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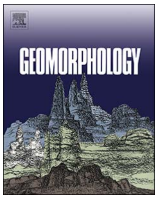

Chasing boundaries and cascade effects in a coupled barrier-marsh-lagoon system

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ABSTRACT

The long-term dynamic evolution of an idealized barrier-marsh-lagoon system experiencing sea-level rise is studied by coupling two existing numerical models. The barrier model accounts for the interaction between shoreface dynamics and overwash flux, which allows the occurrence of barrier drowning. The marsh-lagoon model includes both a backbarrier marsh and an interior marsh, and accounts for the modification of the wave regime associated with changes in lagoon width and depth. Overwash, the key process that connects the barrier shoreface with the marsh-lagoon ecosystems, is formulated to account for the role of the backbarrier marsh. Model results show that a number of factors that are not typically associated with the dynamics of coastal barriers can enhance the rate of overwash-driven landward migration by increasing backbarrier accommodation space. For instance, lagoon deepening could be triggered by marsh edge retreat and consequent export of fine sediment via tidal dispersion, as well as by an expansion of inland marshes and consequent increase in accommodation space to be filled in with sediment. A deeper lagoon results in a larger fraction of sediment overwash being subaqueous, which coupled with a slow shoreface response sending sediment onshore can trigger barrier drowning. We therefore conclude that the supply of fine sediments to the back-barrier and the dynamics of both the interior and backbarrier marsh can be essential for maintaining the barrier system under elevated rates of sea-level rise. Our results highlight the importance of considering barriers and their associated backbarriers as part of an integrated system in which sediment is exchanged.

1. Introduction

Low-lying coasts are often characterized by barrier islands, km-wide stretches of sand separated from the mainland by marshes and lagoons. Barriers commonly serve as buffer zones between the coastal ocean and mainland human population centers and infrastructure, protecting these communities from the most devastating coastal impacts of climate change. Barriers themselves are also some of the most popular tourist and recreational destinations in the US, and constitute some of the most valuable real estate in the country (Heinz-Center, 2000; Morton, 2008). Furthermore, barriers support biodiversity (McLachlan, 1983), provide a range of ecosystem services (Barbier et al., 2010), and protect wetlands that, in turn, support their own diverse ecologies (Day et al., 2008).

Despite the economic and ecological importance of barriers, and their extensive presence along the US East and Gulf coasts, there exists a critical gap in understanding how barrier systems respond to coastal change. In particular, there is a poor understanding of the complex barrier-backbarrier interactions, which results in landward migration rates unprecedented in thousands of years (FitzGerald et al., 2008). In order to fill this gap we build an exploratory numerical model (Murray, 2003) to examine the morphological feedbacks within a barrier-marsh-lagoon system and predict its evolution under projected rates of sea-level rise and sediment supply to the backbarrier environment.

Our starting point is a recently developed morphodynamic model (Lorenzo-Trueba and Ashton, 2014) that couples shoreface evolution and overwash processes in a dynamic framework. As such, the model is able to capture dynamics not reproduced by morphokinematic models, which advect geometries without specific concern to processes. These dynamics include periodic barrier retreat due to time lags in the shoreface response to barrier overwash, height drowning due to insufficient overwash flux as sea level rises, and width drowning, which occurs when the shoreface response rate is insufficient to maintain the barrier geometry during overwash-driven landward migration. The model, however, does not incorporate dynamic processes landward of the barrier, such as erosion and accumulation of

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peat and lagoonal sediments, which influence the space available for sediment to accumulate behind the barrier and hence control the island migration rate that is triggered by sea-level rise (Bruun, 1988).

The two-way interactions between backbarrier marsh and barrier have been recently explored with GEOMBEST + (Walters et al., 2014; Brenner et al., 2015), a modified version of the GEOMBEST model (Stolper et al., 2005; Moore et al., 2010). The study highlighted how the backbarrier marsh can slow down the island migration rate by reducing the space available for sediment to fill, and that overwash facilitates the persistence of a stable backbarrier marsh. Additionally, coupling field observations with GEOMBEST + suggests that sediment overwash allows a narrow marsh to be maintained in a long-lasting alternate state within a range of conditions under which they would otherwise disappear (Walters et al., 2014). Here we propose to further investigate the evolution of barrier and backbarrier environments by coupling a morphodynamic barrier model (Lorenzo-Trueba and Ashton, 2014) with a dynamic model for the evolution of the marsh platform and the marsh boundary with the adjacent lagoon. In particular, we have extended a model developed by Mariotti and Carr (2014) to include both a backbarrier and an interior marsh, and modified the barrier overwash flux to account for the presence of a backbarrier marsh. The resulting model represents a cross-section that spans from the toe of the shoreface to the point where the marshes encroach the mainland, that is, the upper limit of the marine influence (Fig. 1). This modeling framework allows us to explore new feedbacks between barrier and their backbarrier ecosystems that have not been tackled before.

