FORCOAST

Earth Observation Services For Wild Fisheries, Oystergrounds Restoration And Bivalve Mariculture Along European Coasts

Project Deliverable Report

Deliverable Number: 3.8

Deliverable Title: Final Version of FORCOAST Numerical Models for Each Pilot Area

Author(s): Arthur Capet, Leo Barbut, Francisco Campuzano, Luis Ferrer, Elisaveta Peneva, Diego Pereiro, Jun She, Vilnis Frishfelds, Marie Maar, Stefano Querin, Luc Vandenbulcke

Work Package Number: WP3

Work Package Title: Service Design

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

FORCOAST Project Information	
Project full title	Earth Observation Services For Wild Fisheries, Oystergrounds Restoration And Bivalve Mariculture Along European Coasts
Project acronym	FORCOAST
Grant agreement number	870465
Project coordinator	Ghada El Serafy, Deltares
Project start date and duration	1st November 2019, 30 months
Project website	https://forcoast.eu

Deliverable Information	
Work package number	WP3
Work package title	WP3 - Service Design
Deliverable number	3.8
Deliverable title	Final Version of FORCOAST Numerical Models for Each Pilot Area
Description	This deliverable describes the operational setup of the final numerical models used for each pilot site (task 3.3).
Lead beneficiary	ULiège
Lead Author(s)	Arthur Capet
Contributor(s)	Leo Barbut, Francisco Campuzano, Luis Ferrer, Elisaveta Peneva, Diego Pereiro, Jun She, Vilnis Frishfelds, Marie Maar, Stefano Querin, Luc Vandenbulcke
Revision number	1.3
Revision Date	30/04/2022
Status (Final (F), Draft (D), Revised Draft (RV))	F

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Dissemination level (Public (PU), Restricted to other program participants (PP), Restricted to a group specified by the consortium (RE), Confidential for consortium members only (CO))	PU

Document History			
Revision	**Date**	**Modification**	**Author**
0	June 2021	Pilot contributions	Pilot Leaders
1.0	28-06-2021	Drafting	Arthur Capet
1.1	30-06-2021	Review, formatting	Luis Rodriguez
1.2	25-04-2022	Addressing comments raised in the Feb 2022 review (see table below). In particular: - Update on model's evolution since D3.7 - Removing any reference to unscheduled expected future developments. - addition of "Overview of validation efforts" for each pilot section, including clear references to section of D5.4.	Arthur Capet
1.3	29-04-2022	Review, formatting	Luis Rodriguez

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Approvals				
	Name	**Organisation**	**Date**	**Signature (initials)**
Coordinator	Ghada El Serafy	Deltares	29-04-2022	GES
WP Leaders	Arthur Capet	ULiège	29-04-2022	AC

Feedback by reviewers		
Date	**Comment**	**Response**
11/02/2022	The deliverable adequately describes the models to be used for each site.	-
11/02/2022	Given the delays, and limited time left in the project, one would expect a clear vision on the models that are validated, or not, and details on the state of advancement of these different validations. However, in the document all detailed information is pushed back towards deliverable 5.4 the end of the project (initially M34), which does not allow the reviewers to evaluate the overall project progress and performance in the meantime.	* Before entering the detail of proposed actions, we would like to stress that the comment rightly highlights an issue that relates to the original FORCOAST implementation plan, but that cannot be considered as a failure of this deliverable of WP3 with respect to assigned tasks in the DoA. Specifically, this issue lies in the fact that the validation of ocean data provided by pilot models, that is coordinated in WP5, has been scheduled at M28. This is part of the original FORCOAST implementation plan. * This being said, we acknowledge that earlier documentation of model skills would have been more appropriate as it would indeed have allowed a more proper referencing of the portfolio of pilot models described within D3.8. Yet, we cannot embed in D3.8 the validation results that are being compiled by WP5. Also, to meet the reviewer's requests we have included in the revised 3.8 additional sections (for each pilot) "overview of validation efforts", which include clear references to sections of D5.4. A draft preliminary version of D5.4 is provided to the reviewers upon resubmission of D3.8

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

		(D5.4 being only scheduled in June 2022 according to the adopted recovery plan).
11/02/2022	Comparing Figure 2.3.1 and 2.3.2, it's good to see that progress was made and further progress was foreseen to occur in 2021, but this information was not updated for the review meeting in December.	We took opportunity of this revision opportunity to provide a final version of the tables (i.e. excluding any future extension beyond the H2020 FORCOAST project lifetime).
11/02/2022	Examples on the difficulty to obtain a clear view on what is done and what is left to do, measured in time, can be found in the following elements. These should be communicated with better precisions about any difficulties and progress made so far, and time estimated to complete each task: "The database for validation is being completed and details of this validation work will be presented" "grids were tested though not operational yet." "The SWH variable from the nested NW wave model is being validated" "The validation of the Galway Bay model has been based on [...] Details of this validation work will be presented" "The biogeochemical model for the Limfjord is under development" "The integration with NRT satellite data provided by CNR is in progress" "The integration of NRT daily discharge data (at least for the main rivers) is in progress."	Throughout this revision of D3.8 we pay attention that the use of future tense is generally avoided unless duly complemented with precise temporal estimates. Note however that the description (and eventual implementation) of validation tasks pertain to D5.4.
11/02/2022	For two of the pilot areas, Belgium and Ireland, the comment is that biogeochemical components will not be implemented, and instead, satellite-derived chlorophyll will be used. Again, this change of approach is only briefly mentioned, and it's not described how	Note that not all services modules relies on biogeochemical data. In particular, Service Modules developed by these pilot teams (Belgium and Ireland) do not. Also, the absence of biogeochemical variables aren't detrimental to the deployment of the envisioned service for those pilots. More generally, throughout this revision, the implication of any adjustments in

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

	biogeochemical parameters other than chlorophyll are dealt with. Also, what about the fact this is a forecast model, and the satellite data is historical in nature, plus there will be missing data due to clouds? These multiple changes in the approach are not trivial, and need further explanation in terms of how the Pilots and performance will be affected.	model implementation regarding the deployment/transferability of service modules is now detailed explicitly.

PROPRIETARY RIGHTS STATEMENT

This document contains information, which is proprietary to the FORCOAST consortium. Neither this document, or the information contained within may be duplicated, used or communicated except with the prior written permission of the FORCOAST coordinator.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Executive Summary

This deliverable D3.8 provides a description of all downscaled models being implemented within FORCOAST to provide marine information at a user-relevant spatial scale, and to enable the deployment of Service Modules (SMs) (described in D3.9 and D3.10). The collection of FORCOAST pilot models provides a portfolio of marine information sources with, at least, spatial resolution below 1km and forecast period of three days in all cases.

The present deliverable covers the description of Pilot Models and highlights changes operated since former delivery in D3.7. Mostly, those changes are limited in terms of model engines and spatial domains, and consists of additional validation exercises, setup of operational delivery systems and extension of the forecasting period.

This deliverable marks the achievement of MS8 - “Final version of numerical models ready to run operationally and produce services”.

As an appendix, D3.8 provides a detailed reference list for pilot model data provisions, in order to feed the operational uptake and cloud deployment of the service module post-processings that is being set up within WP4.

Table of Contents

Executive Summary 7

1 Introduction 10

2 Overview 10

2.1 Spatial Domains and Resolutions 10

2.3 State Variables 12

2.4 Model Engines 13

2.4 Operational data distribution 14

3 Pilot Models - Specific Description 15

3.1 Pilot 1 - Portugal 15

3.2 Pilot 2 - Spain 20

3.3 Pilot 3 - Bulgaria 22

3.3.1 General Description 22

3.4 Pilot 4 - Belgium 24

3.5 Pilot 5 - Ireland 26

3.6 Pilot 6 - Denmark 27

3.7 Pilot 7 - Romania 31

3.8 Pilot 8 - Italy 33

4 Conclusion 35

5 References 36

Appendix – Pilot Data Provision 40

List of Figures

Figure 2.1.1: Domains of the FORCOAST Pilot models. 9

Figure 2.1.2 : Spatial resolutions and bathymetry ranges covered by the different FORCOAST models (for some models, spatial resolution varies across the domain). 9

Figure 2.3.1 : State variables and level of operational delivery : at the time of D3.7 10

Figure 2.3.2 : State variables and level of operational delivery : Current status 11

Figure 3.1.2 : LisOCean operational system domain, grid and current bathymetry. The red rectangle indicates the area covered by the nested Longa domain. 16

Figure 3.2.2 : (Pilot 2) Example of sea surface currents and temperature (top), and sea surface salinity and trajectories of several virtual floats (bottom) obtained with the EusKOOS model. 19

Figure 3.6.1: Spatial coverage of the LIMFJORDEN_FORCAST_PHY_01 product. 25

Figure 3.6.2 : (Pilot 6) Model diagram showing the pelagic (green circles) and benthic (brown circles) state variables and associated fluxes (blue boxes) in the ERGOM-DK model. 26

Figure 3.7.1 : (Pilot 7) the three two-way nested domains and bathymetry. 28

List of Tables

Table 2.3.1: Model engines used by FORCOAST partners 12

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

1 Introduction

The objective of D3.8 is to provide a complete description of the downscaled models implemented within the frame of FORCOAST to provide marine information at a scale that is relevant to users.

For completeness, this deliverable reports a full description of the regional models of FORCOAST, even if some setups have remained unchanged since the previous model inventory reported in D3.7. Therefore some descriptions and figures were reported from D3.7, while new sections highlight evolution achieved through the lifetime of the project until the time of reporting of this document. Note that FORCOAST is mostly devoted to the development of downstream services exploiting the marine information provided by local (pilot) models, rather than to development of such models.

2 Overview

2.1 Spatial Domains and Resolutions

Figure 1 provides an European overview, as well as specific maps of the FORCOAST Pilot domains. It illustrates the wide geographical distribution of the FORCOAST pilot cases, in terms of marine conditions: tidal dynamics, presence of large rivers, bathymetry slope, distance and influence from the open ocean and atmospheric regimes. This diversity is precious to the project in the sense that it denotes a consortium expertise covering a large scope of marine and coastal phenomena.

The specifications of FORCOAST models, that were built prior to the project lifetime and following regional specificities, are relatively heterogeneous. The finest spatial resolution (considering embedded models) reaches below 500 m in four of the FORCOAST pilots, and is below 1 km in all cases (Fig. 2). Regarding coastal dynamics, most pilots have their shallower cells above 5 m depth, thus resolving relatively shallow areas, while some (3 pilots) do consider wetting-drying scheme, which is better adapted for coastal simulations in tidally dynamic areas.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

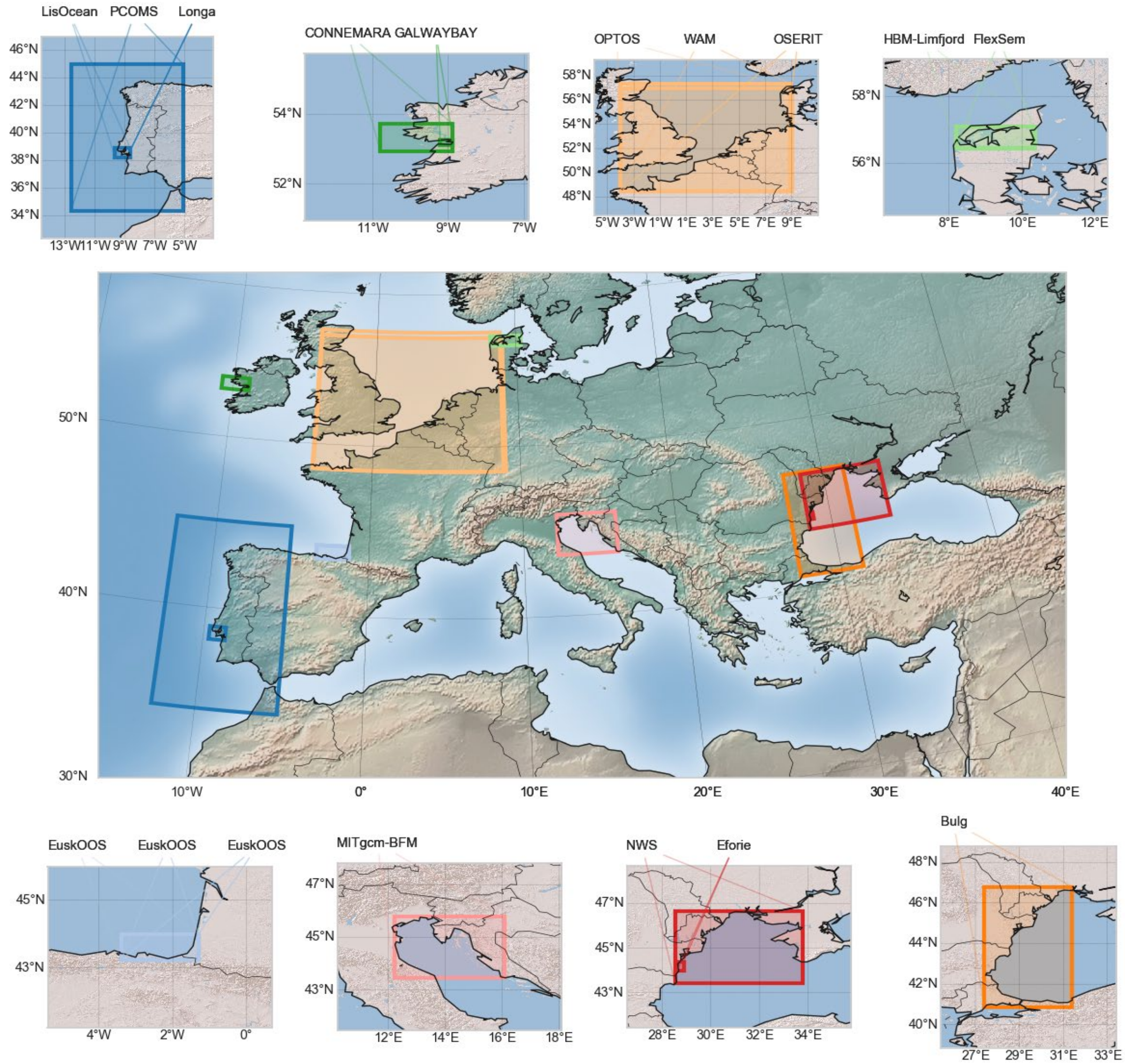


Figure 2.1.1: Domains of the FORCOAST Pilot models.

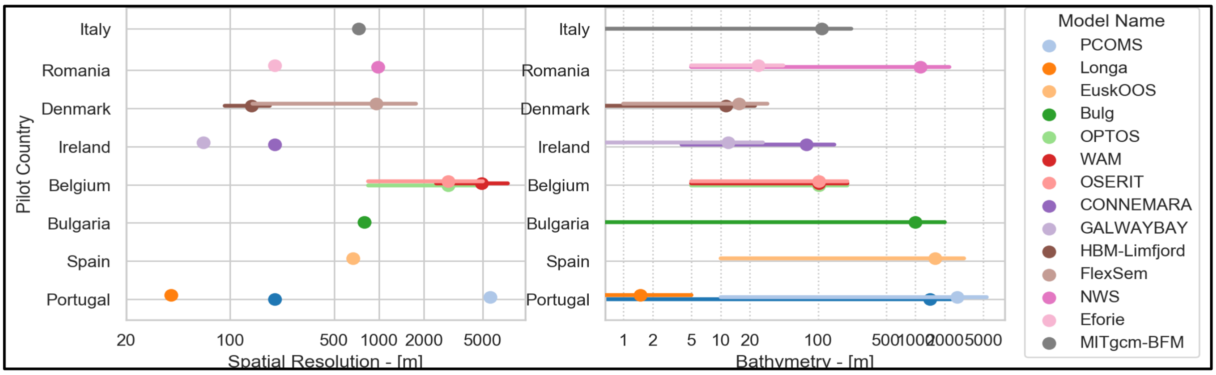


Figure 2.1.2 : Spatial resolutions and bathymetry ranges covered by the different FORCOAST models (for some models, spatial resolution varies across the domain).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

2.3 State Variables

The FORCOAST regional models present an important inhomogeneity in terms of resolved variables. The usual variables of hydrodynamical models (temperature, salinity, currents) are operationally currently available in 7 pilots (Fig. 3). Biogeochemical models are actually operationally available for 3 pilots.

Dispersal modelling modules (used for oil spills, coastal pollution such as bacterial outbreaks, eggs and larval dispersal) are implemented through service modules on a user-case basis, and are thus not reported in terms of operational model marine data production.

Only one pilot (Denmark) provides sea-ice information operationally (it is also the only pilot where this variable is relevant). No pilots actually provide simulations concerning suspended sediment, although some (Ireland and Romania) report dedicated modelling efforts, on a non-operational basis.

