CONNECT – Local coastal monitoring service for Portugal

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ABSTRACT

CONNECT provides a local, high-resolution, coastal monitoring service. It integrates model-based forecasts and observations to provide physical and biogeochemical data on Portuguese estuaries. The service is demonstrated in two use cases, the Tagus estuary and the Mondego estuary.

1. Introduction

Coastal areas provide multiple ecosystem services and are key for the blue economy. These systems harbor ecologically important habitats for fish, shellfish and birds, act as buffers for nutrient and contaminant loads entering the ocean, and support diverse human activities. The increasing human activities in coastal areas, coupled with the impacts of climate change, are rising the hazards within these systems. As a result, quantifying and anticipating how human-induced or climate-driven factors influence coastal systems has become essential to support their sustainable management and to meet the objectives of environmental directives and policies.

CONNECT offers a shelf-to-estuary-river, high-resolution, coastal monitoring service that integrates model-based forecasts and observations. It provides physical and biogeochemical data on Portuguese estuaries to the Copernicus Marine Service (CMEMS), enhancing the management, monitoring and forecasting of water quality and coastal inundation. This service integrates two operational coastal data infrastructures:

- the UBEST coastal observatory (Rodrigues et al., 2021; https://ubest.lnec.pt) that focuses primarily on model forecasts partly forced by CMEMS regional models.
- the CoastNet monitoring infrastructure (Castellanos et al. 2021; França et al. 2021; https://coastnet.pt) that provides near real-time observations from *in-situ* sensors, and remote sensing data mainly from CMEMS.

By combining complementary sources of information, the integrated service: i) enhances confidence in both the model results and the observations by allowing automatic cross-comparison of data sources; ii) fosters the early detection of numerical and measurement anomalies (e.g., drifting time series due to biofouling); iii) strengthens the robustness by creating redundancy in the data access; iv) promotes the adoption of common formats and a seamless integration with CMEMS; v) simplifies the extension to other coastal systems, given the adaptability and transferability of the underlying service.

The new integrated service strengthens the support of the implementation of the Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD), the Floods Directive (FD), and other EU policies, such as the Green Deal, by providing further and integrated historical and real-time information on physics and biogeochemistry.

This paper describes the main characteristics of the CONNECT coastal service (section 2) and its use cases, in particular the demonstration of the service in the Tagus and Mondego estuaries (section 3). Final remarks are presented in section 4.

2. The CONNECT service

2.1. The CONNECT service in a nutshell

CONNECT (https://connect.lnec.pt/) is a user-friendly service that seamlessly integrates and shares through a dedicated WebGIS portal layers of physical and biogeochemical data from model forecasts and *in-situ* and remote observations (Fig.1). These layers are aggregated at different spatial and temporal scales. The integrated service is globally accessible, comprehensive, flexible, and modular. It was designed to be easily customizable and transferable to other coastal systems.

The main features of the CONNECT coastal service are:

i) shelf-to-estuary-river, high-resolution, circulation and water quality operational modeling to produce daily forecasts of local physical and biogeochemical variables;

ii) near real-time physical and biogeochemical data from *in-situ* observation networks, and EO-based data from CMEMS;

iii) river flows at the models' upstream boundaries predicted using Artificial Intelligence;

iv) automatic model-observations comparison, enhancing confidence in both;

v) indicators and weekly reports of the modeled and observed variables that summarize both the physical behavior and the water quality status of the coastal systems;

vi) a dedicated WebGIS portal, providing open access to the data and related physical and water quality indicators;

vii) seamless integration with CMEMS regional models and EO data.

Further details about the main features of the CONNECT coastal service are presented in the next sections.

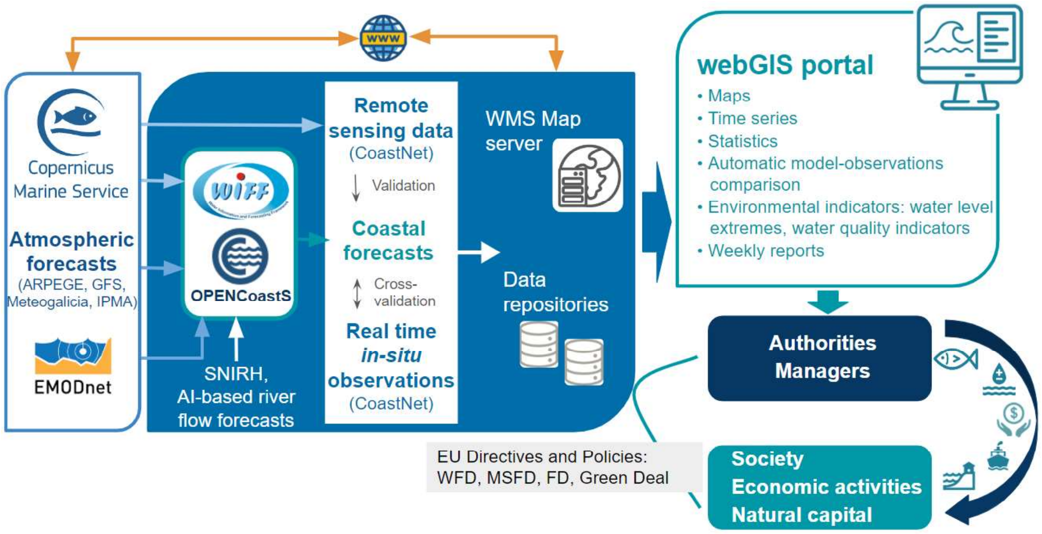


Fig. 1. Overall architecture and components of the CONNECT coastal service.

