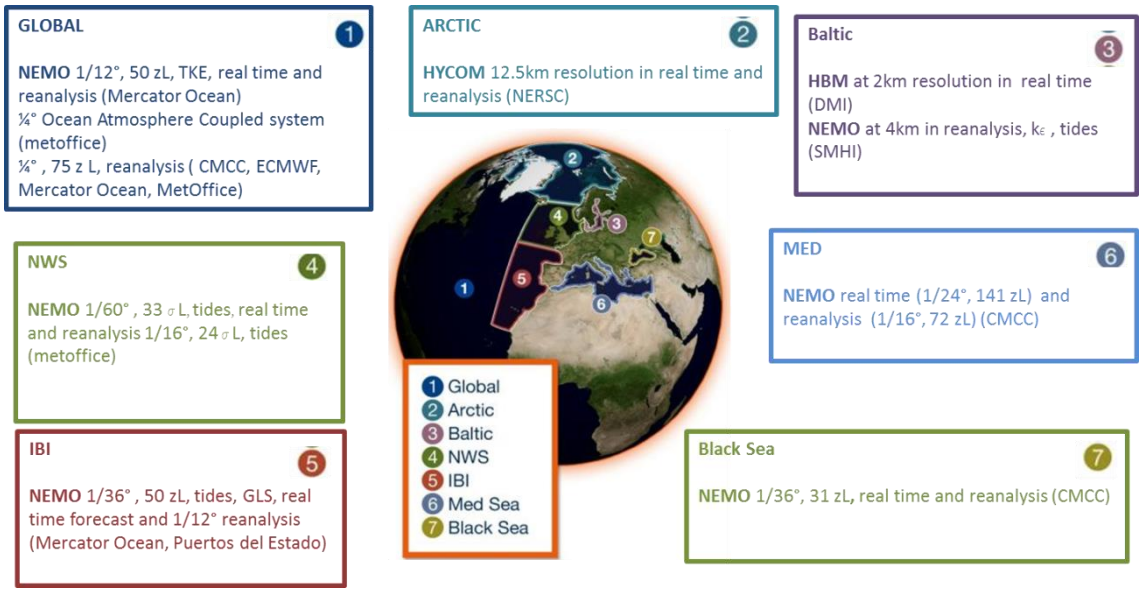

Figure 4 : Main description of the current systems operated in each MFC

3. Evolution of CMEMS operational systems

The R&D roadmap priorities (STAC, 2018) captures the short (Tier 1), medium-term (Tier 2) and longer-term (Tier 3) research and development needed to maintain systems at state-of-the-art and respond to evolving user needs. Overarching themes of needed innovation of research are :

1. Ocean **circulation** modelling, **mesoscale** and other **interactions**, ocean-wave and ocean-ice coupling
2. **Biogeochemistry** and ecosystems in the marine environment
3. Interactions with the **coastal** ocean
4. Ocean-atmosphere **coupling**, reanalysis and **indicators**, and **climate** change
5. Cross-cutting developments on **observation**, **assimilation** and product **quality** improvements

with the following priorities

1. Circulation models for the global ocean, regional and shelf seas
2. Sub-mesoscale - mesoscale interactions and processes
3. Coupled ocean-marine weather information, surface currents and waves
4. New generation of sea-ice modelling
5. Modelling and data assimilation for marine ecosystems and biogeochemistry
6. Seamless interactions between CMEMS and coastal systems
7. Coupled ocean-atmosphere models with assimilative capability
8. Ocean climate products, indicators and scenarios
9. Observation technologies and methodologies
10. Observing systems: impact studies and optimal design
11. Advanced assimilation for large-dimensional systems
12. High-level data products and big data processing

Long term development perspective is not yet fully defined for all the MFC and will evolved every year depending of improvement of the models used in each center. The three main priorities that will be addressed in IMMERSE project are “1. Circulation models for the global ocean, regional and shelf seas”, “2. Sub-mesoscale - mesoscale interactions and processes”, “6. Seamless interactions between CMEMS and coastal systems” and main system evolution already planned in the CMEMS production center are summarised on Figure 5 and concerns following topics :