Marine information relating to surface waves are operationally available in 4 pilots (as the products provided by the Bulgarian pilot extend over the domain of Romanian Pilot).

To summarize, evolution since D3.7 in terms of model variables consists of additional specific validation exercise for hydrodynamic variables (see Fig. 2.3.1 and 2.3.2)

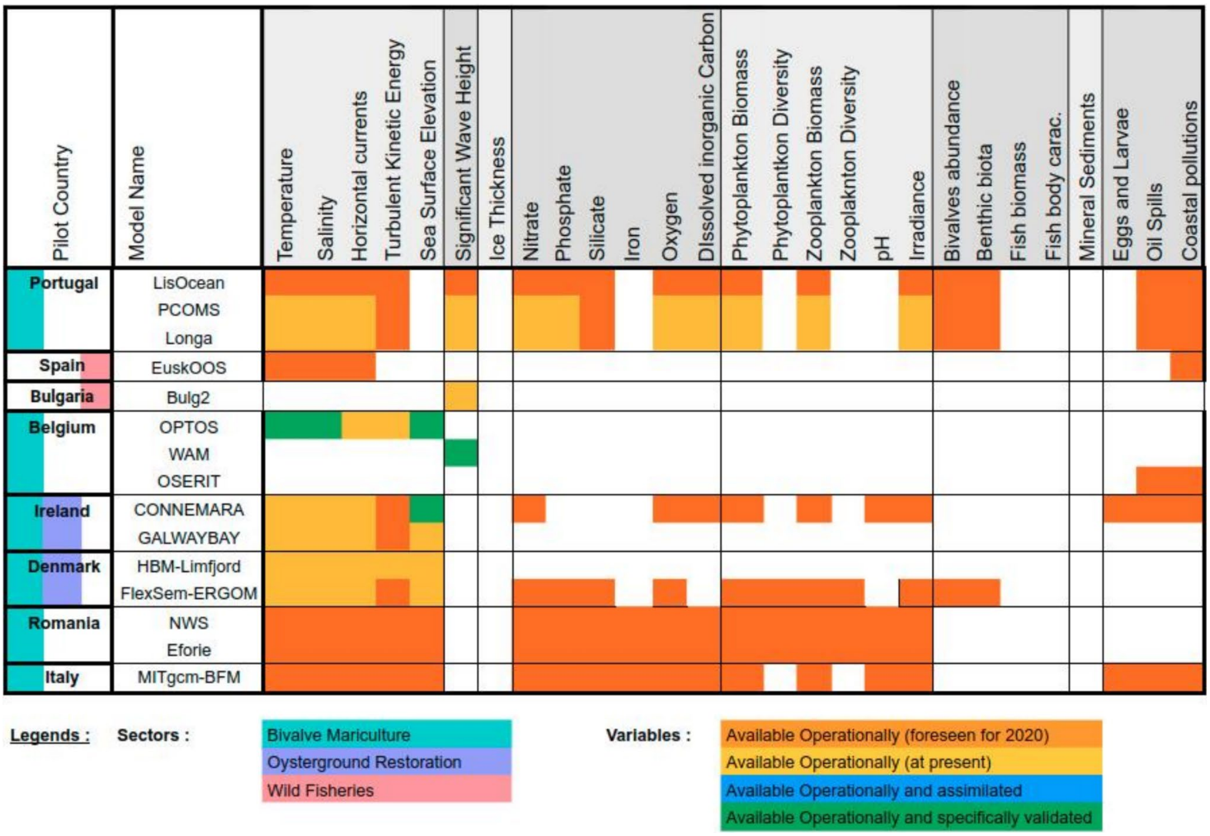


Figure 2.3.1 : State variables and level of operational delivery : at the time of D3.7

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

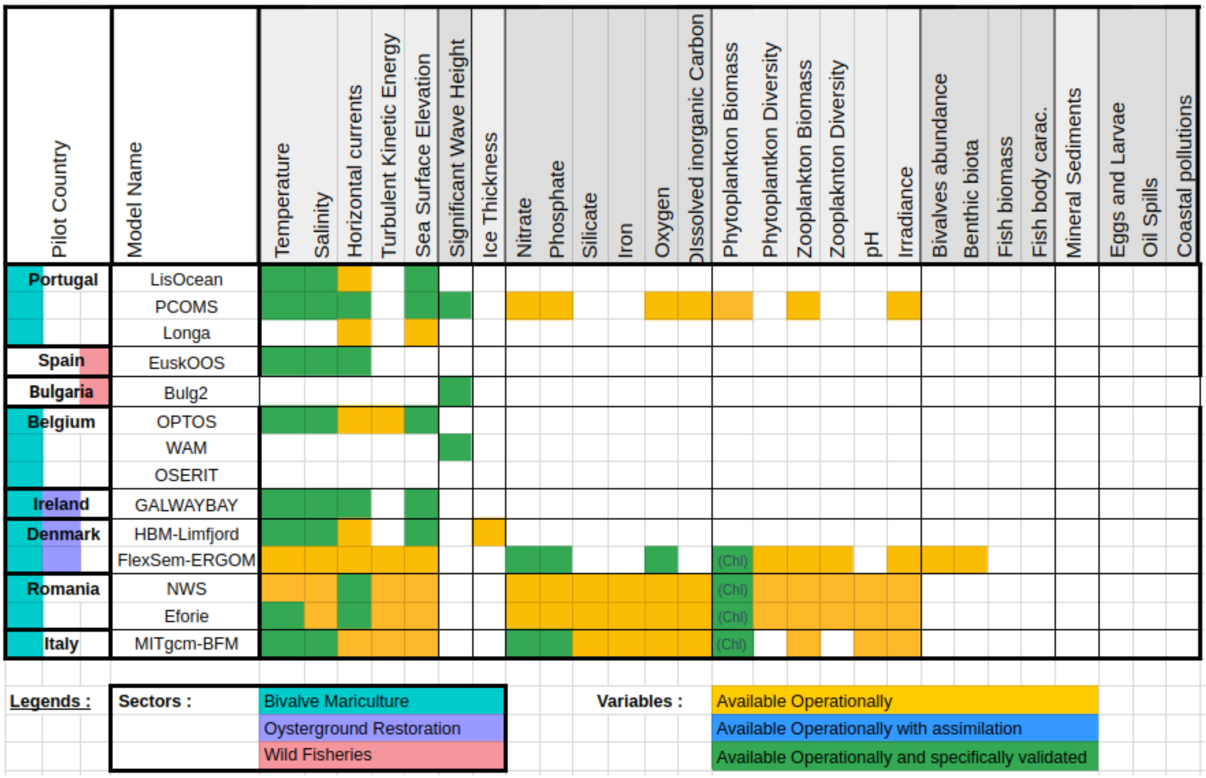


*Figure 2.3.2 : State variables and level of operational delivery : Current status. Captions: **Operationally available**: Data are produced on a routine forecast basis, and a distribution platform is set up (eg. THREDDS) ; **Available Operationally with data assimilation** : The data production involves data assimilation; **Available Operationally and specifically validated** : There is a dedicated section showing validation results for this variables in D5.4, either in forecast or hindcast mode.*

2.4 Model Engines

A large variety of model engines are used amongst the different FORCOAST pilots. Per engine, we mean a given model software. All engines are summarized in Table 1, which provides reference websites or publications. In fact, the only models being used in more than one pilot are used in two pilots only, being those models ROMS (Hydrodynamics and particle drift / dispersal), NEMO (Hydrodynamics) and WAM (Wave). This being stated, the table indicates that the consortium gathers a large expertise in terms of existing marine modelling solutions.

Type	Model Engine	Pilots	Website / Reference
Hydrodynamics	**ROMS**	Spain, Ireland	https://www.myroms.org/
	NEMO	Bulgaria, Romania	https://www.nemo-ocean.eu
	MOHID	Portugal	http://www.mohid.com/
	COHERENS	Belgium	http://odnature.naturalsciences.be/coherens/
	HBM	Denmark	http://ocean.dmi.dk/models/hbm.uk.php
	Flexsem	Denmark	https://marweb.dmu.dk/Flexsem/
	MITgcm	Italy	http://mitgcm.org/

Biogeochem.	**MOHID**	Portugal	http://www.mohid.com/
	ERGOM-DK	Denmark	https://projects.au.dk/memc/models/
	BAMHBI	Romania	https://doi.org/10.1016/j.pocean.2008.01.002 https://doi.org/10.1016/j.ocemod.2016.03.006
	BFM	Italy	http://bfm-community.eu/
Particle Drift / Dispersal	**MOHID**	Portugal	http://www.mohid.com/
	ROMS	Spain, Ireland	https://northweb.hpl.umces.edu/LTRANS.htm
	Ichtyop	Ireland	https://www.ichthyop.org/
	OpenDrift	Bulgaria	https://github.com/opendrift/opendrift/wiki
	NEMO	Romania	https://www.nemo-ocean.eu
	MITgcm -	Italy	http://mitgcm.org/
Waves	**WAM**	Belgium, Bulgaria	https://github.com/mywave/WAM
	WW3/SWAN	Portugal	https://polar.ncep.noaa.gov/waves/wavewatch/manual.v5.16.pdf

Table 2.3.1: Model engines used by FORCOAST partners

2.4 Operational data distribution

A substantial evolution achieved since D3.7 consists of the several implementation of operational data delivery systems (eg. THREDDS or ERRDAP servers), intended to connect the local data produced at pilot level with the Service Module components and transpose the post-processing scripts of service modules (see D3.10) at the cloud level. In dialogue with WP4, each pilot model was asked to describe in a table (Appendix 1), the reference of data access, data formats, grid specifications, data volume, etc. Using a common system of variable name convention (CF 1.7). The purpose of collecting this information systematically, is to facilitate the execution of services modules from the central platform, ie. separating the following steps: Data acquisition from pilot sites, execution of service module post-processing through containerized scripts, display of SM outputs through the central dashboard or notification system.

Appendix 1, thus consists of an overview containing the following columns :

- **Pilot** : Name and contacts of representative modellers.
- **Type :** Model/Remote sensing. The table indeed also collects references for the most appropriate local remote sensing data.
- **Variables :** provided with reference to CF convention standard variable names. A list of such names and definitions is given as in an additional page of the appendix.
- **Access :** Reference (link) towards the data distribution server.
- **Example filename :** One instance of filename. All data are provided in NetCDF files.
- **Variable name :** Variable id used in the netcdf file.
- **Grid file :** filename for grid references, if not included in the data file (ie. “in-file”).
- **Longitude, latitude, depth and time variable name** : as used in the netcdf file.
- **WMS :** In case where a WMS server is directly available.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 870465.

- **Hind cast and Forecast period :** Temporal extensions of the datasets.
- **Domain :** reference for the FORCOAST domains.
- **Grid definition :** regular / unstructured.
- **Data Storage size** : data volume for the file containing the variable
- **Number of time step** : number of temporal layers within a single file.
- **Additional comments**

3 Pilot Models - Specific Description

3.1 Pilot 1 - Portugal

3.1.1 General description

A) The Western Iberia operational model (PCOMS)

The Portuguese Coast Operational Modelling System (hereafter referred as PCOMS) is the operational modelling system that covers the Western Iberia regional ocean being designed to provide an operational solution for the Portuguese continental coast. This system provides operational hydrodynamics and biogeochemical forecasts for the Western Iberia regional ocean since 2009 and 2012 respectively, being probably the first operational model of its kind covering western Iberia. The PCOMS system has been broadly described in previous publications (Mateus *et al.*, 2012; Campuzano, 2018).

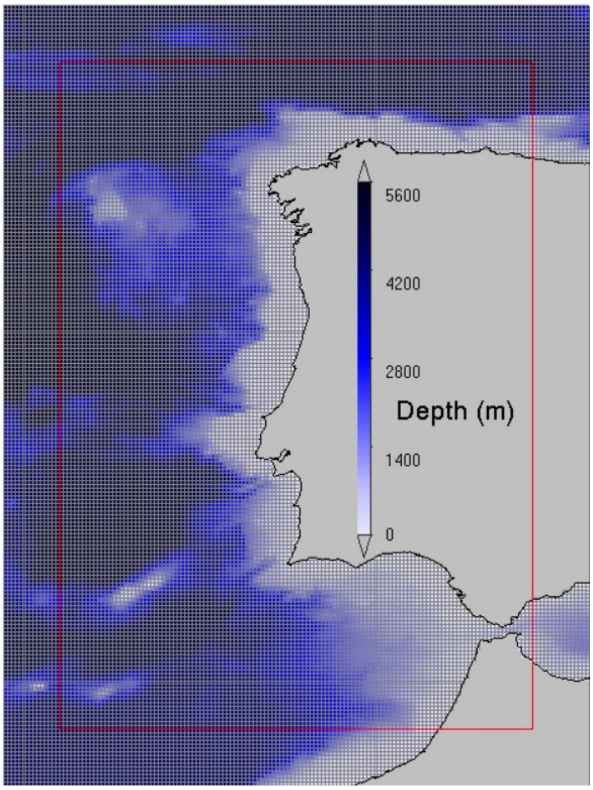


Figure 3.1.1 : PCOMS regional ocean operational system domains, grids and current bathymetry. The red rectangle indicates the outer limit of the Portugal domain

The PCOMS is a 3D full baroclinic hydrodynamic and biogeochemical regional ocean operational model application covering the Iberian Atlantic coast and its adjacent ocean that downscales the Mercator-Océan PSY2V4 (Releases 1-4; hereafter referred as MERCATOR) North Atlantic solution (Drillet *et al.*, 2005). Its performance relies strongly on its core: the MOHID Water model, part of the MOHID Water Modelling System (http://www.mohid.com; Neves, 2013).

The MOHID Water Modelling System is an open source numerical model (https://github.com/Mohid-Water-Modelling-System) which code is continuously improved and updated by the MOHID community. The MOHID Water model is capable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

of simulating a wide range of processes, i.e. hydrodynamics, transport, water quality, oil spills, in surface water bodies (oceans, coastal areas, estuaries and reservoirs).

The PCOMS system is composed of two nested domains: WestIberia (2D) and Portugal (3D), with constant horizontal spatial resolution of 0.06°, covering the Iberian Atlantic coast and its contiguous ocean. The WestIberia domain covers the area limited to the following range of latitudes (33.48 °N, 45.90 °N) and longitudes (4.20 °W, 13.50 °W) resulting in a grid of 207 x 155 cells with maximum depths around 5600 m. The Portugal domain covers the area comprising the latitudes (34.38 °N, 45.00 °N) and the longitudes (5.10 °W, 12.60 °W) resulting in a grid of 177 x 125 cells and maximum depths around 5300 m. The Portugal domain is located centred in the West Iberia domain leaving 15 cells of difference in every direction. Vertically, the Portugal domain uses a hybrid discretisation consisting of a sigma domain with 7 layers from the surface until 8.68 m depth, with variable thickness decreasing up to 1 m at the surface, on top of a Cartesian domain with 43 layers with thickness increasing towards the bottom. The vertical distribution of the Cartesian domain is inspired by vertical discretisation used by the MERCATOR solution that serves as initial and boundary conditions (Drillet *et al.*, 2005). For the vertical turbulent viscosity, the PCOMS model uses the GOTM (General Ocean Turbulence Model) model (http://www.gotm.net; Burchard *et al.*, 1999) coupled in the MOHID model (Ruiz-Villareal *et al.*, 2005).

The WestIberia domain (2-dimensional) is forced on its open boundary only by astronomical tides provided by the FES2014 version of the FES (Finite Element Solution) global tidal model (Carrère *et al.*, 2016). The Portugal domain (3-dimensional) receives the water levels from the WestIberia domain and merges them at the open boundary with the CMEMS Global Ocean 1/12° Physics Analysis and Forecast updated Daily (GLOBAL_ANALYSIS_FORECAST_PHY_001_024).

The PCOMS system downscales the CMEMS Global Ocean 1/12° Physics Analysis and Forecast updated Daily (GLOBAL_ANALYSIS_FORECAST_PHY_001_024) (hereafter referred as CMEMS_PHY) for the West Iberian Atlantic coast and its contiguous ocean. The PCOMS system uses the available properties of the CMEMS_PHYMERCATOR solution to initialize the velocity, water level and temperature and salinity fields. Additionally, those fields are used as open boundary conditions (OBCs) being included by nudging so boundary values do not diverge from the general circulation values imposed at the boundary. This is a common practice in ocean regional models especially for long-term integration (Chen *et al.*, 2013).

Since 2012, the PCOMS is coupled to the MOHID WaterQuality module. This module includes inorganic and organic forms of nitrogen and phosphorus on its dissolved and particulate forms as the source of nutrients. Oxygen, nutrient, phytoplankton and zooplankton concentrations are modified based on the phytoplankton growth, respiration and predation by zooplankton limited by the availability of light and nutrients.

