The Douro Estuary: Modelling comparison for floods prevention

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Abstract: Estuarine areas have been intensively studied due to their complex physical processes and the societal importance of their ecosystem services. To perform a deeper hydrodynamic study allowing an accurate representation of the physical processes, numerical models are essential.
This work performs a comparison of the two 2DH estuarine models, included in the modelling suites OpenTelemac and Delft3D. The aim is to understand how the different numerical schemes might influence the models' output. The models were applied to one of the main Portuguese estuaries: the Douro River estuary. The strong floods that the estuarine region periodically suffers, with economic losses and damages to the local protected landscape areas and hydraulic structures, show the importance of a complete characterization of the areas at risk and how they might be affected. Both models were configured with the same initial and boundary conditions and similar bathymetries. The simulations presented herein use a pre-breakwater construction configuration. However, a post-breakwater construction configuration was also defined and results will be presented at the conference. A special interest will be attached to the role of the Cabedelo sandbar, as this is expected to break for strong river discharges thus diminishing the flooding risk.

Key words: Estuarine modelling, Douro River, hydrodynamics, model comparison, floods.

1. INTRODUCTION

Numerical modelling can be of interest for a broad range of ecosystem services, helping to define the most adequate zones for water catchment, tourism activities, aquiculture, fisheries, and new infrastructures, among others. Models are able to provide a deep understanding of the hydrodynamic processes and erosion/accretion patterns, becoming a tool to assess and predict the effects of hazardous events, and strongly support estuarine and coastal management, promoting the safety of populations.

The studied area is the Douro River estuary and neighbouring coastal areas. It is one of the major rivers of the Iberian Peninsula and flows into the Atlantic Ocean through a highly dynamic mesotidal narrow urban estuary (9.8 km^2 of area; 21.6 km-long) surrounded by two cities: Porto and Vila Nova de Gaia. The freshwater flow rate, controlled by the Crestuma dam and highly depending on the hydroelectric power demand, can reach more than 13000 m^3/s (Azevedo *et al*., 2010), subjected to an inter-annual variability with differences between dry and rainy years. The annual pattern of caudal variability presents a normal behaviour for its latitude: stronger in winter and weaker in summer related with the annual precipitation cycle which is higher between October and May, and lower during July, August and September (Gómez-Gesteira *et al*., 2011).

The strong floods that this estuarine region periodically suffers, with related economic losses and damages to neighbouring structures, increase the importance of its complete characterization. The Cabedelo sand spit and the São Paio Bay, a Nature Reserve, have undergone an evolution due to the breakwater construction, reducing the depth of the natural reserve and increasing the sand spit area (Bastos *et al*., 2012).

Previous studies of the Douro estuary had limited scopes, usually lacking integrated approaches towards a comprehensive morpho-hydrodynamic characterization. Azevedo *et al*. (2008), Magalhães *et al*. (2002) and Mucha *et al*. (2003, 2004) focused on ecological aspects and pollution impacts, and Bastos *et al.* (2012) studied the evolution of the sand spit contour and topography using surveys. In terms of modelling simulations, Azevedo *et al*. (2010) defined river flow scenarios using a 3D hydrodynamic model, but the study is limited to point stations inside the estuary region. Araújo *et al*. (2013) simulated river floods with the ADCIRC model providing a valuable contribution to model development, but defocused from the social risks of floods. Mendes *et al*. (2013) evaluated the potential effect of sea level rise with the MOHID (2D) model but they implement a low resolution grid. Portela (2008) also used a 2DH model geared towards a sediment dynamics description.

This study intends to analyse the hydrodynamics of the Douro River estuary at a non-flood and flood scenarios, along a comparison between the outcomes of two of the most used high-resolution numerical models: Delft3D and OpenTelemac.

2. DATA AND NUMERICAL MODELS CONFIGURATION

Both Delft3D and OpenTelemac have been extensively used on many estuarine and maritime studies reflecting their suitability to perform this work. A 2DH configuration was selected for both models. The grids (see Figure 1) covers the entire estuarine region from Crestuma to the mouth of the Douro River and also the adjacent coastal area. It was constructed using bathymetric data provided by the Hydrographic Institute of the Portuguese Navy (IH). This data was complete at the open ocean with GEBCO, a global gridded bathymetric data with a 30 arc-second resolution (Becker *et al*., 2009). The different datasets were interpolated and smoothed to build the final grid. Delft3D uses a regular finite difference grid, while OpenTelemac uses a finite element mesh. Tidal forcing in OpenTelemac was obtained from the TPXO.2 tidal model (Egbert *et al*., 1994). For Delft3D the main astronomic harmonic constituents were used. The river discharge at Crestuma-Lever dam was provided by Energias de Portugal (EDP). Two different simulations were performed with each model.