1. **Resolution** : At global scale a new configuration will be developed at 1/36°, at regional scale objective is to reach kilometric resolution with homogeneous resolution to ~500m in the Baltic sea and with AGRIF two way nesting zooms in the IBI area for example.
2. **Coupling** : Ocean, waves, atmosphere, sea ice and biogeochemistry coupling will be improved to reach a better consistency between all the components of the operational systems and to allow multivariate assimilation between all the components. Waves coupling is the priority with more or less complex coupling depending of the system, operational scenario and availability of coupling interfaces, parameterisations in the mixing scheme and boundary conditions. Coupling with atmosphere will be also improved using fully couple strategy or using Atmospheric Boundary Layer.
3. **Tides** : The tides should be included in all the systems with wetting and drying parameterisations depending of the region and of the model resolution and z~ vertical coordinate to reduce numerical mixing.
4. **Ensemble** : Ensemble analysis and forecast will be developed and used in several systems, perturbation to provide satisfactory ensemble spread is a key issue but high performance computing is also crucial to be able to performed ensemble simulations.
5. Move to **NEMO** : The Baltic MFC will move to NEMO for all the CMEMS configurations and the Arctic MFC currently using HYCOM model will performed tests with NEMO especially when the generalised vertical coordinates (z~) will be fully available in the NEMO standard version.

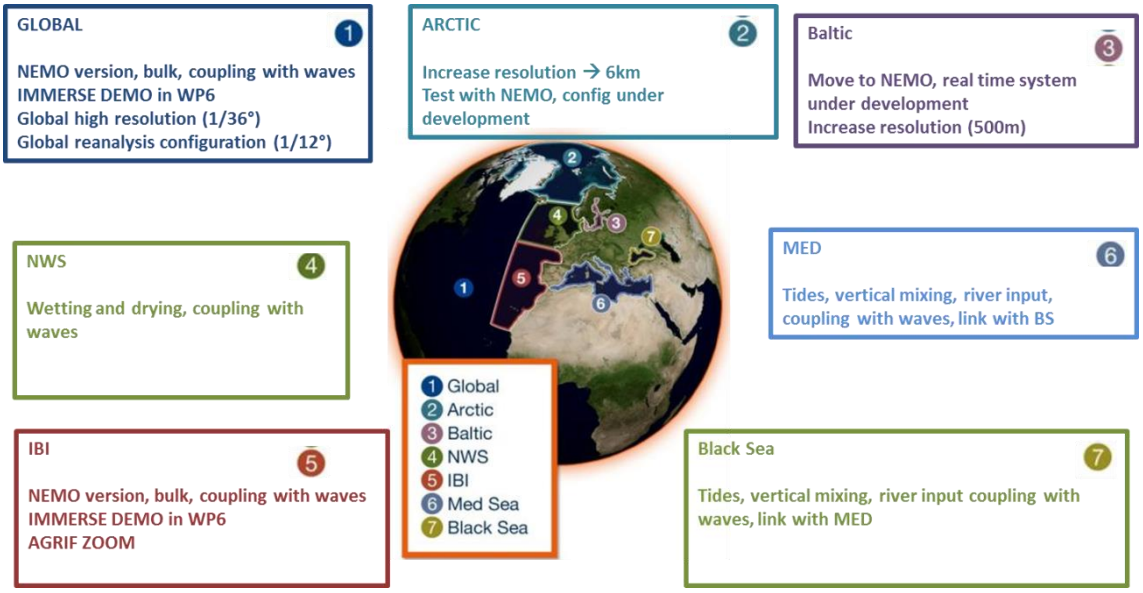

Figure 5 : Main evolution of the characteristics of the CMEMS systems

4. IMMERSE expected improvements for CMEMS systems

In this section we highlight main developments performed in each IMMERSE work package that will impact the CMEMS production centers.

WP2 : Quality control & dissemination

The NEMO maintain, evolution and test of the reference version of the code is done and is available for all user including CMEMS production center. NEMO user support will be helpful for production center moving to NEMO code. The procedure for documenting NEMO configuration (D2.2) will be useful for all CMEMS MFCs.

WP3 : Kernel

The new temporal scheme that will be developed could be used by all MFC who will benefit of improvement of performances, of compatibility with other available schemes in NEMO and also compatibility with AGRIF toolbox. Evolution of the vertical coordinates and capability to merge several type of vertical coordinates will be crucial for systems including tides but also to improve circulation around sills or straits

WP 4 :HPC

HPC is a crucial issue for CMEMS production center as main objectif in the next period is to reach kilometric resolution, to transition to ensemble analysis and forecast and to increase coupling complexity between the component of the systems (ocean, waves, atmospheres, biogeochemistry, sea ice). It is also important as adapting operational production on new computer facilities is crucial activities in operational center. Improvement of performances and code scalability will be performed on new platforms with configuration as close as possible as CMEMS configurations (in term of size, version of the model, resolution …) and implemented several level of parallelism, IO improvement and AGRIF optimisation will directly benefit to the CMEMS systems.

