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Regional assessment of storm related overwash and breaching hazards on coastal barriers

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A B S T R A C T

Coastal communities are threatened by the impact of severe storms that may cause significant loss of life and damage to properties. Among the main processes behind such impacts on coastal barriers are the occurrence of overwash and breaching during storm events. In order to estimate potential losses associated with a particular event, the above processes must be properly parameterized. Here, we propose a novel methodology to estimate overwash and breaching hazards suitable for a regional scale analysis (Ø 100 km). For the overwash hazard assessment, the method is based on the application of the approach developed by Donnelly (2008) that allows the parametrisation of the overwash hazard considering both flow velocity and flow depth. Moreover, the inland extension of the associated hazard, which is critical to assess subsequent vulnerability, can also be estimated following this methodology. The proposed method requires the selection of a runup formula validated for the study area, a storm beach profile, a runup lens angle, and a percolation constant for infiltration. To assess the breaching, hazard, a new multivariable evaluation is proposed that allows ranking the potential of breaching. The multivariable evaluation combines overwash and erosion hazards as well as their extensions with the main morphological characteristics of the barrier, resulting in the breaching hazard index, that ranks from 0 to 5 (no breaching to inlet formation). Inland breaching extension is also relevant for the vulnerability assessment. The breaching extension can be estimated using historical or contemporary analogues of the nearest flood deltas. The developed approaches were applied to Ancão Peninsula (Algarve, Portugal) as a demonstration example. The advantages of the present approach are: adaptability to various environments where overwash and/or breaching processes are important, time efficiency on evaluating overwash and breaching hazards, and the assessment of hotspot areas at a regional scale.

1. Introduction

Densely populated coastal areas will very likely face risks derived from intense extreme events capable of creating hazards with severe consequences for property, infrastructure or even life (Smith et al., 2015). Furthermore, recent studies have predicted that climate change will increase the coastal risk (Vousdoukas et al., 2017; Vitousek et al., 2017). In an attempt to reduce the consequences, an effort must be taken to adequately identify, compare and rank the more vulnerable areas and threats. In order to achieve that, large scale assessment tools need to be developed (Van Dongeren et al., 2014; Ferreira et al., 2016).

Coastal barriers are highly dynamic environments that serve as natural protection for coastal communities and backbarrier lagoon systems, which commonly include high value ecosystem services. The main processes associated with storm events on barrier islands are coastal erosion, overwash/inundation and, in extreme cases, barrier breaching (McCall et al., 2010; Roelvink et al., 2003). These processes, on a long-term timescale (decades to centuries), contribute to the natural evolution and survival of barriers driving inland retreat through rollover and inhibiting barrier drowning, (Lorenzo-Trueba and Ashton, 2014). However, on a shorter timescale (seasonal to interannual) they represent potential hazards to local communities (populations and activities), as well as, to natural ecosystems (habitat and ecosystem services destruction and/or degradation). Some of those hazards can result in changes with significant cascade effects that may considerably alter the nature of the system. In order to design better policies and future strategies, it is necessary to predict possible overwash and breaching locations (hotspots) for assessing the consequences of storm events.

The elevated complexity of overwash and breaching processes has traditionally made their estimation difficult. Nowadays, extended and

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detailed numerical morphodynamic models have been developed for calculating overwash, erosion and breaching (McCall et al., 2013; Roelvink et al., 2009). However, their application demands high computational capacities and high resolution input data, making them unfeasible for large (regional scale) applications, i.e., of the order of tens or hundreds of kilometres, or for a first assessment to determine the most vulnerable areas. Overwash related hazard studies have been developed and applied in a large variety of coastal environments with great success (Rodrigues et al., 2012; Benavente et al., 2006; Stockdon et al., 2007). Most of the studies use the Storm Impact Scale developed by Sallenger (2000) to estimate the hazard magnitude. These approaches, although providing valuable information on the processes involved in the wave-dune interaction, often only consider the possibility of occurrence without differentiating the degree of hazard for the same return period (Rodrigues et al., 2012; Ferreira et al., 2006). Alternatively, the overwash potential has been used as a proxy of the hazard magnitude (Matias et al., 2013). However, this approach does not provide information on the overwash characteristics beyond the dune crest or about the total overwash extension, which are crucial parameters for the translation of the hazards into vulnerability and impact. Overwash extent has been previously associated with return periods using historical analysis of a series or aerial photos (Garcia et al., 2010). This method requires extensive datasets of aerial photographs spanning over several decades, is time consuming, and restricted to natural dune systems with no human intervention/occupation.

