HISEA DELIVERABLE 4.3

HIGH RESOLUTION MODEL REQUIREMENTS AND SPECIFICATIONS

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Lead beneficiary	HIDROMOD
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Executive Summary

In the framework of HiSea the use of high resolution models with the objective to achieve this goal of a better understanding of the processes and provide information at scales compatible with the user's activities and requirements represents one of the key elements considering that it effectively contributes to improved representations of unresolved but relevant processes.

Usually, modeling can provide significant progress in which concerns a **better understanding of a local dynamic** (hydrodynamic, waves patterns, water quality, etc.) through a combination of **increasing model resolution**, advances in observations and processes understanding. In many types of modeling, including hydrodynamic and water quality modelling, the resolution of data and models plays an important role in representing physical and chemical processes, therefore the choice of the "most appropriate resolution" must be done in line with the requirements of the issue to solve, the data and the computer resources available.

It is also true that some parameters observe more variability along with space than others and, as a consequence, some parameters must be calculated with higher resolution than others. This is the reason why this deliverable aims at addressing the following question: **in view of the specific needs of the problem to address which is the minimum required resolution the models must have in order to provide reliable solutions to which the users may rely upon to make decisions**? The answer to this question depends on the specific problem that needs to be solved and the level of accuracy and uncertainty accepted as fair by the user. For instance, for a Regional Coastal Authority, the information provided by Copernicus Global or Regional models may be sufficient, but for an aquaculture industry, located in a coastal lagoon, requiring information about water level, water temperature and water quality, probably only a model with a resolution of some tens of meters will be able to provide the information with an acceptable level of accuracy and uncertainty.

Linked with the issue of model resolution is also the issue of uncertainty and accuracy of the model results. Taking as reference the kind of services that HiSea intends to provide, mostly related to the day to day operations and management, the level of confidence the users may expect from the provided information is a key point. This means that numerical methodologies able to reproduce the conditions observed locally, as closely as possible, are required. The majority of the users are exploiting facilities in a limited coastal area (ranging from some hundreds of meters to some few kilometres) and as such, hardly any model with a resolution of some tens of kilometres will be able to properly represent the local conditions with the required accuracy.

In this document, some examples of different applications to different problems are used to illustrate these issues and some guidelines are proposed to help define the most appropriate model resolution required to answer specific questions.

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1 Introduction

HiSea aims to provide a set of customized and ready to use services focused on the needs of different coastal users such as navigation safety, ports operations, aquacultures, etc. These services will enable the exploitation of the added value offered by integrated Remote Sensing (RS) technologies (satellite, airborne and ground based), in-situ measurements, Copernicus Marine Service and ICT.

One relevant component of these services is the use of local high-resolution models that may provide a more reliable insight into the processes that are occurring at the scales of interest at the locations of the different users. Presently the European Union's Earth observation and monitoring programme, Copernicus, already produces a wealth of data and information on the marine, land, and atmosphere, which is available on a free open and full basis, leading to major changes in our understanding of the variability of the coastal environment.

As part of these Copernicus data, there are relevant global and regional numerical modelling results (historic, reanalysis, forecasts) that are already producing a vast amount of data that may be directly used to fulfil the needs of a broad community, and responding directly to strategic knowledge-based society needs for a sustainable coastal environment. This is especially true in cases where the knowledge at the regional scale level is enough to fulfil the user's requirements (e.g. sea spatial planning, regional monitoring programs, offshore navigation, fisheries, etc.).

However, as we intend to address more detailed coastal processes with relevance to local users (specifically ports and aquacultures) usually the resolution of these regional models it is not enough to properly describe the system dynamics at the local business scale. Taking into consideration that higher resolution Copernicus models, such as IBI or MedSea, provide results with resolutions in the order of 3-4 km, it is easy to understand that these models are insufficient to properly describe the process at the scale of a port or an aquaculture farm. This is even more true for ports or aquaculture farms located in areas such as estuaries or coastal lagoons for which the Copernicus global and regional models have no usable results.

In these cases, the availability of models with resolutions that are compatible with the relevant scale for the area of interest can add value to end users. Specifically, the provision of added-value information can contribute to improving business efficiency (optimization, forecasts, alerts, etc.), increasing safety and providing better knowledge of the local processes which in turn establishes the cause-effect relationships that may lead to adopting proper preventive actions when required.

The other side of this issue is that higher resolution requires increasing computational resources and usually extra data to properly validate the models' results. It is also important to keep in mind that usually higher resolution allows to have more accurate results and lower levels of uncertainty but this is not always the case. Depending on the required answer (namely in terms of temporal scales and/or data required) a high-resolution model may not necessarily lead to more accurate results. For this reason, the choice of the model resolution should always be linked with the specific questions and the type of answer expected. In order to illustrate these issues, some practical examples are described in this deliverable, to provide evidence that shows that a selected resolution is linked with the problems to solve and the required answers.

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2 HiSea Use Cases

Marine and coastal managers, based on accurate and complete information about the region under their jurisdiction, need to make decisions to maintain the social, economic, and ecological health of marine and coastal areas and to operate, plan and manage their activities at sea. HiSea is offering a service co-designed with the end-users and provide high resolution water quality data at sea, providing relevant knowledge for different coastal activities such as ports and aquaculture. HiSea proposes to transform the wealth of marine data collected by Sentinel satellites and generated by different Copernicus services to provide hindcasts, nowcasts, and forecasts of the metrics relevant to decision making and deliver a fully integrated service which is easy to use.

Specifically, the HiSea project targets the following objectives resulting in products and services:

- an innovative and cost-effective service that will enable an intensive use of Copernicus Products providing a tailored user accurate and reliable information resulting from the integration of different data sets;
- a platform capable to simulate different response actions in case of crisis management and/or seasonal events. These simulations are based on models being daily operated and to make use of an innovative approach of using "active upon request models". This approach enables the development of a growing catalogue of high resolution models that may be activated at any time upon user request and maintained at a low cost;
- the integration of data from different sources such as external providers, data from local databases andlocal high-resolution model output. The service offered as the end product is based on the harmonization of different types of data and the added value is in their fusion and merging including estimates of the uncertainties including data provided by the users through a crowd service concept;
- the ability to receive daily reports with information on selected parameters or events and /or ask to be notified in case of some foreseen (critical) situation is met (warnings and alerts);
- the derivation of a set of secondary variables such as key performance indicators focused on the different activities requirements.

These services will first be address to two targeted sectors: ports and aquacultures which are identified as prepared to take immediate advantage of the service information being developed.

In the case of the ports, high resolution information on water quality parameters is relevant for operational water pollution response systems and to derive port key performance indicators (KPI). In addition, the physics that drives the water quality status (meteorology, waves, currents, salinity, temperature, etc.) represents relevant information for increasing the operations' efficiency and for improving safety.

In the case of aquaculture, information relevant for the management of daily operations (e.g. seawater temperature, storms, rain, water quality parameters, etc.) and derived key performance indicators (KPI) will be provided. In this case, the capability to gather and disseminate information provided by different farmers will also help to perceive more rapidly the potential risk of disease dissemination if the latest is detected in a limited number of aquaculture farms. In all cases, the provision of mobile crowdsourcing information may play a relevant role.

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2.1 Aquaculture sector

The aquaculture sector is booming in many parts of the world, while in Europe, it is highly competitive. However, companies face many costs and challenges which may represent barriers in a sector dominated by small and medium-sized enterprises (SMEs) with limited funding capacities.

Aquaculture is broadly divided into fresh or brackish water farming, and saltwater farming. Farms can be land-based, where fish and shellfish are grown in tanks of different shapes made with natural or artificial materials, or else offshore, with the fish and shellfish in cages, rafts, baskets or long-line systems. Insurance schemes must be adapted to the environment and the rearing system, as the risks involved are different. There is little similarity between growing trout in a river-based operation and growing sea bream in offshore cages.

Fishery and aquaculture production is strongly constrained by environmental conditions, with wide ranging impacts including changes in growth rates of cultured animals and wild stock habitat distributions. Advance warning of suboptimal conditions allows for proactive management responses and helps maintain industry profitability in an uncertain environment. Improved management of marine resources, with the assistance of such forecast tools, is also likely to enhance industry resilience and adaptive capacity under climate change. To this end, Earth Observation and models have proved to be complementary. Short-term environmental fluctuations, combined with long-term climate-related trends, often require adjustments in fishing, farming, and management practices. Seasonal forecasts from dynamical ocean-atmosphere models of high-risk conditions in marine ecosystems in the coming months can be very useful tools for fishery managers. These forecast variables include water temperature, rainfall, and air temperature, and are considered skilful up to 3-4 months into the future, depending on the time of year and the region of interest.