Monthly climatological 3D fields of oxygen, nitrate and phosphate from the World Ocean Atlas 2009 (WOA09; Garcia *et al.*, 2010a and 2010b) are used as initial and boundary conditions, in a similar fashion than the MERCATOR properties. Monthly values are only available for the top 500 meters and 1500 m for oxygen and nutrient concentrations respectively; those values were completed until the seabed using the annual average profile

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Since 2011, the PCOMS model application has been continuously in operation. The forecast application runs daily simulating the previous day, to use the best atmospheric forecast available, followed by a 5-day forecast. On a weekly basis, the model simulates the previous fortnight period with the best solution provided by CMEMS_PHY. The readiness, reliability and availability of the PCOMS results allow development of downstream services and they are accessible through the MARETEC Thredds Data Server (http://thredds.maretec.org).

B) The Lisbon Metropolitan Area Operational Model (LISOCEAN)

Typical downscaling techniques consist of running simultaneously nested models. In those cases, the running time is defined by the most downstream model which usually has the smallest time step and is the slowest model. In order to surpass this difficulty, a delayed mode (offline) technique has been designed to provide boundary conditions to the local models at the open ocean boundaries. The Window Downscaling Technique consists in saving a 3D window of model results from a Regional model application with a high temporal resolution, around 900 seconds, able to represent the main processes coming from the open ocean (i.e. the tide signal) that serve as boundary conditions to other coastal and estuarine models with higher horizontal resolution. Afterwards, in delayed mode the local model is implemented as a nested model of the window of results. The described technique allows the local model to run independently, saving running time and reducing redundancy, while improving results. This technique also does not increase the running time of the upstream models and allow running several downstream models at the same time. The window downscaling technique is implemented in several estuaries in the Portuguese coast, including the Tagus estuary, which is also able to provide boundary conditions to even more refined local models (i.e. Campuzano *et al*., 2012).

The LISOCEAN model application :

This model application includes both the Tagus and the Sado estuaries as well as the ocean region covering as far as 120 bathymetric isoline and the Tagus and Sado submarine canyons. Its main objective is to provide high resolution hydrodynamics and biogeochemical information on these highly influenced areas in regards to socio-economics, one of which including a FORCOAST Pilot Areas - Sado estuary.

The current implementation of the LISOCEAN domain covers the area limited to the following range of latitudes (33.23 °N, 38.96 °N) and longitudes (8.66 °W, 9.65 °W) resulting in a grid of 285 x 355 cells with maximum depths around 2800 m. Vertically, a hybrid discretisation consisting of a sigma domain with 7 layers from the surface until 8.68 m depth, with variable thickness decreasing up to 1 m at the surface, on top of a Cartesian domain with 37 layers with thickness increasing towards the bottom has been implemented, following the same discretization of the PCOMS domain.

Although other boundary conditions have been tested, two modelling strategies are implemented for the FORCOAST project, running the models operationally in 2D and 3D versions, the 2D version of the model allows an extended forecast of the tides, including the meteorological and river effect. The 3D LisOcean open boundary conditions consist of a Flather radiation scheme and a relaxation scheme towards the PCOMS model. This 3D version better resolves the baroniclinc circulation. The 2D application has been put into place since CMEMS forecasts are limited to 10 days while to provide the service the aquaculture demands we need a 14-day forecast that includes the atmospheric effect and a year forecast for long-term planning.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Atmospheric conditions are implemented using the IPMA-provided AROME model implementation with 2.5 km grid resolution and a temporal resolution of 1h with forecast of 48 h. Followed by WRF computed at IST with grid and temporal resolutions of 3 km and 1 h respectively, with a forecast of 3 days, and followed by NCEP operational Global Forecast System 0.25 Degree (National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce. 2015) onwards. In the land boundary, the model is forced by near real time river data from the Sado and Tagus rivers obtained from the EMODnet physics portal (https://portal.emodnet-physics.eu/) and MOHID Land modelled river temperature. This domain also generates a window of results for the Longa domain. This window covers the entire region of the Longa domain with a temporal resolution of 720 s.

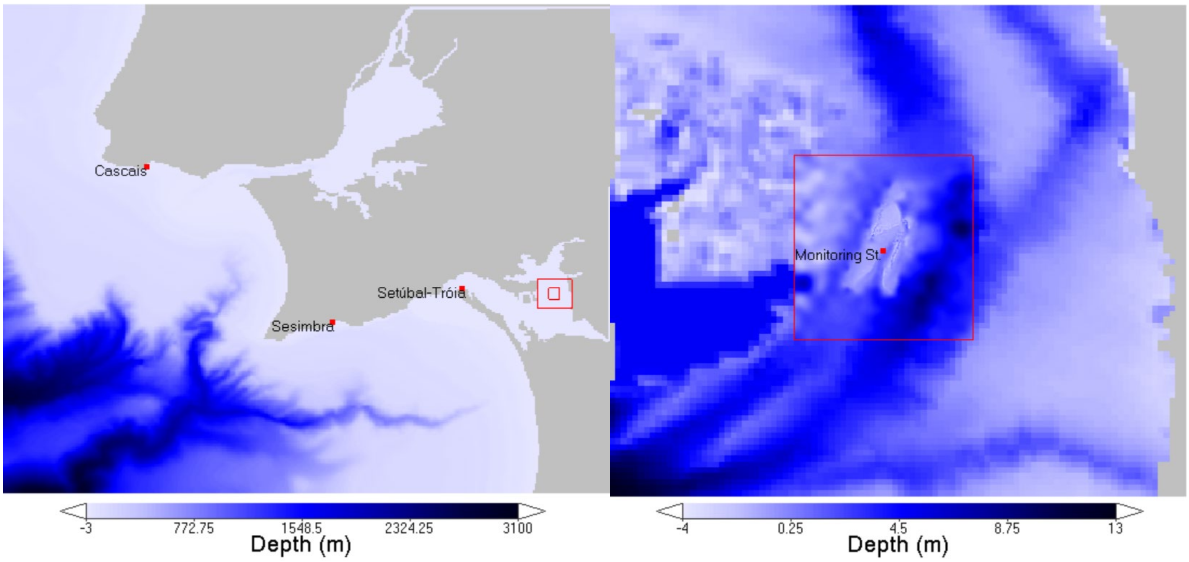


Figure 3.1.2 : LisOcean operational system domain, grid, bathymetry and location of the tidal gauges used for validation (left). The red boxes indicate the areas covered by the nested Longa domains. Longa 40- and 8- m domains (Right) indicating the location of the monitoring area.

C) The Aquaculture Production Area (Longa)

To improve the solution provided to the aquaculture site located in the "Longa" island inside the Sado estuary, a nested domain with 40 m grid resolution was implemented, covering the area limited to the following range of (38.476 °N, 38.502 °N) and longitudes (8.739 °W, 8.761 °W). Vertically, a hybrid discretisation consisting of a sigma domain with 7 layers from the surface until 8.68 m depth, with variable thickness decreasing up to 1 m at the surface, on top of a Cartesian domain with 3 layers with thickness increasing towards the bottom has been implemented, following the same discretization of the LisOcean domain. An 8-meter higher resolution domain was implemented for the Longa area, respectively.

Its open boundary condition is set by the LisOcean domain where it is nested, and includes the Flather radiation scheme together with a flow relaxation scheme with a temporal decay of 720 s. Atmospheric forcing is provided by the same solution as that of the LisOcean domain - the IPMA's AROME implementation for the Portuguese coast with 3 km grid resolution and hourly fields.

The numerical grids were populated using bathymetric information derived from the EMODnet Hydrography portal (http://www.emodnet-hydrography.eu) with local information including some bathymetry studies provided by ExporSado for the Longa aquaculture production area.

3.6.7 Overview of validation efforts

The validation of the LisOcean model has been based on the following observation so far:

- Tide gauges at Cascais, Sesimbra and Setubal-Troia tidal gauges (See Figure 3.1.2).
- The monitoring station at the ExporSado Longa production site.
- Portuguese Environmental Agency historical campaigns in the Sado Estuary.
- Monitoring campaigns from other projects.
- Remote sensing Sea Surface Temperature products.

The database for validation has been completed and details of this validation work will be presented at D.5.4 Final coordinated pilot model evaluation report.

3.1.2 Modification since D.3.7

- Realistic river discharges have been developed and implemented for the Sado estuary. Near real time reliable flow data was not available near the Sado river mouth. For this reason, realistic river flow was derived based on the closest data available, combining water levels and flow curve from neighbouring stations with satisfactory results. This development was co-implemented by CoLAB +ATLANTIC and near real time and historic river flow for the Sado river is made available to the general public through the EMODnet physics portal.
- Two model applications were developed during this time using the LisOcean grid. A model forced only with FES2014 tides so we can provide long forecasts of tidal conditions, and another simple model application that is able to run daily 10 days forecasts including the meteorological conditions effects. With this set of model applications, we can support the different temporal needs required by ExporSado in an operational way.
- The meteorological forcing of the model was adapted to receive inputs with the following preference: IPMA AROME 2.5 km (for the next 48h), WRF from IST 3 km (until 5 days forecast), GFS 25 km (up to 15 days forecast). The application now switches from one meteorological forcing to the next available following this order of preference. This set up allows us to benefit from the highest possible spatial resolution and the longest meteorological forecasts. Currently, we update our GFS forecast daily including the next 14 days. The CMEMS Global physics model is limited to 10 days so it can limit our forecast limit following a downscaling method.
- In the land boundary, the model is forced by near real time river data from the Sado and Tagus rivers obtained from the EMODnet physics portal (https://portal.emodnet-physics.eu/).
- New 8-m resolution domain was designed for the “Longa” production area
- Installation of the monitoring station is almost completed which would help in the validation process.
- PCOMS open boundary conditions moved from MERCATOR (Drillet *et al.*, 2005) to CMEMS_PHY.
- Tidal forcing moved from FES2004 (Lyard *et al.*, 2006) to FES2014.

3.1.3 Operational distribution

Output of the hydrodynamic models can be found on the MARETEC THREDDS server :

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 870465.

http://thredds.maretec.org/thredds/catalog/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/catalog.html

Atmospheric variables resulting from WRF integration are available at :

http://thredds.maretec.org/thredds/METEO_Catalog.html

Specifications on data structure and volume relevant to services modules are provided in Appendix 1.

3.2 Pilot 2 - Spain

3.2.1 General description

The Regional Ocean Modeling System (ROMS) is the hydrodynamic model used to estimate current, temperature and salinity fields in the southeastern Bay of Biscay. ROMS is an evolution of the S-Coordinate Rutgers University Model (SCRUM), as described by Song and Haidvogel (1994). The numerical aspects of ROMS have been described in detail by Shchepetkin and McWilliams (2005). Here we use the ROMS_AGRIF version developed at IRD (Debreu et al., 2012). ROMS has been used to model the water circulation in the study area (e.g., Ferrer et al., 2007, 2009, 2015; Ferrer and Caballero, 2011; Caballero et al., 2014; Laiz et al., 2014; and Legorburu et al., 2015).

The ROMS domain used in the operational system covers the southeastern Bay of Biscay, extending from 43.24º N to 44º N and from 3.4º W to 1.3º W, with a mean horizontal resolution of 670 m. Vertically, the water column is divided into 32 sigma-coordinate levels; these are more concentrated within the surface waters, where most of the variability occurs. The bathymetry was obtained from the European Marine Observation and Data network (Vasquez et al., 2015). This bathymetry was smoothed to ensure stable and accurate simulations (Haidvogel et al., 2000).

The hourly atmospheric forcing inputs used in ROMS are provided by two agencies: MeteoGalicia and Euskalmet (meteorological agency of Galicia and the Basque Country, respectively). These data (with a 12-km and 1-km horizontal resolutions, respectively) are obtained using the Weather Research and Forecasting model (WRF). A more detailed description of this model can be found in Skamarock et al. (2005). The WRF variables used in ROMS are the following: wind and air temperature at 10 and 2 m above sea level, respectively, precipitation rate, relative humidity, and long- and short-wave radiation fluxes. The air-sea heat and momentum fluxes are calculated using the bulk formulae of Fairall et al. (1996, 2003). These two different atmospheric forcing inputs are generating two different ROMS outputs.

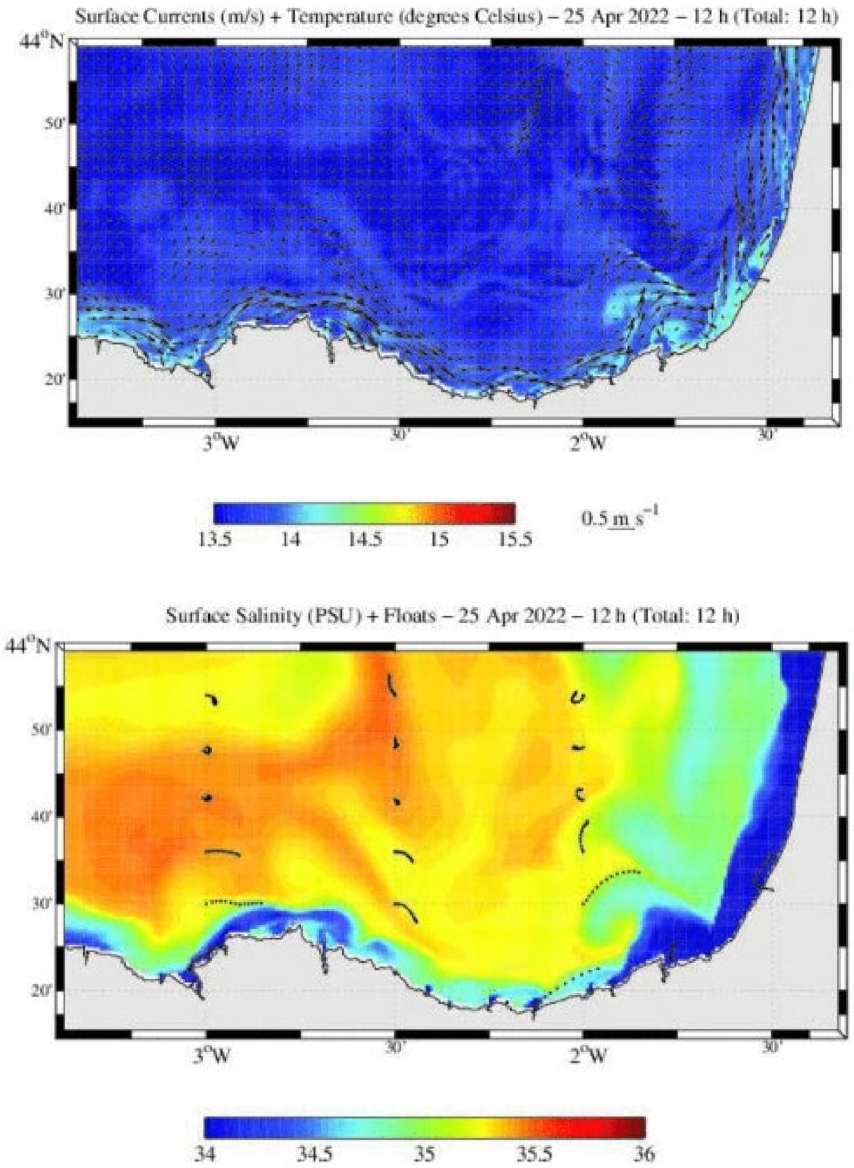
At present, the conditions applied to the open boundaries are estimated using the outputs obtained by the Iberian-Biscay-Irish Monitoring and Forecasting Center, IBI-MFC, based on the Nucleus for European Modelling (NEMO). From these outputs, we use the hourly averaged fields for the following variables: velocity, temperature, salinity and sea surface height. These fields are used only at the boundary points to reduce the size of the input files with information of 3D variables. Everyday ROMS is initialized in the whole domain with the updated data from NEMO, which include assimilation data of previous days. The objective of this initialization is to correct the possible deviations of ROMS due to the non-use of data assimilation.

The ROMS simulation includes the last daily averaged freshwater discharges (real-time data) from the following rivers: Adour, Barbadun, Nervion, Butron, Oka, Lea, Artibai, Deba, Urola, Oria, Urumea, Oiartzun and Bidasoa. With the aforementioned information, we obtain 96-h forecasts for the study area. The online Lagrangian particle tracking module existing in ROMS is also activated and is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

generating forecasts of the 96-h evolution of several virtual particles released in the study area at high-temporal resolution (one minute). Several floats are located at the sea surface to forecast the drift of harmful algal blooms, especially towards the Mendexa region (a pilot aquaculture farm), marine litter or other type of pollution, and for search and rescue applications. Recently, the French version of the ROMS model has been updated and its new name is CROCO (Coastal and Regional Ocean COmmunity model, https://www.croco-ocean.org). Some examples of forecasts obtained with CROCO (sea surface currents and temperature, and salinity and float trajectories) and a satellite image on 25 April 2022 are shown in Figure 4.

