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A simple model to estimate the impact of sea-level rise on platform beaches

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ABSTRACT

Estimates of future beach evolution in response to sea-level rise are needed to assess coastal vulnerability. A research gap is identified in providing adequate predictive methods to use for platform beaches. This work describes a simple model to evaluate the effects of sea-level rise on platform beaches that relies on the conservation of beach sand volume and assumes an invariant beach profile shape. In closed systems, when compared with the Inundation Model, results show larger retreats; the differences are higher for beaches with wide berms and when the shore platform develops at shallow depths. The application of the proposed model to Cascais (Portugal) beaches, using 21st century sea-level rise scenarios, shows that there will be a significant reduction in beach width.

1. Introduction

There is an increasing consensus that an accelerating sea-level rise (SLR) scenario due to climate warming will have significant impacts on the coastal zone (Church et al., 2013). Therefore, the existence of tools to evaluate the potential influence of sea-level rise on shoreline evolution is of prime importance. At a timescale useful for long-term management purposes (50–100 years, e.g. Esteves, 2014) quantitative approaches have clearly been dominated by the Bruun conceptual model (Bruun, 1962) and, to a lesser extent, by the Inundation Model or historical trend analysis (e.g. Walkden and Dickson, 2006; Brunel and Sabatier, 2007). These approaches have been developed for open coast sandy beaches with a doubtful applicability to beaches that develop on shore platforms, as explained below.

The use of historical trend analysis, with the extrapolation of past shoreline evolution rates to estimate future trends, is only valid for a stationary forcing and consequently is not appropriate under accelerating sea-level rise scenarios (Ferreira et al., 2006). Moreover, this approach depends on the correct evaluation of long-term coastline changes and on the assumption that these changes can be attributed to sea-level changes only — conditions that are hardly ever met.

The Inundation Model is suitable only in cases where, in response to sea-level rise, the beach profile remains invariant (Brunel and Sabatier, 2007). This is not the case for sandy beaches where the morphodynamic response is usually translated into sediment redistribution along the profile. The Bruun rule of erosion (Bruun, 1962), based on the concept of the equilibrium profile, has been subject to a great deal of controversy; while some authors claim its validity (e.g. Leatherman, 2001; Zhang et al., 2004) others question its applicability to natural systems (e.g. Thieler et al., 2000; Cooper and Pilkey, 2004; Davidson-Arnott, 2005; Aagaard and Sørensen, 2012.). Nevertheless, according to Stive (2004) this is the only model that can be used operationally, which explains its wide use. The Bruun model has also been modified for other environments like barrier islands (Dean and Maurmeyer, 1983) and soft cliffs (Bray and Hooke, 1997). The model considers two major assumptions: i) the beach is represented by a 2D cross-shore profile, with no significant alongshore inputs or outputs and ii) the equilibrium profile consists entirely (up to the closure depth) of sand (or cohesive material). While the first assumption can be extended to platform beaches, the latter cannot because this type of beach is usually limited to the upper section of the profile and the beachface ends against a rocky shore platform. The limitations of the sea-level response models described above hamper their use in platform beaches.

The development of a model that can be used in shore platform beaches should acknowledge the constraints imposed by a hard bottom (such as a shore platform) on beach profile morphodynamics. Larson and Kraus (2000) developed a method to represent non-erodible bottoms in beach profile change modeling. Trenhaile (2004) studied beach accumulation and dynamics of profiles developing on shore platforms by simulating different wave regimes and sediment grain sizes on platform surfaces that could have a convex, concave or linear shape. Following this pioneer work, other studies on platform beaches (e.g. Kennedy and Milkins, 2014; Trenhaile, 2014) and soft rock shores (Walkden and Hall, 2005) have also recognized the influence of the shore platform morphology on the response of these beaches to sea-

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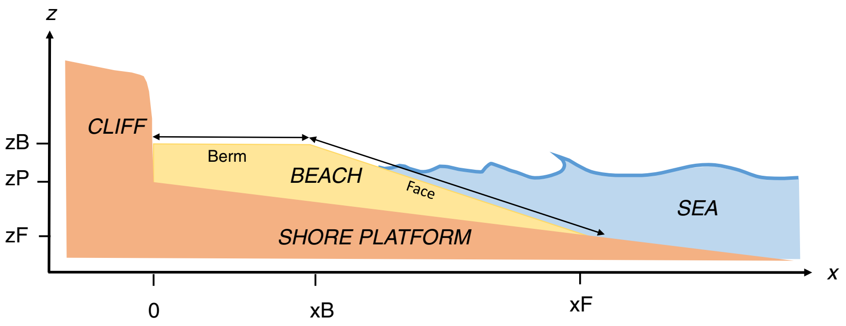

Fig. 1. Schematic representation of a platform beach profile (*xF*, *zF*: coordinates of offshore end of the beach; *xB*, *zB*: coordinates of the berm crest; *0*, *zP*: coordinates of the landward limit of the shore platform).

level rise. However, as the interaction between waves and beaches perched on shore platforms in a context of sea-level rise is complex and far from being fully understood (Kennedy and Milkins, 2014), the use of existing process-based models to forecast platform beach response to sea-level rise still is a challenging task and remains confined within the research community.

