

Sea level rise impact in Lagrangean transport at Tagus estuary and Ria de Aveiro lagoon

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ABSTRACT

The main aim of this research is to assess the sea level rise impact in the Lagrangean transport in two Portuguese coastal systems (Tagus estuary and Ria de Aveiro lagoon), namely in their salt marshes, throughout the application of the 2D hydrodynamic numerical model MOHID, coupled with a Lagrangean particle-tracking module. The hydrodynamic model was previously implemented and validated to Tagus estuary and Ria de Aveiro lagoon. The models were used to determine the Lagrangean paths of passive particles released in selected areas of both estuaries. In order to determinate the sea level rise impact in particles transport two scenarios were adopted: actual sea level and local sea level rise projection.

The results indicate that Lagrangean trajectories are changed by sea level rise, revealing that nutrient and cohesive sediments dispersion might be affected in the future scenario, both in the Tagus estuary and in the Ria de Aveiro lagoon. Consequently, changes in hydrodynamics could influence the actual equilibrium of the systems behaviour and affect the normal state of the contingent biological communities, namely salt marshes.

KEY WORDS: Numerical modelling, Lagrangean transport, sea level rise, salt marshes.

INTRODUCTION

The knowledge of estuaries and lagoons hydrodynamic features is a crucial feature to recognize the systems behaviour itself as well as the ecosystems that depend on it. Sediment transport or phytoplankton and organic matter dispersion are essential to understand the aquatic ecosystems dynamics and could be investigated through the analysis of some hydrodynamics features of these coastal systems. Nowadays, there is a special concern about the possible impact of sea level rise in the actual hydrodynamic patterns of coastal systems and consequently in coastal ecosystems like salt marshes (Valentim, 2012).

Salt marshes are among the most productive ecosystems of the biosphere. They represent a critical interface between land and sea, providing a unique habitat for a large number of species, being essential elements in the ecological structure of estuarine systems. However, it is still difficult to understand some physical and biological interactions at salt marshes, as well as their response to climate change. Sea level rise (SLR) is one of the most important climate change effect in coastal systems. Its impact might induce important modifications in these systems circulation and consequently in their ecological and biological values (Sousa et al., 2010).

The main aim of this research is to assess the sea level rise impact in the Lagrangean transport in two Portuguese coastal systems (Tagus estuary and Ria de Aveiro lagoon), namely, in their salt marshes.

The Tagus Estuary (Fig.1) is a mesotidal coastal plain estuary with a surface area of about 320 km² and a mean volume of 1900×10⁹ m³. About 40% of the estuary's total area is tidal flats (Fortunato et al., 1999; Dias and Valentim, 2011). The estuary width varies between 2 and 15 km and the average depth is 10.6 m. (Fortunato et al., 1997). The tidal propagation and fluvial discharge from the major tributaries modulate the hydrology of the estuary (Vaz et al., 2011). The Tagus river is the major source of freshwater with an annual average flow of approximately 400 m³/s

(Neves, 2010). Other freshwater inputs to the estuary, the Sorraia and Trancão rivers, are comparatively small, with average annual discharges of about 35 and 2.5 m³/s, respectively (Neves, 2010). Tagus estuary is ebb dominated, with floods typically one hour longer than ebbs (stronger velocities during ebbs), and thus inducing a net export of sediments (Fortunato et al., 1999). The area affected by tides reaches 80 km landward of Lisbon and the maximum tidal currents achieve about 2.0 m/s (Gameiro et al., 2007).

The Ria de Aveiro (Fig.1) is a mesotidal lagoon located in the Northwestern Portuguese coast. It presents a very complex geometry and is characterized by large areas of intertidal flats and a web of narrow channels (Dias and Picado, 2011). The lagoon covers an area of 83 km² at high tide (spring tide) and 66 km² at low tide, is 45 km long, 10 km wide and is connected to the sea by a 350 m wide inlet, fixed by two jetties (Dias & Lopes, 2006). Four main branches radiate from this sea entrance: Mira, S. Jacinto, Ílhavo and Espinheiro channels (Picado et al., 2010). This system is also characterized by a large number of other smaller channels between which lie significant intertidal areas, essentially mudflats, salt marshes and old salt pans (Picado et al., 2010). The average depth of the lagoon relative to the mean sea level is about 3 m (Picado et al., 2010). The lagoon hydrodynamics is tidally dominated and the strongest currents are observed at the inlet channel, reaching values higher than 2 m/s (Vaz et al., 2009a). Dias (2001) and Lopes et al. (2006) characterized the first half of the main channels of the Ria de Aveiro lagoon as ebb dominated and the second half as flood dominated. As the lower lagoon is ebb dominated there is a trend to export sediments to the ocean (Picado et al., 2010). The total mean estimated freshwater input is approximately 1.8×10⁶ m³ during a tidal cycle, being the major fluvial input the Vouga (50 m³/s average flow), which is very small (2.5%), when compared to the mean tidal prism at the mouth of