The storage memory requirement for the 3D and hourly outputs (current, temperature and salinity fields) for one day of forecast is 0.58 Gb. The webpage to see the forecasts, only for the next four days, is located at http://www.euskoos.eus/ and the thredds with the netcdf outputs is located at http://thredds.euskoos.eus. Here the files with format "date_exp.nc" (for example, date = 20210625) contain the surface hourly data obtained with ROMS and the files with format "date_fronts_exp.nc" contain the sea surface temperature fronts estimated from the ROMS temperature fields.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

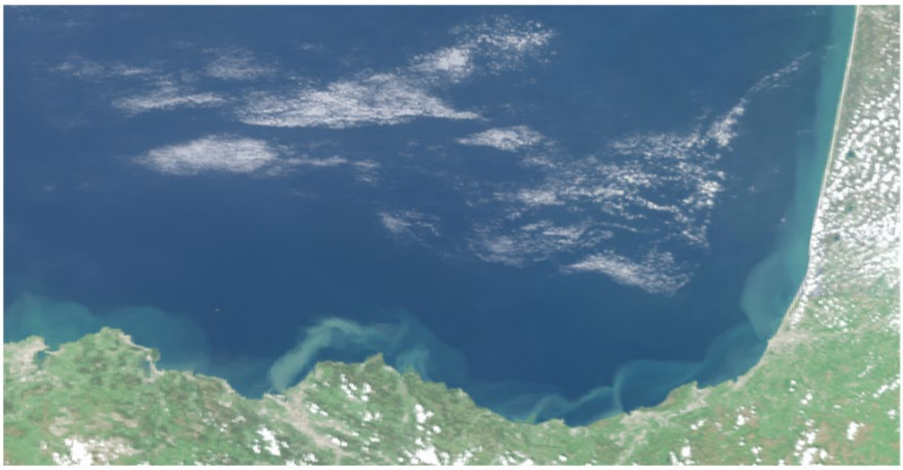


Figure 3.2.2 : (Pilot 2) Example of sea surface currents and temperature (top), sea surface salinity and trajectories of several virtual floats (middle) obtained with the EusKOOS model and satellite image (bottom) on 25 April 2022.

3.6.7 Overview of validation efforts

The CROCO implementation was validated in forecast mode on the basis of subsurface temperature, salinity and currents (fixed buoy, D5.4 Sect. 3.2.1.1), surface currents (High-frequency radar data, D5.4 Sect 3.2.1.2). Process-oriented validation (i.e. targeting front properties) were based on remote-sensing sea surface temperature products (D5.4 Sect. 3.2.2).

3.2.2 Modification since D.3.7

No significant changes reported, except from the adoption of last updates of the CROCO community model.

3.2.3 Operational distribution

Operational data provision are provided through the following THREDDS server

http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html

Specifications on data structure and volume relevant to services modules are provided in Appendix 1.

3.3 Pilot 3 - Bulgaria

3.3.1 General Description

The Pilot 3 involves implementation of a service in support of wild fishery consisting of three major components, the results of which will be available to users. The service will cover the EEZ zone of Bulgaria and Romania.

A) Implementation of a layer with additional information on the upwelling events in the region of interest, based on the products coming from CMEMS.

The classic oceanographic techniques are used evaluate the Ekman transport and the upwelling in the chosen area. The needed information for the estimation comes the operational CMEMS Black Sea physical modelling system (marine.copernicus.eu). The system is based on the Nucleus for European Modelling of the Ocean v.3.6 (NEMO, Madec at al., 2012). The model horizontal grid resolution is 1/27 x1/36 (~3 km) and 31 z-levels with partial steps and the bathymetry is based on the GEBCO data (www.gebco.net). The assimilation is performed by a three-dimensional variational data assimilation system (3DVAR) that ingests all hydrographic profiles (mostly autonomous profilers ARGO), sea level anomaly data from available altimetry missions and sea surface temperature measurements retrieved from infrared sensors on-board polar-orbiting satellites. The state variables used in the upwelling definition is sea surface temperature and currents from the surface up to the 100 m depth. These variables are regularly monitored by the operational CMEMS team and their quality is evaluated in the relevant Quality Information Document (CMEMS-BS-QUID-007-001).

B) Implementation of a nested wave model

The wave products are generated using a WAM Cycle 4.6.2 3 km Black Sea model. WAM is based on the spectral description of the wave conditions in frequency and directional space at each of the active grid points of a chosen model area. The energy balance equation, complemented with a suitable description of the relevant physical processes is used to follow the evolution of each wave spectral component. A full description is given by the WAMDI group (1988), Komen et al. (1994), Günther et al. (1992), Janssen (2008) and Bidlot et al. (2007) Staneva et al. (2019).

The basin-scale WAM runs on a model grid situated between 40°51’36” N to 46°48’15” N and 27°22’12” E to 41°57’45” E, with a spatial resolution of about 3 km. It calculates the two-dimensional energy density spectrum at each of the 44699 active model grid points in the frequency and directional space. The solution of the energy balance equation is provided for 24 directional bands at 15° each, starting at 7.5° and measured clockwise with respect to true north, and 30 frequencies logarithmically spaced from 0.042 Hz to 0.66 Hz at intervals of $\Delta f/f = 0.1$. The wave model takes into account depth refraction and wave breaking and is driven by the one-hourly analyzed ERA5-U10-wind fields (spatial resolution 0.25°*0.25°) that are generated by the atmospheric IFS model of the ECMWF. Starting in 2002, the setup (BLKSEA_REANALYSIS_WAV_007_006) includes a continuous data assimilation into the wave model fields using satellite data (wind speed and significant wave height) recorded by the radar altimeters of Jason-1 (2002/01-2013/06), Jason-2 (2013/06-2019/02) and Jason-3 (2019/02-2019/06).

For the Western Black Sea a downscaled high-resolution model is implemented, using at the open boundary the spectral information derived from the basin-scale CMEMS Black Sea Model. The spectral information is extracted at each boundary grid point. The resolution of the western Black Sea wave model is 1 km. The geographical coverage of the nested western Baltic Sea area is: 40.87083 S ==> 46.80416 N and 27.41250 W ==> 31.42083 E.

In addition to the standard CMEMS variables for the Black Sea case study new information is requested for the fisheries, namely extreme characteristics (50th, 95th and 99th percentiles) as well as maximum wave high and crest (Hmax and Cmax, Benetazzio et al, 2018).

The SWH variable from the nested NW wave model is validated against the available satellite data as regular in-situ observations are lacking in the area.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 870465.

3.6.7 Overview of validation efforts

All CMEMS satellite measurements that are available for the entire two-year time period (Sentinel-3a, Sentinel-3b, Cryosat-2, SARAL/Altika, Jason-3, CFOSat, and HaiYang-2b; product WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001) have been used to compare the significant wave height with the corresponding wave model results in hindcast mode (cf. D5.4 Sect. 3.3.1).

3.3.2 Modification since D.3.7

No significant changes reported.

3.3.3 Operational distribution

No operational data distribution system is scheduled for this pilot.

3.4 Pilot 4 - Belgium

3.4.1 General description

OPTOS is the chain of hydrodynamic models used to estimate current, temperature and salinity fields in the Southern North Sea and Eastern English Channel. This model is based on COHERENS (COupled Hydrodynamical Ecological model for REgioNal Shelf seas), a multi-purpose modelling system based on a 3D numerical hydrodynamical model. COHERENS is available to the scientific community as a free and well-documented open source code (http://odnature.naturalsciences.be/coherens/).

WAM is the model used to predict directional spectra along with wave properties such as significant wave height, mean wave direction and frequency, swell wave height and mean direction, and wind stress fields corrected by including the wave induced stress and the drag coefficient at each grid point at chosen output times. The WAM model is a 3rd generation model which integrates the basic transport equation describing the evolution of a two-dimensional ocean wave spectrum without additional unplanned assumptions regarding the spectral shape. There are three explicit source functions which describe the wind input, non-linear transfer and whitecapping dissipation. There is an additional bottom dissipation source function and refraction terms are included in the finite-depth version of the model. The model runs on a spherical latitude-longitude grid.

The so-called observations are actually fetched from the Copernicus Marine Environment Monitoring Service (CMEMS) programme. Mean error, coefficient correlation and root mean square error are used to assess model performance.

Physical models are coupled with two Lagrangian transport model:

- OSERIT, already implanted in forecast, is a 3D oil drift and fate model accessible through a user-friendly web application. Complex, real-life scenario-based simulations can be setup to fit a wide range of emergency situations that might arise at sea.
- The larval transport model LARVAE&CO (Lacroix et al., 2013) was developed to assess flatfish larval dispersal, recruitment at nurseries and connectivity between spawning grounds and nurseries (Barbut et al., 2019) as well as the impact of climate change on sole recruitment and connectivity in the North Sea (Lacroix et al. 2018). This model has also been used, after some adaptations to other species such as blue mussels and flat oysters, to assess for instance the impact of artificial hard substrates on marine organism's dispersal (project UK-INSITE-UNDINE2), or the possibility of oyster bed restoration (BE-Oyster restoration project3). The

model has not been validated yet due to lack of data. Statistical summary of this hindcast model will be used to predict arrival on spat in the farm.

The models output many parameters describing the physical state of the sea and the wave energy distribution. The observations are actually fetched from the Copernicus Marine Environment Monitoring Service (CMEMS) program. Only a subset of parameters are provided in the observations database (Sea Level; Sea Surface Temperature; Sea Surface Salinity; Significant Wave Height; Zero Up-crossing Frequency) and are used to assess model performance in 21 station by using Mean error, coefficient correlation and root mean square error.

3.6.7 Overview of validation efforts

The observations selected to validate the model in hindcast mode are fetched from the Copernicus Marine Environment Monitoring Service (CMEMS) programme. Mean error, coefficient correlation and root mean square error are used to assess model performance at the NOS (North Sea Shelf) and BCZ (Belgian Coastal Zone) scale.

The sea level simulations were evaluated in hindcast mode against tidal gauge data. Simulations are globally very efficient, with ratio close to 1, and high correlation (D5.4 Sect. 3.4.1.1). Sea surface temperature (D5.4 Sect. 3.4.1.2) and salinity (D5.4 Sect. 3.4.1.3) were compared to in-situ station data, and discussed in details w.r.t to the different spatial scales. Significant Wave Height simulations are compared to in-situ platform data (D5.4 Sect 3.4.1.4). As a general rule, there is no clear seasonal tendency in the time series of the significant wave height error. The biases, RMSE and correlations are stable across the seasons. The average correlation of simulated Significant Wave Heights with respect to the observations is 0.885 while the average bias is 0.109.

The forecasting skills of the model's suite are documented in the multi-model ensemble forecasting skill assessment, available from the website of NOOS (http://noos.eurogoos.eu/, see examples in D5.4 Sect 3.4.2). Finally, further process-oriented validation efforts were dedicated to the seasonal variability of the sea surface temperature in the BCZ area (D5.4 Sect. 3.4.3).

3.4.2 Modification since D.3.7

The biogeochemical as described in the deliverable D3.7 will not be implemented in the project. The use of satellite data to assess chlorophyll concentration is more relevant in support of farming activity.

There are no other changes on the model since the deliverable D3.7 .

3.4.3 Operational distribution

The complete list of physical variables produced by the model are accessible online on https://erddap.naturalsciences.be/erddap/index.html. That regroups physical variables from the hydrodynamical model (as current velocity, sea surface elevation, salinity or temperature) and from the wave model (waves height, period, direction). Data are available for a 5 years period with an hourly on the model grid and for a 10 years period with a 10 minutes at 73 stations of the North Sea (mainly located on the belgian coastal zone). Data are updated daily with a 5 days forecast. All this data are compliant with the INSPIRE regulations on metadata.

Specifications on data structure and volume relevant to services modules are provided in Appendix 1.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

3.5 Pilot 5 - Ireland

3.5.1 General description

The hydrodynamic model is the Galway Bay model, which has been developed based on a ROMS offline nesting application inside the Connemara Operational model. It is a refinement of the latter by a factor of three, resulting in 336 x283 grid cells and a horizontal resolution of less than 70 meters. It covers the eastern and innermost part of the Galway Bay and has 8 vertical layers. Time series of water levels, 2-D and 3-D momentum, temperature and salinity are provided every hour.

Surface forcing is obtained from the hourly 0.1º ECMWF atmospheric fields. At the open boundaries, clamped boundary conditions have been imposed for 3-D momentum and tracers, whilst a combination of Chapman and Flather conditions have been applied for the free-surface and the barotropic velocity. Heat fluxes are calculated from the bulk formulae and surface freshwater fluxes are obtained from the prescribed rainfall rates and the evaporation rates computed by the model. A wetting and drying scheme has been introduced to allow for proper representation of intertidal areas. Near real-time freshwater inputs from the Corrib, Clarin and Dunkellin rivers have been added to the model, where water level data is obtained from the Office of Public Works (OPW). Moreover, freshwater inputs from a Submarine Groundwater Discharge (SGD) occurring at Kinvara Bay have been added from a karst hydrogeological model developed by researchers from Trinity College Dublin.

3.6.7 Overview of validation efforts

The validation of the Galway Bay model has been based on the following observation platforms so far:

1. ADCP moorings providing ocean current time series for a period of 2-3 months in summer 2018.
2. A tide gauge at Galway Port.
3. Temperature and salinity time series from moorings located at Kinvara and Killeenaran.
4. CTD profiles taken from surveys the 18th of May, 18th of August and 5th of November 2021.

Details of this validation work will be presented at D.5.4 Final coordinated pilot model evaluation report.

3.5.2 Modification since D.3.7

- The biogeochemical module for the Connemara Operational model as described in deliverable D.3.7 will not be implemented in FORCOAST. Remote sensing (e.g. CMEMS product **OCEANCOLOUR_NWS_BGC_HR_L4_NRT_009_209**) data for assessing chlorophyll concentration has been determined a more suitable product in support of the farming industry in the bay. In Galway Bay, Service Module A3 Prospection for New Sites will be applied to determine the suitability of oyster growth in different areas throughout the bay. Conversations with stakeholders have revealed that, in order to assess optimal areas for oyster development, the main parameters that should be taken into consideration are four: temperature, food availability, sediment resuspension and, most importantly, salinity. Temperature and salinity will be derived from the oceanic model. Chlorophyll-a concentration can be used as a proxy for food availability. Chlorophyll-a concentration and sediment resuspension can be determined more reliably from remote-sensing observational platforms. Of course, biogeochemical models have the advantage of providing forecasts and not being affected by clouds. However, forecasts are not of interest for this application: only long-term,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

climatological data is needed for SM-A3 to assess the growth suitability. In addition, a reliable biogeochemical model in the bay would require: a. periodic samplings of the nutrient concentration from the multiple freshwater sources in the bay, and b. a thorough understanding of the sediment composition of the seabed. Since these conditions to develop a reliable biogeochemical model are not met, remote-sensing observations should be regarded as more appropriate for this application.

- Accuracy of freshwater inputs into the model has been improved. Instead of using monthly or long-term averages, real-time data based on water level measurements are being used not only for the Corrib River, but also for the Clarin and Dunkellin rivers, which are particularly important given their proximity to the farming areas in the bay. These water level measurements are provided by the Office of Public Works (OPW). In addition, in the early stages of development of the model, a constant annual average flux of 12 m^3/s was being used for simulating the SGD at Kinvara Bay. Now, after collaboration with researchers from Trinity College Dublin, a daily climatology (based on a 2007-2019 time series) for the SGD is available, thus making it possible to reproduce the seasonal cycle. This flux is obtained from a hydrogeological model based on the water level of turloughs to the south of Galway Bay.
- High sedimentation rates can increase oyster mortality. CMEMS remote sensing product **OCEANCOLOUR_NWS_BGC_HR_L4_NRT_009_209** can be used to derive sea water turbidity and the mass concentration of suspended matter in the bay as well. **The choice of using remote-sensing data instead of models is explained above.**

3.5.3 Operational distribution

Model data (temperature, salinity, u, v, w, sea level) is available from the thredds server at

http://milas.marine.ie/thredds/catalog.html

3.6 Pilot 6 - Denmark

Two systems are implemented in the Danish pilot - the HBM and Flexsem systems - which are described independently below.

3.6.1 General description- HBM

The circulation model HBM is used in the two-way nested operational configuration for hindcast simulations and in the single domain, stand alone model configuration using CMEMS operational products as a forecasting model. HBM model and configuration have been continuously developed by DMI (Danish Meteorological Institute) since 2000 (She et al., 2007; Berg and Poulsen, 2012; Murawski et al., 2021).