2.2. Observations

The CoastNet – Portuguese Coastal Monitoring Network is a Research Infrastructure of the National Roadmap of Research Infrastructures since 2014 and is integrated in the DANUBIUS-RI pan-European research infrastructure. CoastNet is designed to improve the monitoring of coastal ecosystems, by collecting blue and green data and making them available in near real-time. The Tagus, Mondego and Mira estuaries have been continuously monitored since 2017. ODAS buoys (part of the Environmental and Biological Monitoring System - EBMS) provide autonomous measurements of environmental variables (salinity, temperature, conductivity, dissolved oxygen, pH, chlorophyll-a, and turbidity) along the estuarine gradient. Data are available in near real-time in the CoastNet geoportal (http://geoportal.coastnet.pt).

The Coastal Remote Sensing System (CRSS) also provides several EO products for the Portuguese coast. This EO-based information includes standard (e.g. sea surface temperature, chlorophyll-a concentrations, mainly from CMEMS) and in-house innovative products (e.g., upwelling index).

2.3. Forecasts

The daily forecasts are produced with the SCHISM – Semi-implicit Cross-scale Hydroscience Integrated System Model modeling suite (Zhang et al., 2016), operated by the WIFF – Water Information Forecast Framework (Fortunato et al., 2017; Rogeiro et al., 2018) and OPENCoastS (https://opencoasts.ncg.ingrid.pt, Oliveira et al., 2020, 2021) services.

WIFF is a Python-based software designed to assemble all the procedures necessary to produce daily predictions reliably and consistently. It handles the generic aspects required to operate forecast systems automatically, such as coupling different solvers, retrieving forcings, and running simulations. WIFF is also utilized in the backend of the OPENCoastS service's on-demand forecast systems.

SCHISM is an open-source, fully parallelized, unstructured grid model, designed for the seamless simulation of 3D baroclinic circulation across river-estuary-ocean scales. It includes modules for surface waves (Roland et al., 2012) and water quality (Rodrigues et al., 2009, 2012), among others.

The CONNECT service produces simulations in both 2D barotropic (including waves) and 3D baroclinic modes, with the latter incorporating biogeochemistry variables. WIFF and OPENCoastS force SCHISM at the ocean boundary with physical and biogeochemical variables from the CMEMS IBI - Atlantic - Iberian Biscay Irish Ocean Physics and Biogeochemical Analysis and Forecast regional models (Aznar et al., 2016; Gutknecht et al., 2019; Lorente et al., 2019; Mason et al., 2019; Sotillo et al., 2015, 2021). The river boundaries are forced with extrapolations of observations from the SNIRH – National Water Resources Information Service (https://snirh.apambiente.pt/) and climatology. Predictions from Artificial Intelligence models for the Tagus and Mondego rivers flow are also available. Atmospheric forcings are taken from Meteogalicia or IPMA – Portuguese Institute for Sea and Atmosphere meteorological forecasts.

2.4. Indicators

The synthesized information is evaluated from model forecasts or observations and includes statistics (mean, minimum, maximum, percentile-90) of selected variables and water quality and ecological status indicators. The following indicators are available:

- the physiochemical status of nutrients and dissolved oxygen, based on APA – Portuguese Environmental Agency's method (official method implemented by APA for the WFD - described in Cereja et al., 2021).
- the Ecological Quality Ratio - EQR (Brito et al., 2012) that uses chlorophyll-a as a proxy of phytoplankton biomass.
- the Trophic index - TRIX (Vollenweider et al., 1998) that aggregates information on four key water quality variables (chlorophyll-a, dissolved oxygen, dissolved inorganic nitrate and phosphate).

