Hydrodynamic models ensembles to improve estuarine forecasting under climate change scenarios

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Abstract – Numerical models are essential tools for simulating the hydrodynamics of aquatic systems, making it possible to anticipate and predict the effects of anthropogenic interventions, extreme events and climatic changes, and promoting effective and integrated coastal management. However, the results of the models present uncertainties related to errors and inaccuracies in the analysis of the results and in the initial and forcing conditions. Given the need to have accurate forecasts, it is crucial to implement new solutions to avoid such errors. One of these solutions is the ensemble technique. In this research work two numerical models were chosen to predict the hydrodynamics of two Portuguese estuaries considering various sea level rise and extreme events scenarios. The models' results were combined using a weighted average, which improved the accuracy of the outcomes. Results point at an aggravation of the flood level associated with extreme events in the Douro estuary due to the configuration of the river mouth, but with little effect of the sea level rise. In the Minho estuary, on the other hand, a clear effect of the sea level rise along the estuary is estimated, with a reduction in velocities and increased flood areas.

Keywords: Estuaries, hydrodynamics, numerical models, extreme events, climate change.

1. INTRODUCTION

Estuaries are strategically important from an environmental, economic, and social point of view. To reduce their vulnerability, it is crucial to understand their hydrodynamics. Numerical models can simulate them, providing the basis of efficient management frameworks. However, model results always present uncertainties, and there is a need to develop and implement new methodologies to increase their accuracy. In this work, the ensemble technique is proposed as a reliable tool to improve estuarine forecasting, being implemented for two Portuguese regions: Douro and Minho estuaries.

The Douro estuary is a narrow, highly dynamic, urban estuary with torrential regimes that produce strong currents and severe floods. Its dynamics are mainly forced by river flows. On the south bank of the mouth, a sand spit partially obstructs the entrance protecting the estuary (Figure 1). In 2008, some maritime works intended to stabilize this spit, including the construction of a detached breakwater and the extension of the northern breakwater. These works have interfered with local hydro-morphodynamics, causing a significant increase in the surface area and volume of the sand spit in a relatively short period (10 years). Consequently, the spit has become more robust and less likely to rupture during flood events. More severe impacts of upstream flooding can thus be expected, causing economic losses and structural damage (Bastos et al., 2012; Iglesias et al., 2019a).

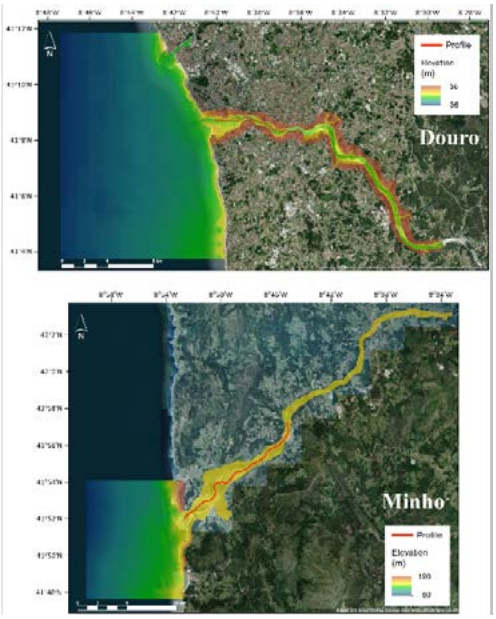

Figure 1. Douro and Minho estuaries. Topo-bathymetric data considered for grid construction and longitudinal profiles selected to extract the water elevation.

The Minho estuary presents a low level of urbanization/industrialization, and a great diversity of habitats. It is a marine dominated estuary with a strong siltation. The lower estuary presents a widening, producing a decrease in the flow velocity, favourable conditions for sedimentation and high residence times (Figure 1). The accretion patterns have caused bathymetric restrictions to navigation and the appearance of islands and sandbanks during low tide (Iglesias et al., 2019a; Melo et al., 2020). Sea level rise conditions could augment this effect, diminishing even more the velocities in the lower estuary and incrementing the sedimentation processes.

The distinct physical patterns of these two estuarine regions revealed the need for local approaches and dedicated studies to understand the dynamics of each region and support the mitigation of the risks associated with extreme events, man-made interventions and climate change effects.