The HBM forecasting model has been set-up as a single domain model covering the Limfjord: longitude 8.13-10.32 °E, 56.46-57.11 °N in regular longitude and latitude grid. Wet boundary conditions are derived from the CMEMS North West Shelf product NWS MFC in the West: NORTHWESTSHELF_ANALYSIS_FORECAST_PHY_004_013 (updated once daily) and CMEMS BAL MFC products in the East: BALTICSEA_ANALYSISFORECAST_PHY_003_006 (updated twice daily). Both marine forecasting centers (MFC) provide hourly instantaneous values for salinity and temperature, and 15 min. data for sea surface height. Meteorological forcing is provided by the DMI-HARMONIE model with approximately 2.5 km horizontal resolution. The atmospheric forecast is updated 4 times per day. River runoff is provided by the Swedish E-Hype model.

The HBM hindcast model uses the same model configuration in the Limfjord area, but is 2-way nested into DMI's operational model configuration for the North Sea, Baltic Sea and the transition zone. The reason for setting it up the hindcast model in a nested model is the low, monthly time resolution of the CMEMS NWS MFC and BAL MFC reanalysis data sets, used for boundary forcing. Boundary forcing in hourly time resolution is required to resolve the high frequent dynamic and the in the Limfjord.

The Limfjord configuration uses a regular horizontal grid in latitudes and longitudes, with a resolution of about 1/10 nautical miles (lat: 1/600 degrees; lon: 1/360 degrees). The grid is a staggered Arakawa C-grid. The dataset of the scalar variables are centered in the T point of the grid; at the grid cell node. The velocity components in the corresponding physical reanalysis are located half-way between adjacent grid cell nodes on the face of the grid cell in the respective direction. That is, the components of the velocity vector (u, v) have spatially staggered locations.

VARIABLE	GRID	LON MIN	LON MAX	LAT MIN	LAT MAX	XPOINT	YPOINT
All scaler variables	S, T, U, V, SSH, ice	8.126°E	10.324°E	56.464°N	57.113°N	780	390

Domain coverage and vertical levels : The product domain is displayed in Fig. 2. The grid type is on a regular latitude-longitude projection.

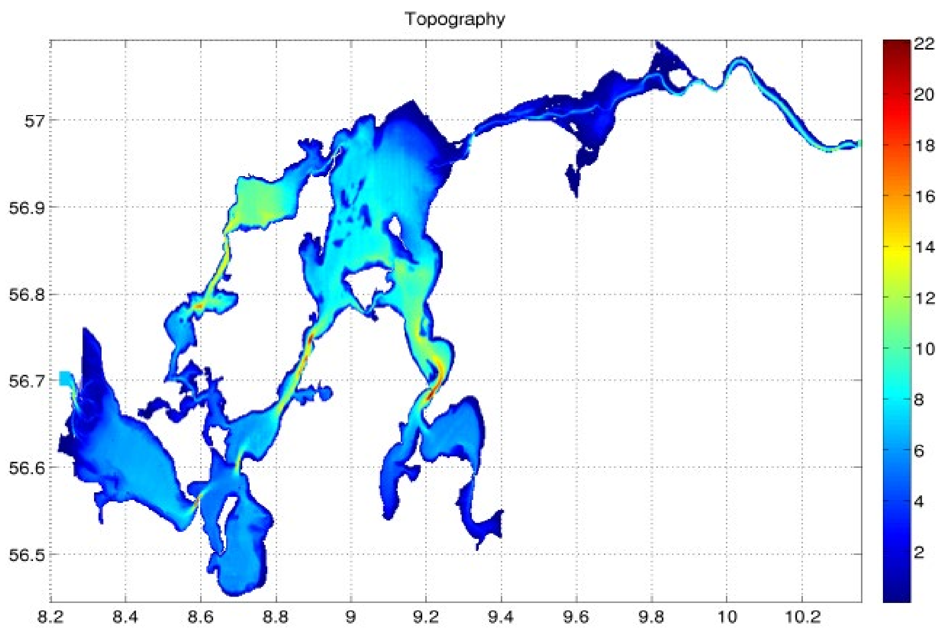


Figure 3.6.1: Spatial coverage of the LIMFJORDEN_FORCAST_PHY_01 product.

The model has 23 native vertical levels, with a thickness of 2m at the surface, 1m below the surface, and a varying thickness of up to 5m at the lowest layer near the sea bed, to account for the spatial varying bathymetry. The largest depth of the model is 28m at Oddesund.

3.6.2 General description- Flexsem

FlexSem is a modular marine modeling framework containing a 3D hydrodynamic model, which easily can be coupled to biogeochemical-, sediment transport- and agent based- modules (Larsen et al. 2020). The setup for the Limfjord has 6686 elements in an unstructured grid, 13 layers and a total of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

44456 computational cells. The spatial resolution varies between 142 and 1770 meters and the model is forced on open boundaries by surface height, velocities, temperature and salinity from the HBM model. 2D meteorological forcings of wind speed and temperature affect the surface and 39 fresh water sources contribute fresh water to the model (Thodsen et al. 2018). The biogeochemical model for the Limfjord has been developed and calibrated and is based on the Danish (DK) version of the ERGOM model (Maar et al. 2018). The ERGOM model simulates the cycling of N, and P (Neumann 2000, Maar et al. 2011, Wan et al. 2012). The 10 state variables describe concentrations of four dissolved nutrients (NO3, NH4, PO4), three functional groups of phytoplankton (diatoms, flagellates, picoalgae), micro- and mesozooplankton, detritus and oxygen (Figure 6). The model considers the processes of nutrient uptake, growth, grazing, respiration, recycling, mortality, settling, nitrification and denitrification. The pelagic ERGOM model is two-way coupled to a sediment biogeochemical model through sedimentation and resuspension of organic matter and diffusive fluxes of nutrients and oxygen (Petersen et al. 2017). Pelagic detritus and diatoms sediment into an organic detritus pool and a dead diatom pool, respectively, in the unconsolidated top layer of the sediment. Organic matter in the unconsolidated sediment can be resuspended, respired or gradually transferred to the consolidated sediment layer. Recycled nutrients (NH4, PO4 and SiO2) in the sediment porewater are exchanged with the bottom water through diffusion and a fraction of the recycled NH4 is lost in a coupled nitrification-denitrification process. Under oxidized conditions, PO4 is retained in the sediment by adsorption to metals and released, when the sediment becomes reduced. Benthic suspension feeders ingest phytoplankton and detritus in the bottom water, whereas deposit feeders ingest freshly deposited diatoms and detritus in the sediment. The pelagic- and benthic model parts were previously validated against monitoring and research data (Maar et al. 2011, Maar et al. 2016, Petersen et al. 2017, Maar et al. 2018).

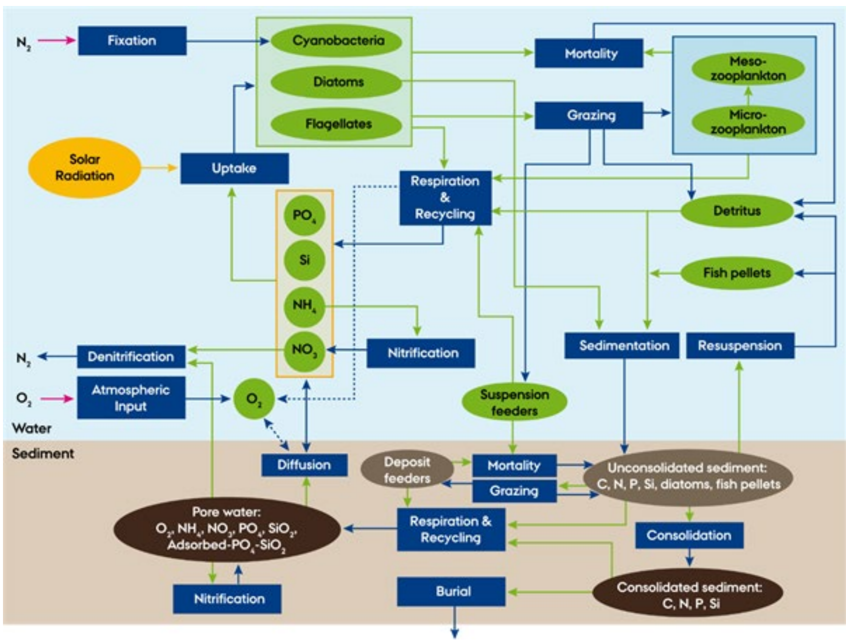


Figure 3.6.2 : (Pilot 6) Model diagram showing the pelagic (green circles) and benthic (brown circles) state variables and associated fluxes (blue boxes) in the ERGOM-DK model.

3.6.3 Overview of validation efforts - HBM

Limfjord validation studies of physical environmental parameters focus on salinity and temperature (cf. D5.4 Sect. 3.6.1.2) , which are important parameters for aquafarm siting and operations, as well as sea level (cf. D5.4 Sect. 3.6.1.1), which is an important parameter for marine safety assessments. The scope of the validation assessments includes (1.) hindcast validation of the 5-years hindcast simulation (2015-2019), (cf. D5.4 Sect. 3.6.1); (2.) process-oriented validation, analysing storm surge forecasting and diurnal warming prediction capacity (cf. D5.4 Sect. 3.6.3) and (3.) forecast validation of operational product (2021-2022) (cf. D5.4 Sect. 3.6.2). Forecast validation uses the entire range of 6 days forecasts for a lag-time dependent validation.

Extensive validation work has been carried out using measurements from 11 tide gauge stations, 30 in-situ salinity and temperature profiles stations throughout the fjord, as well as CMEMS satellite SST data (2021-2022) and on-site temperature data, at the aquafarming site KFO.

Denmark's coastlines are particularly vulnerable to floodings generated by storm surges. Sea level is therefore an essential parameter for the pilot service. Sea level hindcast-validation-assessments demonstrate the good model performance of the HBM model, with centralised Root-Mean-Square-Error (cRMSE) of less than 9.72 cm in the entire Limfjord, including tide gauge station Lemvig (9.18 cm), near the aquafarming site KFO. Simulations with cRMSE values lower than 10cm are considered a successful forecast/hindcast. Process-oriented-validation of 19 storm surge events, exceeding 1.35 m in the period 2015-2019 reveals the exceptional performance of HBM. None of these 19 events have been missed. Forecast validation of storm Malik (January 2022) reveals that the model errors (cRMSE) remain rather constant at a value of 7 cm over the first 3 days and increase gradually to 11 cm at the 6th day.

Hydrographical conditions in the Limfjord: water temperature and salinity are very dynamic. High resolution fjord model applications, shallow water physics and adequate boundary implementations are required for a pilot service with good enough model quality for aqua farming applications (oyster restoration). Temperature hindcast-validation assessments reveal a small, average cold bias of -0.2^{o}C near the surface, which reduces with depth. Average cRMSE values are 0.42 ^{o}C at the surface and 0.37 ^{o}C at 4.5-5 m. These are considered good results. The process oriented validation of diurnal warming predictions using hourly data in very shallow waters at aquafarming site KFO reveals that the model is able to capture these events. The timing of the diurnal warming events is very good. Temperature forecast-validation shows relatively good skill for profile observations and satellite SST data, in summer time, but a slightly negative bias in winter. As a result, the overall model bias is negative: -0.4 ºC. The cRMSE is small, less than 0.7 ºC. There is almost no increase of cRMSE with forecast range up to 6 days, from 0.7 ºC at day 1 to 0.8 ºC at day 6.

3.6.7 Overview of validation efforts - Flexsem

The hydrodynamical-ecological model FlexSem-ERGOM was run for the period 2009 to 2017. We consider the first two years spin-up and carry out the model validation for the years 2011 to 2017 (CF. D5.4 Sect. 3.6.1.3). Observed values for nutrients (Dissolved inorganic nitrogen (DIN =NO_x +NH_4) and dissolved inorganic phosphate, (PO_4)), chlorophyll a and bottom oxygen concentrations were downloaded from the Danish National Database (www.odaforalle.au.dk) for 4 stations distributed across the fjord. Observations exist for all seasons and for all years in the modelled period (2011 to 2017). A larger number of stations (18 in total) were available for oxygen validation, but mainly for the summer period with hypoxia. Salinity, temperature and water level was validated in previous publications (Pastor et al. 2021, Schourup-Kristensen et al. 2021).

3.6.3 Modification since D.3.7 - HBM

Compared to the existing model setup in D3.7, following changes and improvements have been made for providing a better forecast for oyster farming in Limfjorden.

1. A single domain Limfjord model setup has been implemented, with lateral boundary condition from CMEMS forecasts from NWS MFC in North Sea and BAL MFC in Baltic Sea;
2. The radiation transfer formula was modified to improve the shallow water temperature simulation. Results showed that the shallow water temperature was significantly improved.
3. A comprehensive calibration and validations has been made, especially for water temperature and salinity
4. the system has been set for operational forecast

3.6.4 Modification since D.3.7 - Flexsem

Updated forcing data from HBM was applied at the open boundaries. A new turbulence module was implemented that improved salinity simulations. The ecological model was calibrated and validated against National monitoring data. Silicate was removed from the ERGOM model because there is no data on river Si-loads to the Limfjord and the system is N-limited. No other substantial changes reported.

3.6.5 Operational distribution - HBM

HBM Forecasting cycle starts either from 0 or 12 hour (UTC) of the day. Model run starts from time ~1.5 days back taking into account updates of CMEMS boundary forecasts. Each forecast is 132 hours long. The FTP archive holds the data for 7 days. The data can be accessed via following:

- Server: ftp.dmi.dk
- User: forcoast
- Pass: DGHMTSJ.kumvvhf

3.6.5 Operational distribution - Flexsem

No operational distribution server is implemented yet for the specific variables of Flexsem. Since unstructured grid data are not adapted for most of FORCOAST's service modules, the fact that FlexSem outputs are not delivered operationally is not hampering their transferability for the Danish Pilot. In particular, the SM-A3 module that uses Flexsem outputs is currently based on hindcast simulations stored in-house that are interpolated to a raster grid.

3.7 Pilot 7 - Romania

3.7.1 General description

The forecasting system is composed of a physical model (NEMO 3.6) and a biogeochemical model (BAMHBI), implemented on the north-western part of the Black Sea, using 59 unevenly distributed vertical layers. The bathymetry is based on GEBCO 2019 with manual adjustments along the coastlines to reflect dams and other coastal infrastructure. The model area comprises the shelf break

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Initial conditions and lateral boundary conditions are provided by interpolation of CMEMS Black Sea MFC (Analysis-Forecast product). River data are obtained from SESAME and PERSEUS products. The biogeochemical variables are transported online by the physical model. No data assimilation is performed.

The BAMHBI model describes the food web from bacteria to gelatinous carnivores through 28 state variables. It is conceived with the Black Sea in mind, e.g. it explicitly represents the processes in the suboxic and anoxic layers. Biogeochemical processes in anaerobic conditions have been represented using an approach similar to that used in the modelling of diagenetic processes in the sediments lumping together all the reduced substances in one state variable. In this way, processes in the upper oxygenated layer are fully coupled with anaerobic processes in the deep waters, allowing performing long term simulations. This fully coupling between aerobic, suboxic and anoxic processes is absolutely necessary for performing the long term reanalysis. Processes typical of low oxygen environments like denitrification, anaerobic ammonium oxidation (ANAMMOX), reduced decomposition efficiency have been explicitly represented (Gregoire et al., 2008). Moreover, the model includes a representation of diagenetic processes (Capet et al., 2016) using an efficient and economic representation as proposed by Soetaert et al., 2000. The incorporation of a benthic module allows to represent the impact of sediment processes on important biogeochemical processes such as sediment oxygen consumption (that is responsible for the generation of hypoxic conditions in summer), the active degradation of organic matter that determines the vigour of the shelf ecosystem (~30 % of the primary production produced in shelf waters is degraded in the sediment) and the intense consumption of nitrate by benthic denitrification that filters a substantial part (~50 %) of the nitrogen brought by the north-western shelf rivers (the Danube being the most important one) and modulates primary production in the deep basin.

The forecasting system comprises a second level centered on the Constanta-Eforie area. The horizontal resolution is 200m, and the model is nested in the first level using the AGRIF nesting tool. The bathymetry is obtained from local measurements and smoothed toward the GEBCO bathymetry at the model boundaries.

The validation effort is using *in situ* observations collected by the FORCOAST Pilot 7 team, and satellite chlorophyll images.