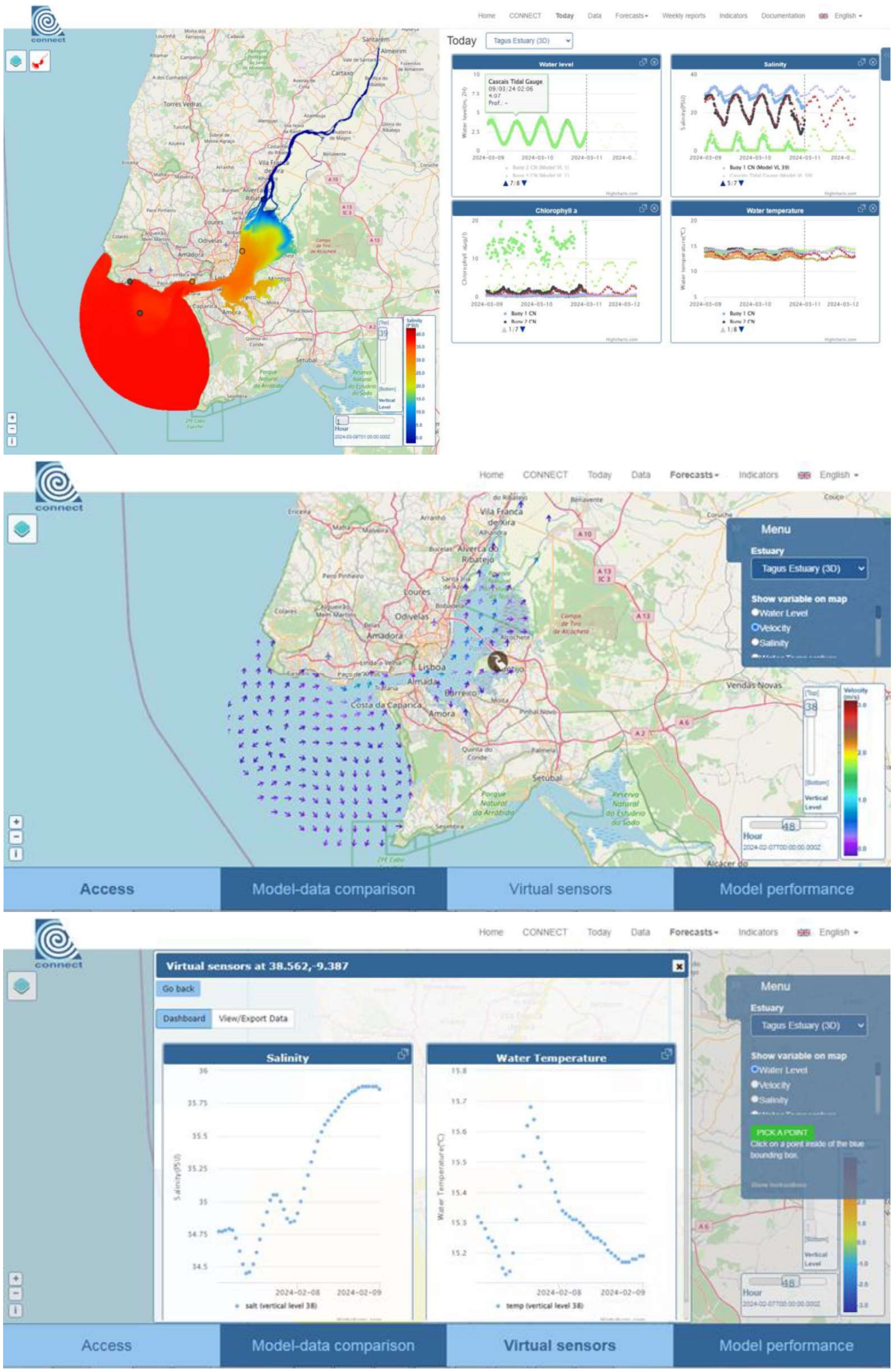
Further details about the calculation of these indicators can be found in the cited references.

2.5. CONNECT WebGIS portal

The CONNECT service WebGIS portal (https://connect-portal.lnec.pt) has the following dashboards (Fig. 2):

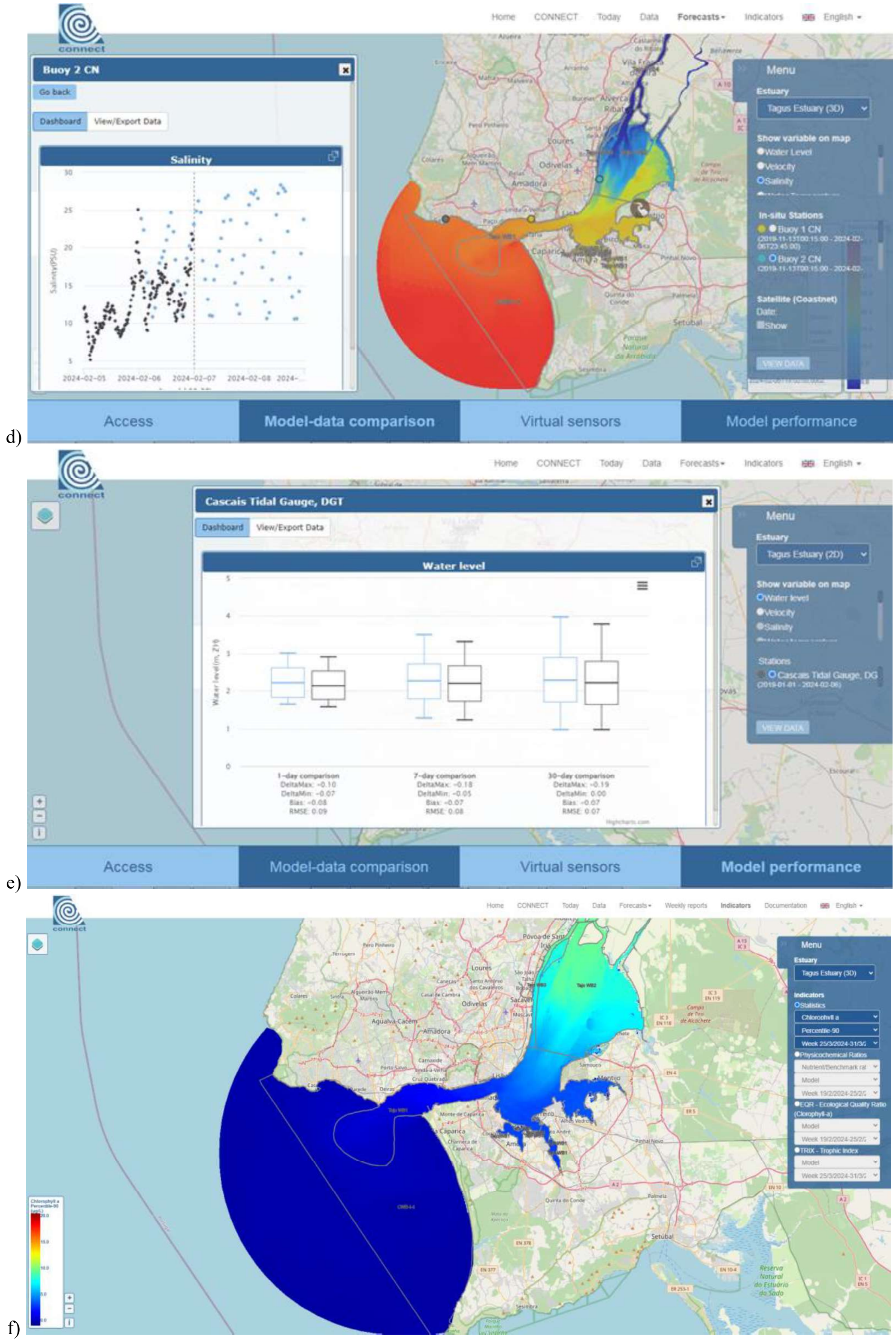
- **Today** is an operational dashboard that presents a snapshot of the current state of the coastal system, which embeds all the available observations and forecasts. Data are available for the current day, the past 48 hours and the next 24 to 48 hours. This dashboard is easily configured by the users for their particular interests, providing mechanisms to show or hide the features that they wish to see.
- **Data** provides access to the CoastNet geoportal where the user can download the available data from the CoastNet monitoring network.
- **Forecasts** displays a 48-hour forecast of physical and biogeochemical variables from the operational models. The user can also compare the model results with the available *in-situ* and satellite observations and access model performance metrics.