2.2 Ports sector

Sea related activities are set to increase and the growth in maritime traffic is already a reality. This growth must be aligned with increasing environmental constraints and must comply with the achievement of the 'Good Environmental Status' foreseen by the Water Framework Directive. The adoption of improved and efficient behaviours based on wider incorporation of available information and knowledge is indeed required from the industry and the common citizens.

Each port infrastructure determines an impact on the territory and on the surrounding environment, a variable impact is based on multiple factors, including the size of the port, the volume of traffic on and the functionality. There is, therefore, an urgent need for the introduction of specific collection and recycling protocols and their implementation for the resolution and reduction of environmental problems arising.

At the moment, in order to monitor water quality in the ports, regular sampling campaigns are conducted. The areas of study include both intra-port waters (mass of water heavily modified by the presence of ports), as well as a control station representative of the extra-port waters (mass of coastal water). The monitoring of the water quality includes indicators of biological water quality, such as phytoplankton (concentration of chlorophyll-a) and other water quality indicators as turbidity, oxygen saturation, total hydrocarbons, faecal contamination as well as nutrients and other pollutants.

Large ports as the Valencia Port are located within or in close proximity to densely populated urban areas that could be critically affected by air pollution and water pollution. In addition, being major nodes linking and bringing together international transport chains and related economic activities, port areas are often part of critical geographical areas when it comes to environmental quality considerations.

Although port-related emissions or marine spillages contribute only for a part to environmental problems in port and surrounding areas, these problems can affect negatively the image of ports vis-a-vis their surrounding zones and put serious pressure on port development ambitions. In fact, environmental aspects as air and water are often at the heart of the political and societal debate about economic development plans and port development projects as previously mentioned. Therefore, the main challenge that port authorities face is to apply appropriate surveillance mechanisms in order to manage, control and reduce environmental pollutions.

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3 From global to regional to local

3.1 Service chain

Earth Observation (EO) comprises the use of *in situ* and remote sensing technologies to monitor the land, sea, and atmosphere. Much of the world's population and ecological economy is centred in coastal areas. Coastal change has helped to create the beautiful coastal landscape (i.e. cliffs, beaches, and estuaries), but the coasts have always been shaped by natural processes and human activity (i.e. flood defence, ports and piers as well as aquaculture and fishing industries).

The HiSea project proposes to promote the uptake of Copernicus globally, exploiting the added value of integration of Copernicus Products (remote and local data and models results) and other diverse data sources (both local, regional or global) with ICT (enhancing new frontiers opened by web) to deliver a set of user focused services.

These services are assured by an operational system capable to produce enhanced information resulting from the interlacement of various data sources into comprehensive information customized to the users' needs using data transformation processes such as data assimilation, data fusion algorithms and high resolution models.

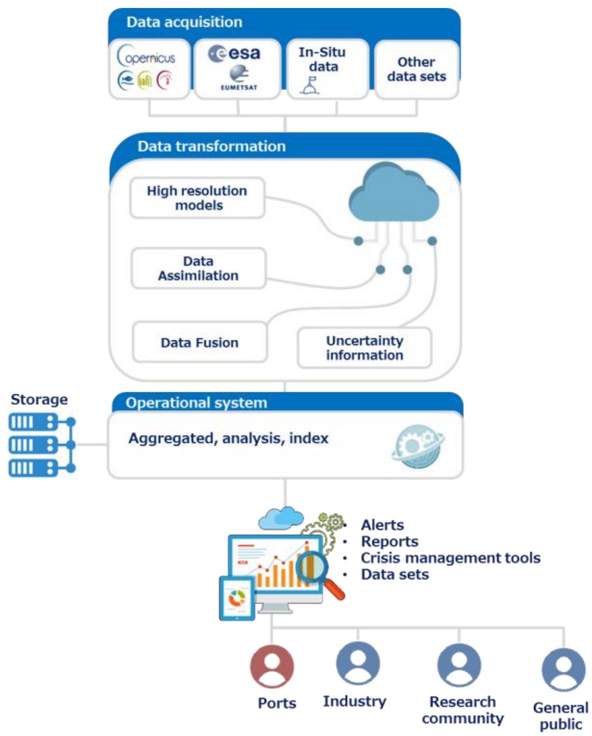

Figure 1: HiSea service

Copernicus Marine Service (CMEMS) provides numerous products for the Global Oceans and the European Seas including historical data, hindcast (reanalysis), near-real time forecasts, and forecasts. The temporal resolutions vary from hourly and daily to monthly. Furthermore, fine, medium and coarse spatial resolution products are available. Certain CMEMS model products use data assimilation of Sea Surface Temperature, sea level, or Chlorophyll-a into the models.

Models and observations (in-situ and satellite) are available covering different physical and water quality variables such as:

- Biological (e.g. nutrients, plankton, primary production, Chlorophyll-a, oxygen, transparency, turbidity);
- Physical (e.g. salinity, temperature, current velocity, sea surface height, bottom stress);
- Wave (e.g. wave swell, wave mean direction, wave mean period, and significant height).

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As summarized in the above Figure 1 the proposed service includes the capability to provide local resolution forecasts delivering model results with resolutions more in agreement with the ports' specific needs. This means for instance to get wave or currents information at scales capable of properly describe the conditions along the navigation channels, or meteorology, water quality, and air quality information at scales compatible with the ports scales. The setup of these high-resolution models starts with large scale meteorological, oceanographic and water and air quality forecasts (e.g. CMEMS, CAMS, ECWMF, GFS, etc.). The outputs of these higher-level solutions are then successively used to provide boundary conditions to higher resolution models (*Figure 2*).

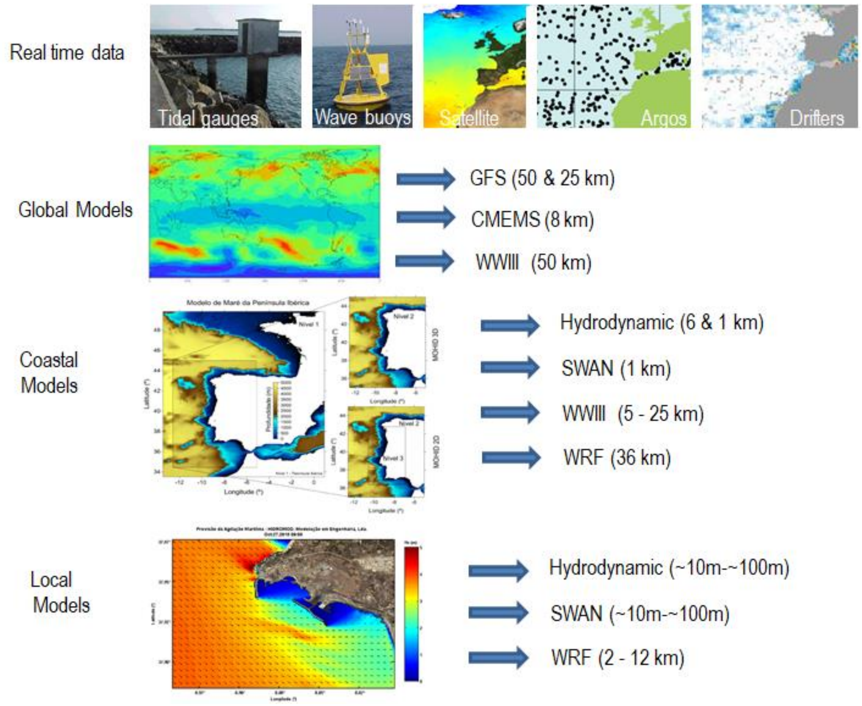

Figure 2: Exemple of different model resolutions

The high-resolution models (coastal or local) make use of CMEMS global and regional oceanographic models and water quality models and of NOAA GFS or other available services such as ECWMF or ICON, meteorological models to define their boundary conditions and initial conditions. Additional data from Satellite or other sources may be used in data assimilation processes or for model validation.