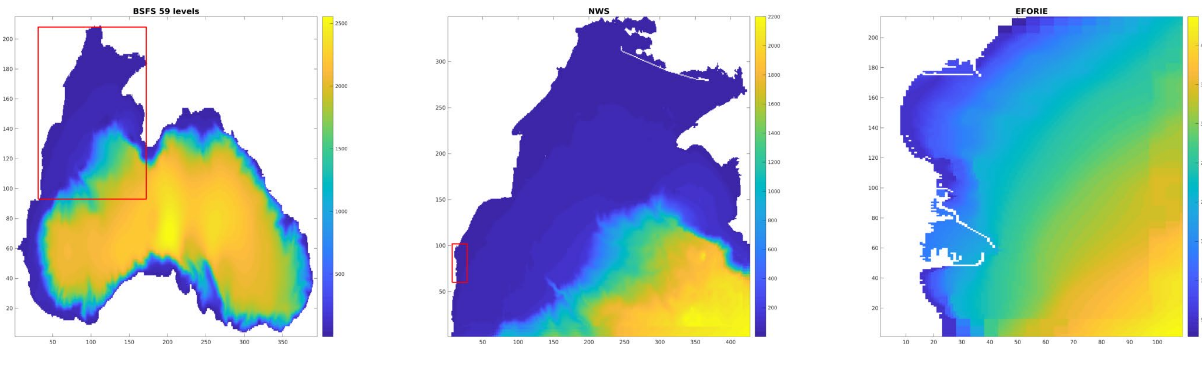


Figure 3.7.1 : (Pilot 7) the three two-way nested domains and bathymetry.

3.7.2 Overview of validation efforts

The validation efforts that will be presented in D5.4 focus on the Pilot area of interest (Eforie grid), and addressed specifically Sea surface temperature, chlorohyll-a concentration and horizontal currents. Since no data assimilation is considered, the validation is considered to address the forecast mode.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Predictions of sea-surface temperature (D5.4 Sect. 2.7.1.1) in the Eforie grid were compared to remote sensing estimates (L4 CMEMS product 010_006). As a summary, the time-average of the bias in the Eforie model is -0.28°C, and the corresponding RMSD is 0.87°C. For indicative purposes, similar metrics obtained from the CMEMS BS-MFC simulations leads to a RMS 0.40°C, of course comparison is limited here since the CMEMS BS-MFC system is routinely assimlating SST while the Eforie model does not.

Model predictions of chlorophyll-a concentrations (D5.4 Sect. 2.7.2.2) have been compared to the L4 CMEMS product 009_212, for both the Eforie grid and the large scale CMEMS BS-MFC products. Generally speaking, both models tend to under-estimate chlorophyll-a concentrations during the summer months, and slightly overestimate it during winter. Even without data assimilation, the Eforie model has similar bias and RMSD values as the CMEMS model product.

Simulated sea surface currents (D5.4 Sect 2.7.1.3) have been compared to ADCP measurements (2019 & 2021) within the Eforie and NWS domains. Moderate to good agreements were depicted for dominant flow direction, while current velocity are in average 18% less intense than observed in the Eforie grid at the sampled sites.

3.7.2 Modification since D.3.7

The model is now a double-nest. The initial plan was to use 2 grids: the North-Western shelf (NWS) at 1km resolution, and Eforie-Constanta at 200m resolution; and to use an open boundary condition from the CMEMS Black Sea model (3km resolution, 31 vertical levels). This boundary condition would have been provided in daily or hourly files (to be examined); and evidently there would be no feedback from NWS to the Black Sea model. Instead, the Pilot 7 model now runs all 3 grids together (2-way nesting, Fig. 3.7.1) so that the interface between the Black Sea and North-Western Shelf grids is seamless.

3.7.3 Operational distribution

All model variables are available on the Pilot Thredds server http://www.seamod.ro:8080/thredds

3.8 Pilot 8 - Italy

3.8.1 General description

The modelling system is based on the high-resolution MITgcm-BFM coupled model for the northern Adriatic Sea (Cossarini et al., 2017, Silvestri et al., 2020) implemented at OGS. The model is initialized and driven by the downscaling of the nominal products (hydrodynamics and biogeochemistry) of the CMEMS Mediterranean Sea Monitoring and Forecast Centre. In the present forecast mode, the simulations are run daily, featuring a 7-day hindcast/spin-up period and a 3-day forecast. The integration with NRT satellite SST products provided by CNR will be finalised by the end of summer 2022 and it will increase the accuracy of the hindcast products, as well as the forecast. In particular, L4 SST data stored in the Pilot THREDDS server will be assimilated in the model hindcast via a surface nudging scheme.

The MITgcm hydrodynamic and transport modules are at the core of the MITgcm-BFM coupled hydrodynamic-biogeochemical model (D3.7, Fig. 11). The biogeochemical processes are included via the BFMcoupler package, and integrated in space and time by the MITgcm. Hydrodynamic and biogeochemical variables can be assimilated by using either native MITgcm modules, or assimilation schemes affecting the coupler, or both.

The model domain (northern Adriatic Sea) has been discretized with a horizontal resolution of 1/128° (850 × 600 m) and 27 unequally spaced vertical levels. The bathymetry spans north of latitude 43.5° N

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

and explicitly considers the 19 major rivers flowing into the basin. At the moment, river flow rates are derived from up-to-date climatologies, modulated in order to have the maximum and minimum values in spring/autumn and summer/winter, respectively. The integration of NRT daily discharge data for the Po river (the main freshwater source of the basin) will be implemented in May 2022. The model setup also includes the contribution (in terms of nutrients) of the main urban wastewater discharge points along the italian coast.

The meteorological forcing (air temperature, pressure and humidity, wind velocity, heat fluxes and precipitation) is obtained from a high resolution Limited Area Model (ALADIN) run by the Slovenian Environmental Agency (ARSO). Initial and daily open boundary conditions along the southern side of the domain are derived from the CMEMS modelling system.

Model resolution and set-up guarantee a proper simulation of the main basin and sub-basin scale features of the northern Adriatic Sea, both from the hydrodynamic and biogeochemical point of view. An example of model output is shown in Fig. 3.8.1.

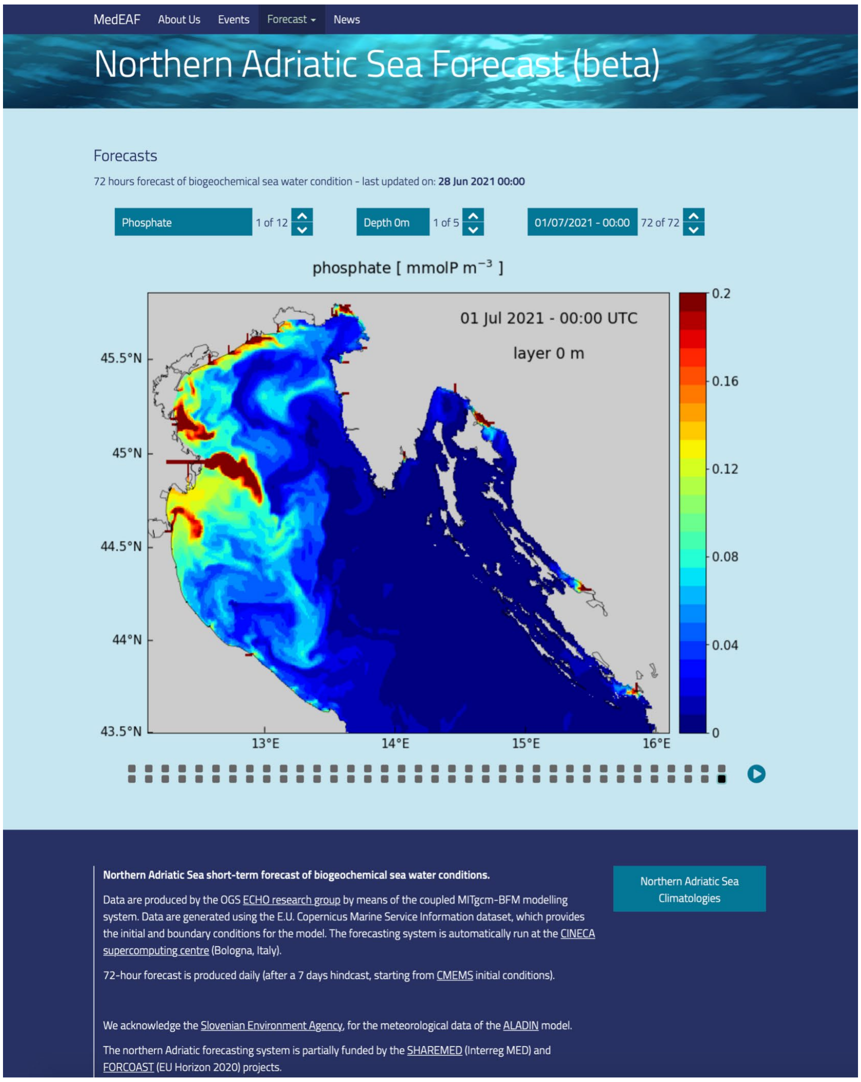


Figure 3.8.1: (Pilot 8) The MITgcm-BFM northern Adriatic forecasting system, updated daily on the website http://medeaf.ogs.it/adriatic

3.6.7 Overview of validation efforts

The validation efforts (detailed in D5.4) are focused on both the long-term hindcast simulation (reanalysis, D5.4 Sect. 3.8.1) and short-term forecast products (D5.4 Sect. 3.8.2).

An updated hindcast validation for the 2006-2017 period will be finalised in May 2022 and it will consider all the main physical (e.g., temperature, salinity) and biogeochemical (e.g., nutrients, chlorophyll) variables.

As regards the NRT validation of the forecast products, time series of remote sensing surface chlorophyll-a and SST are produced on a daily basis and compared with model output. The dataset is updated daily starting from March 2022 and the procedure (download, spatial averaging, publication on the webpage: http://medeaf.ogs.it/nrt-NA-validation) will be fully operational in May 2022. The last available maps of both chlorophyll and SST are also published for a preliminary visual comparison of model and satellite data.

3.8.2 Modification since D.3.7

Compared to the previous version (hindcast mode), the model now is fully operational, with daily forecasts that have been recently extended from 2 to 3 days, which makes it more consistent with the rest of the FORCOAST pilot models.

3.8.3 Operational distribution

Model outputs are delivered operationally on the Pilot THREDDS server:

https://dsecho.ogs.it/thredds/catalog/modelCatalog.html

4 Conclusion

We collected in this deliverable D3.8 a complete description of the pilot models providing marine information at user-relevant spatial and temporal frames within the pilots of FORCOAST.

With respect to the initial model inventory described in D3.7, only minor changes are to be reported concerning the modelling setup themselves. This mostly consists of refinement of boundary conditions or domain nesting protocols (Pilot 1, 5, 6, 7), extension of forecasting period (Pilot 1, 8), and refinement of process formulation (Pilot 4, Light penetration scheme). Mostly, the substantial advances between D3.7 and D3.8 consist of validation exercises operated at pilot levels (cf. Figure 2.3.2), and the widespread use of operational data distribution platforms. Details and results of those validation procedure are presented in D5.4 Both items are essential components required to consolidate this collection of pilot models as components of a single centralized operational marine information platform.

Despite the disparity in terms of state variables, we consider that the operational data delivery system achieved here is fit for the purpose of deploying several service modules in other pilots than those where they have been developed, in accordance with the transferability objectives set for the services. This constitutes a key asset of the system of services designed with FORCOAST. In particular, the decoupling between data provision (this deliverable) and service-specific post-processing units (ie. the service modules, D3.10) enables a continuous evolution of the overall FORCOAST service portfolio. Such evolution can directly emerge from:

- Evolution of local pilot models.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

- Extension of state variables being made operationally available to enhance the transferability of service modules.
- Inclusion of additional high-resolution marine models.
- Transferability of additional service modules exploiting the current collection of pilot model data provision.

5 References

Ardhuin F, Rogers WE, Babanin AV, Filipot J-F, Magne R, Roland A, Van der Westhuysen AJ , Queffeulou P, Lefevre JM, Aouf L, Collard F (2010) Semi-empirical dissipation source functions for ocean waves. Part I: definition, calibration, and validation. J Phys Oceanogr 40:1917–1941

Barbut L., Groot Cgrego C., Delerue-Ricard S., Vandamme S., Volckaert F.A.M., Lacroix G. 2019. How larval traits of six flatfish species impact connectivity. Limnology & Oceanography 64:1150-1171. https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.11104

Benetazzo A. et al (2018)Characterizing the signature of a spatio-temporal wind wave field, August 2018Ocean Modelling 129, DOI: 10.1016/j.ocemod.2018.06.007

Berg, P., and Poulsen, J. W. (2012). Implementation Details for HBM. DMI Technical Report No. 12-11. Copenhagen: Danish Meteorological Institute, 149.

Bidlot J-R, Janssen PAEM, Abdalla S (2007) a revised formulation for ocean wave dissipation and its model impact. ECMWF, Technical Memorandum Nr. 509.

Caballero, A., Ferrer, L., Rubio, A., Charria, G., Taylor, B.H., Grima, N., 2014. Monitoring of a quasi-stationary eddy in the Bay of Biscay by means of satellite, in situ and model results. Deep-Sea Res. Pt. II 106, 23-37.

Campuzano F (2018). Coupling watersheds, estuaries and regional seas through numerical modelling for Western Iberia. PhD Thesis, Instituto Superior Técnico, Universidade de Lisboa, Portugal.

Capet, A., Meysman, F. J. R., Akoumianaki, I., Soetaert, K., & Grégoire, M. (2016). Integrating sediment biogeochemistry into 3D oceanic models: A study of benthic-pelagic coupling in the Black Sea. Ocean Modelling, 101, 83–100.

Capet, A., Fernández, V., She, J., Dabrowski, T., Umgiesser, G., Staneva, J., Mészáros, L., Campuzano, F., Ursella, L., Nolan, G., & El Serafy, G. (2020). Operational Modeling Capacity in European Seas—An EuroGOOS Perspective and Recommendations for Improvement. *Frontiers in Marine Science*, *7*, 129.

Carrere L, Lyard F, Cancet M, Guillot A, Picot N. FES 2014, a new tidal model - Validation results and perspectives for improvements, presentation to ESA Living Planet Conference, Prague 2016.

Cossarini G., Querin S., Solidoro C., Sannino G., Lazzari P., Di Biagio V., Bolzon G. (2017). Development of BFMCOUPLER (v1.0), the coupling scheme that links the MITgcm and BFM models for ocean biogeochemistry simulations. Geosci. Model Dev., 10, 1423–1445.

CMEMS-BS-QUID-007-001 http://marine.copernicus.eu/documents/QUID/CMEMS-BS-QUID-007-001.pdf

Dannheim J., Beermann J., Lacroix G., De Mesel I., Kerckhof F., Schön I., Degrear S., Birchenough S., Garcia C., Coolen J.W.P., Lindeboom H.J. 2018. Understanding the influence of man-made structures on the ecosystem functions of the North Sea (UNDINE). Final Report. 47pp.

Debreu, L., Marchesiello, P., Penven, P., Cambon, G., 2012. Two-way nesting in split-explicit ocean models: Algorithms, implementation and validation. Ocean Model. 49-50, 1-21.

De Mesel I., D. Kapasakali, F. Kerckhof, L. Vigin, G. Lacroix, L. Barbut and S. Degraer (2018). Ostrea edulis restoration in the Belgian part of the North Sea: Feasibility study. Royal Belgian Institute of Natural Sciences, Operational Directorate Natural Environment, Marine Ecology and Management. pp. 89

Drillet Y, Bourdalle-Badi R, Siefrid L, Le Provost C. Meddies in the Mercator North Atlantic and Mediterranean Sea eddy-resolving model. Journal of Geophysical Research. 2005; 110(C3): C03016. DOI: 10.1029/2003JC002170.

Dulière V., Gypens N., Lancelot C., Luyten P., Lacroix G. 2019. Origin of nitrogen in the English Channel and Southern Bight of the North Sea ecosystems. 2019. Hydrobiologia 845: 13-33. https://doi.org/10.1007/s10750-017-3419-5

Dulière V., Ovidio F. and Legrand S., 2013. Development of an Integrated Software for Forecasting the Impacts of Accidental Oil Pollution-OSERIT. Final Report. Brussels: Belgian Science Policy Office 2013–65p. (Research Programme Science for a Sustainable Development)

Fairall, C.W., Bradley, E.F., Rogers, D.P., Edson, J.B., Young, G.S., 1996. Bulk parameterization of air-sea fluxes for Tropical Ocean-Global Atmosphere Coupled-Ocean Atmosphere Response Experiment. J. Geophys. Res. 101 (C2), 3747-3764.

Fairall, C.W., Bradley, E.F., Hare, J.E., Grachev, A.A., Edson, J.B., 2003. Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. J. Clim. 16 (4), 571-591.

Ferrer, L., Caballero, A., 2011. Eddies in the Bay of Biscay: A numerical approximation. J. Mar. Syst. 87 (2), 133-144.

Ferrer, L., González, M., Valencia, V., Mader, J., Fontán, A., Uriarte, Ad., Caballero, A., 2007. Operational coastal systems in the Basque Country region: Modelling and observations. In: Chung, J.S., Kashiwagi, M., Losada, I.J., Chien, L.-K. (Eds.), Proceedings of the 17th International Offshore (Ocean) and Polar Engineering Conference, vol. 3, 1-6 July 2007, Lisbon, Portugal, pp. 1736-1743.

