Implementation and validation of an operational forecasting system for nearshore hydrodynamics with OPENCoastS

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Abstract: Knowledge and anticipation of storm impacts on coastal communities require accurate and timely characterization of nearshore circulation and water levels. To this aim, OPENCoastS provides operational tools which bring state-of-the-art hydrodynamic modelling within reach of coastal authorities. In the present communication, this online, open service is used to build a forecast system for the ocean beaches south of the Mondego river mouth. The system relies mainly on SCHISM modelling suite, forced with a global tide model and with pressure and wind fields originating from freely available sources; an implementation of WAVEWATCHIII in the North Atlantic provides the wave boundary conditions. SCHISM results are validated with historical offshore wave records and with waves and tidal data acquired at Cova-Gala beach and in the Mondego river estuary. Model's performance after this validation opens the way for the implementation of operational morphodynamic forecasts, as is currently being achieved within MOSAIC.pt project.

Key words: forecast, OPENCoastS, surge, tides, waves.

1. INTRODUCTION

Short-term predictions of coastal hydrodynamics are relevant to meet multiple societal needs. These include recreational bathing safety, commercial harbour management, or the mitigation of natural and man-made disasters. Methods to establish those predictions range from simple empirical relationships based on offshore waves and tidal predictions, to sophisticated models based on free-surface flow equations and coupled to models for spectral wave generation and propagation. Over the last two decades, modelling suites were developed to achieve such predictions, and some are now freely available (e.g. Delft3D, SCHISM, TELEMAC-MASCARET). Model domains and boundaries may be forced by forecasted tides, forecasted fields of atmospheric pressure and wind, and continental water inputs. Nowadays, these forcing are freely accessible from multiple sources online. Nonetheless, the technical skills for gathering the data and setting up the models, as well as the required access to supercomputers, still limit the use of this technology. The OPENCoastS platform (Oliveira *et al.*, 2020) was built to overcome those limitations and to bring the technology several steps closer to non-skilled users. Provided that the user is able to upload a formatted computational grid with an appropriate bathymetry, this online service allows to run the SCHISM modelling suite (Zhang *et al.*, 2016) in forecast mode, with the full spectrum of forcing covering the North Atlantic Ocean.

In the present communication, we aim at demonstrating the capacity of the system to simulate nearshore waves and water levels near and within Figueira da Foz harbour, which lies within the estuary of the Mondego river on the wave-exposed western coast of Portugal (*Fig. 1a*). Section 2 presents the implementation of the model over an area covering Figueira da Foz shelf to the inner estuary of the Mondego river, and over which measurements of off- and nearshore wave climate and of water levels across the estuary exist. The comparison of model results with measurements is then presented in Section 3. Finally, the last section discusses the quality and limitations of the hydrodynamic results, and draws the links between the presented hindcast and the forecast capabilities offered by OPENCoastS.

2. MODEL IMPLEMENTATION

2.1. Study area and in-situ data

The model was built to simulate the hydrodynamics near and within the Figueira da Foz harbour entrance (*Fig. 1b,c*). South of the harbour's southern jetty, the Cova-Gala water-front was the targeted area and was instrumented on March 2020 (Nahon *et al.*, 2020). The water-front consists in sandy beaches interrupted by five cross-shore groynes. On March 10 morning, at low tide, the dissipative beach between groynes E2 and E3 was surveyed and instrumented (*Fig. 1d*). A cross-shore profile of three pressure transducers (PT1-3) was deployed to measure wave parameters during an equinoctial tidal cycle. The gathered data completed an heterogeneous dataset composed of an offshore wave record (Barstow and Haug, 1994), a record of

