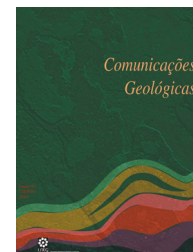# Prediction of overwash in alongshore variable barrier islands

Previsão da ocorrência de galgamentos em ilhas barreira com variabilidade longilitoral

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Artigo Curto
Short Article

Abstract: Overwash prediction is very important for coastal zone management. This work intends to identify alongshore variations in storm impact and evaluate the role of sub-aerial and submerged morphologies in overwash occurrence. For this study, 24 cross-shore topo-bathymetric profiles were set on Barreta Island (Ria Formosa barrier island system, Portugal). Pre- and post-overwash surveys were made between August 2012 and April 2013. During overwash events, tidal levels and wave parameters at breaking were obtained. Overwash occurred under storm and non-storm conditions, the latter coincident with spring high-tide. Beach morphology was spatially variable, and changeable from one overwash episode to the next. Predictions of overwash occurrence were made using the Overwash Potential, defined as the difference between runup and barrier elevation. Several runup equations were tested, and the results compared to the actual observations. The selected predictor provided an accuracy of 88% for the identification of the locations where overwash occurred. This study proves that nearshore and foreshore morphologies have a major impact on the longshore distribution of overwash.

Keywords: SWAN, Runup, Storm, Coastal hazards.

Resumo: A previsão da ocorrência de galgamentos é muito importante para a gestão da zona costeira. Este trabalho pretende identificar as variações longitudinais do impacto de tempestades e avaliar o papel das variações morfológicas sub-aéreas e submersas na ocorrência do galgamento. Para este estudo foram definidos 24 perfis topo-batimétricos na Ilha da Barreta (sistema de ilhas barreira da Ria Formosa, Portugal). Foram efetuados levantamentos pré- e pós-galgamento entre Agosto de 2012 e Abril de 2013. Durante os eventos de galgamento, foram obtidos os níveis de maré e os parâmetros de onda na rebentação. Os galgamentos ocorreram quer em condições de tempestade, quer em condições de não-tempestade, as últimas coincidentes com preia-mar de águas vivas. A morfologia de praia foi espacialmente variável e diferente nos vários eventos de galgamento. As previsões da ocorrência de galgamento foram efetuadas através do cálculo do Potencial de Galgamento, definido como a diferença entre a elevação do *runup* e da barreira. Foram testadas várias equações de *runup* e os resultados foram comparados com as observações reais. A equação selecionada proporciona um rigor de 88% na previsão dos locais onde ocorreram processos de galgamento. Este estudo demonstra que as morfologias emersas e submersas exercem um grande impacto na distribuição longilitoral do galgamento.

Palavras-chave: Programa SWAN, Elevação de espraio, Tempestade, Riscos costeiros.

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1. Introduction

Overwash associated with major storms may seem catastrophic, however, in the longer perspective (hundreds of years), overwash can be considered as a nearly continuous process, shaping and reshaping coastal barriers (Leatherman, 1988). Where overwash processes are allowed to occur, the net volume of sand is often maintained, with the morphology translating shoreward (Dolan & Godfrey, 1973). Accurate prediction of overwash is of obvious importance for coastal flood risk assessment and management. Sallenger (2000) developed a conceptual model for predicting storm responses, including an overwash regime. In this model, overwash occurrence depends on the relation between the maximum elevation of runup on the beach and dune crest level. However a detailed analysis of the influence of other foreshore factors and alongshore variability is still needed. The objectives of the current work are to identify and describe longshore variations in storm impacts along a barrier island; and to evaluate the role of sub-aerial and submerged morphological variations in overwash occurrence.

2. Study area

The study area is located on the western section of Barreta Island, which is part of the Ria Formosa barrier island system, in southern Portugal. The western part of Barreta Island starts downdrift of Ancão Inlet. This inlet was artificially relocated in June 1997 (Vila-Concejo *et al.*, 2003) and has been migrating eastward towards the study area. The typical barrier sedimentary environments in the study area are: a reflective beach face on the seaward side of the barrier, and a an extensive washover terrace until the lagoon.