Ferrer, L., Fontán, A., Mader, J., Chust, G., González, M., Valencia, V., Uriarte, Ad., Collins, M.B., 2009. Low-salinity plumes in the oceanic region of the Basque Country. Cont. Shelf Res. 29 (8), 970-984.

Ferrer, L., Zaldua-Mendizabal, N., Del Campo, A., Franco, J., Mader, J., Cotano, U., Fraile, I., Rubio, A., Uriarte, Ad., Caballero, A., 2015. Operational protocol for the sighting and tracking of Portuguese man-of-war in the southeastern Bay of Biscay: Observations and modeling. Cont. Shelf Res. 95, 39–53.

Garcia HE, Locarnini RA, Boyer TP, Antonov JI, Baranova OK, Zweng MM, Johnson DR (2010a). World Ocean Atlas 2009, Volume 3: Dissolved Oxygen, Apparent Oxygen Utilization, and Oxygen Saturation. S. Levitus, Ed. NOAA Atlas NESDIS 70, U.S. Government Printing Office, Washington, D.C., 344 pp.

Garcia HE, Locarnini RA, Boyer TP, Antonov JI, Zweng MM, Baranova OK, Johnson DR (2010b). World Ocean Atlas 2009, Volume 4: Nutrients (phosphate, nitrate, silicate). S. Levitus, Ed. NOAA Atlas NESDIS 71, U.S. Government Printing Office, Washington, D.C., 398 pp.

Grégoire, M., Raick, C., & Soetaert, K. (2008). Numerical modeling of the deep Black Sea ecosystem functioning during the late 80's (eutrophication phase). Progress in Oceanography, 76(9), 286-333.

Günther H, Hasselmann S, Janssen PAEM (1992) the WAM Model Cycle 4.0. User Manual. Technical Report No. 4, Deutsches Klimarechenzentrum, Hamburg, Germany. 102 pages.

Haidvogel, D.B., Arango, H.G., Hedström, K., Beckmann, A., Malanotte-Rizzoli, P., Shchepetkin, A.F., 2000. Model evaluation experiments in the North Atlantic Basin: Simulations in nonlinear terrain-following coordinates. Dyn. Atmos. Oceans 32 (3-4), 239-281.

Janssen PAEM (2008) Progress in ocean wave forecasting. J Comput Phys 227:3572-3594.

Komen GJ, Cavaleri L, Donelan M, Hasselmann K, Hasselmann S, Janssen PAEM (1994) Dynamics and Modelling of Ocean Waves, Cambridge University Press.

Lacroix G., Barbut L., Volckaert F.A.M. 2018. Complex response of projected sea temperature and wind change on flatfish dispersal. Global Change Biology, 24:85-100., https://doi.org/10.1111/gcb.13915

Lacroix G., Maes G.E., Bolle L.J., Volckaert F.A.M., 2013. Modelling dispersal dynamics of the early life stages of a marine flatfish (Solea solea L.). Journal of Sea Research 84:13-25. Doi: 10.1016/j.seares.2012.07.010

Lacroix G., Ruddick K., Park Y., Gypens N., Lancelot C., 2007. Validation of the 3D biogeochemical model MIRO&CO with field nutrient and phytoplankton data and MERIS-derived surface chlorophyll a images. Journal of Marine Systems, 64(1-4): 66-88. Doi: 10.1016/j.jmarsys.2006.01.010

Laiz, I., Ferrer, L., Plomaritis, T.A., Charria, G., 2014. Effect of river runoff on sea level from in-situ measurements and numerical models in the Bay of Biscay. Deep-Sea Res. Pt. II 106, 49-67.

Lancelot C, Spitz Y, Gypens N, Ruddick K, Becquevort S, Rousseau V, Lacroix G, Billen G. 2005. Modelling diatom and Phaeocystis blooms and nutrient cycles in the Southern Bight of the North Sea: the MIRO model. Marine Ecological Progress Series 289 : 63-78

Larsen J. Maar, M., Mohn, C. Pastor Rollan, A. (2020). A versatile marine modelling tool applied to arctic, temperate and tropical waters. Plos One 15(4): e0231193

Legorburu, I., Ferrer, L., Galparsoro, I., Larreta, J., 2015. Distribution of river-borne particulate Pb in the Basque continental shelf (Bay of Biscay). Environ. Earth Sci. 74 (5), 4261–4279.

Lyard F, Lefevre F, Letellier T, Francis O (2006). Modelling the global ocean tides: modern insights from FES2004, Ocean Dynamics, 56: 394-415.

Maar, M., Larsen, J., Dahl, K., Riemann, B. (2018). Modelling the environmental impact of offshore fish farms in the inner Danish waters. Aquac Environ Interact 10:115-133

Maar M, Markager S, Madsen KS, Windolf J, Lyngsgaard MM, Andersen HE, Møller EF (2016) The importance of local versus external nutrient loads for Chl a and primary production in the Western Baltic Sea. Ecol Model 320:258-272

Maar M, Møller EF, Larsen J, Madsen KS, Wan ZW, She J, Jonasson L, Neumann T (2011) Ecosystem modelling across a salinity gradient from the North Sea to the Baltic Sea. Ecol Model 222:1696-1711

Madec, G., and the NEMO team, 2016. NEMO Ocean Engine, Note du Pole de modelisation de l'Institut Pierre-Simon Laplace No 27, ISSN No 1288-1619.

McCormack, T., Gill, L. W., Naughton, O., Johnston, P. M. (2014). Quantification of submarine/intertidal groundwater discharge and nutrient loading from lowland karst catchment. Journal of Hydrology, 519:2318-2330.

Mateus M, Riflet G, Chambel P, Fernandes L, Fernandes R, Juliano M, Campuzano F, de Pablo H, Neves R (2012). An operational model for the West Iberian coast: products and services, Ocean Science, 8: 713-732.

Murawski, J, She, J, Mohn, C, Frishfelds, V & Woge Nielsen, J 2021, 'Ocean Circulation Model Applications for the Estuary-Coastal-Open Sea Continuum', Frontiers in Marine Science, bind 8, 657720. https://doi.org/10.3389/fmars.2021.657720

Nagy, H., Lyons, K., Dabrowski , T. (2020). A Regional Operational and Storm Surge Model for the Galway Bay: Model Configuration and Validation. Ocean Sciences Meeting, San Diego, CA USA.

NCEP/NWS/NOAA/U.S. Department of Commerce. 2015, updated daily. *NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D65D8PWK. Accessed† 26 Mar 2021.

Neumann T (2000) Towards a 3D-ecosystem model of the Baltic Sea. J Mar Syst 25:405-419

Neves R (2013). The MOHID concept. In: Ocean modelling for coastal management - Case studies with MOHID. M. Mateus & R. Neves (eds.), IST Press, Lisbon, Portugal, pp. 1-11.

Pastor A, Larsen J, Hansen FT, Simon A, Bierne N, Maar M (2021) Agent-based modeling and genetics reveal the Limfjorden, Denmark, as a well-connected system for mussel larvae. Mar Ecol Prog Ser 680:193-205. https://doi.org/10.3354/meps13559

Petersen ME, Maar M, Larsen J, Møller EF, Hansen PJ (2017) Trophic cascades of bottom-up and top-down forcing on nutrients and plankton in the Kattegat, evaluated by modelling. J Mar Syst 169:25-39

Ruiz-Villarreal M, Bolding K, Burchard H, Demirov E (2005). Coupling of the GOTM turbulence model to some three-dimensional ocean models. In: Marine turbulence: theories. Observations and Models. Results of the CARTUM Project. HZ Baumert, J Simpson, J Sündermann (eds), Cambridge University Press, Cambridge, pp. 225–237.

Shchepetkin, A.F., McWilliams, J.C., 2005. The regional oceanic modeling system (ROMS): A split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Model. 9 (4), 347-404.

She J., Berg P., Berg J. 2007. Bathymetry impacts on water exchange modelling through the Danish Straits. J. Mar. Syst., 65 (1–4) (2007), pp. 450-459, 10.1016/j.jmarsys.2006.01.017

Silvestri, C., Bruschi, A., Calace, N., Cossarini, G., De Angelis, R., Di Biagio, V., Giua, N., Peleggi, M., Querin, S., Saccomandi, F., Salon, S., Solidoro, C., Spada, E. (2020). CADEAU project - final report. Figshare. https://doi.org/10.6084/m9.figshare.12666905.v1

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Wang, W., Powers, J.G., 2005. A description of the Advanced Research WRF Version 2. NCAR Technical Note, NCAR/TN-468+STR, 88pp.

Song, Y.T., Haidvogel, D.B., 1994. A semi-implicit ocean circulation model using a generalized topography-following coordinate system. J. Comp. Phys. 115 (1), 228-244.

Staneva, J., Behrens, A., Ricker, M., & Gayer, G. (2020): Black Sea Waves Analysis and Forecast (CMEMS BLK-Waves 2016-present) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS), doi:10.25423/CMCC/BLKSEA_ANALYSIS_FORECAST_WAV_007_003

Staneva, J., Behrens, A., Ricker, M., & Gayer, G. (2020): Black Sea Waves Reanalysis (CMEMS BLK-Waves) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS), doi:10.25423/CMCC/BLKSEA_REANALYSIS_WAV_007_006

Staneva, J., Behrens, A., Gayer, G., & Aouf, L. (2019): Synergy between CMEMS products and newly available data from SENTINEL. In: Schuckmann, K., et al. (2019): Copernicus Marine Service Ocean State Report, Issue 3, Chapter 3.3, Journal of Operational Oceanography, doi:10.1080/1755876X.2019.1633075

Thodsen H., Molina-Navarro E., Nielsen J.W., Larsen J., Maar M. (2018). Afstrømning og næringsstoftilførsel til Limfjorden baseret på tre forskellige modeller. Aarhus Universitet, DCE. Teknisk rapport fra DCE-Nationalt Center for Miljø og Energi, no. 115, 20p.

Vasquez, M., Mata Chacón, D., Tempera, F., O'Keeffe, E., Galparsoro, I., Sanz Alonso, J. L., Gonçalves, J. M. S., Bentes, L., Amorim, P., Henriques, V., McGrath, F., Monteiro, P., Mendes, B., Freitas, R., Martins, R., and Populus, J. 2015. Broad-scale mapping of seafloor habitats in the north-east Atlantic using existing environmental data. J. Sea Res. 100, 120–132.

Pastor A, Larsen J, Hansen FT, Simon A, Bierne N, Maar M (2021) Agent-based modeling and genetics reveal the Limfjorden, Denmark, as a well-connected system for mussel larvae. Mar Ecol Prog Ser 680:193-205. https://doi.org/10.3354/meps13559

WAMDI group: Hasselmann S, Hasselmann K, Bauer E, Janssen PAEM, Komen GJ, Bertotti L, Guillaume A, Cardone VC, Greenwood JA, Reistad M, Zambreski L, Ewing J (1988) The WAM model – a third generation ocean wave prediction model, J Phys Oceanogr 18: 1775-1810.

Wan Z, She J, Maar M, Jonasson L, Baasch-Larsen J (2012) Assessment of a physical-biogeochemical coupled model system for operational service in the Baltic Sea. Ocean Sci 8:683-701

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870465.

Appendix – Pilot Data Provision

CF CONVENTIONS

https://cfconventions.org/Data/cf-standard-names/29/build/cf-standard-name-table.html

	CF standard name	Common name	Units	Dimension Longitude	Dimension Latitude	Dimension Depth
Coordinate	longitude					
	latitude					
Hydrodynamics	eastward_sea_water_velocity	Zonal Velocity	m s-1	x	x	x
	northward_sea_water_velocity	Merdional Velocity	m s-1	x	x	x
	upward_sea_water_velocity	Vertical velocity	m s-1	x	x	x
	ocean_vertical_heat_diffusivity	Vertical eddy diffusivity	m2 s-1	x	x	x
	ocean_vertical_diffusivity	Vertical eddy diffusivity	m2 s-1	x	x	x
	sea_water_temperature	Temperature	K	x	x	x
	sea_surface_temperature	Surface temperature	K	x	x	
	sea_water_temperature_at_sea_floor	Bottom temperature	K	x	x	
	sea_water_salinity	Salinity	-	x	x	x
	sea_surface_salinity	Surface salinity	-	x	x	
	sea_water_salinity_at_sea_floor	Bottom Salinity	-	x	x	
	ocean_mixed_layer_thickness_defined_by_mixing_scheme	Mixed Layer Depth	m	x	x	
	water_surface_height_above_reference_datum	Sea Water Level	m	x	x	
	turbulent_generic_length_scale	Turbulent Generic Length Scale	m3 s-2	x	x	x
	turbulent_kinetic_energy	Turbulent Kinetic Energy	m2 s-2	x	x	x
Waves	sea_surface_wave_significant_height	significant wave height	m	x	x	
	sea_surface_wave_mean_period	mean wave period	s	x	x	
	sea_surface_wave_stokes_drift_x_velocity	Stoke Drift Zonal Velocity	m s-1	x	x	
	sea_surface_wave_stokes_drift_y_velocity	Stoke Drift Meridional Velocity	m s-1	x	x	
	sea_surface_wave_mean_period_from_variance_spectral_density_second_frequency_moment		s	x	x	
	sea_surface_wave_period_at_variance_spectral_density_maximum		s	x	x	
Bio	mass_concentration_of_chlorophyll_a_in_sea_water	Chlorophyll	kg m-3	x	x	x
	mass_concentration_of_phytoplankton_expressed_as_chlorophyll_in_sea_water	Chlorophyll	kg m-3	x	x	x
	mole_concentration_of_nitrate_in_sea_water	Nitrate	mol m-3	x	x	x
	mole_concentration_of_phosphate_in_sea_water	Phosphate	mol m-3	x	x	x
	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	Oxygen	mol m-3	x	x	x
Index	hsi_suitability_index	Species favorability	-	x	x	x
	upwelling_area	Identified upwelling events area	-			
Bathymetry	bathymetry	Depth	m	x	x	x
	sea_floor_depth_below_sea_level	Depth	m	x	x	
	land_binary_mask	Mask		x	x	
Meteorology	x_wind	Wind Velocity X	m s-1	x	x	
	y_wind	Wind Velocity Y	m s-1	x	x	
	air_pressure	atmospheric pressure	Pa	x	x	
	air_temperature	air temperature	K	x	x	
	precipitation_amount	Rain	kg m-2	x	x	
	downwelling_shortwave_flux_in_air	Solar Radiation	W m-2	x	x	