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2. METHODS

The applied numerical models were openTELEMAC-MASCARET and Delft3D, already calibrated and validated for the two selected estuarine regions (Iglesias et al. 2019a, Iglesias et al. 2019b, Melo et al. 2020; Iglesias et al., 2021, Melo et al., 2021). The superensembles were constructed following previous results found by Iglesias et al. (2022), where the models were run for historical conditions to calibrate the ensemble with in situ measurements of water elevation. In this work, Iglesias et al. (2022) found that the ensembling of model outputs using the absolute error (for low river flow simulations) and the squared error (for high river flow simulations) as weighting coefficients outperformed the individual model solutions as well as other techniques of ensemble construction. This was observed for all considered scenarios, at all sampling points and in both estuaries studied. The squared error values obtained in Iglesias et al. (2022) were therefore considered here as the weights to construct the superensemble for future conditions.

The future scenarios superensembles considered extreme fluvial discharge (EFD) and extreme sea level (ESL). EFDs for 50, 100 and 1000-year return periods were calculated for each estuary considering that the river flow, provided by Portuguese hydrometric stations, follows Gumbel's law. ESL values for historical simulations as well as for RCPs 4.5 and 8.5 scenarios for 2100, for the same return periods considered in the EFD, were extracted from Vousdoukas et al. (2017), for the Douro and Minho locations (Table 1).

Table 1. Scenarios considered for the 2100 hydrodynamic conditions forecasting

	Return period (years)	River flow (m^3/s)		Scenario	Water elevation (m)
		Douro	Minho		
S1	50	17357	5365	Historical	3.9
S2				RCP 4.5	4.4
S3				RCP 8.5	4.7
S4	100	19814	6038	Historical	4.0
S5				RCP 4.5	4.5
S6				RCP 8.5	4.8
S7	1000	27962	8262	Historical	4.3
S8				RCP 4.5	4.8
S9				RCP 8.5	5.0

3. RESULTS AND CONCLUSIONS

Using the obtained superensemble results for the two estuaries, the water elevation was projected along a longitudinal profile for each of the simulated scenarios (Figure 2). Results showed a clear difference between the hydrodynamic behaviours of the two estuaries. Superensemble outcomes for the Minho estuary, which is dominated by the tide and therefore by oceanographic conditions, showed a pronounced effect of rising sea levels on estuarine hydrodynamics, mainly in the lower estuarine region, but noticeable in the entire estuary. Whereas, for the Douro estuary, which is heavily dominated by the river flow, the effect of sea level rise was hardly noticeable during flood events, and the extension of the flood areas can be directly linked with the river flow imposed in the simulations.

It was demonstrated that the ensembles technique is an effective tool to improve the numerical modelling results for estuarine regions, and should be applied to provide the stakeholders and policymakers with accurate results that support their actions.

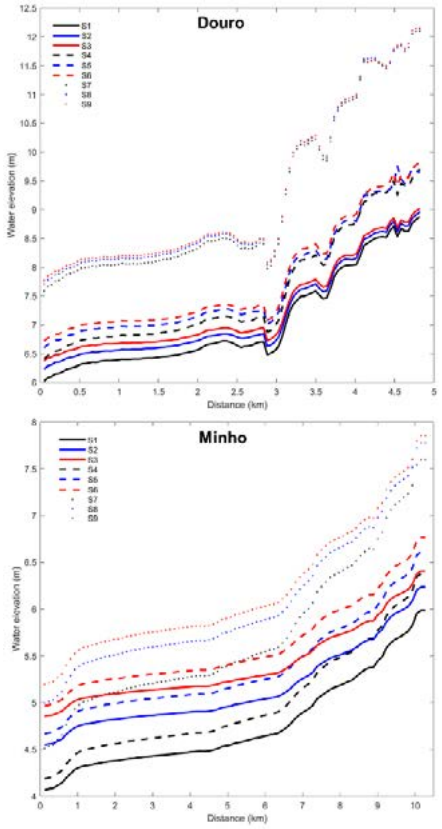

Figure 2. Longitudinal profiles of water elevation in Douro and Minho estuaries.

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