Tides are semi-diurnal and mesotidal, with a mean tidal range of about 2 m that can reach up to 3.5 m during spring tides. The offshore wave climate is dominated by west-southwest waves (71% of occurrences, Costa *et al.*, 2001). Average annual significant offshore wave height (Hs) is 1.0 m and average peak period (Tp) is of 8.2

seconds (Costa *et al*., 2001). Storm events in the region (defined as Hs≥3.0 m) correspond to 1% of the offshore wave climate (Costa, 1994). Western Barreta has a northwest-southeast orientation such that it is directly exposed to dominant W-SW waves.

3. Methods

To study longshore variations in overwash, 24 cross-shore topo-bathymetric profiles were set on Barreta Island. Surveys were performed from August 2012 until April 2013 (11 surveys), in order to measure pre-overwash and post-overwash conditions. Profile measurements were made using a Real-Time Kinematic Differential Global Positioning System (RTK-GPS), over a total extent of 1600 m. Bathymetric surveys followed the orientation of topographic profiles until a depth of about -12 m MSL. They were made using an RTK-GPS, coupled with an eco-sounder, with data-syncronization and navigation assured by the software Hypack. This method has an estimated average error of 0.030 m (Horta, J. & Pacheco, A., oral communication).

Predicted tidal levels from the Instituto Hidrográfico de Portugal were used, and storm surge evaluated by the comparison between predicted levels and the observations from a tidal gaude located in Huelva, Spain (60 Km to the East). Offshore wave data were recorded by the Instituto Hidrográfico de Portugal using a directional wave-rider buoy offshore Cape Santa Maria (Costa, 1994). Numerical wave modelling with SWAN (Simulating Waves Nearshore; Booij *et al*., 1999) was used to explore nearshore wave conditions during overwash. A nested scheme composed of three regular grids was used; with grid resolutions of 50 m x 50 m for the regional grid, 18 m x 18 m for the background grid (larger map of Fig. 1) and 5 m x 5 m for each of the detailed grids (smaller map of Fig. 1, as an example). Breaking wave heights were obtained for several positions alongshore.

The likelihood of overwash occurrence was estimated using the overwash potential, OP (described in Matias *et al.*, 2012):

$$OP = R_2 + \eta - h_c \qquad (1)$$

where R_2 is the 2% exceedance level for vertical runup, including setup and swash, h_c is the barrier crest elevation, and η is sea level. When OP is positive, overwash occurs because the predicted runup elevation is higher than the barrier crest, and vice-versa. The results from one of the events were used to investigate the applicability of a number of wave runup predictors (R_2), similarly to what was done with data from overwash laboratory experiments BARDEX (Matias *et al.*, 2012) and BARDEX II (Matias *et al.*, 2013). The tested runup equations were developed by Hunt (1959), Guza & Thornton (1982), Holman (1986), Mase (1989), Powell (1990), Nielsen & Hanslow (1991), van der Meer & Stam (1992), Komar (1998), Ruggiero *et al.* (2001), Lorang (2002), Hughes (2004) and Stockdon *et al.* (2006). The description of each equation can be found in Matias *et al.* (2012).
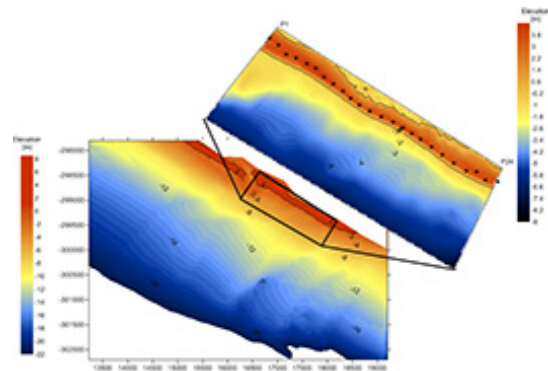

Fig. 1. Topo-bathymetric maps of the study area, including the extensive background survey (until -22 m) and a detailed survey from 2nd and 3rd of October 2012. Ancão Inlet is visible in the background survey, at NW of the study area. The stars on the top map represent the location of the barrier crest in each of the 24 profiles.

Fig. 1. Mapas topo-batimétricos da área de estudo, incluindo o levantamento de referência maior (até aos -22 m) e o levantamento de detalhe efetuado a 2 e 3 de outubro de 2012. A Barra do Ancão é visível no levantamento de referência, a NW da área de estudo. Os símbolos em estrela no mapa do topo representam a localização da crista da barreira em cada um dos 24 perfis.