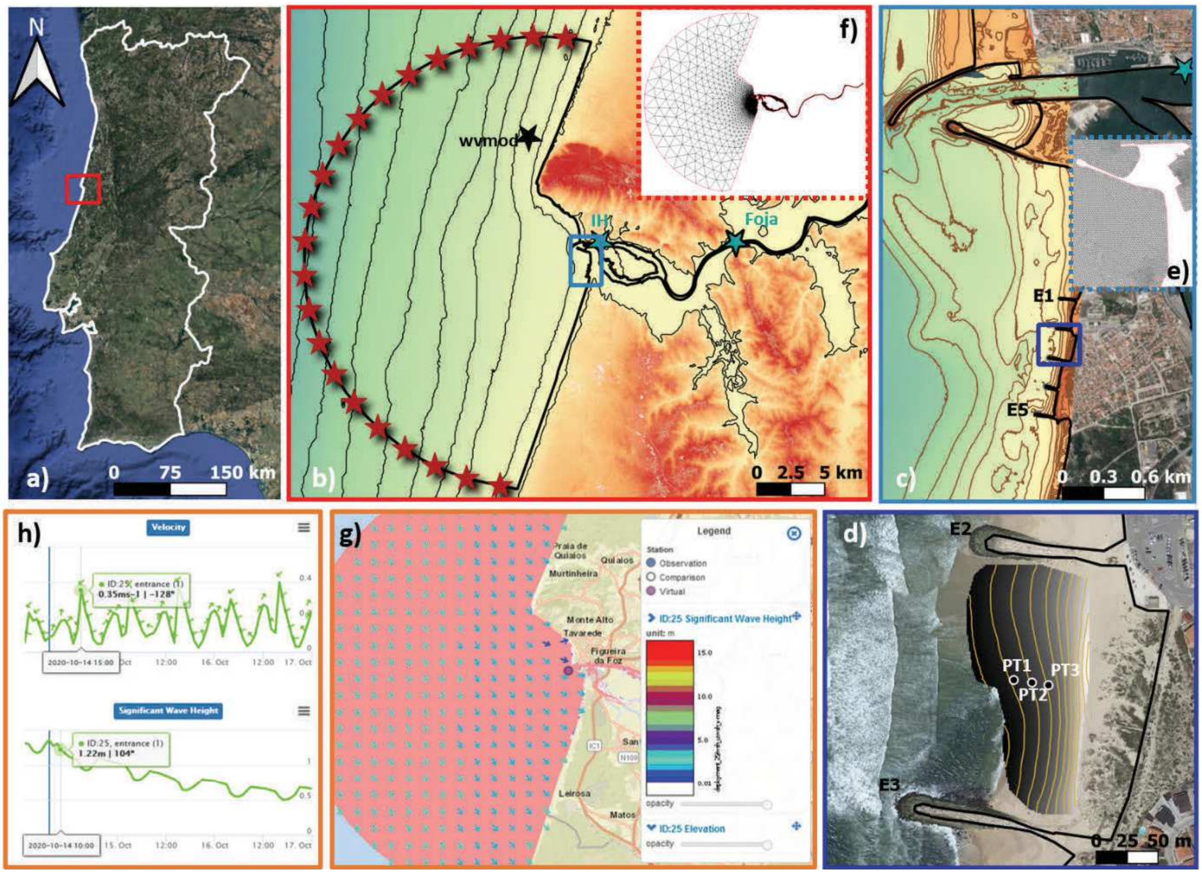

Fig. 1. SCHISM implementation in the Figueira da Foz harbour area; ***a)*** *study area location on the western coast of Portugal;* ***b)*** *Model domain boundary (bold black lines), on top of EMODNET digital terrain model (thin black lines stand for bathymetric contours at 10-meter interval and from 80 m depth to 10 m above chart datum), the red stars materialize points of the model's oceanic open boundary where offshore waves and tide are imposed, black and blue stars respectively indicate wave buoy and tidal gauge positions;* ***c)*** *zoom over the area of interest with the COSMO 2019 topo-bathymetric model on top of Google Satellite background, and with bathymetric contours at 2-meter interval, starting at 10 m depth chart datum, E1-E5 refer to the five groynes of the Cova-Gala waterfront;* ***d)*** *beach cell between groynes E2 and E3, where pressure transducers (PT1-3) were collocated on March 10, 2020, contour lines of the surveyed area are shown with a 0.5 m interval and start at +1 m chart datum, bold black line stands for the model boundary;* ***f-e)*** *SCHISM's horizontal unstructured grid, in red is the computational domain boundary and in black are the triangular grid elements with an edge length ranging from 2 km offshore to 20 m in the nearshore, harbour and river areas;* ***g-h)*** *examples of model output visualization in OPENCoastS: significant wave height and mean wave direction above water elevation and location of model's virtual stations (****g****), and 48-h forecast of current velocities and significant wave height at virtual stations (****h****).*

tidal elevation measured at Foja pumping station along the Mondego river (Azevedo *et al.*, 2012) and a record of elevation measured at the harbour tidal gauge (courtesy of the Portuguese Instituto Hidrográfico, IH). The location of the three monitoring stations is shown on *Fig. 1b*, and respectively interest the periods of January 1995 (wvmod), February 2012 (Foja) and March 2020 (IH). Therefore, the model was run for those three periods with the same computational grid and forcings.