A practical example is the hydrodynamic modelling system implemented for some local sites in Portugal. From the data provided by external providers such as the Global Forecast System (GFS) for the meteorological forcing, the Copernicus Marine Service for the low frequency ocean dynamics and the FES2014 global tidal solution for the tide forcing, a coastal solution based on MOHID model is produced.

MOHID PT (cf. Table 16) provides a 5.5 day's hydrodynamic forecast (+ 1 day hindcast) including the scales that characterize regional marine processes (e.g., tidal forcing, atmospheric forcing, etc.). The system is based on a downscaling methodology and runs with a 0.06 degree of horizontal resolution.

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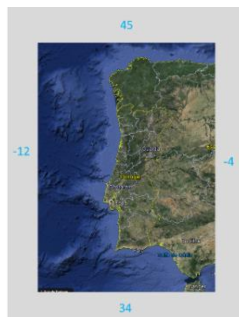
Table 1: Data information for the regional/coastal MOHID PT product

Data Information	
Model identifier	MOHID PT
Domain Name	Portugal
Available Variables	Sea level (m), current speed (ms^{-1}), current direction (°), seawater temperature (°C), seawater salinity
Geographical coverage	
Areas	Northern Spain, Portugal, Gibraltar Strait
Spatial resolution	0.06 degree
Outputs	Hourly (surface maps for entire area) and 10 minutes (time series of local stations)
Temporal coverage	From 2014-08-01 T00:00:00Z, still going
Validation Stations	Ferrol, Coruña, Villa García, Vigo, Viana do Castelo, Leixões, Aveiro, Figueira da Foz, Nazaré, Peniche, Cascais, Lisboa, Sesimbra, Tróia, Sines, Lagos, Faro, Faro Oceânica, Vila Real de Sto. António, Huelva, Tarifa, Algeciras, Ceuta, Aguarda, Caes, Monican 1, Monican 2, Alfredo Ramalho, Estaca de Bares, Villano Sisargas e Silleiro
Vertical coverage	From -5470 to 0 m
Forecast	5.5 days
Update frequency	Daily

This MOHID PT regional model (*Figure 3*) is then used to feed local high-resolution models with necessary initial and open boundary conditions. Downscaling further from MOHID PT, local solutions are produced with resolutions of tens to hundreds of meters according to local requirements.

Such is the case of the Douro-Leixões 3D baroclinic hydrodynamic model that integrates the Douro estuary model with the coastal model to properly simulate the Douro river freshwater plume that, in some weather conditions, affects the operation of Leixões port (*Figure 4*). The final purpose was to solve the Leixões port hydrodynamic with resolutions of tens of meters to properly answer the users' needs in terms of the description of the processes.

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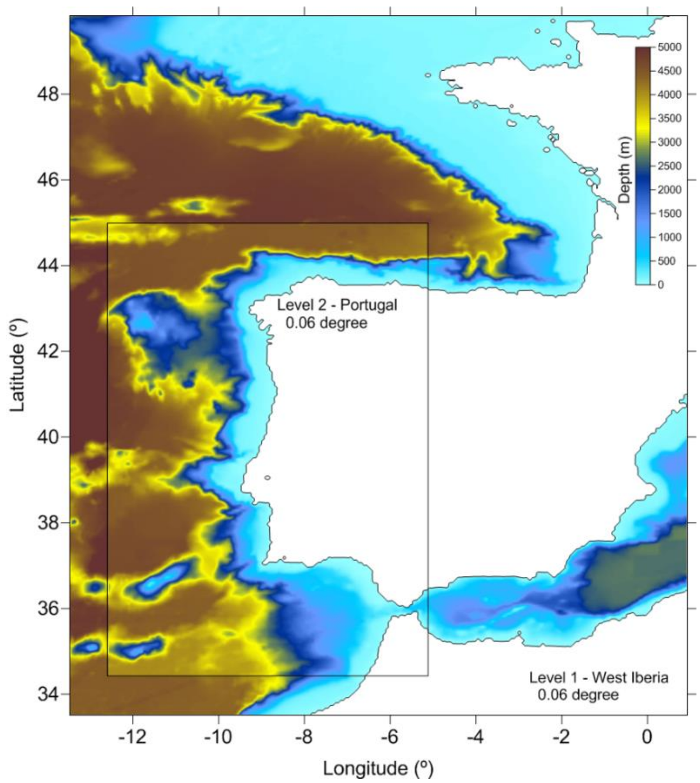

Figure 3: Nested models implemented for the Portugal region (MOHID PT) based on CMEMS global solution

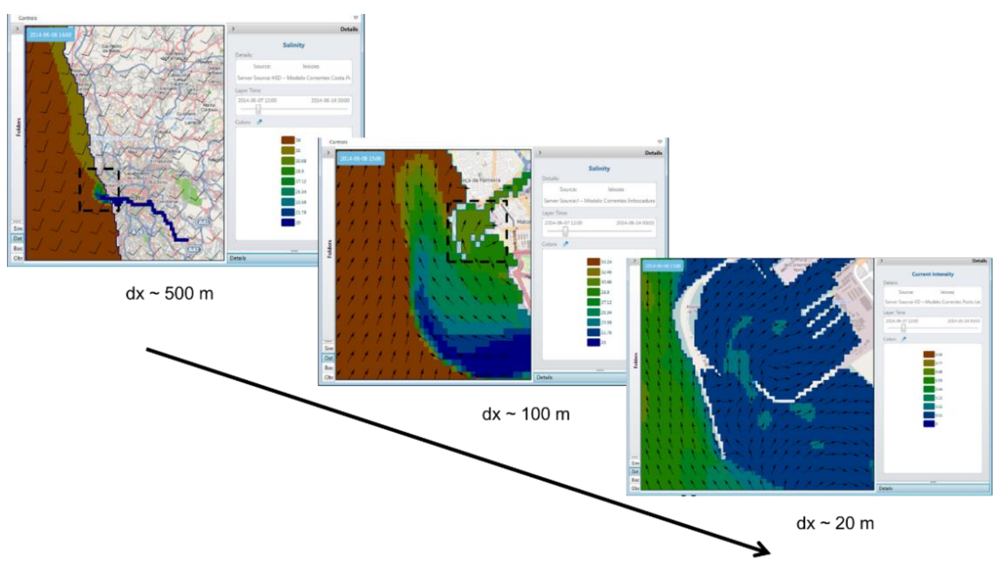

Figure 4: Cascade of models, starting on MOHID PT regional solution, set up to provide a high-resolution solution for Leixões port

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Marine Copernicus products play a key role in this operational chain as it supports oceanographic forecasts that are being delivered. Beyond its intrinsic value as a direct source of data, Marine Copernicus data is the base of a whole operational chain providing the required boundary conditions to run nested hydrodynamic (and biogeochemical) models capable to deliver higher resolution information.

3.2 User uptake benefits

Unexpected environmental events can cause serious disruptions and long-term delays which might be very costly. The capability to anticipate problematic situations or get in-time proper support to help in the decision making process may contribute to relevant cost reduction and safety increase.

Although some times the exact quantification of the benefits for the service users may not be a straightforward task (especially in which concerns the benefits related with the safety increase) it is a fact that the return in efficiency improvement in operations such as those related with ports or aquacultures may be quite relevant and be translated in some thousands of Euros a year (depending of the dimension of the operation). In practice, the recognition by the users of the added value of this information must be translated which in the end translates their willingness to pay for the provided services.

The advantages for the users that are benefiting from these services include:

- Get information instead of data;
- Receive tailored information on selected parameters;
- Get access to all the required information (meteorology, currents, waves, water quality, etc.) relating forecasts, or data (real time, satellite, etc.) through a single access point;
- be in time notified in case some foreseen (critical) situation is likely to be met;
- Get access to continuous updated models for validation reports.

and are:

- Focused on users' specific requirements (provides exactly the required information in the required formats);
- Making all the required data and forecasts available through a single access point (meteorology, oceanography, waves, water quality, etc.);
- Providing continuously updated validation reports (enabling an effective assessment of the models' performance and reliability).

3.3 Service quality control

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A relevant aspect of the information produced with the support of high-resolution models is the requirement of maintenance of reliable quality control. In view of a large number of data sources and parameters that are daily managed it is necessary to keep continuous auditing procedures in order to keep a continuous model results validation, identify the processes that are failing, assess the respective causes and adopt the required corrective or preventive measures.

