Evaluation of Single Waves Effects on the Morphology Evolution of a Coastal Lagoon Inlet

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ABSTRACT


In morphodynamic simulations of coastal lagoons should be included the several processes that contribute to sediment transport and consequently to bathymetric changes. The individual contribution of the tidal currents, waves, wind and rivers discharge should be considered to better characterize the study area evolution. In the work presented herein, an evaluation of single wave effects on the bathymetric changes of a coastal inlet is presented, by neglecting the forcing of wind and rivers discharge in the numerical simulations and filtering the changes produced by the tidal currents. The bathymetric changes, the residual sediment fluxes and the sedimentation rates induced by eight monochromatic waves at the inlet were analyzed. It was concluded that the influence of the simulated waves on the morphodynamics is restricted to the inlet and adjacent nearshore. Additionally, the changes in the bathymetry and residual sediment transport are strongly dependent on the wave height forcing rather than on their frequency of occurrence. These conclusions emphasize the importance of independently analyze each wave, to better understand its impact in coastal systems dynamics.

ADDITIONAL INDEX WORDS: Morphodynamic, erosion, accretion, Ria de Aveiro

INTRODUCTION

The morphologic changes occurring in estuaries and coastal lagoons inlets are very complex, due to the combined effects of tidal currents and waves, representing presently one of the most interesting subjects in coastal research. The development and application of morphodynamic modeling systems, that simulate the morphologic changes, the hydrodynamics, the wave propagation and the sediment transport, under the forcing of tides, waves, river discharge and wind, are one of the possible avenues for investigating these complex systems (Fortunato and Oliveira, 2004; Cayocca, 2001; Castelle et al., 2007). However, the application of morphodynamic model systems to real systems is not effortless and some simplifying approaches have to be made. From these approaches the importance of each forcing agent in driving the morphologic changes may be better understood.

A possible approach consists in neglecting one or more forcing agents. Frequently, only the tidal currents are considered to force the sediment transport (Xie et al., 2009). In other research works, the morphologic changes induced by tidal currents coupled with a monochromatic wave or a wave regime is studied. Bertin et al. (2009a) considered particular wave conditions in order to investigate the influence of waves on residual sediment transport at a wave-dominated inlet. These authors also performed morphodynamic simulations considering a wave regime and wind forcing in sediment transport. Lam et al. (2007) simulated and described the morphodynamics of a tidal inlet system, investigating the effects of tides, waves, river flows and system configuration.

Cayocca (2001) used a schematic wave climate to determine a unique set of representative mean annual conditions, to study the long term morphological modeling of a tidal inlet. Also Castelle et al. (2007) considered offshore wave conditions representative of the littoral drift, to investigate the dynamics of a wave-dominated tidal inlet and its influence in adjacent beaches.

From a simplified wave regime composed by a set of monochromatic waves is possible to evaluate of the influence of every single wave in the morphologic changes of the study site. This analysis can be seen as a previous study of the complete wave regime influence on the morphodynamics at any study area.

This work intends to improve the knowledge about the morphodynamics of a coastal lagoon inlet located in the NW of the Iberian Peninsula: the Ria de Aveiro lagoon. Few works concerning this subject were performed and published before: Oliveira et al. (2007) and Plecha et al. (2010a) considered sediment transport forced only by tidal currents when studying the morphodynamics of this lagoon inlet.

Works concerning the influence of representative waves in sediment transport are even scarcer. Plecha et al. (2010b) established the wave climate influence on this lagoon inlet considering an entire wave regime. However these authors didn’t analyze the influence of each individual wave of the representative regime on the inlet morphologic changes.

Plecha et al. (2007) computed a simplified wave regime that produces a longshore sediment transport at a beach equivalent to the induced by the complete wave regime. This simplified wave regime was obtained by modifying the method proposed by
Chonwattana et al. (2005) and was applied to the Ria de Aveiro coastal lagoon inlet.

Herein the single waves effects on the morphologic evolution are evaluated by analyzing numerical bathymetric changes, residual sediment fluxes and sedimentation rates evaluated at several sections at the inlet.