4. Results and discussion

Throughout all surveys of the monitoring period the barrier profile was variable alongshore. The barrier was generally narrower in the middle section (around profile P10, Fig. 2) where the barrier width reached only 70 m at MSL. The wider barrier was permanently located on the northwestern end of the study area (profiles P1-P5, Fig. 2), where the barrier is 150 m wide.
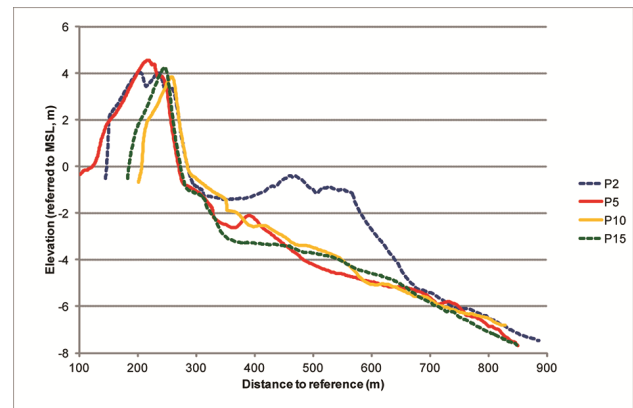

Fig. 2. Topo-bathymetric profiles extracted from the survey undertaken on the 2nd and 3rd of October 2012. Represented profiles are from locations P2 (at NW), P5, P10 and P15, as examples of different barrier sub-aerial and submerged morphologies.

Fig. 2. Perfis topo-batimétricos extraídos do levantamento efetuado em 2 e 3 de Outubro de 2012. Os perfis representados estão localizados em P2 (a NW), P5, P10 e P15, como exemplos de diferentes morfologias de barreira quer subaéreas, quer submersas.

The overall shoreline alignment was not rectilinear; rather it exhibited prominent and reentrant areas, visible in figure 1 (barrier crest represented by stars). The irregularities were not rhythmic and display variable

locations from one survey to the next. The beach face was generally steep (Fig. 2), with average beach slope of 0.1. The beach face occasionally exhibited beach cusps with variable wave-length and changing location but that rarely extended throughout the entire study area. In the nearshore, between -3.5 m to -4 m MSL, sand bars were observed (around profiles P9-P11 of Fig. 1). These morphologies, often related to rip-bar systems, are not rhythmic topography *sensu stricto* as a wavelength could not be attributed. There was no systematic alongshore repetition of features with similar characteristics; rather there were sand bars with different dimensions along the nearshore of the barrier (Fig. 1). Nevertheless, the most striking morphological feature of the nearshore was the ebb tidal delta and swash bars of Ancão Inlet (profile P2 of Fig. 2), that limits the study area to the northwest (Fig. 1).

The effects of six overwash events were measured during the study period. Overwash occurred twice under storm conditions and four times under non-storm conditions, but coinciding with spring high-tides. Overwash occurrence of November 2012 was related to a storm event, over which Hs reached maximum values of 3.8 m, with a tidal level of 1.4 m MSL. Non-storm overwash was, on the other hand, promoted by significantly lower waves (Hs = 0.8 m) recorded on March 12, 2013, but coincident with equinoctial spring tides, which reached a level of about 1.5 m above MSL. However, for this last event overwash did not occur in many of the profiles.

To investigate the differences in overwash characteristics along the study area, the overwash episode that generated the most variable barrier response was selected as case study. This was a non-storm overwash measured on the 2nd of October 2012, promoted by waves with offshore Hs = 0.89 m, Tp = 9.1 s and a tide level of 1.35 m above MSL. Storm surge level for that day was negligible. Results of SWAN model for breaking conditions in the nearshore showed that Hsb varied from 0.80 m to 1.25 m (Fig. 3), with the highest waves breaking on top of the ebb delta of Ancão Inlet.

