

## Tidal evolution in Ria de Aveiro: dependence on geomorphologic changes

João M. Dias<sup>1</sup>, Leandro Vaz<sup>1</sup>, Renato Mendes<sup>1</sup>, Carina L. Lopes<sup>1</sup>, Sandra Plecha<sup>1</sup>, Ana Picado<sup>1</sup>, Nuno Vaz<sup>1</sup>

<sup>1</sup>Departamento de Física & CESAM, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193, Aveiro, Portugal. joao.dias@ua.pt; leandrovaz@ua.pt; rpsm@ua.pt; carinalopes@ua.pt; sandraplecha@ua.pt; ana.picado@ua.pt; nuno.vaz@ua.pt

### 1. Introduction

In recent years several geomorphological changes induced by anthropogenic changes and natural causes occurred in Ria de Aveiro. Human interventions include dredging operations of the inlet channel and of the main channels performed to improve the navigation, as well as land reclamations carried out for the expansion of harbor infrastructures. Simultaneously, it was found a natural trend for the deepening of the lower lagoon main channels considering that this area is ebb dominated (Dias, 2001), as well as an increase in the lagoon flooded area due to the destruction of several salt pan walls in consequence of the abandon of the salt exploitation and of the increasing marginal erosion induced by higher currents found inside the lagoon.

As consequence, changes in local tides are being reported along the last years by the populations living in the lagoon margins, indicating higher tidal ranges that flood the marginal farmland during high tides and hindering the navigation along the shallow channels during low tide. The effects of geomorphologic changes on the lagoon hydrodynamics were also researched in several studies (e.g. Araújo *et al.*, 2008; Picado *et al.*, 2010; Dias and Picado, 2011). In the first of these studies analytical and numerical modeling and *in situ* data were used and the results revealed an increase of  $M_2$  amplitude and a decrease of its phase from 1987 to 2003 along the lagoon main channels, as well as its dependence on the inlet deepening. The remaining studies referred used numerical modeling experiments to demonstrate that the increase of the lagoon flooded area results in slight decrease of  $M_2$  amplitude and an increase in its phase lag. Moreover, an intensification of the tidal currents, tidal prism and tidal asymmetry is revealed. Consequently, it has been verified that the sea level changes occurring along Ria de Aveiro are strongly dependent on the local geomorphologic modifications, however the individual effect of each one of the geomorphological changes is still unproved.

This work proposes to research the individual impacts of each one of the main geomorphological modifications that occurred in local tidal dynamics of the Ria de Aveiro, using numerical experiments and *in situ* data analysis.

### 2. Methodology

Sea level measurements performed along the lagoon during 1987/88, 2002/03 and 2012/13 were used to determine and analyze the  $M_2$  constituent amplitude and phase changes along the time in several stations distributed along the entire lagoon. The geomorphological evolution of Ria de Aveiro between 1987 and 2012 was also assessed analyzing the results of several topo-hydrographic surveys carried out over this period at the inlet area, as well as the results of two general topo-hydrographic surveys carried out in 1987/88 and 2011/12.

Baroclinic finite volume numerical models (MOHID and ELCIRC) were implemented to the Ria de Aveiro in a 2D mode. Several numerical bathymetries were built using the topo-hydrographic data available, and the models calibrated and validated using the referred sea level data. Then several simulations with real and schematic bathymetries were performed, including inlets with different depths and the enlargement of the lagoon area comprising the flooding of several salt pans. The numerical predictions were used to determine the amplitude and phase maps of the  $M_2$  constituent for the entire lagoon as well as differences between the results for all the scenarios under study.

*In situ* data and predictions were compared and analyzed to assess the importance of the lagoon geomorphodynamics on the tidal properties of the entire lagoon.

### 3. Results and Discussion

Difference between the results of the topo-hydrographic surveys shows that the lagoon experienced mostly a deepening of its main channels over the time. Particularly, the inlet channel depth increased

significantly, showing in some areas a 10 meters deepening. In the lagoon main channels the maximum deepening ranged between 3 meters in Mira channel and 8 meters at the lower reaches of S.Jacinto and Espinheiro channels. The results for the  $M_2$  harmonic constants show an amplitude increase and a phase decrease from 1987/88 to the present, with higher differences than those found in the study of Araújo *et al.* (2008).