Pilot	Type	Variable (CF name convention see sheet 1)	Access (thredds)	Example file name	Variable name (in .nc files)	Grid file	longitude variable name	latitude variable name	depth variable name	time variable name	WMS	Timestep	Hindcast period	Forecast Period	Domain	Spatial Resolution	Grid definition	Data storage size	Number of timestep in a file	Comments
Pilot 1 - Portugal	Model	sea_water_salinity	http://thredds.maretec.org/thredds/catalog/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/catalog.html	http://thredds.maretec.org/thredds/fileServer/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc	long_name: sea water salinity standard_name: sea_water_salinity		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	265.8 Mbytes	9	
	Model	sea_water_temperature	http://thredds.maretec.org/thredds/catalog/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/catalog.html	http://thredds.maretec.org/thredds/fileServer/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc	long_name: sea water temperature standard_name: sea_water_temperature		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	265.8 Mbytes	9	
	Model	northward_sea_water_velocity	http://thredds.maretec.org/thredds/catalog/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/catalog.html	http://thredds.maretec.org/thredds/fileServer/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc	long_name: northward sea water velocity standard_name: northward_sea_water_velocity		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	265.8 Mbytes	9	
	Model	eastward_sea_water_velocity	http://thredds.maretec.org/thredds/catalog/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/catalog.html	http://thredds.maretec.org/thredds/fileServer/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc	long_name: eastward sea water velocity standard_name: eastward_sea_water_velocity		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	265.8 Mbytes	9	
	Model	downwelling_shortwave_flux_in_air	http://thredds.maretec.org/thredds/METEO_Catalog.html	not uploaded yet	long_name: downwelling shortwave flux in air standard_name: downwelling_shortwave_flux_in_air		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	not yet implemented	9	
	Model	X_Wind	http://thredds.maretec.org/thredds/METEO_Catalog.html	not uploaded yet	long_name: x wind standard_name: x_wind		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	not yet implemented	9	
	Model	Y_Wind	http://thredds.maretec.org/thredds/METEO_Catalog.html	not uploaded yet	long_name: y wind standard_name: y_wind		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	not yet implemented	9	
	Model	air_pressure_at_mean_sea_level	http://thredds.maretec.org/thredds/METEO_Catalog.html	not uploaded yet	long_name: air_pressure_at_mean_sea_level standard_name: air_pressure_at_mean_sea_level		lon	lat	depth	time	http://thredds.maretec.org/thredds/wms/MOHID_WATER/LISOCEAN_0.003DEG_50L_3H/FORECAST/2020101800.nc?service=WMS&version=1.3.0&request=GetCapabilities	3h	2019-onwards	Not yet implemented in thredds	LisOcean	200m	regular	not yet implemented	9	
	Model	precipitation		not configured yet																
Pilot 2 - Spain	Model	sea_water_temperature	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_fronts_exp.nc	sst		lon	lat		Filename (yyyymmdd_fronts_exp)		Hourly	-	4 days	SE BoB	670 m	regular	3.09 Mb	24	
	Model	sea_water_temperature_fronts	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_fronts_exp.nc	fronts_sst		lon	lat		Filename (yyyymmdd_fronts_exp)		Hourly	-	4 days	SE BoB	670 m	regular	3.09 Mb	24	
	Model	sea_water_temperature	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_exp.nc	temp		longitude	latitude	depth	Filename (yyyymmdd_exp)		Hourly	-	4 dyas	SE BoB	670 m	regular	18.1 Mb	24	
	Model	sea_water_salinity	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_exp.nc	salt		longitude	latitude	depth	Filename (yyyymmdd_exp)		Hourly	-	4 dyas	SE BoB	670 m	regular	18.1 Mb	24	
	Model	northward_sea_water_velocity	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_exp.nc	u		longitude	latitude	depth	Filename (yyyymmdd_exp)		Hourly	-	4 days	SE BoB	670 m	regular	18.1 Mb	24	
	Model	eastward_sea_water_velocity	http://thredds.euskoos.eus/thredds/catalog/testAll/catalog.html	20210609_exp.nc	v		longitude	latitude	depth	Filename (yyyymmdd_exp)		Hourly	-	4 days	SE BoB	670 m	regular	18.1 Mb	24	
	Remote sensing	mass_concentration_of_chlorophyll_a_in_sea_water	CMEMS OCEANCOLOUR_GLO_CHL_L4_NRT_OBSERVATIONS_009_033		mass_concentration_of_chlorophyll_a_in_sea_water															
	Remote sensing	potential_temperature	CMEMS SST_GLO_SST_L4_NRT_OBSERVATIONS_010_001		sea_surface_temperature															
Pilot 3 - Bulgaria	Model	upwelling_area	No operational delivery																	
	Remote sensing	hsi_suitability_index	No operational delivery	20180606_hsi.tif	hsi_suitability_index		lon	lat	surface	Filename(yyyymmdd_hsi.tif)		1d	3 years	-	BLKSEA	1km x 1km	regular	3 Mb		
	Model	sea_surface_wave_significant_height	No operational delivery	20191002_h-HZG--WAVES-BSeas3-BS-b2020*.nc			lon	lat	surface											
	Model	sea_surface_wave_mean_period	No operational delivery	20191002_h-HZG--WAVES-BSeas3-BS-b2020*.nc			lon	lat	surface											
Pilot 4 - Belgium	Model	sea_surface_temperature	https://erddap.naturalsciences.be/erddap/griddap/NOS_HydroState_V1.html	NOS_HydroState_V1_6819_7b73_04cc.* (free outputformat: nc, txt, csv, ...)	sea_surface_temperature,	in-file	Lon	Lat	surface	Time		hourly	1 year	5 days	North Sea (NOS)	0.041666 in lon and 0.08333 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	sea_surface_salinity	https://erddap.naturalsciences.be/erddap/griddap/NOS_HydroState_V1.html		sea_surface_salinity	in-file	Lon	Lat	surface	Time		hourly	1 year	5 days	North Sea (NOS)	0.041666 in lon and 0.08333 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	eastward_sea_water_velocity	https://erddap.naturalsciences.be/erddap/griddap/NOS_HydroState_V1.html		bottom_baroclinic_eastward_sea_water_velocity surface_baroclinic_e	in-file	Lon	Lat	surface and bottom	Time		hourly	1 year	5 days	North Sea (NOS)	0.041666 in lon and 0.08333 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	northward_sea_water_velocity	https://erddap.naturalsciences.be/erddap/griddap/NOS_HydroState_V1.html		bottom_baroclinic_northward_sea_water_velocity surface_baroclinic_	in-file	Lon	Lat	surface and bottom	Time		hourly	1 year	5 days	North Sea (NOS)	0.041666 in lon and 0.08333 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	upward_sea_water_velocity	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		bottom_upward_sea_water_velocity surface_upward_sea_water_velocity	in-file	Lon	Lat	surface and bottom	Time		hourly	1 year	5 days	North Sea (NOS)	0.041666 in lon and 0.08333 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	sea_surface_wave_significant_height	https://erddap.naturalsciences.be/erddap/griddap/WAM_ECMWF.html and https://erddap.naturalsciences.be/erddap/griddap/WAM_UKMO.html	WAM_ECMWF_d61b_a29e_1c27.* (free outputformat: nc, txt, csv, ...) or V	hs	in-file	Lon	Lat	na	Time		10 min	1 year	5 days	North Sea (NOS)	0.1 in lon and 0.066 in lat	regular	depending on erddap variables requested	as requested on erddap form	
	Model	sea_surface_wave_mean_period	https://erddap.naturalsciences.be/erddap/griddap/WAM_ECMWF.html and https://erddap.naturalsciences.be/erddap/griddap/WAM_UKMO.html	WAM_ECMWF_d61b_a29e_1c27.* (free outputformat: nc, txt, csv, ...) or V	tm_1	in-file	Lon	Lat	na	Time		10 min	1 year	5 days	North Sea (NOS)	0.1 in lon and 0.066 in lat	regular	depending on erddap variables requested	as requested on erddap form	
Pilot 5 - Galway	Model	eastward_sea_water_velocity	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		u	in-file	lon_u	lat_u	z_u	ocean_time		1h	1 year	3 days	Galway Bay	70 m	Regular	48.6 Mb	1	
	Model	northward_sea_water_velocity	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		v	in-file	lon_v	lat_v	z_v	ocean_time		1h	1 year	3 days	Galway Bay	70 m	Regular	48.6 Mb	1	
	Model	upward_sea_water_velocity	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		w	in-file	lon_rho	lat_rho	z_w	ocean_time		1h	1 year	3 days	Galway Bay	70 m	Regular	48.6 Mb	1	
	Model	sea_water_temperature	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		temp	in-file	lon_rho	lat_rho	z_rho	ocean_time		1 h	1 year	3 days	Galway Bay	70 m	Regular	48.6 Mb	1	
	Model	sea_water_salinity	http://milas.marine.ie/thredds/catalog/IMI_ROMS_HYDRO/GALWAY_BAY_NATIVE_70M_8L_1H/ANALYSIS/catalog.html		salt	in-file	lon_rho	lat_rho	z_rho	ocean_time		1 h	1 year	3 days	Galway Bay	70 m	Regular	48.6 Mb	1	
	Remote sensing	sea_water_turbidity	CMEMS OCEANCOLOUR_NWS_BGC_HR_L4_NRT_009_209		TUR	in-file	lon	lat		time		1 day	23 years	-	NE.Atl.+W.Med.	1 km	Regular		1	
	Remote sensing	mass_concentration_of_suspended_matter_in_sea_wate	CMEMS OCEANCOLOUR_NWS_BGC_HR_L4_NRT_009_209		SPM	in-file	lon	lat		time		1 day	23 years	-	NE.Atl.+W.Med.	1 km	Regular		1	
	Remote sensing	mass_concentration_of_chlorophyll_a_in_sea_water	CMEMS OCEANCOLOUR_NWS_BGC_HR_L4_NRT_009_209		CHL	in-file	lon	lat		time		1 day	23 years	-	NE.Atl.+W.Med.	1 km	Regular		1	
Pilot 6 - Denmark (HBM)	Model (Harmonie) interpolated	eastward_wind	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	uwind	in-file	lon	lat		time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model (Harmonie) interpolated	northward_wind	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	vwind	in-file	lon	lat		time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	sea_surface_elevation	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	elev	in-file	lon	lat		time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	sea_ice_area_fraction	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	ice_cov	in-file	lon	lat		time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	sea_ice_thickness	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	ice_thk	in-file	lon	lat		time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	eastward_sea_water_velocity	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	uvel	in-file	lon	lat	depth	time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	nothward_sea_water_velocity	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	vvel	in-file	lon	lat	depth	time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	sea_water_salinity	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	salt	in-file	lon	lat	depth	time		1h	12h	5 days	North Sea/Baltic sea	185 m	Regular	520 MB	132	
	Model	sea_water_temperature	ftp://forcoast@ftp.dmi.dk	outgoing/lim_hr_nest_wsid2021061712.nc	temp	in-file	lon	lat	depth	time		1h	12h	5 days	North Sea/Baltic sea	`85 m	Regular	520 MB	132	
	Model	sea_water_temperature_at_sea_floor	sharepoint AU	not uploaded yet	temp	in-file	lon	lat	bottom	time		monthly	2009-2017	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
	Model	sea_water_salinity_at_sea_floor	sharepoint AU	not uploaded yet	salt	in-file	lon	lat	bottom	time		monthly	2009-2018	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
	Model	Bottom stress	sharepoint AU	not uploaded yet	stress	in-file	lon	lat	bottom	time		monthly	2009-2019	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
	Model	mass_concentration_of_chlorophyll_a_in_sea_water	sharepoint AU	not uploaded yet	chla	in-file	lon	lat	bottom	time		monthly	2009-2020	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
	Model	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	sharepoint AU	not uploaded yet	oxygen	in-file	lon	lat	bottom	time		monthly	2009-2021	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
	Model	mass_concentration_of_detritus_in_sea_water	sharepoint AU	not uploaded yet	detritus	in-file	lon	lat	bottom	time		monthly	2009-2022	-	Limfjorden	155-3200 m	unstructured	not yet implemented	12	
Pilot 7 - Romania	Model	eastward_sea_water_velocity	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_U_20201203-20201203.nc	vozocrtx	in-file	nav_lon	nav_lat	depthu	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_T_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	37 Mb	24	
	Model	northward_sea_water_velocity	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_V_20201203-20201203.nc	vomecrty	in-file	nav_lon	nav_lat	depthv	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_T_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	37 Mb	24	
	Model	upward_sea_water_velocity	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_W_20201203-20201203.nc	vovecrtz	in-file	nav_lon	nav_lat	depthw	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_W_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	72 Mb	24	
	Model	ocean_vertical_heat_diffusivity	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_W_20201203-20201203.nc	votkeavt	in-file	nav_lon	nav_lat	depthw	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_W_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	72 Mb	24	
	Model	sea_water_temperature	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_T_20201203-20201203.nc	votemper	in-file	nav_lon	nav_lat	deptht	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_T_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	64 Mb	24	
	Model	sea_water_salinity	http://seamod.ro:8080/thredds/catalog/PHY/catalog.html	http://seamod.ro:8080/thredds/fileServer/PHY/2020/12/2_EFORIE_1h_20201201_20201231_grid_T_20201203-20201203.nc	vosaline	in-file	nav_lon	nav_lat	deptht	time_centered	seamod.ro:8080/thredds/wms/PHY/2021/04/1_NWS_1h_20210401_20210430_grid_T_20210401-20210401.nc?service=WMS&version=1.3.0&request=GetCapabilities	1h	20190101 - Present	3d	Eforie	200 m	Regular	64 Mb	24	
	Model	sea_surface_wave_significant_height	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/2021/05/20210501_h-HZG--WAVES-BSeas3-BS-b20210501_sm-sv07.00.nc	VHM0	in-file	lon	lat		time	https://nrt.cmems-du.eu/thredds/wms/bs-hzg-wav-an-fc-h	1h	20190504 - Present	/	BLKSEA	3 km	Regular	138 Mb	24	
	Model	sea_surface_wave_mean_period	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/2021/05/20210501_h-HZG--WAVES-BSeas3-BS-b20210501_sm-sv07.00.nc	VTM10	in-file	lon	lat		time	https://nrt.cmems-du.eu/thredds/wms/bs-hzg-wav-an-fc-h	1h	20190504 - Present	/	BLKSEA	3 km	Regular	138 Mb	24	
	Model	sea_surface_wave_stokes_drift_x_velocity	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/2021/05/20210501_h-HZG--WAVES-BSeas3-BS-b20210501_sm-sv07.00.nc	VSDX	in-file	lon	lat		time	https://nrt.cmems-du.eu/thredds/wms/bs-hzg-wav-an-fc-h	1h	20190504 - Present	/	BLKSEA	3 km	Regular	138 Mb	24	
	Model	sea_surface_wave_stokes_drift_y_velocity	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h	ftp://nrt.cmems-du.eu/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/Core/BLKSEA_ANALYSISFORECAST_WAV_007_003/bs-hzg-wav-an-fc-h/2021/05/20210501_h-HZG--WAVES-BSeas3-BS-b20210501_sm-sv07.00.nc	VSDY	in-file	lon	lat		time	https://nrt.cmems-du.eu/thredds/wms/bs-hzg-wav-an-fc-h	1h	20190504 - Present	/	BLKSEA	3 km	Regular	138 Mb	24	
	Remote sensing	sea_surface_temperature	ftp://nrt.cmems-du.eu/Core/SST_BS_SST_L4_NRT_OBSERVATIONS_010_006/SST_BS_SST_L4_NRT_OBSERVATIONS_010_006_c_V2	ftp://nrt.cmems-du.eu/Core/SST_BS_SST_L4_NRT_OBSERVATIONS_010_006/SST_BS_SST_L4_NRT_OBSERVATIONS_010_006_c_V2/2020/12/20201203000000-GOS-L4_GHRSST-SSTfnd-OISST_UHR_NRT-BLK-v02.0-fv02.0.nc	analysed_sst	in-file	lon	lat		time	https://nrt.cmems-du.eu/thredds/wms/SST_BS_SST_L4_NRT_OBSERVATIONS_010_006_c_V2	1d	19920101 - 20210605	/	BLKSEA	1 km	Regular	14 Mb	1	
	Remote sensing	mass_concentration_of_chlorophyll_a_in_sea_water	ftp://nrt.cmems-du.eu/Core/OCEANCOLOUR_BS_CHL_L4_NRT_OBSERVATIONS_009_045/dataset-oc-bs-chl-multi-l4-interp_1km_daily-rt-v02	ftp://nrt.cmems-du.eu/Core/OCEANCOLOUR_BS_CHL_L4_NRT_OBSERVATIONS_009_045/dataset-oc-bs-chl-multi-l4-interp_1km_daily-rt-v02/2020/12/20201203_d-OC_CNR-L4-CHL-INTERP_MULTI_1KM-BS-DT-v02.nc		in-file					https://nrt.cmems-du.eu/thredds/wms/dataset-oc-bs-chl-multi-l4-interp_1km_daily-rt-v02	1d	20160425 - Present	/	BLKSEA	300 m	Regular	1.4 Mb	1	
Pilot 8 - Italy	Model	eastward_sea_water_velocity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		U	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	northward_sea_water_velocity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		V	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	upward_sea_water_velocity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		W	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	ocean_vertical_heat_diffusivity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		diff_KzT	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	ocean_vertical_salt_diffusivity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		diff_KzS	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	file name could contain: 1. "bulletin" date (run date) 2. hindcast/forecast date 3. hour e.g., T_NADRI_14062021_16062021_14:00:00.nc each bulletin could be delivered as a tar file (e.g., NADRI_14062021.tar), with Pilot name and run date (containing all the hourly NetCDF files)
	Model	sea_water_temperature	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		T	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	sea_surface_temperature	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		SST	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	sea_water_salinity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		S	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	sea_surface_salinity	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		SSS	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	ocean_mixed_layer_thickness_defined_by_mixing_scheme	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		mld	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	mass_concentration_of_phytoplankton_expressed_as_chlorophyll_in_sea_water	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		Pl	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	mole_concentration_of_nitrate_in_sea_water	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		N3n	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	mole_concentration_of_phosphate_in_sea_water	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		N1p	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Model	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	https://dsecho.inogs.it/thredds/catalog/testForcoast/catalog.html		O2o	in-file	lon	lat	depth (cell center)	time		1h	7d	3d	northern Adriatic	1/128° (~750 m)	Regular	16 MB (to be compressed into NetCDF4)	1	
	Remote sensing	sea_surface_temperature (L4)	ftp-gos.artov.isac.cnr.it												northern Adriatic					
	Remote sensing	sea_surface_temperature (L3)	ftp-gos.artov.isac.cnr.it												northern Adriatic					
	Remote sensing	mass_concentration_of_chlorophyll_a_in_sea_water	ftp-gos.artov.isac.cnr.it												northern Adriatic					