2.2. Computational grid and bathymetry

The SCHISM modelling system uses a single unstructured grid to discretize the horizontal space. Here, it was used in depth averaged (2DH) mode, with a two-way coupling between the circulation and wave modules. Both modules were run over a single triangular grid composed of 49684 nodes and 94892 elements (*Fig. 1e,f*). The grid boundary was created with QGis software and the original triangulation was made using GMSH plugin (Lambrechts *et al.*, 2008). The inland boundary was digitized over Google Satellite imagery and follows coastal and harbour structures. Then, it follows the margins of the Mondego river main channel. The river bathymetry was used from Azevedo *et al.* (2012), the nearshore topo-bathymetric survey from August 2019 was downloaded from the COSMO monitoring program website, and the offshore bathymetry was extracted from EMODNET online platform. Over the entire domain, the bottom friction was represented using a Manning formulation, with Manning's parameter set to 0.023 $m^{-1/3}.s$, following Azevedo *et al.* (2012). In the wave model, wave breaking was parameterized using a Battjes and Janssen (1978) formula, with gamma parameter set to 0.68 to optimize the match between modelled and observed significant wave heights.

2.3. Open boundary conditions and model forcing

SCHISM's computational domain was forced using ERA5 reanalysed atmospheric fields (available within 5 days real time). The inverted barometer effect was imposed on the model oceanic boundary and wind drag was imposed over the whole domain. Combined with the inverted barometer were the tidal prediction issued from FES2014 (Carrere *et al.*, 2014). Wind fields were also used for wave generation within the domain as well as to force an unstructured WAVEWATCH III (WW3, WW3DG, 2019) model for the North Atlantic Ocean. Hindcasted WW3 spectra were interpolated onto SCHISM's offshore boundary points. The only arbitrary defined forcing was the river flow input which was set as 5 $m^3.s^{-1}$. Last but not least, the mean water levels in SCHISM for the three simulated period were defined after Antunes (2019).

3. RESULTS AND DISCUSSION (1)

3.1. Open coast waves and water levels

With the above detailed configuration, the model was run for January 1995, February 2012 and for March 2020. In January 1995, the modelled offshore significant wave height (Hs) was compared to observations from a directional wave buoy (*Fig. 2*). Observed and modelled values present an overall good match. In terms of average Hs, the model slightly underestimates observations (*Table I*) and seems to underestimate the wave height during the peak of storms (*Fig. 2*). In March 2020, offshore Hs was around 2 m when the PTs were deployed. Nearshore observations of Hs present a good matchwith observations, although at PT3 location, closest to the shore, the root mean square difference (Drms) reaches about 20% of the average Hs at this location. It is expected that the absence of wave reflection in the model could significantly contribute to this discrepancy. In terms of nearshore elevations, at the three locations the bias accounts for most of the total Drms. At this point, it was not established whether the observed offset would come from the model or the data. However, as described in the next section, the good match between the predicted

Table I. Bias and root mean square differences between modelled and observed significant wave height and elevation at the 5 locations indicated on Fig.1.

	Hs (m)		Elevation (m)	
	Bias	Drms	Bias	Drms
wvmod	-0.53	0.77	-	-
IH	-	-	-0.01	0.04
Foja	-	-	-0.07	0.12
PT1	0.11	0.13	0.15	0.15
PT2	-0.04	0.06	0.26	0.26
PT3	-0.16	0.18	0.13	0.14