- **Indicators** provides synthesized information using indicators and statistics for the circulation and water quality status that allows the user to assess possible changes in the coastal system dynamics and biogeochemistry.
- **Weekly reports** summarize the essential information of the estuary from the past week.



a) b) c)

Fig. 2. Overall view of the CONNECT webGIS portal: (a) Today dashboard, (b) Access to model forecasts, (c) Virtual sensors, (d) Model-observations comparison, (e) Model performance, (f) Indicators, (g) Weekly reports.



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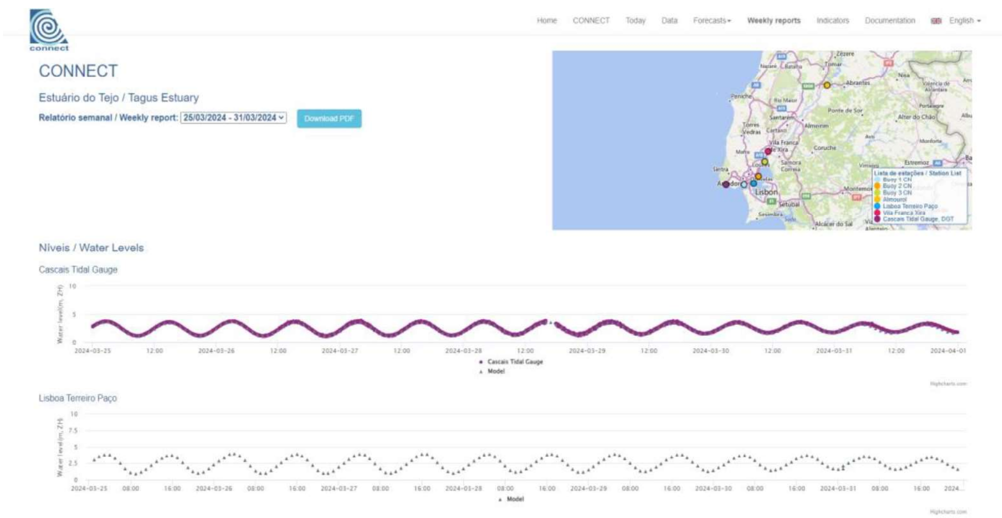

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3. Use cases

The added-value of the CONNECT service is demonstrated in the Tagus and the Mondego estuaries.

The Tagus estuary, the second largest in Europe, holds a natural reserve and a major harbor (Lisbon). Its margins are intensively occupied by about 1.5 million inhabitants and support diverse uses, which contribute to several water quality problems. The estuary's margins are also prone to inundation from various sources, a problem exacerbated by climate change. Model and observation data provided by the CONNECT coastal service support the assessment of the estuary's ecological status in the context of the WFD, and quantify its contribution to the adjacent coastal area, supporting the MSFD. The service also helps to anticipate flooding events, thus contributing to the efficiency of the civil protection agents.

The Mondego estuary is a Ramsar site supporting endangered species of birds and a diverse intertidal macroinvertebrate community. The estuary shelters a commercial harbor, supports the national production of rice and hosts fish farms. On its margins, the population is exposed to compound flooding. The CONNECT coastal service predicts environmental conditions that can cause inundations and endanger ecosystems and economic activities (e.g., navigation). The service also provides physical-chemical data (e.g., salinity, temperature) to support the WFD and indicators for the protection of the ecosystems.

The CONNECT Tagus and the CONNECT Mondego services are under operation since January 2024 and July 2024, respectively. Both services are briefly described in the next sections.