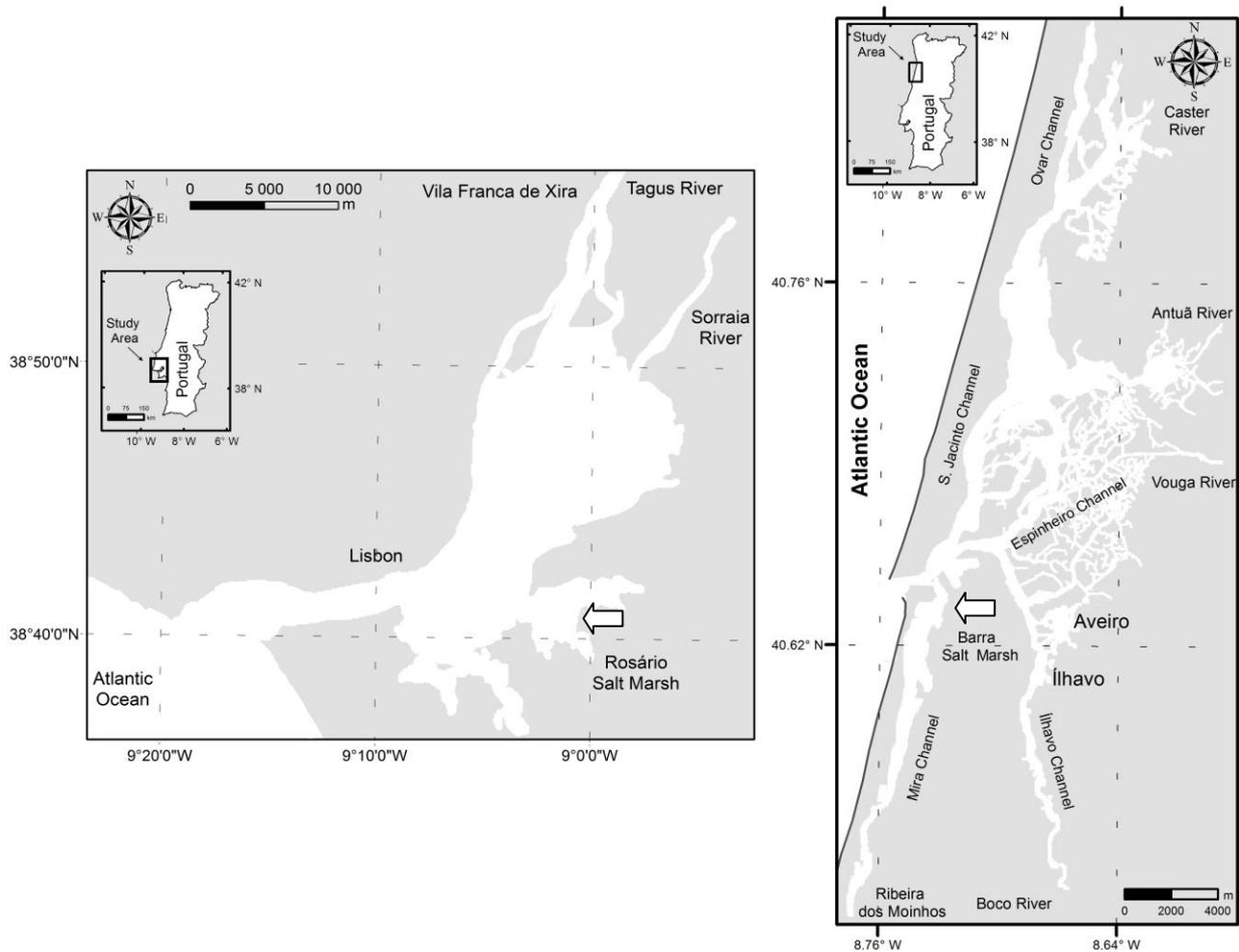


Figure 1. Tagus estuary (left) and Ria de Aveiro lagoon (right) locations. The arrow indicates the salt marsh area analysed in this work (Rosário salt marsh in Tagus estuary and Barra salt marsh in Ria de Aveiro).

approximately $70 \times 10^6 \text{ m}^3$ (Moreira *et al.*, 1993; Picado *et al.*, 2010).