2. Coupled model description

Our model approach assumes an idealized cross-section (Fig. 1) that connects the shoreface, the barrier, and the backbarrier. The backbarrier, defined here as the region between the barrier and the upper limit of the marine influence, includes three units: a backbarrier marsh (or rear fringing marsh), a lagoon, and an inland marsh. The barrier model component accounts for the interaction between shoreface dynamics and overwash flux, and the marsh-lagoon component explicitly describes marsh edge processes of both the backbarrier marsh and the interior marsh, and accounts for the modification of the wave regime associated with lagoon width, which coincides with the wave fetch.

2.1. Barrier dynamics

Our model focuses on two primary barrier system components or behavioral elements: the marine domain represented by the active shoreface, and the backbarrier environment, where the infrequent process of overwash controls landward mass fluxes. As described in Lorenzo-Trueba and Ashton (2014), the evolution of the barrier system can be fully determined with the rates of migration of the shoreface toe $\dot{x}_T = dx_T/dt$, the shoreline $\dot{x}_S = dx_S/dt$, the landward end of the subaerial portion of the barrier $\dot{x}_B = dx_B/dt$, and the change of the barrier height $\dot{H} = dH/dt$ (Fig. 1). These rates can be written in terms of the sediment flux at the shoreface Q_{SF}, the sea-level rise rate $\dot{z}$, the total overwash flux Q_{OW}, the top-barrier overwash component $Q_{OW,H}$ and the backbarrier overwash component $Q_{OW,Bm}$ (Figs. 1 and 3):

$$\dot{x}_T = 4Q_{SF}\frac{H + D_T}{D_T(2H + D_T)} + \frac{2\dot{z}}{\alpha} \tag{1}$$

$$\dot{x}_S = \frac{2Q_{OW}}{2H + D_T} - 4Q_{SF}\frac{H + D_T}{(2H + D_T)^2} \tag{2}$$

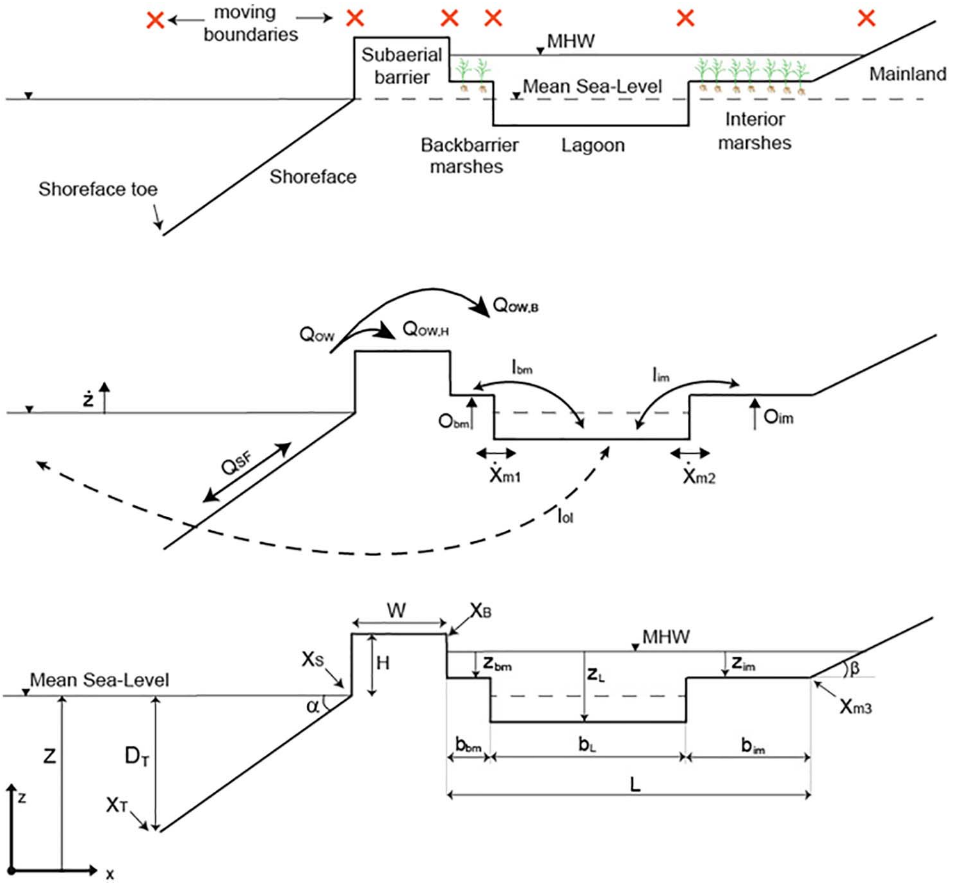

Fig. 1. Cross-shore barrier-marsh-lagoon-marsh-mainland model set up, including (a) the different geomorphic domains and their moving boundaries, (b) key processes that drive the evolution of the moving boundaries, (c) state variables. This is the general cross-section of the system, but note that the model can also account for scenarios in which backbarrier and/or inland marshes completely disappear (i.e., $b_{bm} = 0$ and/or $b_{im} = 0$).