As a result, it should be kept running a service auditing service allowing to keep a track of the quality of provided services. These auditing procedures should, at least, cover the following topics: 1) procedures; 2) indicators for each procedure and 3) quantification of each indicator.

1. Procedures

The procedures audited are:

- Information Technology (IT) services - to guarantee the operability of daily forecasts
- Forecasting accuracy – to provide a quantitative estimate of the expected quality of the forecasts

2. Indicators

The indicators that should be evaluated are at least:

IT Services	• Server accessibility * • Data sources (real time data and model runs) • Client Interface (frontend) • Alerts (failure, false positives, etc.)

** In the case of server accessibility the service-level agreement (SLA) of 99.9% should be fulfilled*

Forecasting accuracy	• The correlation coefficient (R) • Root Mean Square Error (RMSE);

3. Quantification

The period for quantification should cover at least a 6 months period in order to guarantee that statistical metrics are representative. The quantification of indicators must be made by the following methodology for the days defined to audit.

IT Service	Server accessibility	A query is run in order to ask for databases the data flaw periods of each data source scheduled on the platform. Downtimes server larger than 1 hour are crossed with data flaw periods

	Data sources (real time data and model forecasts)	Quantified evaluating the successful/unsuccessful tasks scheduled in the platform for the total days audited $Data\ Source\ = \frac{Nº\ days\ sucessful}{Total\ days\ audited} \times 100$
	AquaSafe Interface Client	It is assumed that the number of days calculated for the server accessibility is the same that the interface client is unavailable
	Alert reports disseminations via email	Quantified evaluating the number of reports sent via email for the total days audited. Note that the number of reports must be concordant with the type of report (e.g., daily, weekly, monthly) $Reports\ = \frac{Nº\ Reports\ per\ day/week/month}{Total\ days\ audited} \times 100$

Forecasting accuracy	Correlation coefficient	$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}}$
	RMSE	$RMSE = \sqrt{\frac{\sum_1^n (pi - ai)2}{n}}$
	NRMSE	$NRMSE = \frac{RMSE}{4 * STDEV}$

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4 Examples

4.1 HiSea test sites

4.1.1 Forecasting requirements

Statistics of the European Commission on aquacultures show that the seafood production by aquaculture is on an increasing trend and will continue to be for a long time, especially in Greece. This gives the opportunity for the new facilities of aquaculture. A profitable and environmentally low impact site should be selected for the long term sustainability of the aquaculture operations. The relevant water quality variables, availability of nutrients and the effects of the produced biomass in the aquaculture area could only be forecasted by the use of local hydrodynamics, seabed features, benthic communities, and other ecological characteristics. This forecasted information is useful for farmers in terms of scheduling the feed operations and in the assessment of environmental impact if the facility operates as required for legal operation under the rule. In most cases, numerical forecasting techniques are not yet utilized to alert the aquaculture farmers on changes in water quality. Numerical models and subsequent forecast models can offer a great service to the sector enabling the user in decision making.

4.1.2 High-resolution requirements for water quality

Though existing services, such as Copernicus Marine Environment Monitoring Service (CMEMS), are trying to incorporate the demand of the aquaculture end user community for wider water quality data, the spatial resolution of such information is not yet matching the requirements of the aquaculture sector. The required resolution for aquaculture operations ranges from a few ten meters to a hundred meters, whereas the existing operational data services are in the spatial resolution of a few kilometers. **These demand-supply gaps require the development of high-resolution coastal water modelling with a focus on water quality parameters.**

4.1.3 Greek case study description (Selonda aquaculture site)

In this case study in Greece (Figure 5), a flexible grid refinement is utilized to ensure finer grid resolution at the area of interest and coarser resolution in the open sea where the refinement is not necessary. This enables a balance between computational time and the fine resolution model output requirements at the aquaculture sites. The refinement of the grid cells is 3.55 km at the open ocean boundaries and 220 m near the point of interest near the coast (*see* Figure 6).

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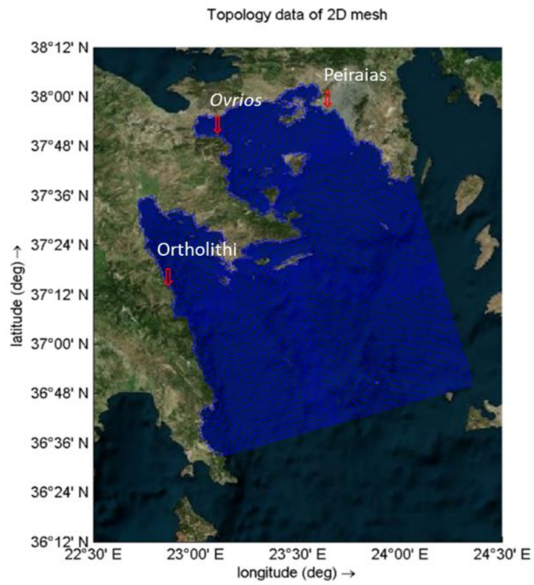

Figure 5: HiSea study case

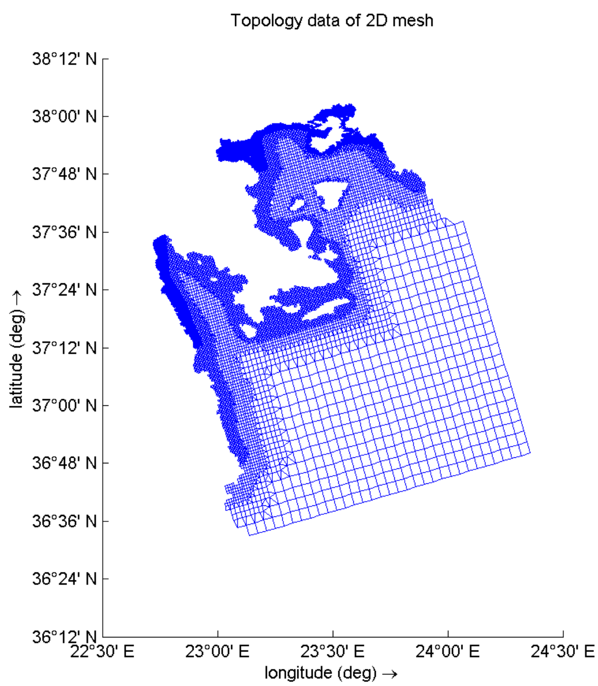

Figure 6: Model spatial domain and grid setup

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4.1.4 Boundary condition. Nesting with CMEMS

The coarser spatial data from existing services are used as boundary data for developing new high-resolution models. This means saving resources needed for the collection of spatial-temporal hydrodynamic and water quality data for defining boundary conditions. In this case, the model utilizes CMEMS boundary data in two different segments (east and south boundary) with each of the boundary provided with hydrodynamic information such as tidal signals, temperature, salinity, advection velocities, and water level fluctuation due to the density change. Preliminary results are shown in Figure 7 to Figure 11. The water quality information such as dissolved oxygen, NO_3, PO_4, particulate organic carbon, etc., will also be utilized for the water quality simulations.