WP5 : Interactions

Interaction between components of the systems is key issue to improve analysis and forecast. In IMMERSE the interaction between all the components used in CMEMS operational system will be addressed as the Atmospheric Boundary Layer that will be used at least in the GLO MFC, the interaction with Sea Ice model that will be used by GLO, ARC and BAL MFC and interaction with biogeochemistry and with waves that will be implemented in all MFCs.

WP6 : Demonstration

The demonstration work package is fully design to test IMMERSE development in future CMEMS configuration as the global 1/36° configuration that will be used to performed real time forecast, the global 1/12° that will be used to performed interannual reanalysis and the IBI high resolution configuration including two way nesting zoom at kilometric resolution.

WP7 : Integration with EO data

The IMMERSE project doesn't address the question of data assimilation but a strong link with observations is done and is related to cross cutting activity performed in CMEMS especially in the Product Quality Working Group where common strategy to validate model, reanalysis, forecast from variable to ocean processes at several space and time scale is developed.

WP8 : Downstream case studies

CMEMS is really an user driven service and if the downstream case studies is not part of the service it is really important to provide to user information on ability/usefulness of the available product for downstream application. The link with coastal application, coastal modelling and downscaling will be done with improvement of toolbox and protocol to provide useful information for coastal application.

5. IMMERSE developments and integration in CMEMS systems

The two main phases in IMMERSE are a first 2-year period dedicated to development and stabilisation of a new NEMO version (NEMO5.0) and then a second 2-year period dedicated to improvement of the development and demonstration of the benefit in realistic *DEMO* configurations. Each *DEMO* configuration developed in IMMERSE framework to quantify benefit of NEMO developments is specific and related to individual developments. The IMMERSE planning and the integration in the CMEMS systems are described in figure 6. At this first stage, connexion with CMEMS production centers is already organised for the GLO and IBI MFCs. Detail of the IMMERSE development that will be integrated in other MFC will be defined during the project.

GLO MFC

Two demonstrations of WP6 are directly related to GLO MFC.

The global 1/36° will be mostly impacted by High Performance Computing development objective is to improve i) parallelisation of the code (better exploitation of memory hierarchies; separation in different executable of nemo component to run in parallel), ii) The use of the first version of the new temporal advance scheme developed in WP3 and iii) Input/output that is a bottleneck to produce simulation with such huge configuration (an increase of IO-servers is planed) . Performance objective is directly link with operational constraints to produce around 10-day forecast in less than 2-hour.

The final configuration that will be used to provide operational global forecast in CMEMS in 2025 will be based on this IMMERSE *DEMO* and will include a coupling with the Atmospheric Boundary layer , with the waves, with a sea ice model including rheology adapted for such resolution, with the biogeochemistry. Objectif is to really improve representation of the meso scale (and part of the sub mesoscale) in adequation with high resolution large swath altimetry satellite measurements that will be available from 2022 thanks to the SWOT mission.

The global 1/12° will be dedicated to produce long interannual reanalysis (between 30 to 50-years). One recurrent weakness is the representation of dense water, not well control by data assimilation. To tackle this point, one of the main developments expected to be integrated in this updated global configuration concern two way nesting including horizontal refinement and local adjustment of the vertical grid to improve representation of dense water overflow especially in the Denmark Strait and Gibraltar Strait.

The final configuration that will be used to provide global reanalysis in CMEMS in 2025 will be based on this IMMERSE *DEMO* and will include ensemble data assimilation scheme to provide over long

term period good representation of the ocean variability, trend and water mass formation with better estimate of the uncertainties.

IBI MFC

The demonstration over the IBI area consist in a "IBIzoom" at kilometric resolution to improve modelisation of meso and sub mesoscale in this area. Main developments that will be integrated in this *DEMO* are optimisation of AGRIF including local adaptation of the vertical grid on the shelf and interaction with other components like atmosphere, waves and biogeochemistry.

The final configuration that will be used to provide real time forecast over IBI domain will be based on this IMMERSE *DEMO* and will include AGRIF zoom to improve the representation of the circulation on the shelf and exchange between deep ocean ocean and shelf area to provide better. A first validation meso-scale representation will be addressed through a dedicated validation task.