OP was computed using the 12 equations mentioned above for the computation of the runup. Alongshore variable Hsb was used for the computation of runup. All equations, except one failed to accurately predict the majority of swash/overwash cases. The most accurate OP (88% accuracy) was obtained with Mase (1989) equation, which correctly predicted the storm impact for 21 profiles (Fig. 4). Such predictions are given by:

$$OP = 1.86 H_{b} \zeta^{0.71} + \eta + h_t \qquad (2)$$

where ζ is the Irribaren Number (Battjes, 1974) given by:

$$\zeta = tan\beta (H_s/L_0)^{-0.5} \qquad (3)$$

where *tanβ* is beach slope and L_o is the deep-water wave length. OP inaccurate predictions were located closer to Ancão Inlet (P1 and P2) and at P8 (Fig. 4). For profiles P1 and P2, overwash was predicted but it did not occur. The swash bars that form part of the ebb delta of Ancão Inlet

induced higher breaking waves (Fig. 3), but also breaking positions seaward than in other parts of the barrier. The dissipation of energy at such seaward locations frequently caused wave reformation and a second wave breaker. This induced a runup excursion that did not reach the barrier crest. For profile P8 was the reverse; no overwash was predicted (OP = -0.22 cm, Fig. 4) because of a combination of the lowest Hsb (0.8 m, Fig. 3) with a flatter beach face slope (0.11).
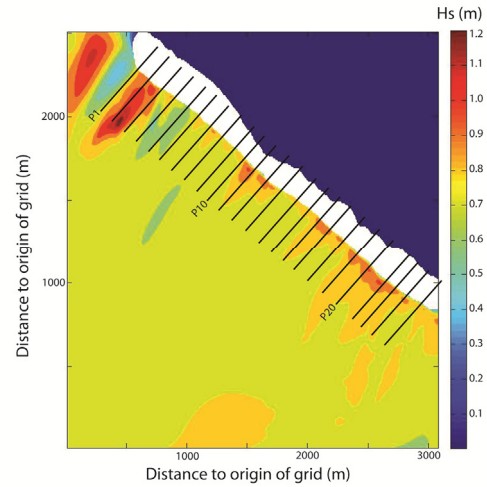

Fig. 3. Distribution of significant wave height (Hs) on the study area during the overwash event of October 2012. The profile location is also represented.

Fig. 3. Distribuição da altura significativa de onda (Hs) na área de estudo durante o evento de galgamento de outubro de 2012. A localização dos perfis também está representada.
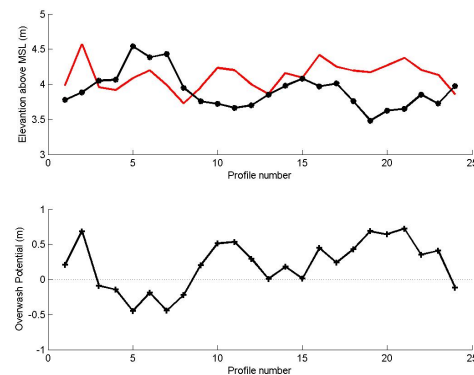

Fig. 4. Upper panel: Barrier crest elevation (in black and connected dots) along the study area, from Northwest (to the left) to Southeast (to the right) and computed runup elevation (in red) for the same locations, for October 2012 event. Overwash is expected when the red line is above the black line. Lower panel: Overwash Potential computed for all profiles. Positive values of Overwash Potential in the lower panel are indicative of overwash.

Fig. 4. Painel superior: Elevação da crista de barreira (a preto e com círculos) ao longo da área de estudo, de Noroeste (à esquerda) para Sudeste (à direita) e elevação do *runup* calculado (a vermelho) para as mesmas localizações, para o evento de outubro de 2012. Prevê-se a ocorrência de galgamento quando a linha vermelha se encontra acima da linha preta. Painel inferior: Potencial de Galgamento calculado para todos os perfis. Os valores positivos do Potencial de Galgamento no painel inferior são indicativos de galgamento.

5. Conclusions

During the study period, the barrier exhibited significant alongshore variations, including variations in barrier width, beach slope, beach cusps and swash bars. Irregularities in the nearshore that influenced breaking waves, were mostly related to sand bars that were moving downdrift from Ancão Inlet or were remnants of ebb delta sediments from previous Ancão Inlet positions.

Overwash occurrence was predicted using OP, which was tested using several runup predictors. Mase (1989) equation was the most accurate, with 88% of correct prediction of swash/overwash. Shortcomings in the application of OP as presented here may arise from not including important spatial variables such as the distance between the barrier crest and breaker positions, or beach berm positions. The incorporation of these morphological variables is a crucial step towards more accurate predictions.

Acknowledgements

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