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Assessing the extreme overwash regime along an embayed urban beach

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ABSTRACT

Coastal overwash is one of the most important hazards affecting the coastal zone and therefore has been the focus of several studies related to the establishment of setback lines. However, studies of extreme overwash (EO) events along urban beaches backed by a seawall or structure are scarce, and reveal the difficulties associated with its assessment, measurement and validation. The Nazaré coastal urban area (located on the west coast of Portugal) is developed adjacent to an embayed reflective beach and is subject to frequent and localized inundation due to EO events capable of overtopping the protection seawall. The current work develops a methodological approach to simulate total water levels (TWL) and seawall overtopping occurrences in time and space, with the ultimate goal of identifying the factors that govern the extreme overwash regime. The method uses multi-decadal time series of site-specific wave and tide, and high-resolution topo-bathymetric data, and recreates the TWL time series for a 36-year period. The model is successfully validated against video imagery and maximum swash line data that provide information on the reach of the water levels measured during modal and extreme TWL conditions along the studied beach. This study establishes the importance of the interaction of the modal and extreme hydrodynamic processes with the beach and backshore morphology. The Nazaré embayment is in equilibrium with the alongshore-varying modal wave conditions, resulting in higher vulnerability of the most sheltered sector during extreme events.

1. Introduction

Coastal overwash has long been identified as an important phenomenon in coastal dynamics and evolution, and therefore has been the focus of several studies, especially along barrier islands and low-profile coasts (e.g., Donnelly et al., 2006). In the last 15 years, studies on this phenomenon have focused on the evaluation of coastal hazard zones and determination of setback lines (e.g., Healy and Dean, 2000; Sallenger, 2000; Ruggiero et al., 2001; Ferreira et al., 2006; Raposeiro et al., 2013). Ultimately, knowledge of water levels that cause extreme overwash (EO) events is important for determining the dimensions of coastal protection interventions, so that they are constructed with sufficient crest elevation to minimize overtopping and reduce overwash to acceptable levels (Pullen et al., 2007; Linham and Nicholls, 2010). Although a number of studies exist on overwash and overtopping assessment, both on beaches and structures, studies on extreme events that affect urban beaches backed by seawalls are still lacking.

Several authors have developed models to assess total water levels (TWL) that lead to coastal overwash and inundation, taking into account the major controlling variables: tide, surge, wave and morphology (e.g., Ruggiero et al., 2001; Garrity et al., 2006; Serafin and Ruggiero, 2014; Stockdon et al., 2014). Overwash starts when maximum elevation reached by the free surface of the ocean (TWL) exceeds the beach or dune crest height (Donnelly et al., 2004), allowing for a steady sheet of water to run over these features. However, only EO events are able to reach landward of the backshore. In urbanized beaches, seawalls may have replaced dunes in providing protection against overwash-related inland inundation. Overtopping of these structures during EO events may damage coastal property and infrastructure and cause injury to people.

Triggering processes of EO events correspond to extreme wave run-up (R), and/or extreme surge levels, and the most favorable conditions for the occurrence of extreme overwash are met when peak intensity of both variables and high tide coincide. However, the joint probability of occurrence of very high values of all the above variables is smaller than the probability of occurrence of each variable in isolation and is more representative of an extreme event (Prime et al., 2016).

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Furthermore, whereas the behavior of the tide is susceptible to a deterministic approach, the other forcing variables are not.

A number of authors have studied wave run-up and developed empirical solutions for its estimation (e.g., Holman, 1986; Mase, 1989; Nielsen and Hanslow, 1991; Van der Meer and Stam, 1992; Grüne and Wang, 2001; Pullen et al., 2007). The available formulations typically include the characteristics of the incident waves (typically the deepwater wave height and length - H_0, L_0) and of the affected surface, commonly described by the surf similarity parameter, also known as the Irribarren number - ξ (Battjes, 1974):

$$\xi = \frac{\tan\beta}{\sqrt{H_0/L_0}} \qquad (1)$$

where tanβ describes the bed slope.

Review of the literature, however, reveals a number of limitations to the ability of accurately predicting run-up levels and thus overwash events. These drawbacks are related to lack of large and consistent observational records, but most importantly, to site specificities, such as the nearshore bathymetry and beach topography, that influence the nearshore wave parameters (e.g., Matias et al., 2014; Stockdon et al., 2014). Complexity is added by the varying water levels during storms, including the tide that controls the breaking of the waves and the reach of the wave run-up, as well as by the constantly reshaping of the beach profile by waves. The work by McCall and others (e.g. McCall et al., 2014, 2015) has advanced the application of process-based numerical models in the prediction of storm hydrodynamics and beach response, particularly on gravel beaches. Still, wide application and validation of overwash models is still lacking, especially in sheltered embayments where the longshore distribution of overwash has seldom been investigated.