**STUDY AREA**

The Ria de Aveiro lagoon is located in the northwest of the Iberian Peninsula and is characterized by several channels and intertidal areas, resulting in a very complex morphology (Figure 1). The lagoon has a maximum width of 10 km and its length measured along the longitudinal axis is 45 km, covering an area of 83 km² at high tide (spring tide) that is reduced to 66 km² at low tide (Dias and Lopes, 2006). The lagoon is connected to the Atlantic Ocean through an artificial inlet. The average depth (cf. Figure 1) at the inlet region is 5-10 m (relative to chart datum), except in the navigation channels where dredging operations are frequently carried out.

Ria de Aveiro hydrodynamics is tidal dominated. Tides are classified as mesotidal and semi-diurnal, with an average range at the inlet of 2 m (Dias et al., 2000). The lagoon receives freshwater from two main rivers, but their discharge is negligible when compared to the flux related to the tidal prism. The influence of rivers discharge is only noticeable at the upper parts of the lagoon (Vaz and Dias, 2008) and therefore is neglected in this study. The adjacent coastal zone of Ria de Aveiro, as well as the inlet ebb-delta, is subjected to a highly energetic wave climate, with a yearly mean significant wave height of 2-2.5 m, wave periods of 9-11 s corresponding to WNW to NNW swell (Andrade et al., 2002). During the winter, the significant wave height frequently exceeds 5 m (Ferreira et al., 2008).

The wave climatology induces a strong littoral drift southward (1-2x10⁶ m³year⁻¹; Andrade et al., 2002). An equivalent longshore sediment transport (LSTR) is produced by the simplified wave regime presented in Table 1 (Plecha et al., 2007).

**METHODS**

The main goal of this study is to identify the wave characteristics that induce the largest changes in the inlet morphology. The set of waves used was obtained by grouping waves from a complete wave regime in height classes of 1 m (Plecha et al., 2007) and is presented in Table 1. These 8 monochromatic waves differ in height, period and direction, and have different frequencies of occurrence. The characteristics presented in Table 1 were obtained at the breaker line and the 0º incident direction ($\alpha_{b,eq}$) is referenced to the West-East direction. The angles are measured counter clockwise.

The offshore characteristics of each one of these monochromatic waves was imposed as boundary forcing in the morphodynamic modeling system MORSYS2D (Fortunato and Oliveira 2004; Bertin et al. 2009b). This modeling system simulates the non-cohesive sediment dynamics forced by tides, waves, wind, river flows and is composed by three modules: ELCIRC, SWAN and SAND2D. For the present study the influence of wind and river flows was neglected. The ELCIRC (Zhang et al. 2004) is a hydrodynamic model that calculates tidal elevations and currents through the finite volume technique applied to the shallow water equations.

The wave module SWAN (Booij et al., 1999) computes wave propagation solving the wave action density balance equation adapted to nearshore zones.

The computation of the sand transport by semi-empirical formulae and the update of the bottom topography are performed

<table>
<thead>
<tr>
<th>Wave number</th>
<th>Frequency (%)</th>
<th>$H_{b,eq}$ (m)</th>
<th>$\alpha_{b,eq}$ (º)</th>
<th>$T_{p,eq}$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.29</td>
<td>0.87</td>
<td>-21.72</td>
<td>8.65</td>
</tr>
<tr>
<td>2</td>
<td>45.74</td>
<td>1.56</td>
<td>-23.80</td>
<td>9.28</td>
</tr>
<tr>
<td>3</td>
<td>24.75</td>
<td>2.50</td>
<td>-23.25</td>
<td>10.75</td>
</tr>
<tr>
<td>4</td>
<td>9.71</td>
<td>3.42</td>
<td>-22.72</td>
<td>11.50</td>
</tr>
<tr>
<td>5</td>
<td>3.87</td>
<td>4.40</td>
<td>-23.70</td>
<td>12.19</td>
</tr>
<tr>
<td>6</td>
<td>1.19</td>
<td>5.39</td>
<td>-25.19</td>
<td>13.76</td>
</tr>
<tr>
<td>7</td>
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<td>-19.60</td>
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<tr>
<td>8</td>
<td>0.13</td>
<td>7.48</td>
<td>-19.60</td>
<td>14.38</td>
</tr>
</tbody>
</table>
by the SAND2D model (Fortunato and Oliveira 2004; Bertin et al., 2009b). Coupled to each monochromatic wave, a tidal elevation forcing was also applied (Fortunato et al., 2002) and simulations were performed for 60 days periods. To compute the sediment transport rate is used the Ackers and White (1973) formulation modified by van de Graaff and van Overeem (1979) in order to take into account the waves effect.