The main objective of this work is to contribute to the study of platform beaches and provide a suitable and simple, yet useful, model to evaluate their response to the effects of sea-level rise. The model is applied to the beaches of Cascais (Portugal) to estimate beach evolution by the end of the 21st century, in response to sea-level rise.

2. Model development

A platform beach is generally limited landward by a cliff and seaward by a shore platform and, generally, does not extend very far into the sea. Depending on geomorphological and sediment delivery constraints, these systems can be considered either open or closed. In closed systems there is no exchange of sediment between the beach and the adjacent shorelines (Masselink and Hughes, 2003). This geomorphological setting constitutes the basis of model development.

The proposed model assumes a two dimensional profile cut in a hard rock substrate over which a fairly small sandy beach develops; the beach overlays a flat, gently-sloping, shore platform. The geomorphological content of this idealized beach comprises a berm and a face, which extends from the berm crest to the hard shore platform. The model assumes that both the beachface and shore platform have a constant slope (Fig. 1); the geometry is similar to a beach that develops over a "linear platform surface" as proposed by Trenhaile (2004).

The model develops on the assumption that the beach profile (including berm height and face slope) is in equilibrium with mean sea-level (MSL) and wave climate. In response to sea-level rise, the model assumes that the profile will preserve the shape but the berm will be raised by the same amount as the rise in sea-level.

If the system is assumed closed (i.e. beach volume is maintained) the thickness of sediment deposited over the berm must be compensated by the erosion of the beachface and landward migration of the crest (Fig. 2). These assumptions are in agreement with the R-DA model (Davidson-Arnott, 2005) for sandy shorelines where the profile response to sea-level rise is translated by an onshore migration of the entire profile. During this processes it is assumed that rocky profile (including the cliff) will remain invariant, which seems a reasonable assumption for hard rock shores as the morphological response timescale is much greater than that for a sandy beach.

For the general case, the beach volume V is given by:

$$V = \int_0^{xF} t(x)dx \tag{1}$$

where $t(x)$ is the beach thickness at distance x and xF is the offshore end of the beach (the base of the beachface).

In response a sea-level rise of magnitude ΔMSL, berm crest retreat (R) can be computed assuming that the beach volume will remain invariant so that:

$$V = V\prime \tag{2}$$

where the prime refers to the beach volume after a change of sea-level.

For the idealized beach represented in Fig. 1, the volume can be defined knowing the berm width (xB), the berm height (zB), the shore platform slope (α) and the beachface slope (β). Using simple geometrical considerations, and considering that the elevation of the landward limit of the shore platform is the origin of the z axis ($zP = 0$), an analytical

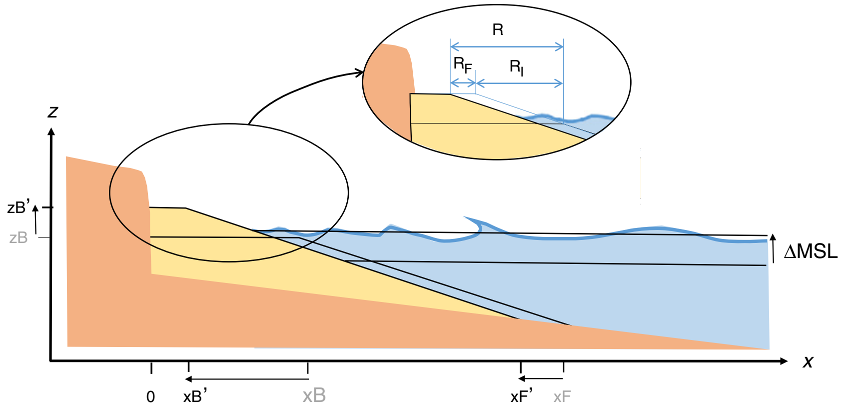

Fig. 2. Schematic representation of the platform beach profile response to sea-level rise (ΔMSL). Dashed lines and gray letters represent reference conditions; R is the berm crest retreat which results from a beachface retreat (R_F) and an inundation related retreat (R_I).