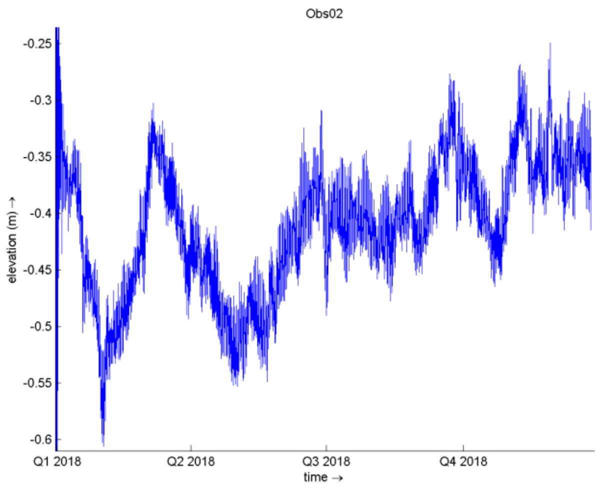

Figure 7: Water level simulation for the location at Peiraias

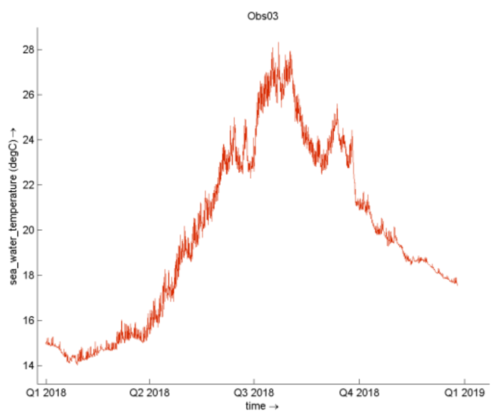

Figure 8: Preliminary temperature simulations for Ovrios

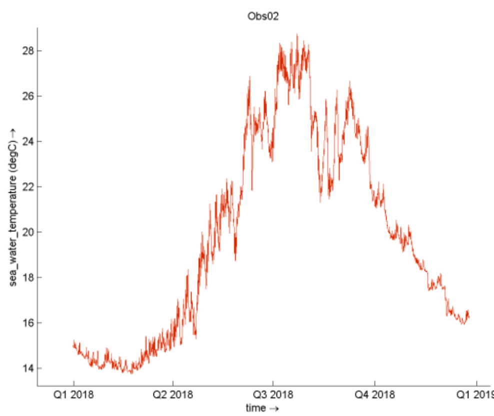

Figure 9: Preliminary temperature simulations for Ortholithi

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Several atmospheric forcing data are required for a better representation of reality. These are wind speed, solar radiation, air temperature, relative humidity, cloud cover, etc. These data are utilized by the model in both hydrodynamic as well as water quality computations, such as water level, temperature, dissolved oxygen etc. In this case, the model is provided with data extracted from the Copernicus Climate Change Service (C3S).

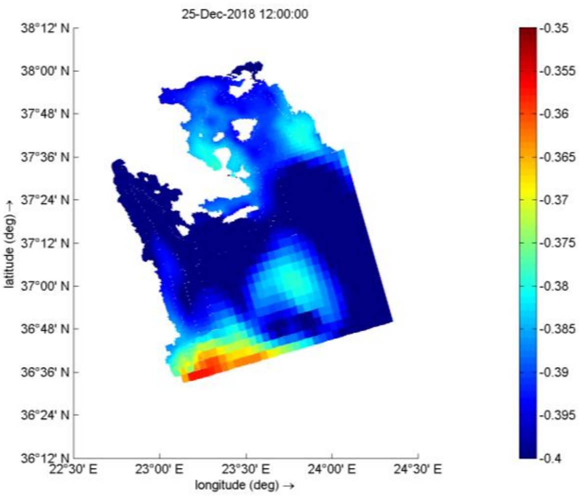

Figure 10: Water level simulation

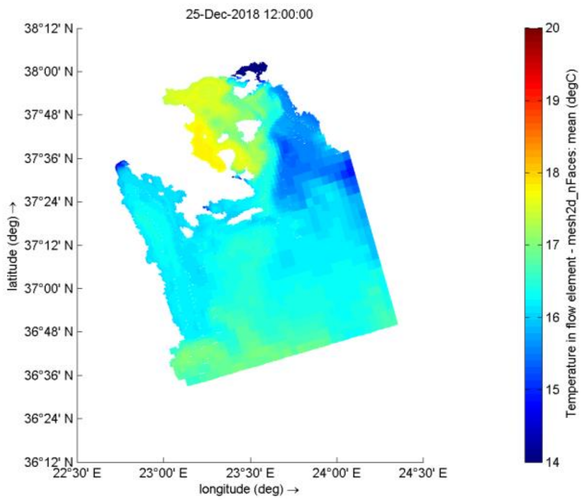

Figure 11: Surface water temperature simulations

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4.2 Other relevant examples

4.2.1 Coastal areas: the Sines case

The Port of Sines is the first largest artificial port of Portugal, and a deep-water port, natural backgrounds to -28 m ZH with specialized terminals that allow the movement of different types of goods. Besides being the main port on the Atlantic seaboard of Portugal due to its geophysical characteristics, it is the main gateway to the energy supply of Portugal: container, natural gas, coal, oil, and its derivatives. Near the port, there is located also a large thermoelectric power plant in which the cooling system also introduces relevant impacts on the coastal water temperature.

Due to these characteristics, the issue of the short-term forecasting of the local meteo-oceanographic conditions (that may restrict the ship movements) and the water quality (that may impact no only the port operations but also the surrounding areas) represents a major concern in socio-economic terms. Moreover, there near the port there are installed the major thermoelectric power plant in Portugal (which cooling process has impacts on the local water temperature) and seabass aquaculture (*cf. Figure 12*) which relies on very high standards in terms of water quality.

Figure 12: Sines port aerial view and Seabass aquaculture cages

In order to provide a daily assessment of the foreseen meteo-oceanographic conditions and water quality parameters for the next days, a local high-resolution modelling system was implemented. The main concerns of the port and the aquaculture are as follows:

- Port: meteo-oceanographic conditions (waves, wind, water level, and currents) and water pollution accidents (oil or other dangerous products).

- Aquaculture: water temperature, chlorophyll, and potential novice products that may be generated by the port operation (dissolved or particulate). Water temperature is one of the most important factors for aquaculture as this property influences all processes that occur in water and it affects the fish's physiological processes (i.e., metabolism, growth and reproduction), see Figure 13.

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- Electric power plant: algae blooms and water temperature.

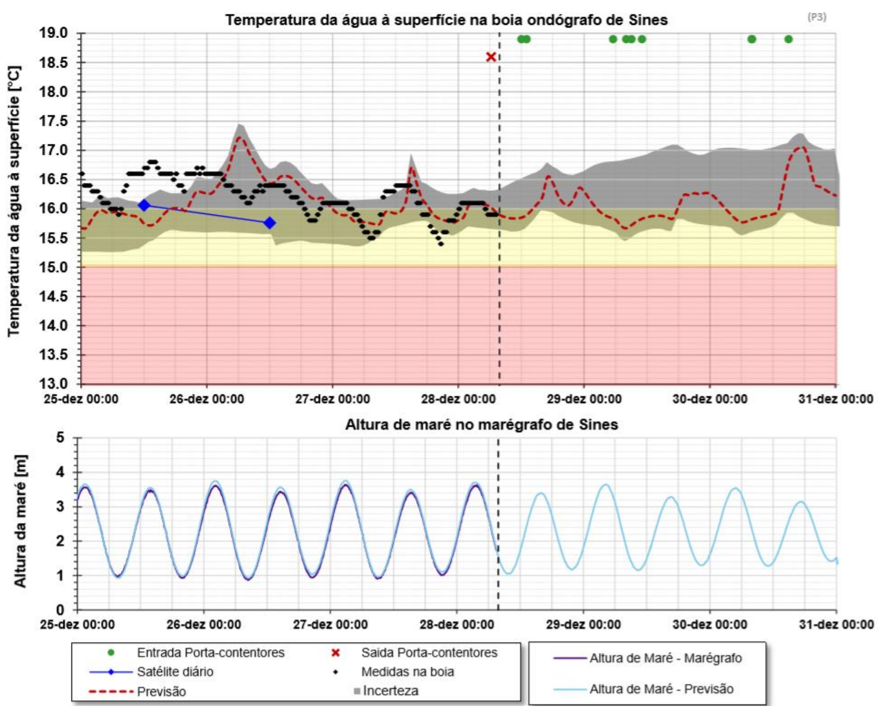

Figure 13 – In the upper panel temperature forecast in a point (grey – uncertainty, red – best forecast) compared with buoy data (black) and satellite data (blue) is presented. In the lower panel, sea level forecast and observations are presented.

The fulfillment of the requirements of these different users it was necessary to implement models with the proper resolution to reproduce the local phenomena as accurately as possible. Given the spatial dimension of the area and the need to properly compute the different parameters at the port basin scale, the modelling system adopted a downscaling strategy with increasing resolution grids, ending up in grids resolutions of the order of 50 m for the hydrodynamic, waves, and water quality.

The high-resolution hydrodynamic model implemented consists of 3 nested levels (1.2 km, 250 m, and 50 m see Figure 14) forced by the results from a Portuguese Coast 3D (PCOMS) model solution. PCOMS is a baroclinic 3D model with a resolution of about 6 km that provides forecasts for the next 6 days. It gets boundary conditions from the meteorological GFS solution, the global tidal solution FES2012 (Carrère et al., 2012), the low frequency CMEMS Global solution and the discharge of the electric power plant cooling system (40 m^3/s, 10^oC above the sea water temperature).