3.1. The CONNECT service demonstrated in the Tagus estuary

In the Tagus estuary the coastal service integrates local data from: i) a 2D depth-averaged model with wave-current interaction and extensive floodable areas to address needs of forecasts for navigation and civil protection; ii) a 3D baroclinic model which couples hydrodynamics and biogeochemistry to assess the water quality status; iii) three CoastNet buoys located along the estuary; iv) other sensors with publicly-available observations, and v) satellite images.

The Tagus estuary models' domains are bound by the following geographical coordinates: 8.675º-9.57º West and 38.41º-39.22º North (Fig. 3). They include the Tagus estuary itself, a coastal area with a 27 km radius, and the downstream stretches of three rivers: the Tagus, the Sorraia and the Trancão. The interface with the CMEMS regional model lies at the open ocean boundary, with an extension of 60 km and depths between 2 and 1330 m. The Tagus models are forced by the CMEMS IBI regional model forecasts of sea surface height and velocities (both models) and salinity, temperature and inorganic nutrients, dissolved oxygen and chlorophyll-a (3D model only). Both models were updated from previous implementations in the Tagus estuary (Fortunato et al., 2019; Rodrigues et al., 2017, 2019, 2021) and validated with historical data prior to their operational implementation. The models are also continuously compared with near-real-time observations and their performance is assessed (e.g., Fig.2d and e, Fig. 4).

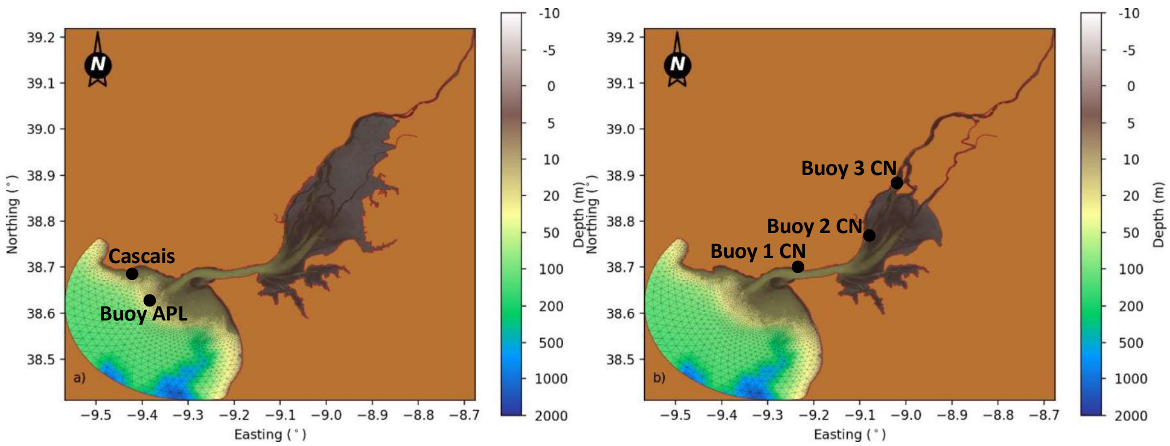

Fig. 3. Horizontal grids and bathymetry of the (a) 2D and (b) 3D models of the Tagus estuary and location of the in-situ monitoring stations.