Lagrangian transport is a very useful tool to understand estuarine dynamics, allowing the analysis of particles fate through the estimate of its trajectory, being extremely valuable in the sediment and nutrient transport interpretation, by simply following the tracks of selected particles (Lopes *et al.*, 2006). This study comprises the application of the 2D hydrodynamic numerical model MOHID, coupled with a Lagrangian particle-tracking module. The hydrodynamic models were previously implemented and validated to Tagus estuary and Ria de Aveiro lagoon. In order to determine the sea level rise impact in the particles transport, two scenarios were adopted: actual sea level and local sea level rise (SLR) projection. The results were focused in specific areas of the systems, one salt marsh in each estuary. With that performance, it is possible to analyse in detail the SLR impact in two salt marshes previously identified as endangered ecosystems: Rosário salt marsh, in Tagus

estuary, and Barra salt marsh, in Ria de Aveiro lagoon (Fig.1) (Valentim, 2012).

METHODS

The numerical model used in this study is MOHID (Martins *et al.*, 2001), a three-dimensional baroclinic finite volume model, designed for coastal and estuarine shallow water applications (Vaz, 2007). MOHID solves the three-dimensional incompressible primitive equations, and assumes the hydrostatic equilibrium as well as the Boussinesq and Reynolds approximations. The model equations were presented in several studies and can be found in Vaz (2007). MOHID has been applied to different coastal and estuarine areas, showing its capability to simulate complex flows features (e.g. Trancoso *et al.*, 2005; Santos *et al.*, 2006; Vaz *et al.*, 2005, 2007, 2009b, 2011; Bernardes, 2007; Malhadas *et al.*, 2009).

In this study, two previously validated set-ups of the MOHID-2D model for the Tagus estuary (Vaz *et al.*, 2011)

and Ria de Aveiro lagoon (Vaz *et al.*, 2007) were applied. Details about the models accuracy to reproduce the tidal dynamics for both applications after the models calibration and validation are described in Vaz *et al.* (2007; 2011). The main forcing considered in the present application were the tide and river discharges for both coastal systems. A period of 32 days (May 2nd to June 3th 2011) was considered to perform the simulations.

The numerical model of Tagus estuary includes a three level nesting model (Vaz *et al.*, 2009b). In the first domain (D1, that covers most of the Atlantic coast of Iberia and Morocco) is applied a tidal driven model, which uses the FES2004 global solution as forcing and has variable horizontal resolution ($0.02^\circ - 0.04^\circ$). The second domain (D2) has a horizontal resolution similar to D1. The third domain (D3) encompasses the whole extension of the Tagus estuary. The numerical grid of D3 presents 335×212 cells of 200 m each. On the open ocean boundary of D3, the model input was the tidal forcing from D2 (Vaz *et al.*, 2011). Rivers inflow were imposed in the landward boundaries considering the mean discharges, $400 \text{ m}^3/\text{s}$, $40 \text{ m}^3/\text{s}$ and $5 \text{ m}^3/\text{s}$ for the Tagus, the Sorraia and the Trancão rivers, respectively (Neves, 2010). The spin-up time was 2 days, the time step of the model was 15 s and a horizontal viscosity of $5 \text{ m}^2/\text{s}$ and a friction drag coefficient of 0.0025 were considered.