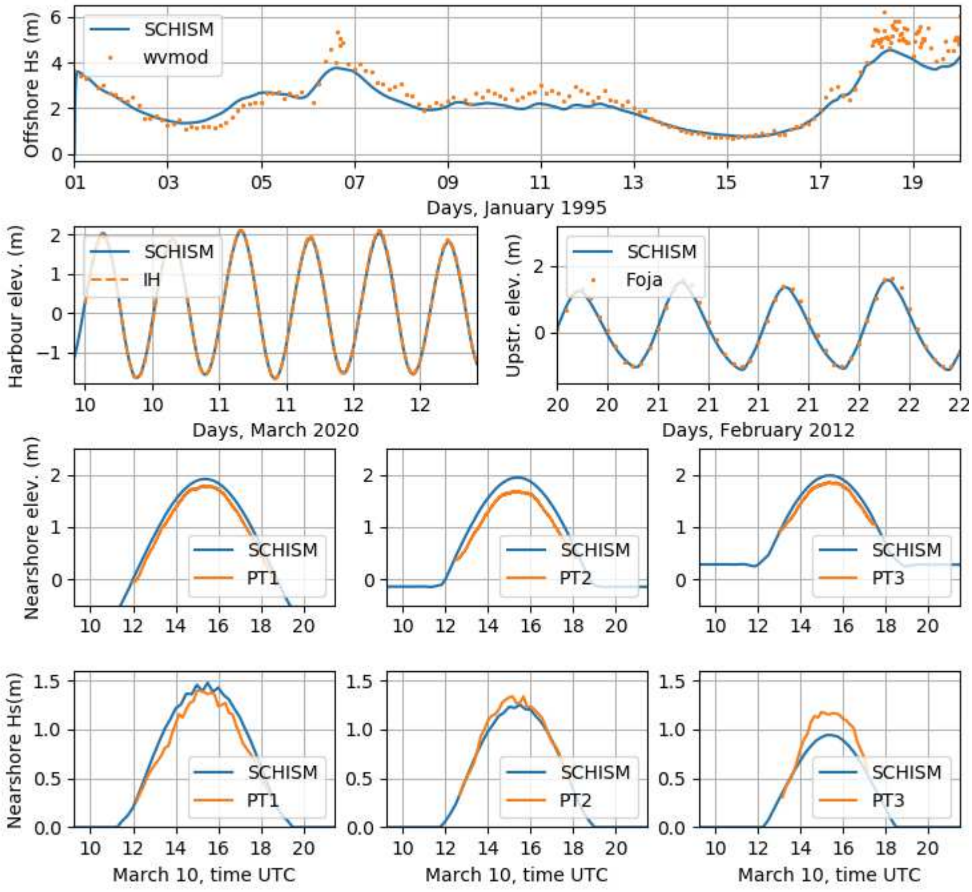

Fig. 2. Plots of modelled (blue lines) and observed (orange points and lines) elevation and significant wave height (Hs) for the different datasets available for validation, names indicated in the observation legends refer to locations indicated on Fig. 1b and 1d.

elevation and the harbour's tidal gauge, suggests that the offset would either come from an overestimated wave-induced set-up or a levelling error in the field data.

3.2. Estuarine water levels

The capacity of SCHISM to reproduce tidal propagation across the harbour entrance, and until the Foja pumping station 14 km upstream, was confirmed (*Fig. 2*). Indeed, modelled and observed elevation present an excellent match at both the IH tide gauge and the upstream station, with Drms values of respectively 4 cm and 12 cm (*Table I*).

4. DISCUSSION (2) AND CONCLUSION

The above results, although perfectible, are in line with the performances described in the literature. A notable fact is that they were obtained with relatively little calibration analysis: decreasing the gamma breaking parameter from default 0.73 to 0.68 improved nearshore prediction of Hs, and increasing Manning's coefficient from default 0.020 $m^{-1/3}.s$ to 0.023 $m^{-1/3}.s$ optimized upstream tidal predictions. Beyond this, all other parameters remained untouched which attests of the maturity of the models that compose the SCHISM modelling suite. Additionally, apart from the grid generation, all the processing and gathering of the forcing data is transparent to any user of the OPENCoastS service. The main advantages for using the system were that, (1) the user does not need to to have access to a supercomputer to run the model, (2) to have the skills to compile and install the model and the required libraries, and (3) to, every day, download the atmospheric forcing and write/adapt the parameter files for he different modules of SCHISM. Therefore, it is expected that most GIS literate users, able to create a grid with available open source tools and online bathymetry, should also be able to produce 48-h forecasts within the whole North Atlantic Ocean, as shown in *Fig. 1g)* & *h)*, and with similar performance. The sole difference with the present implementation would be that, instead of using ERA5 reanalysis, the user would have to choose between GFS and ARPEGE atmospheric forecasts, respectively emanating from the US NOAA and the French Météo France. Ongoing works should soon bring additional evidence that these options maintain the predictions within an acceptable range of performance. Furthermore, like in the case of the online service, the results presented here relied on the use of unstructured WW3, which has not yet been as extensively tested as its structured counterpart. So, it is expected that ongoing testing should lead to improved sea state predictions at the peak of the storm. In terms of nearshore results, at least two developments should help improve model prediction. First, taking into account the wave reflection could help to predict the total Hs, which appears relevant for bathing safety applications. Then, more critical even than the gamma calibration, the availability of an up-to-date bathymetry is necessary for accurate predictions. Two ways to allow this are foreseen and are currently under development: using satellite-derived beach contours and/or constrained morphodynamics simulation to maintain updated the intertidal beach morphology.

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