The single wave influence in the morphodynamics is performed by analyzing for each wave the residual fluxes at the entire study area, the residual sediment flux at seven sections (sc1 to sc7), the sedimentation rates in the regions delimited by the sections (regions I-V) and the bathymetric changes at the study area (see Figure 1, lower panel).

The residual tidal currents contribution was removed from the bathymetric changes results. The tidal currents contribution was obtained numerically simulating a null wave height forcing. In this case the obtained bathymetric changes, residual sediment fluxes in sections 1-7 and sedimentation rate at regions I-V are considered as generated only by the tidal currents. These values were afterward removed from the bathymetric changes, residual fluxes and sedimentation rates obtained for the coupled forcing (tidal current and a monochromatic wave) simulations.

The frequency of occurrence of each wave (Table 1) was taken into account for the residual sediment fluxes and sedimentation rates computation.

**RESULTS**

Herein are presented the results for two waves with distinct characteristics: Wave 2 and Wave 6. The first wave is typical of the adjacent coast of the study area, while Wave 6 is already considered a storm wave with a lower frequency of occurrence. In Figure 2 are illustrated the results obtained for these two waves. The upper panel represents the final bathymetry predicted after 60 days of simulation. At the centre are represented the bathymetric changes between the final and the initial bathymetry, induced by the correspondent monochromatic wave imposed. The white areas represent unchanged depths or changes induced by tidal currents only and the contour lines represent the initial bathymetry. Positive values for bathymetric changes represent accretion and negative values represent erosion trends. The bottom panels illustrate the residual fluxes averaged for two $M_{sf}$ constituent periods ($2 \times 14.78$ days) under the influence of tidal currents and waves.

It is observed that the waves influence on the bathymetric
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Monochromatic waves coupled with tidal currents were imposed as sediment transport forcing for morphodynamic simulations of Ria de Aveiro inlet. The wave induced residual sediment fluxes in the cross sections

CONCLUSIONS

Monochromatic waves coupled with tidal currents were imposed as sediment transport forcing for morphodynamic simulations of Ria de Aveiro inlet. The wave induced residual sediment fluxes in the cross sections
upstream the lagoon mouth are smaller in magnitude than at the inlet, restricting the influence of the waves to the lagoon mouth and adjacent coastline.

For the sections located at and near the inlet (sc1 and sc2), Wave 5 and 6 are those that mostly contribute to the residual sediment fluxes.

Despite the importance of each one of the 8 monochromatic waves to the accurate reproduction of the longshore sediment transport, it can be considered that Waves 1, 7 and 8 are those with the lower contribute to the sediment balance in the study area.

This analysis in terms of residual sediment fluxes and sedimentation rates revealed that each wave has more influence at a given section or region.

This study was useful to identify the most important periods for a complete wave regime that largely contribute for the sediment transport and morphologic changes at the inlet of the study area.

LITERATURE CITED


ACKNOWLEDGEMENTS

The first author of this work is supported by the FCT through a PhD grant (FHR/BD/29368/2006). This work has been partly supported by FCT and by European Union (COMPETE, QREN, FEDER) in the frame of the research projects: POCI/ECM/59958/2004, EMERA, Study of the Morphodynamics of the Ria de Aveiro Lagoon Inlet; GRID/GR1/81733/2006 G-cast, Application of GRID-computing in a coastal morphodynamics nowcast-forecast system and PTDC/AAC-CLI/100953/2008 ADAPTRia, Climate Change Modelling on Ria de Aveiro Littoral - Adaptation Strategy for Coastal and Fluvial Flooding. The authors would like to thank Profs. A.M. Baptista and Joseph Zhang for their contribution with the model ELCIRC (www.stccmop.org/CORIE/modeling/elcire/index.html), and the Aveiro Harbor Administration for providing the bathymetric data and the people involved in the EMERA project, in particular, Maria Virginia Martins, for the sediment characteristics. The authors would like also to thank to André Fortunato, Xavier Bertin and Nicolas Bruneau, from LNEC, for the help provided in the implementation of MORSYS2D to the Ria de Aveiro lagoon.