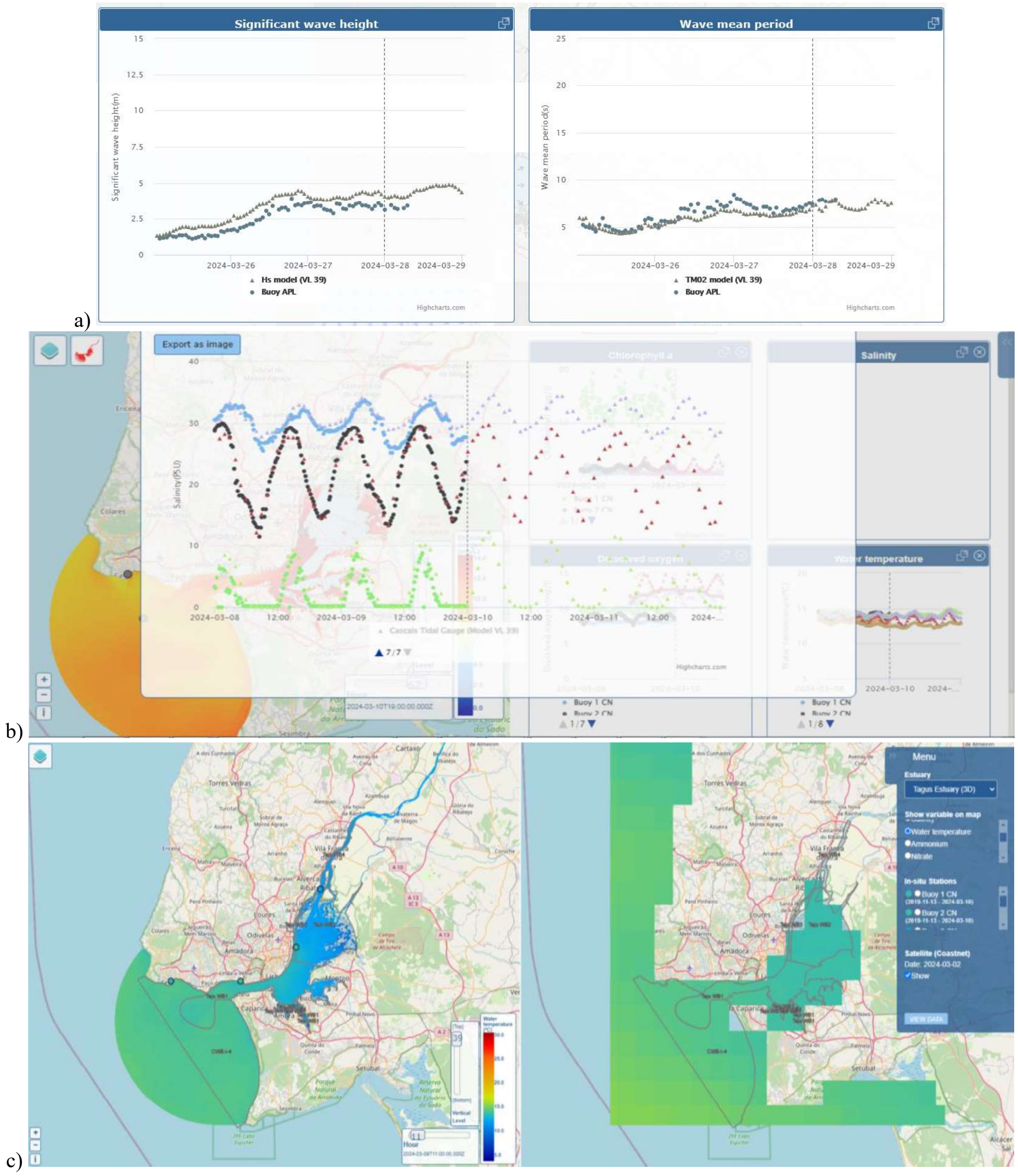

Fig. 4. Forecast validation in the Tagus estuary: (a) comparison between measured and predicted significant wave heights during a major storm; (b) comparison between measured and predicted salinity in the 3 buoys; (c) comparison between temperatures obtained with the 3D model (left), the in-situ sensors (left, circles) and the satellite images (right).

3.2. The CONNECT service demonstrated in the Mondego estuary

The Mondego estuary use case was built upon a previous circulation model for this coastal area (Oliveira et al., 2021). The original 2D, depth-averaged, fully-coupled wave-tide circulation model originally, and still, extends 14 km upstream the Mondego river. For the CONNECT service, it was extended offshore and southward to encompass the Nazaré canyon area (Fig. 5a). Now the 2D model extends up to 70 km offshore, beyond the continental shelf break, and beyond the city of Nazaré located about 65 km south of Figueira da Foz. In the original domain (Fig. 5b), the barotropic model was upgraded into a 3D baroclinic model, to represent temperature and salinity gradients along the estuary.

The overall model area is dotted with 4 in-situ monitoring stations (Fig. 5). The stations allow the service user to assess forecast quality in near real-time. Regarding water level and wave climate, the online data from the Nazaré tidal gauge (Fig. 6a) and the MONICAN offshore wave buoy (Fig. 6b), both operated by the Portuguese navy (*Instituto Hidrográfico*), are streamed into the service to provide insights into the forecast accuracy. In terms of salinity (Fig. 6c) and temperature (Fig. 6d), predictions of the 3D model can be compared on the fly with the Mondego stations from the CoastNet network. The user can also assess the accuracy of water temperature predictions in the oceanic area using satellite imagery (Fig. 7).

Presently, the water temperature at the upstream boundary is imposed based on climatology. This is currently the main limiting factor for this parameter in the upper part of the estuary (Fig. 6d).

4. Final remarks

The CONNECT coastal service is a local, high-resolution, coastal monitoring service, which seamlessly integrates model-based forecasts and observations to provide physical biogeochemical on the estuaries and adjacent coastal area. This service addresses the needs of several authorities responsible for the management of the water bodies, such as assessing the quality of the water masses to address European Directives and anticipating flooding, and provides continuous knowledge about the status of the estuarine and coastal waters. The service is under operation in the Tagus and Mondego estuaries. The implementation of the service in other Portuguese estuaries is also envisioned.

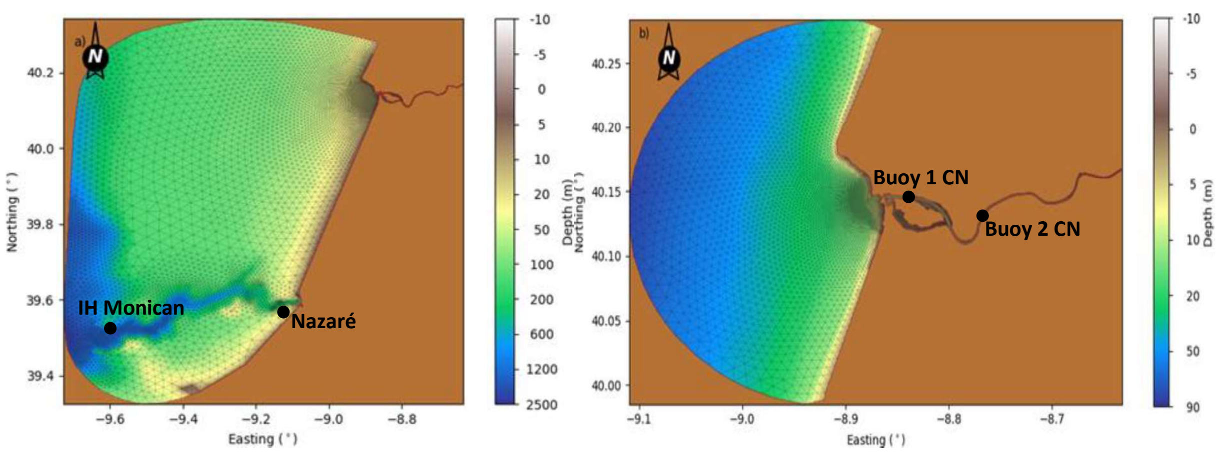

Fig. 5. Horizontal grids and bathymetry of the (a) 2D and (b) 3D models of the Mondego estuary, and location of the in-situ monitoring stations.