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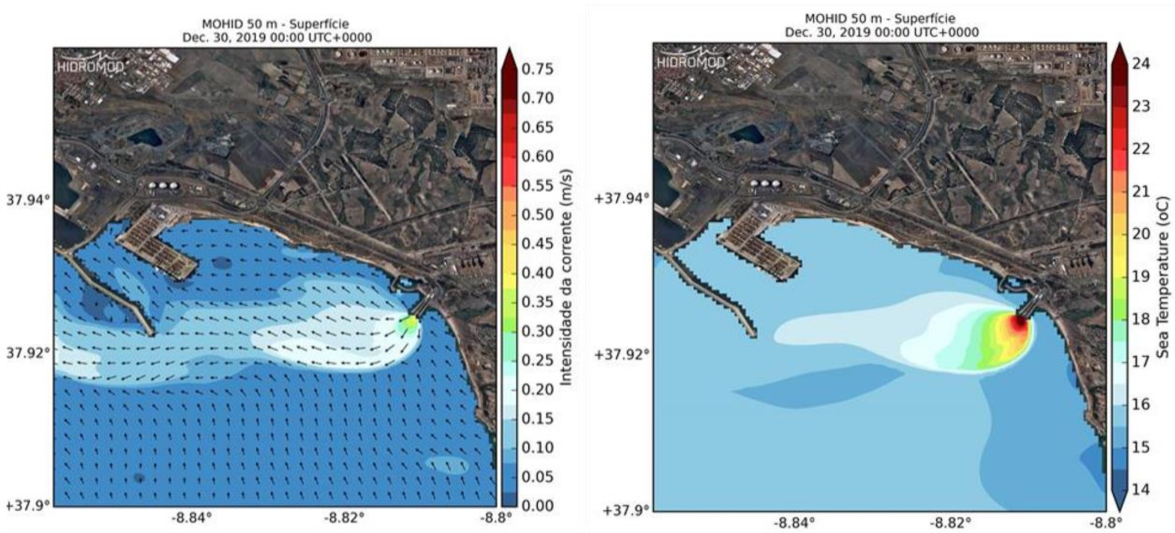

Figure 14 – High resolution surface forecast of velocity (left panel) and temperature (right panel).

Beyond hydrodynamic and water quality, the waves represent another critical aspect for the entire local area (port, aquaculture, and electric power plant). As in the case of hydrodynamic, only a high-resolution model can properly detail the wave patterns affecting these infrastructures (Figure 15). Beyond the direct impact on the structures, in the case of the electric power plant, for some wave and environmental conditions, there are observed the occurrence of algae blooms that have the capacity to clog the cooling water intake system and may lead to unexpected production shutdowns. A warning system to inform in advance about these situations is in place for the last ten years and, until the date, was capable to successfully detect all the potential critical events allowing taking preventive measures to avoid the shutdown of the power plant. Shutdown events were common previous to the forecast system implementation.

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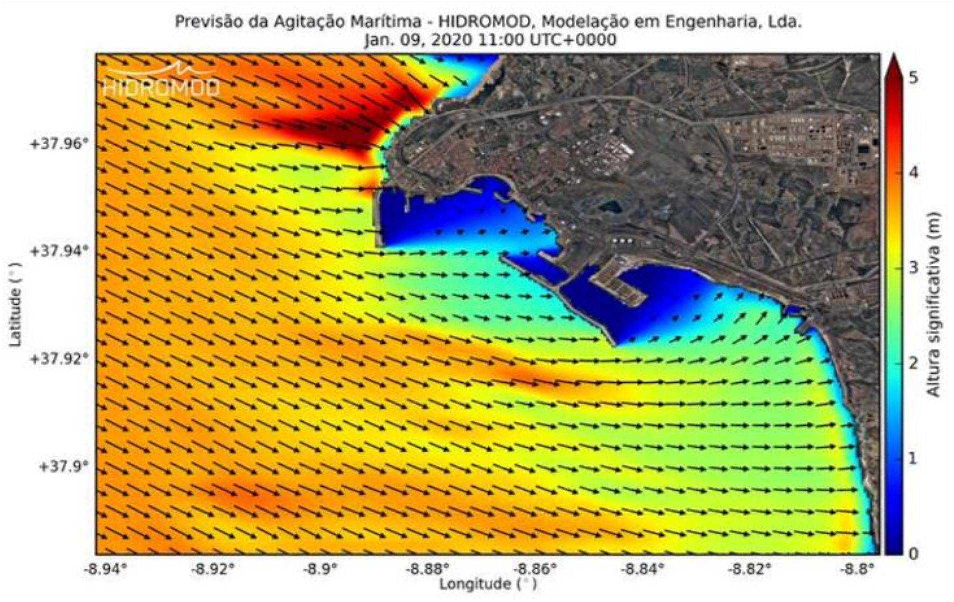

Figure 15 – High resolution of wave forecast.

The local users, beyond having access to detailed information (models, locally measured data a satellite data) via web and mobile app also receive daily reports with selected information in pre-defined points which they consider critical for their activities. There is also an oil-spill tool ready to run and providing oil paths forecasts in case of an accident which will be also available in HiSea platform.

4.2.2 Coastal lagoons and estuaries: the Aveiro and Alvor lagoons

Aveiro coastal lagoon is a shallow mesotidal lagoon located on the Northwest coast of Portugal (Figure 16). It is 45 km long and 10 km wide, is characterized by narrow channels and by the existence of large intertidal areas. In spring tide, the water covers an area of 83 km^2 at high tide reducing to 66 km^2 at low tide (Dias et al., 2000). The lagoon receives freshwater mainly from two rivers: Antua (~5 m^3/s average flow) and Vouga (~50 m^3/s average flow) being Vouga river responsible for about 65% of the freshwater input into the lagoon (Dias et al., 1999). Tides, which are semidiurnal, are the main forcing of circulation. Beyond its rich ecological value, Aveiro lagoon also holds several sea related businesses from which, in this context, we may refer to the port the aquacultures.

Figure 16: Aveiro coastal lagoon

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Due to its location in a sensible area from the environmental point of view, navigation safety and water quality issues are two relevant concerns to local users. In order to provide support to these concerns an operational system providing daily forecasts of waves, hydrodynamic, meteorology and water quality was set up. In this case, the model resolution is mostly conditioned by the channel's width which for a proper definition requires the use of models' grids of a few tens of meters (*Figure 17*).

With an annual throughput of around 3.5 million tonnes, Aveiro is a multi-functional port, which plays a crucial role in serving a wide range of industries in its hinterland, such as the ceramics, chemical, winemaking, metallurgic, wood and derivatives industries, as well as the agricultural food and construction sectors.

ALGAPLUS is an innovative aquaculture company that is producing algae using water flowing from seabream production ponds. Based on the sea level predicted by the lagoon high-resolution model, a simplified model of the water circulation in ALGAPLUS ponds allows predicting the sea level and the water residence time (*Figure 18*).

Figure 17: Aveiro lagoon high-resolution hydrodynamic model

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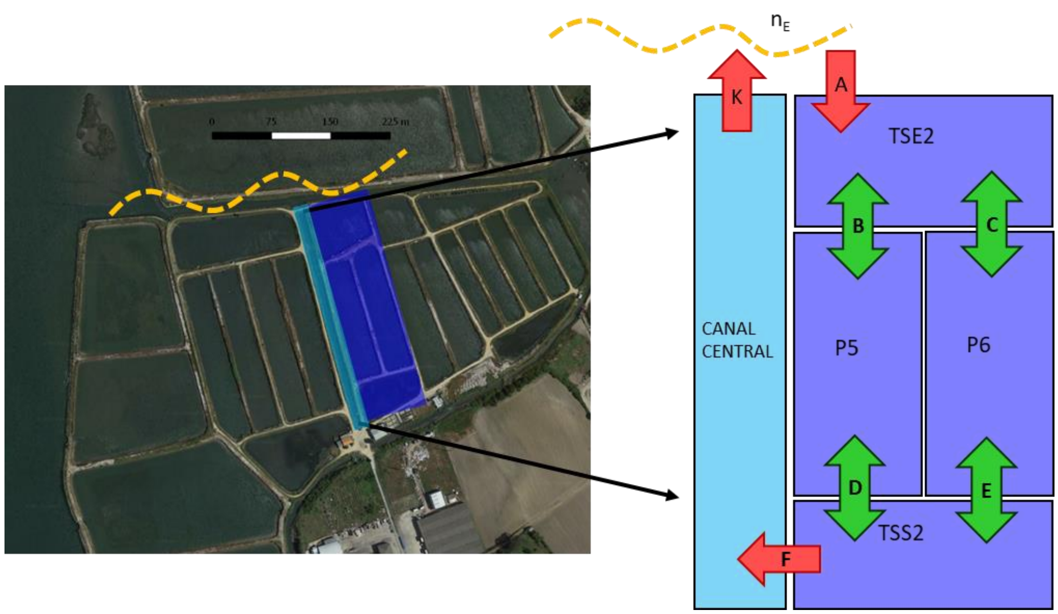