Other MFCs

Integration of IMMERSE development in other MFC will be define during the IMMERSE project depending on development advancement and first result obtain with the demonstration. For example, the work done in IMMERSE on the coupling with wave model, on the Mediterranean basin, will be include in the next MED MFC version system

Downstream applications

Precise inputs and benefits for CMEMS based on the downstream case studies and development of new toolbox will be define during the IMMERSE project.

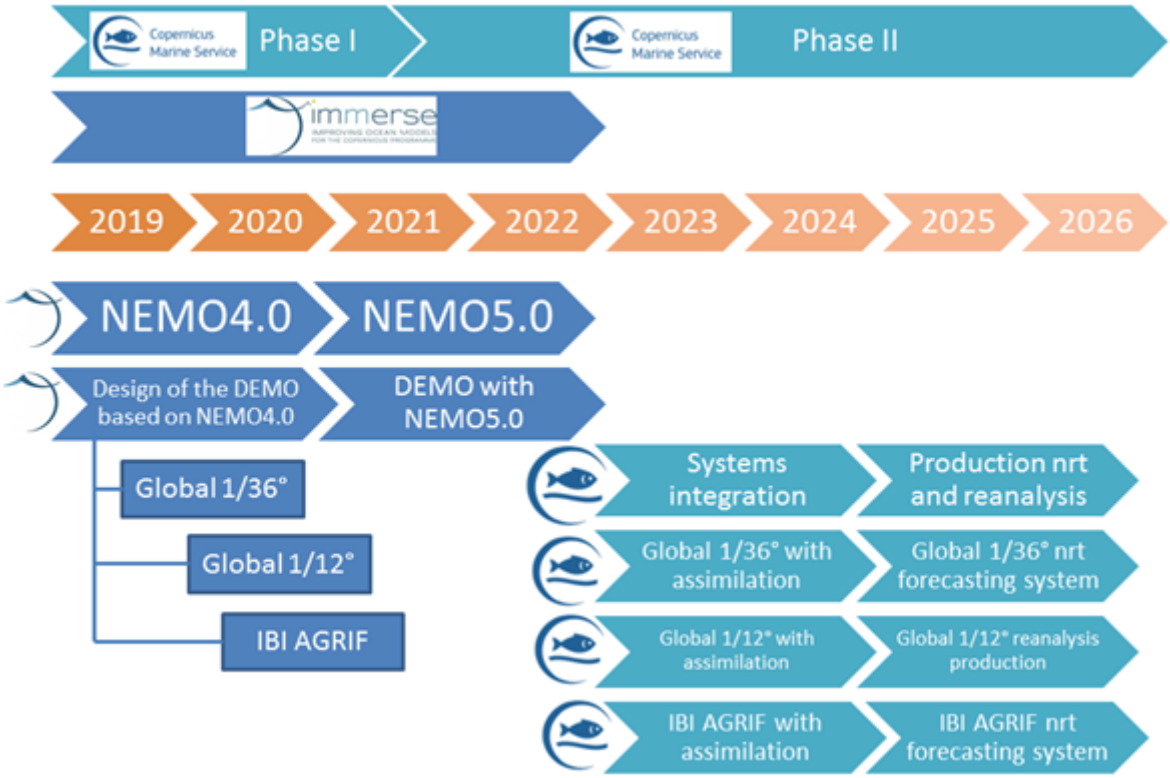

Figure 6 : Planning of IMMERSE development and transfer to CMEMS

Table 1 : Table listing the IMMERSE development, impact in CMEMS and the status of this transfert. This table will be updated for each version of the roadmap

IMMERSE development	**Impact in CMEMS**	**Status (will be updated annualy during the project)**
NEMO versioning		June 2019 Not started
Configurations/simulations versioning, documentation and sharing		June 2019 Not started
Vertical coordinates		June 2019 Not started
Temporal Scheme		June 2019 Not started
Model optimisation and paralelism		June 2019 Not started
Interfaces with coastal model		June 2019 Not started
AGRIF optimisation		June 2019 Not started
Interfaces between components of the systems (sea ice, biogeochemistry, atmosphere, waves …°		June 2019 Not started

6. Conclusion

The roadmap provides an overview of the organisation, links and transfer of development between IMMERSE H2020 project and Copernicus Marine Service. In this first version of this roadmap the developments and planning mainly concern the global and IBI monitoring and forecasting centers as partners of these CMEMS production centers are involved in IMMERSE project. Transfer of development and impact in other CMEMS production centers will be documented in the annual updated version of this roadmap.