The breaching hazard and its assessment at regional scale have received little attention in the literature, with only few works devoted to the topic (Vila-Concejo et al., 2006). Because of the complexity of this process, there is not a simple formula or group of formulas that predict the occurrence of inlet breaching. One of the main reasons is that breaching is a result of a combination and interaction of storm processes with the barrier island morphological characteristics. Hence, there are some limitations on how accurately breaching occurrence can be estimated with the use of a single formula. Similarly to the overwash, the breaching extent also needs to be evaluated. In the case of barrier islands, breaching can lead to the generation of a new inlet system, resulting not only in the permanent loss of dune and beach sections, but also in a rapid change of the neighbouring ecosystems with the creation of flood and ebb tidal deltas (FitzGerald, 1988). The latter highlights the importance of the breaching extent parameter in estimating the associated vulnerability.

Here, we develop two methods to assess coastal risk through the simplification of overwash and breaching processes that allows fast application at a large spatial scale and the identification of areas where the above processes may represent a major hazard (hotspots). The proposed overwash assessment methodology goes beyond the simple overwash potential estimation and computes the overwash depth, velocity, volume and extension. In terms of breaching, a multivariable assessment of physical processes and morphological features of the barrier island is applied to estimate a total score related with the breaching potential. The methodologies proposed here are designed to be applied for both event and response approaches (Divoky and McDougal, 2006; Garrity et al., 2012) to evaluate the overwash and breaching hazards for selected return periods. Both methodologies are described in detail, followed by their application and validation at the Ancão Peninsula (Ria Formosa, Portugal). Finally, the results are discussed and the conclusions arisen from the present work are presented.

2. Methodology of the proposed approach

2.1. Overwash

Based on the Sallenger (2000) impact scale, overwash regime occurs when the maximum level of the runup exceeds the height of the dune or the berm crest while the lower level of the runup is below dune/berm crest height. As mentioned above, the proposed method intends to assess overwash hazard and associated impacts by calculating not only the overwash potential but also overwash depth and extension within the backbarrier area (Ferreira et al., 2007). The theoretical background of the method is based on the combination of the Sallenger (2000) Storm Impact Scale model, the similarity relationship developed by Donnelly (2008) for runup approximation (D08 hereafter), and runup estimation values from empirical equations. A similar regional approach has been applied by Stockdon et al. (2007). who calculated the overwash potential for specific hurricanes. However, they estimated the overwash extent based on morphological changes. The incorporation of the D08 approximation transforms overwash potential into overwash depth and extension. This method is only valid for overwash regimes; inundation regimes (lower runup level higher than the dune crest) cannot be estimated following this approach. The method applied here estimates the water depth at the crest of the profile (h_c) during overwash events based on the assumption that the water profile is linear during the runup (Fig. 1). It also provides an estimation of the total overwash extension and runup flow, velocity and water depth in a continuous way at any overwashed position. These results can be used for a more accurate prediction of vulnerability, estimating the exposure of infrastructures and other assets in the coastal environment.

The h_c (water depth at the crest) can be calculated assuming the D08 similarity relationship and applying equation (1):

$$h_c = \frac{h_o}{X_R}(X_R - X_c) \tag{1}$$

where x_c is the horizontal distance from the storm induced still water level (SSWL) to the beach crest, X_R is the horizontal projection of maximum runup from SSWL, and h_o is the water depth at SSWL (Fig. 1) as defined by Stockdon et al. (2007), that includes tides, surge and wave setup. The estimation of h_o is rather complex and two approaches can be applied. The first option is to substitute the h_o/x_R term by a constant value based on the laboratory measurements made by Schuttrumpf and Oumeraci (2005). Typical values are presented in Table 1 for different slopes.

This constant value is also the tangent of the runup lens ($\tan\beta_w$) divided by the cosine of the beach slope ($\cos\beta$), assuming a linear water surface and the similarity relationship of Fig. 1. The equation can be rearranged using the same similarity relation to:

$$h_c = \frac{\tan\beta_w}{\cos\beta}(X_R - X_c) \tag{2a}$$

The horizontal distances can be equally substituted by the vertical ones into:

$$h_c = \frac{\tan\beta_w}{\sin\beta}(R - D) \tag{2b}$$

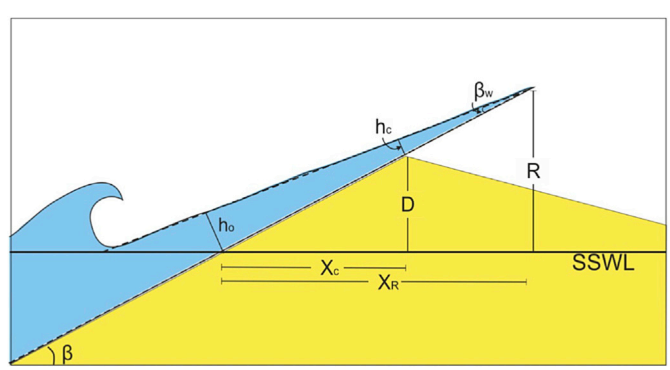

Fig. 1. Sketch of the similarity approximation showing water level at the point of maximum runup, assuming a linear relationship to estimate water depths (adapted from (Schuttrumpf and Oumeraci, 2005). See the text for an explanation of the terms.