Figure 18: ALGAPLUS the water circulation model

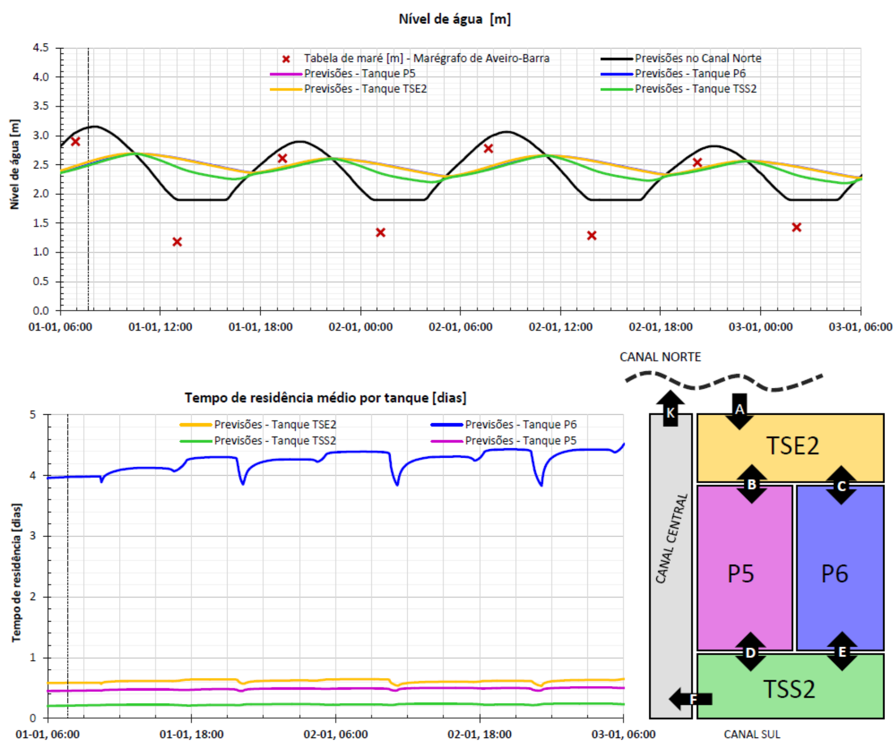

Figure 19: Example of a report sent daily to Algaplus

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The Alvor lagoon is a priority area for conservation located on the Portuguese south coast, classified as a RAMSAR wetland of international importance since 1996 and part of the European Ecological Network, Natura 2000 (Figure 20).

Figure 20: Alvor coastal lagoon

In this case, the main interest is an aquaculture industry located inside the lagoon (Piscicultura do Vale da Lama (PVL)). This facility is producing seabass and seabream in ponds located inside the lagoon that are using water pumped from the lagoon. To this end the knowledge about the time at which the next high tide occurs, and the water levels, temperature, and salinity values, are relevant information for PVL in order to optimize pumping, allowing significant cost savings. In order to fulfill the PVL requirements, a high-resolution model with a horizontal resolution of 40 meters was implemented (see Figure 21 to Figure 23).

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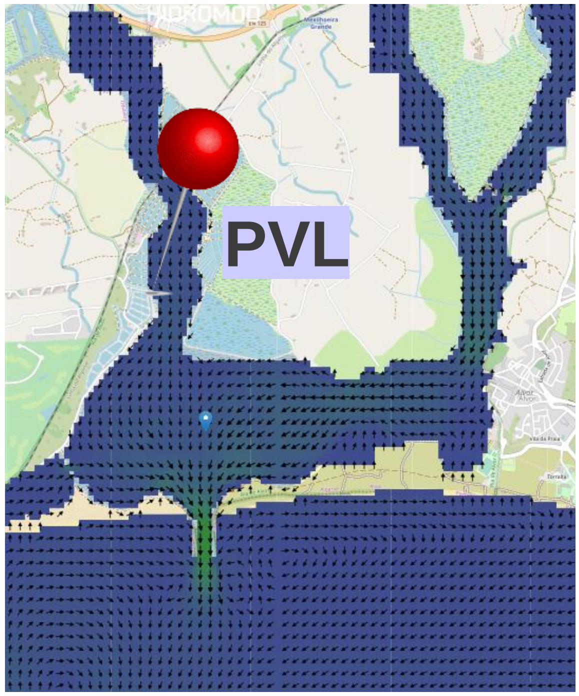

Figure 21: Velocity forecast.

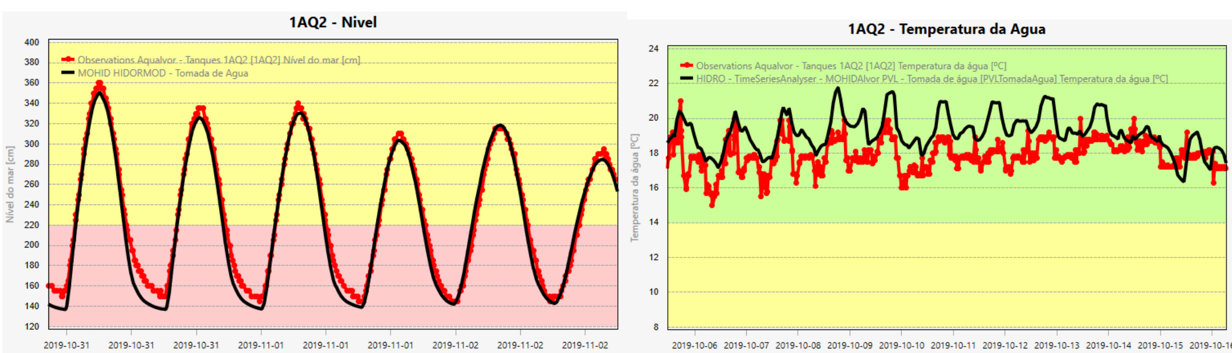

Figure 22: Water level and water temperature at PVL water intake (measured and computed)

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Figure 23: PVL water intake

4.2.3 Inland: the Acuinova case

South of the Ria de Aveiro, in Mira, is located an aquaculture company (Acuinova) currently producing about 2500 tons of turbot in inland tanks (*Figure 24***Error! Reference source not found.**). These tanks receive seawater through a critical pumping system, which represents a major cost for the company. The water temperature and turbidity (*Figure 25*) are the water parameters with a major impact on the operation.

To support this aquaculture operation, it was implemented an operational system with the objective to provide forecasts about the turbidity and water temperature and to optimize the water pumping system (subject to tide action). The system is showing to be able to provide accurate forecasts of both parameters (turbidity and water temperature) and to effectively contribute to optimizing the pumping process taking into consideration the seawater levels.

Figure 24: Acuinova facilities

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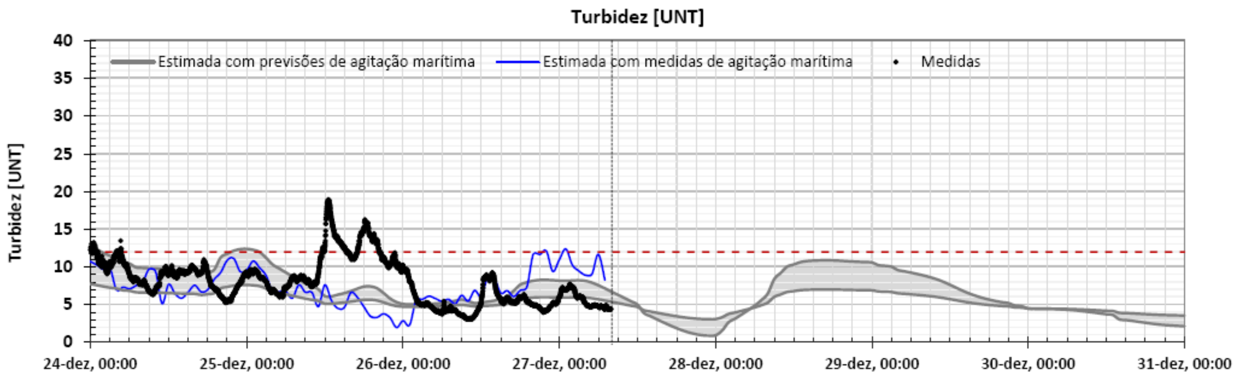

Figure 25: Turbidity at ACUINOVA water intake (measured and computed)

4.2.4 Regional Planning: the Galicia case

INTECMAR is a Public Agency of Regional Government of Galicia (NW Spain) which main goal is to control the quality of the marine environment and the implementation of the regulations as regards the technical and health control of sea products.