Ria de Aveiro grid has 429×568 cells, with dimensions of $40 \times 40 \text{ m}$ in the central area of the lagoon and $40 \times 100 \text{ m}$ in the north and south areas. The time step of the model was 6 s and a horizontal viscosity of $5 \text{ m}^2/\text{s}$ as well as a varying Manning's coefficient between 0.022 and 0.045 ($\text{m}^{1/3}/\text{s}$) was considered. At the sea open boundary, water elevation over the reference level was imposed using tidal harmonic constituents determined using T_TIDE package (Pawlowicz *et al.*, 2002). Rivers inflow were also imposed in the landward boundaries considering average discharges values ($60 \text{ m}^3/\text{s}$, $4.5 \text{ m}^3/\text{s}$, $1.0 \text{ m}^3/\text{s}$, $1.6 \text{ m}^3/\text{s}$ and $3.0 \text{ m}^3/\text{s}$ for Vouga, Antuã, Boco, Caster and Ribeira dos Moinhos rivers, respectively). River discharges values were obtained from the Ria de Aveiro Polis Litoral program, which considered the data presented in the Plano de Bacia Hidrográfica (www.arhcentro.pt).

Moreover, a Lagrangean particle-tracking module was coupled to the hydrodynamic model, which was used to determine the Lagrangean paths of passive particles released in the selected areas of both estuaries (Rosário salt marsh, in Tagus estuary, and Barra salt marsh, in Ria de Aveiro lagoon). The movement of the tracers is determined from the velocity field computed by the hydrodynamic model and by a random component of velocity (Braunschweig *et al.*, 2003, Lopes *et al.*, 2006).

Since one of the main goals of the present work is to study the SLR effects in the Lagrangean particles trajectory, two scenarios in the numerical simulations were evaluated: actual and SLR. The model parameters were kept for both scenarios except the value of the mean sea level. For the actual sea level simulation, the value of 2.08 m was considered, while for the SLR scenario a mean sea level of 2.50 m was considered. This sea level rise value of 0.42 m was adopted based on local projections of the sea level rise in the Portuguese coast for the IPCC A2 storyline (Lopes *et al.*, 2011b).

The results of Lagrangean particles in both systems are represented in Figure 2, showing the particles position

evolution throughout four tidal cycles, for actual and sea level scenario.

RESULTS AND DISCUSSION

According to Sousa *et al.* (2010), global change will affect salt marshes in terms of photosynthesis, growth, biomass allocation and nutrient uptake by plants and, consequently, salt marsh services are likely to be affected. Changes in the flow regime influence the extension and duration of inundation and consequently the vertical and horizontal extent over which salt marsh development takes place (Davidson-Armott *et al.*, 2002) as well as the rate of settlement and hence sediment deposition. Processes that influence the sediment supply to the marsh are likely to have some influence on marsh development (Townend *et al.*, 2011). Consequently, it is anticipated that changes in relative sea level play an important role in the development, maintenance and long-term health of salt marshes (Kolker *et al.*, 2008).

Lagrangean transport investigation allows the analysis of the particles fate, being extremely valuable in the sediment and nutrient transport interpretation (Lopes *et al.*, 2006). In the present study, model results indicate that Lagrangean particles will present larger trajectories in a SLR scenario, possible induced by the changes in the flow regime due to the SLR effects.

More precisely, model results indicate that in actual scenario (Fig.2A,C), Lagrangean particles tend to remain close to the salt marshes areas. In SLR scenario, it is observed that the movement of the particles is larger. In Rosário salt marsh, the particles trajectory includes not only the inside channel area but also extends to the Tagus estuary bay (Fig.2B). In Barra salt marsh, the movement in the SLR scenario reaches the lagoon mouth and the particles exhibit a greater scatter in the adjacent coastal area (Fig.2C). As such, in a climate change scenario, the results suggest that Lagrangean particles scatter on a larger area, not being so centred in a particular zone, as a result of the higher water column high and consequently higher current velocity due to the SLR effects. In terms of salt marshes health, this situation could indicate lower nutrients and cohesive sediments supplement in these salt marshes. Such fact represents a concern because salt marsh production and zonation are influenced by nutrients and environmental characteristics, such as sediments availability or seawater inundation, which are associated, among other factors, with sea level rise (Valiela & Teal, 1974; Townend *et al.*, 2011).

Moreover, considering the salt marshes under study, there are evidences that nowadays tidal currents and sediments exportation trends are increasing in Ria de Aveiro lagoon (Picado *et al.*, 2010; Plecha *et al.*, 2010, 2012; Martins *et al.*, 2011a,b). Local studies show that they will be intensified in the future due to the SLR effects (Lopes *et al.*, 2011a,b). Additionally, according to Valentim (2012), instantaneous velocity currents intensity will increase with SLR in both estuaries, and there is a rising trend for the sediments exportation outwards the systems. Accordingly, these facts together with the results of the present study show that SLR is a serious threat for the salt marshes stability and consequently for the surrounding ecosystems.