The objective of the present work is to investigate the phenomenon of extreme overwash at an embayed sheltered urban beach backed by a seawall (Nazaré, Portugal) by characterizing its occurrence in time and space, supported on high-resolution data and numerical modelling.

A multi-decadal time series of waves and tides was used to assess the long-term characteristics of the hydrodynamic forcing, both the modal and extreme overwash-inducing regimes. High-resolution nearshore bathymetry, and beach and backshore topography were used to generate the spatial variability in the seafloor and beach area along the embayment. A 2-dimensional methodology was assembled to assess TWL, and seawall elevations were used as threshold to detect EO

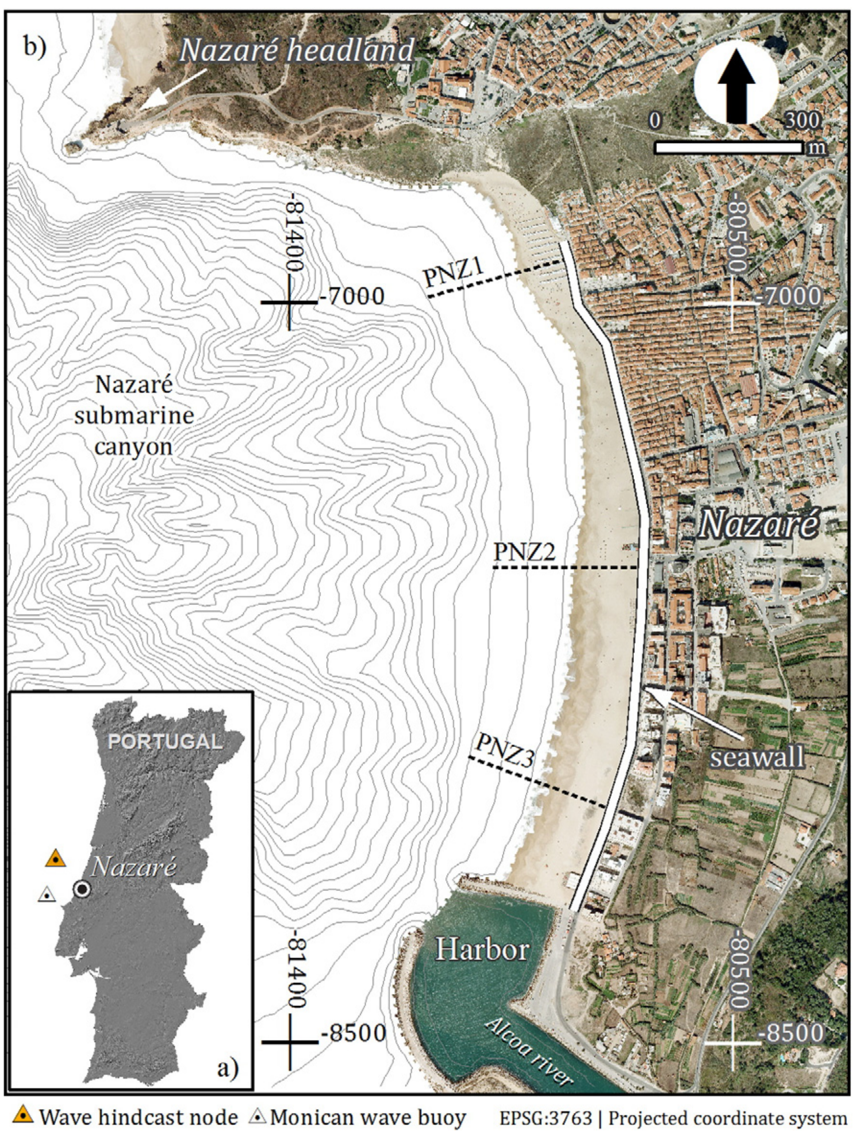

Fig. 1. a) Nazaré, located on the west coast of Portugal, and b) Nazaré embayment, location of the surveyed beach profiles PNZ1 to PNZ3 (dotted lines), and seawall (white alongshore segment). The figure depicts the proximity of the Nazaré submarine canyon head (5 m contour intervals) to the beach.