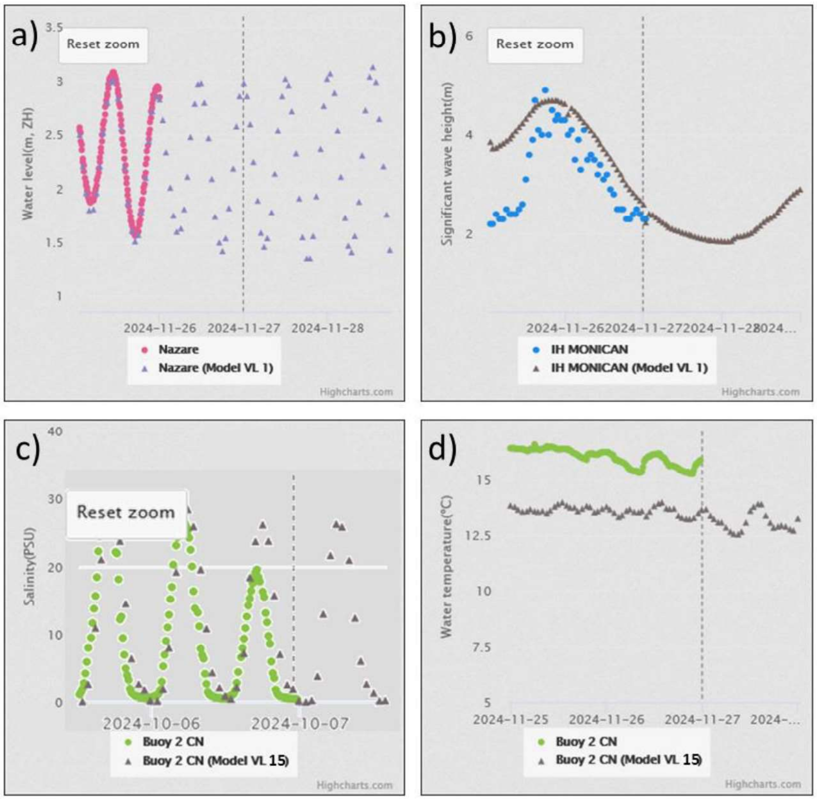

Fig. 6. Forecast comparison with in-situ observations for the Mondego estuary: a) water levels at Nazaré tidal gauge, b) significant wave height at MONICAN offshore wave buoy, c) salinity and d) water temperature at a CoastNet monitoring buoy in the Mondego estuary.

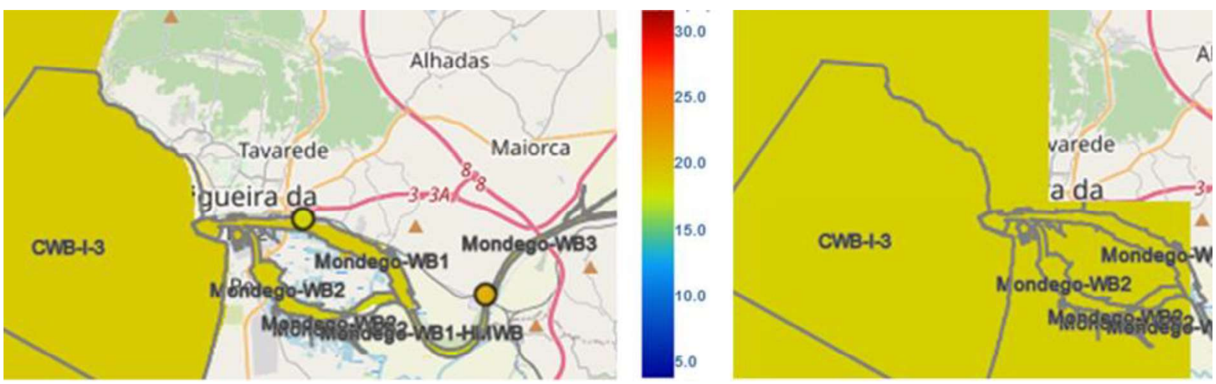

Fig. 7. Cross-scale monitoring of estuarine water temperature in the Mondego estuary: comparison between temperatures obtained with the 3D model (left), the in-situ sensors (left, circles) and the satellite images (right).