As part of these responsibilities, INTECMAR keeps a strong focus on sea monitoring and added value products for aquaculture, fisheries and contingency plans. To this end, it benefits from the support of an operational system that includes different data sources, tools and high resolution models addressing themes such as hydrodynamic, waves, microbiological pollution, water biogeochemical status, and oil spills prevention and response. As part of this system, apart from the Copernicus data, there are in place 6 monitoring platforms, 4 HF Radar stations and 43 CTD sampling stations producing weekly data (*Figure 26*).

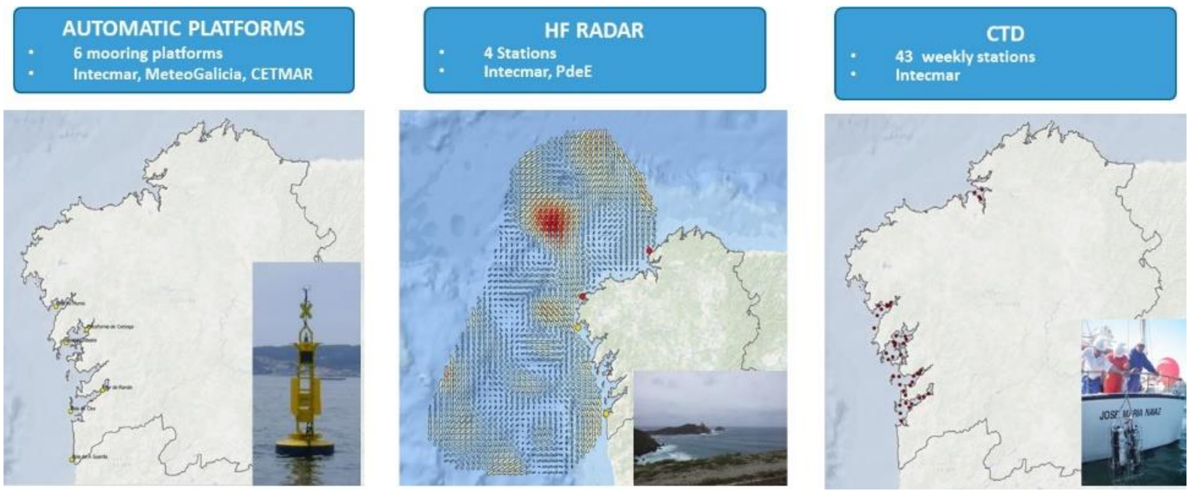

Figure 26: INTECMAR Observing network

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The high resolution modelling system was designed in order to respond to the INTECMAR requirements in the above referred areas. Starting from an oceanographic model with a 2 km resolution based on ROMS, there are a number of higher resolution models based on MOHID, allowing to describe the local processes with the required accuracy: four sub-models with 300 m resolution (*Figure 27*) and two more with 50 m resolution. These high resolution models are being fed with the regional ROMS solution, a meteorological solution based on WRF with 4 km resolution and forecasts of the river discharges based on SWAT model.

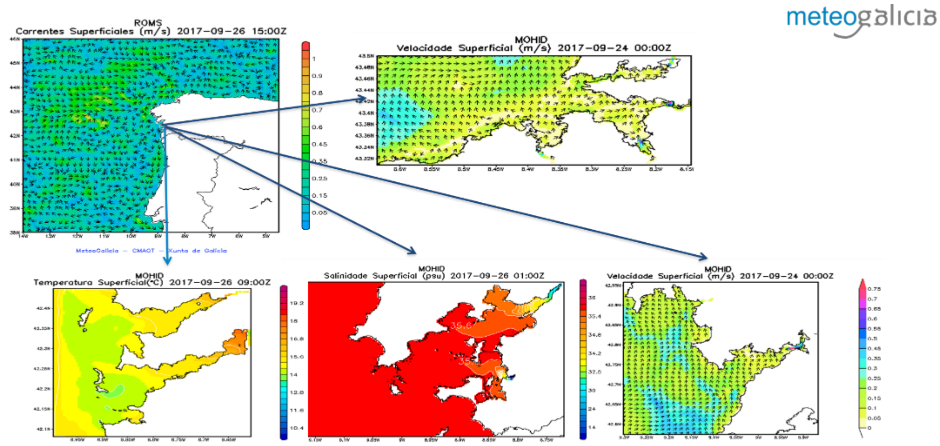

Figure 27: INTECMAR's 300m high resolution models using ROMS solution as starting point

The final purpose of these models is to help in the monitoring network design (selecting the most representative sampling points), checking the risks of eventual microbiological contamination of the mussels cages from new or existing urban discharges (*Figure 28*) and follow and backtrack the path of oil spill events (*Figure 29*).

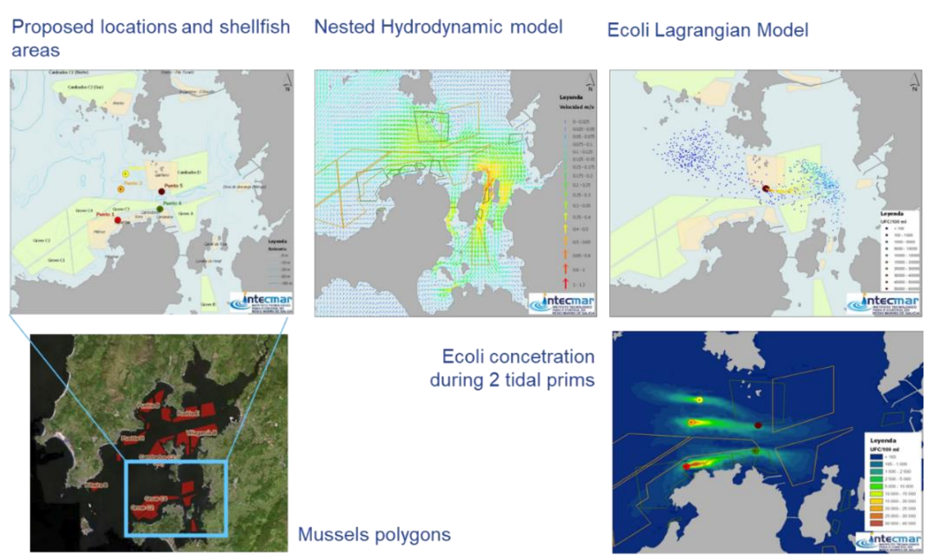

Figure 28: Using high-resolution model to assess the risk of microbiological contamination on the mussel's production areas

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Figure 29: Using high resolution model to backtrack the potential origin of an observed slick

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5 Conclusions

This Deliverable provides a summary of the objectives and potential outcomes related to the use of high resolution models to provide more accurate information to costal activities operation and planning.

The document provides a list of procedures to consider in the process of implementation of a modelling service chain and in the service quality control and presents some illustrative examples where the use of the high resolution models represent an added value for the local businesses.

As a general conclusion one may say that the use of local high-resolution models that may provide a more reliable insight into the processes that are occurring at the scales of interest at the locations of the different users. As we intend to address more detailed coastal processes with relevance to local users (specifically ports and aquacultures) the resolution of publically available regional models (trough Copernicus, NOAA, or other providers) it is not enough to properly describe the system dynamics at the local business scale.

In these cases, the availability of models with resolutions that are compatible with the relevant scale for the area of interest can add value to end users. Specifically, the provision of added-value information can contribute to improving business efficiency (optimization, forecasts, alerts, etc.), increasing safety and providing better knowledge of the local processes which in turn establishes the cause-effect relationships that may lead to adopting proper preventive actions when required.

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