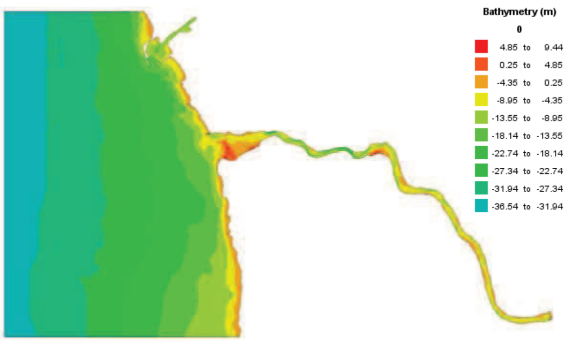

Fig. 1. Models computational domain and bathymetry.

The first simulation is a calibration/validation run performed between 25/Sep/1994 and 04/Oct/1994, with an hourly variation of the river discharge. Data for validation was available from the IH campaigns (Instituto Hidrográfico, 1995). Validation points are identified in Figure 2 and in Table I. The current velocities were measured at three different depths (surface, middle depth and bottom). For comparison with the 2DH simulations, a water column-averaged horizontal current velocity was computed from the campaign data.

The second simulation is a 24 h-long run representing the 09/Jan/1996 historical flood scenario. On this run a constant river discharge of 10500 m^3/s and a constant 1.315 m-high tide free surface elevation were used. The river flow rate was measured by the Centro de Prevenção e Previsão de Cheias (CPPC), downstream from the Crestuma-Lever dam).

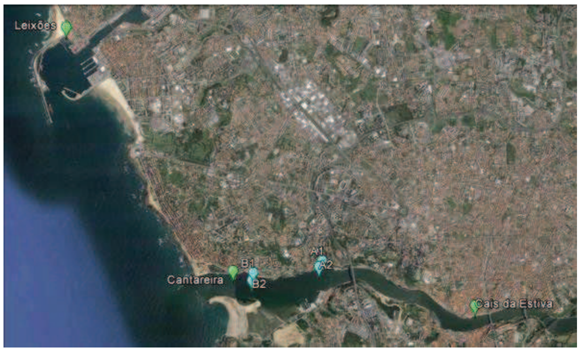

Fig. 2. Location of the validation points. Green for free surface elevation and blue for currents.

Table I. Validation points.

Variable	Name	Latitude (N)	Longitude (W)
Free surface elevation	Leixões	41º 11' 11.814"	8º 42' 16.543"
	Cantareira	41º 8' 44.790"	8º 40' 01.761"
	Cais da Estiva	41º 8' 23.814"	8º 36' 46.522"
Currents	A1	41º 8' 51.011"	8º 38' 49.875"
	A2	41º 8' 47.278"	8º 38' 52.381"
	B1	41º 8' 43.715"	8º 39' 45.539"
	B2	41º 8' 38.958'"	8º 39' 46.465"

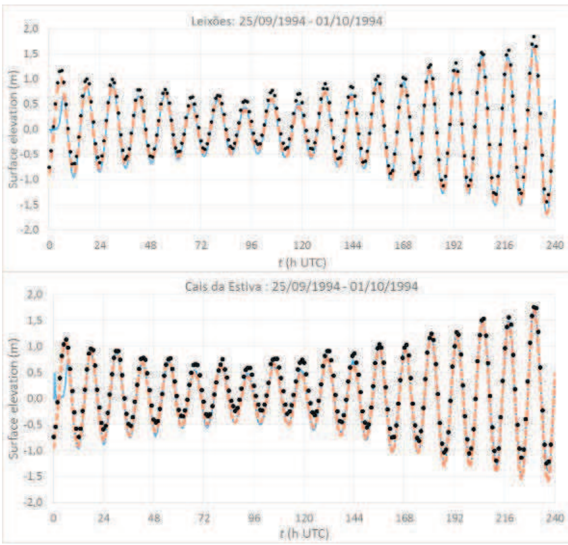

Fig. 3. Validation of the surface elevation (tide). The orange dotted line is for the Delft3D model, and the blue line is for the OpenTelemac model. The black dots represent the tide gauge in situ measurements.

3. RESULTS

3.1. Calibration/Validation simulation

The free surface elevation and the current velocity values were extracted from both models at validation points. Some results are represented in Figures 3 and 4. It can be noticed that the free surface elevations (cf. Figure 3) match relatively well the *in situ* measurements for both models. Nevertheless, both models underestimate the measured free surface elevation by approximately 0.2 m. This difference is also observed when comparing the TPXO.2 boundary condition with the Leixões *in situ* dataset.