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References

Aznar R, Sotillo MG, Cailleau S, Lorente P, Levier B, Amo-Baladrón A, Reffray G, Alvarez Fanjul E (2016) Strengths and weaknesses of the CMEMS forecasted and reanalyzed solutions for the Iberia-Biscay-Ireland (IBI) waters, Journal of Marine Systems, 159, 1–14

Brito AC, Brotas V, Caetano M, Coutinho TP, Bordalo AA, Icely M, Neto JM, Serôdio J, Moita T (2012). Defining phytoplankton class boundaries in Portuguese transitional waters: an evaluation of the ecological quality status according to the Water Framework Directive, Ecological Indicators, 19 (2012), 5-14
Castellanos P, Brito AC, Chainho P, Quintella B, da Costa L, França S, Cabral H, Costa JL (2021) CoastNet Dataset from Mondego, Tejo and Mira Estuaries: Multiparametric measurements during 2020, Frontiers in Marine Science, 8, 707089
Cereja R, Brotas V, Nunes S, Rodrigues M, Cruz JPC, Brito AC (2022), Tidal influence on water quality indicators in a temperate mesotidal estuary (Tagus Estuary, Portugal), Ecological Indicators, 136, 108715
Fortunato AB, Meredith EP, Rodrigues M, Freire P, Feldmann H (2019), Near-future changes in storm surges along the Atlantic Iberian coast. Natural Hazards, 98, 1003–1020
Fortunato AB, Oliveira A, Rogeiro J, da Costa RT, Gomes JL, Li K, Jesus G, Freire P, Rilo A, Mendes A, Rodrigues M, Azevedo A (2017), Operational forecast framework applied to extreme sea levels at regional and local scales, Journal of Operational Oceanography 10(1)
França S, Fonseca VF, Tanner SE, Vasconcelos R, Reis-Santos P, Maia A, Ruano M, Cardoso I, Henriques S, Pais MP, Brandão P, Brito AC, Castellanos P, Chainho P, Quintella B, da Costa L, Costa MJ, Costa JL, Cabral HN (2021) Historical data in the CoastNet Geoportal: snapshot of estuarine fish communities in Portuguese estuaries, Frontiers in Marine Science, 8, 685294
Gutknecht E, Reffray G, Mignot A, Dabrowski T, Sotillo MG (2019) Modelling the marine ecosystem of Iberia-Biscay-Ireland (IBI) European waters for CMEMS operational applications, Ocean Science, 15, 1489–1516
Lorente P, García-Sotillo M, Amo-Baladrón A, Aznar R, Levier B, Sánchez-Garrido JC, Sammartino S, de Pascual-Collar Á, Reffray G, Toledano C, Álvarez-Fanjul E (2019) Skill assessment of global, regional, and coastal circulation forecast models: evaluating the benefits of dynamical downscaling in IBI (Iberia-Biscay-Ireland) surface waters, Ocean Science, 15, 967–996
Mason E, Ruiz S, Bourdalle-Badie R, Reffray G, García-Sotillo M, Pascual A (2019) New insight into 3-D mesoscale eddy properties from CMEMS operational models in the western Mediterranean, Ocean Science, 15, 1111–1131
Oliveira A, Fortunato AB, Rodrigues M, Azevedo A, Rogeiro J, Bernardo S, Lavaud L, Bertin X, Nahon A, Jesus G, Rocha M, Lopes P (2021). Forecasting contrasting coastal and estuarine hydrodynamics with OPENCoastS, Environmental Modelling & Software, 143, 105132
Oliveira A, Fortunato AB, Rogeiro J, Teixeira J, Azevedo A, Lavaud L, Bertin A, Gomes J, David M, Pina J, Rodrigues M, Lopes P (2020), OPENCoastS: An open-access service for the automatic generation of coastal forecast systems, Environmental Modelling & Software, 124, 104585
Rodrigues M, Fortunato AB (2017) Assessment of a three-dimensional baroclinic circulation model of the Tagus estuary (Portugal), AIMS Environmental Science, 2017, 4(6), 763-787
Rodrigues M, Fortunato AB, Freire P (2019), Saltwater intrusion in the upper Tagus estuary during droughts, Geosciences, 9(9), 400
Rodrigues M, Martins R, Rogeiro J, Fortunato AB, Oliveira A, Cravo A, Jacob J, Rosa A, Azevedo A, Freire P (2021) A web-based observatory for biogeochemical assessment in coastal regions, Journal of Environmental Informatics, 38(1), 1-15
Rogeiro J, Rodrigues M, Azevedo A, Oliveira A, Martins JP, David M, Pina J, Dias N, Gomes J (2018), Advances in Engineering Software, 117, 70-79
Sotillo MG, Cailleau S, Lorente P, Levier B, Reffray G, Amo-Baladrón A, Benkiran M, Alvarez Fanjul E (2015) The MyOcean IBI Ocean Forecast and Reanalysis Systems: operational products and roadmap to the future Copernicus Service, Journal of Operational Oceanography, 8, 63–79
Sotillo MG, Campuzano F, Guihou K, Lorente P, Olmedo E, Matulka A, Santos F, Amo-Baladrón MA, Novellino A (2021) River Freshwater Contribution in Operational Ocean Models along the European Atlantic Façade: Impact of a New River Discharge Forcing Data on the CMEMS IBI Regional Model Solution, Journal of Marine Science and Engineering, 9, 401
Vollenweider RA, Giovanardi F, Montanari G, Rinaldi A (1998), Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index, Environmetrics, 9(3), 329-357
Zhang YI, Ye F, Stanev EV, Grashorn S (2016) Seamless cross-scale modeling with SCHISM, Ocean Modelling, 102, 64-81