Therefore, predictable higher rates of SLR represent a concern about the salt marshes ability to respond to this

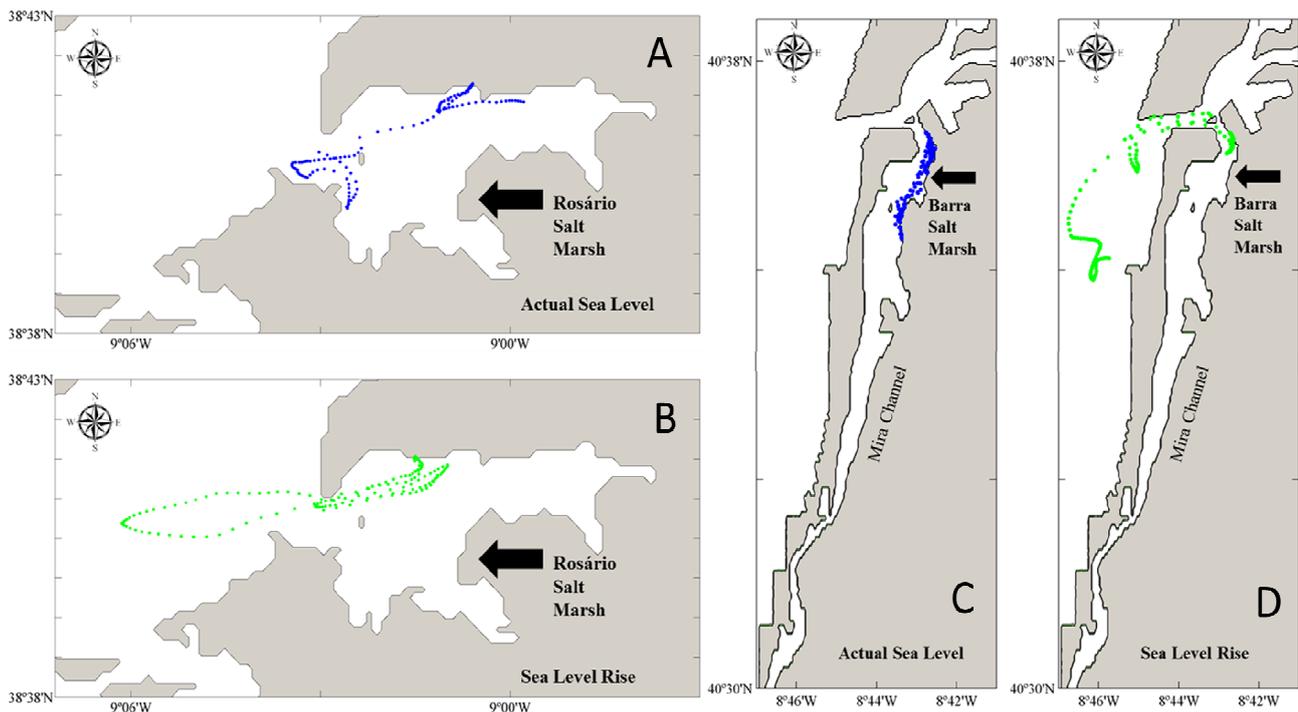


Figure 2. Lagrangean particles model results for Rosário salt marsh in actual (A) and SLR scenarios (B) and for Barra salt marsh in actual (C) and SLR scenarios (D)

threat and maintain their stability and health. As such, their important functions, such as biological productivity, hydrologic flux regulation, biogeochemical cycling of metals and nutrients, habitat for wildlife and natural coastal defence will probably become compromised in a climate change scenario.

CONCLUSION

The Lagrangean trajectories are changed by sea level rise both in the Tagus estuary and in the Ria de Aveiro lagoon, revealing that nutrient and cohesive sediments dispersion might be affected in the future. Consequently, changes in the hydrodynamics are found to influence the actual equilibrium of the systems behaviour and to affect the normal state of the contingent biological communities, namely salt marshes.

The trends found in the present study are unlikely to be unique to Tagus estuary and Ria de Aveiro lagoon and it is suggested that similar analyses are replicated for other tidally dominated systems to improve understanding and characterisation of uncertainty under climate change context.

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