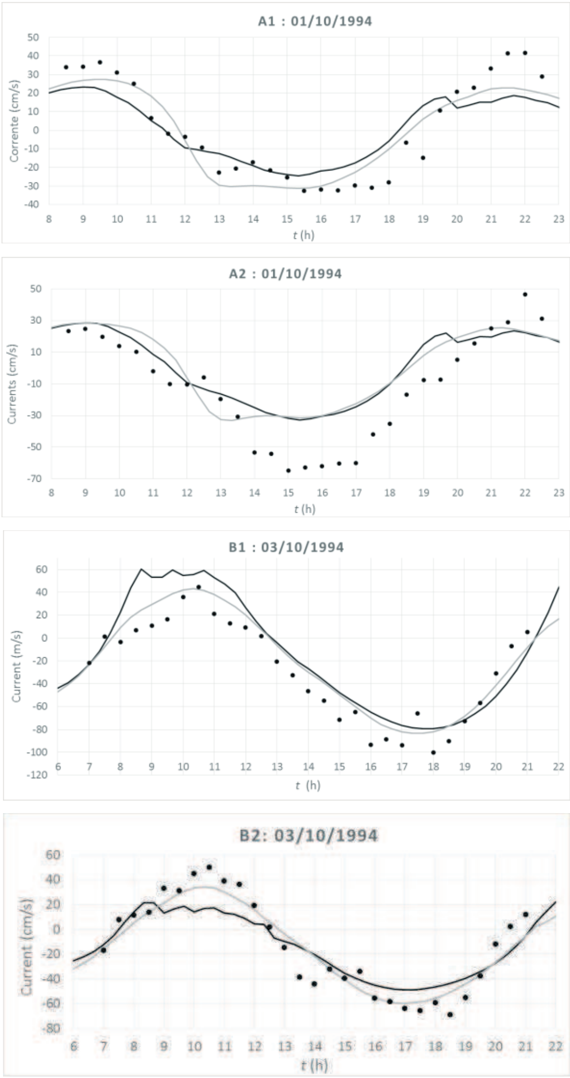

Fig. 4. Currents validation. The grey line is for the Delft3D model, and the black line is for the OpenTelemac model. The dots represent the water column averaged in situ measurements.

As no low pressure systems were located over the region during campaign period, the differences might due to some adjustments on the tide gauge or by some tidal harmonic not considered on the TPXO. The differences are stronger inside the estuarine region (Cais da Estiva) than at the coastal location (Leixões).

The currents (cf. Figure 4) are also relatively well represented, mainly at the A1, B1 and B2 points. The differences observed on the A2 point could be produced in response to the selected Cabeledo sand spit configuration integrated on the models grids.

The sand spit is a highly dynamic structure. It used to change frequently in response to the river flow and there is a lack of available data on its configuration during the 1994 campaigns. Thus the underestimation of the ebb currents for A2 point, might be due to a computational sand spit stronger than the real one.

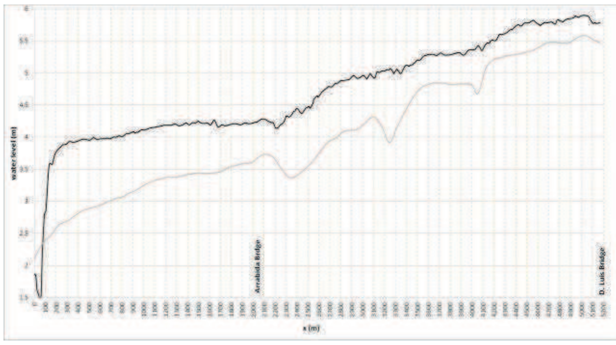

Fig. 5. Free surface elevation for the flood scenario. The grey line is for the Delft3D model, and the black line is for the OpenTelemac model.

Fig. 6. Location of the comparison points for the water level elevation during the 1996 flood.

3.2. Flood scenario simulation

The results obtained for the flood scenario shows a clear difference between the two models, abrupt at the mouth of the estuary region and diminishing upstream. In Figure 5, water lever elevation was plotted along a longitudinal profile traced between the estuary mouth (Cantareira) and the Luís I bridge (cf. Figure 2 and 6). Nevertheless both models show a very high free surface elevation at the Luís I bridge location: 5.5 m for the Delft3D run; 5.75 m for the OpenTelemac run. Historical records for this flood show a measured water elevation of 5.26 m at the Sandeman cellar, and of 5.77 m at Móveis Pina (cf. Figure 6 for locations).

4. CONCLUSIONS

On this work the hydrodynamics of the Douro River estuary were analysed for the 1994 estuarine configuration.

The performed simulations were calibrated and validated using datasets of *in situ* measurements with satisfactory results. A flood scenario was also run to check the water level and the flood risk of some estuarine regions. Results from two numerical models were used.

This work is the first stage on the creation and selection of a computational suite of models for the evaluation and prediction of the Douro River estuary hydrodynamics and morphodynamics. We expect to be able to provide, in the near future, an accurate representation of the physical processes and to predict the effects of human actions, extreme weather events, and climatic changes on estuarine and coastal regions

Acknowledgements

This research was partially supported by the Research Line ECOSERVICES, integrated in the Structured Program of R&D&I INNOVMAR: Innovation and Sustainability in the Management and Exploitation of Marine Resources (NORTE-01-0145-FEDER-000035), funded by the Northern Regional Operational Programme (NORTE2020) through the European Regional Development Fund (ERDF), and by the CNPq through a scholarship granted to the 2nd author (Process 200016 / 2014-8).

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