The  $M_2$  harmonic constants determined from numerical predictions for the deepest bathymetries are in accordance with *in situ* observations, with a significant tidal amplitude amplification and faster tidal propagation. Smaller differences are found at the lagoon central area while higher differences occur at the channels heads, far from the inlet. These results demonstrate that significant changes in tidal amplitude and phase are explained by the bathymetric update, corresponding to a general deepening of the lagoon. The simulations with the schematic bathymetries show that inlet deepening induces higher tidal amplitudes and faster tidal propagation, especially for the highest lagoon's depth, not justifying however the magnitude of the changes found. Actually, the major changes are mainly induced by the overall deepening of the lagoon. Consequently, although important modifications are induced by the inlet deepening, the general lagoon deepening is the main factor controlling the  $M_2$  amplitude and phase changes that are occurring along the lagoon. The lagoon area enlargement was found to play an opposite effect, inducing a decrease in tidal amplitude and an increase in the phase lag, although with minor significance and essentially close to the enlarged areas.

#### 4. Conclusions

From 1987/88 to the present significant tidal amplitude amplification and faster tidal propagation was found, with higher changes than those observed in 2002/03 (Araújo *et al.*, 2008). The tidal properties close to the inlet are strongly dependent on the oceanic tidal characteristics, and therefore smaller differences were found at the lagoon central area. Consequently, the highest differences were found far from the inlet, at the channels heads.

The main geomorphological modifications occurred in Ria de Aveiro were found to induce important changes in the  $M_2$  harmonic constants distribution. The modifications investigated in the lagoon area contribute to reduce the tidal amplitude and increase the phase lag, especially in the surroundings of the new areas considered in the simulations, although found of minor significance. Keeping the overall lagoon depth unchanged, the inlet deepening induces higher amplitudes and a faster propagation, especially when the lagoon's depth is higher, but does not justify the magnitude of the changes found from 1987/88 to the present. Consequently, the major changes found in Ria de Aveiro tidal properties are mainly induced by the overall deepening of the lagoon channels.

#### 5. Acknowledgements

Renato Mendes, Carina Lopes and Ana Picado benefits from PhD grants (SFRH/BD/79555/2011, SFRH/BD/78345/2011 and SFRH/BD/79920/2011, respectively) given by the Portuguese FCT (Fundação para a Ciência e Tecnologia). Nuno Vaz is supported by the Portuguese Science Foundation program Ciência2008. This work has been partly supported by FCT and by European Union (COMPETE, QREN, FEDER) in the frame of the research projects ADAPTARia (PTDC/AAC-CLI/100953/2008), DyEPlume (PTDC/MAR/107939/2008), Pac:Man (PTDC/AAC-AMB/113469/2009), BioChangeR (PTDC/AAC-AMB/121191/2010) and LTER-RAVE (LTER/BIA-BEC/0063/2009).

#### 6. Literature cited

- Araújo, I.B., Dias, J.M. and Pugh, D.T., 2008. Model simulations of tidal changes in a coastal lagoon, the Ria de Aveiro (Portugal). *Continental Shelf Research*, 28, 1010-1025.
- Dias, J.M., 2001. *Contribuição para o Estudo da Hidrodinâmica da Ria de Aveiro*, PhD Thesis, Universidade de Aveiro, 288 pp. <http://nmec.web.ua.pt/ficheiros/PDFs/jdias.pdf>
- Dias, J.M., Picado A., 2011. Impact of morphologic anthropogenic and natural changes in estuarine tidal dynamics. *Journal of Coastal Research*, SI64, 1490-1494.
- Picado, A., Dias, J.M. and Fortunato, A.B., 2010. Tidal changes in estuarine systems induced by local geomorphologic modifications. *Continental Shelf Research*, 30, 1854-1864.