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Alongshore variation in the morphology of coastal dunes: Implications for storm response

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A R T I C L E I N F O

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The geomorphological impact of an extreme storm on a barrier island tends to be modeled using a single cross-shore transect and dependent only on the elevation of the storm surge relative to the height of the dune. The foredune line, however, is rarely uniform and can exhibit considerable variation in height and width alongshore at a range of length scales. The purpose of this modeling study is to determine how alongshore variations in dune height affect barrier island response to extreme storms. The MIKE21 wave and current model is used to predict the morphological response of Matagorda Peninsula, Texas in response to storm surges associated with dune scarping, washover and inundation. The extent and degree of dune-scarping, washover and shoreline erosion is predicted for each storm scenario, with respect to the base morphology of the island and low-pass filtered forms in which small-scale topographic variance is removed. Results suggest that small variations in the height of an otherwise alongshore uniform foredune act as overwash conduits and are unstable, leading to a more variable duneline that is more susceptible to change by subsequent storms. The vertical development of the washover gaps in the duneline is limited and eventually replaced by a lateral expansion that erodes adjacent dunes and leads to a more uniform island elevation. The loss of island elevation is greater for the (original) unfiltered alongshore profile, but relatively uniform duneline is the most unstable and exhibits the greatest morphological change. The different alongshore profile responses suggest that the impact of an extreme storm is sensitive to initial conditions and specifically the pre-storm variability of the crest elevation alongshore. This in turn suggests that the evolution of barrier islands is dependent on storm history until the variability in the duneline elevation reaches a maximum. Further study of barrier island response to storm sequencing with and without post-storm recovery, however, is required to understand the evolution and form for the prototype island.

1. Introduction

The response of a barrier island to an extreme storm depends on the elevation of the storm surge relative to the elevation of the backshore and dune (Sallenger, 2000; Morton et al., 2003). Elevated water levels allow storm waves to erode the backshore and scarp the dune, until such time that either the surge exceeds the height of the dune or it is breached. Erosion of the dune leads to episodic slumping and the redistribution of that sediment either offshore or alongshore, depending on the incident wave and current forcing (e.g. Pye and Blott, 2008; Van Thiel de Vries et al., 2008; Kobayashi et al., 2009; Esteves et al., 2011). As gaps in the dune are breached and the berm crest is exceeded, sediment is transported landward as overwash and deposited in the form of washover fans and potentially terraces if dune breaching is more extensive alongshore (Morton et al., 2000; Sallenger, 2000; Donnelly et al., 2006). The extent and distribution of washover also depends on the duration and approach of the storm (Penland and Suter, 1984), the backbeach morphology, vegetation, and wind strength and direction (Donnelly et al., 2006). The frequency and extent of washover controls the rate of island transgression (see Dolan and Godfrey, 1973; Schwartz, 1975; Byrnes and Gingerich, 1987), and helps to maintain island width and volume in that landward migration (e.g. Godfrey and Godfrey, 1973; Hosier and Cleary, 1977). Overwash causes extensive damage to coastal infrastructure (Bureau of Beaches and Coastal Systems, 2004; Houser, 2009) and loss of life (Donnelly et al., 2006), particularly when it leads to breaching (Stauble, 2001; Kraus et al., 2002; Kraus and Wamsley, 2003). At the same time, washover contributes to ecologically important ecosystems along backbarrier shorelines (Godfrey and Godfrey, 1973), and provides habitat for endangered species, such as piping plover (*Charadrius melodus*).

The impact of a tropical storm or hurricane tends to be modeled as a one-dimensional cross-shore phenomenon in which the storm impact depends on the height of the storm surge relative to the elevation of the dune crest (e.g. Sallenger, 2000; van Rijn, 2009). The foredune is not uniform and can exhibit considerable variability, however, in height, volume and alongshore extent (e.g. Thieler and Young, 1991; Houser et al., 2008; Houser and Mathew, 2011). The exact location of dune erosion and overwash penetration depends on the correspondence of alongshore variations in the incident forcing and existing gaps and low lying

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areas along the duneline (Dolan and Hayden, 1981; Suter et al., 1982; Orford and Carter, 1984). Alongshore variation in the elevation of the dune toe and crest can be used as a simple predictor of overwash susceptibility, and most of the United States coastline has now been categorized using the Sallenger (2000) storm impact scale based on estimated surge and run-up heights (e.g. Wetzell, 2003). The alongshore periodicity of overwash penetration ranges from kilometers (Dolan and Hayden, 1981; Wetzell, 2003; Houser et al., 2008) to tens of meters (Orford and Carter, 1984), and in each case a significant correlation occurs between past overwash history and future susceptibility (Cleary and Hosier, 1979). In this respect, the alongshore variation in dune morphology is reinforced by each successive overwash. The strength of the overwash current through these gaps depends, in part, on the gradient of the water level between the ocean and bay as well as the amount to which the flow is constricted through existing gaps. As shown by Suter et al. (1982), the gradient of the water level across South Padre Island during Hurricane Allen (1980) forced a gravity-driven current of ~0.5 m s^{-1} that was amplified to 2 m s^{-1} when the flow was constricted. Peak flow velocities of between 2.4 m s^{-1} and 3.5 m s^{-1} have been measured at Assateague Island by Fisher et al. (1974) and Fisher and Stauble (1977), respectively. Flow convergence through the dune gaps creates a strong turbulent flow that deepens the throat (Carter and Orford, 1981), and also can laterally erode adjacent dunes and widen and reinforce the gap (Houser et al., 2008; Pries et al., 2008).

Alongshore variations in the duneline not only reflect the overwash history, and also alongshore variations in transport potential and supply for dune growth (White, 1987; Hesp, 2002; Houser et al., 2008), and the development of blowouts (Hesp, 2002). Growing evidence exists that storm disturbance and gradients responsible for dune growth are interdependent and that the alongshore variation in dune height is a reinforced and repeatable pattern (Reice, 1994; Stallins and Parker, 2003; Houser et al., 2008). As discussed by Stallins and Parker (2003), the longshore variation in dune morphology (in North Carolina and Georgia) is part of a complex biogeographic feedback in which vegetation reinforces disturbance patterns. Disturbance by overwash promotes the development of horizontally extensive rhizomes, which in

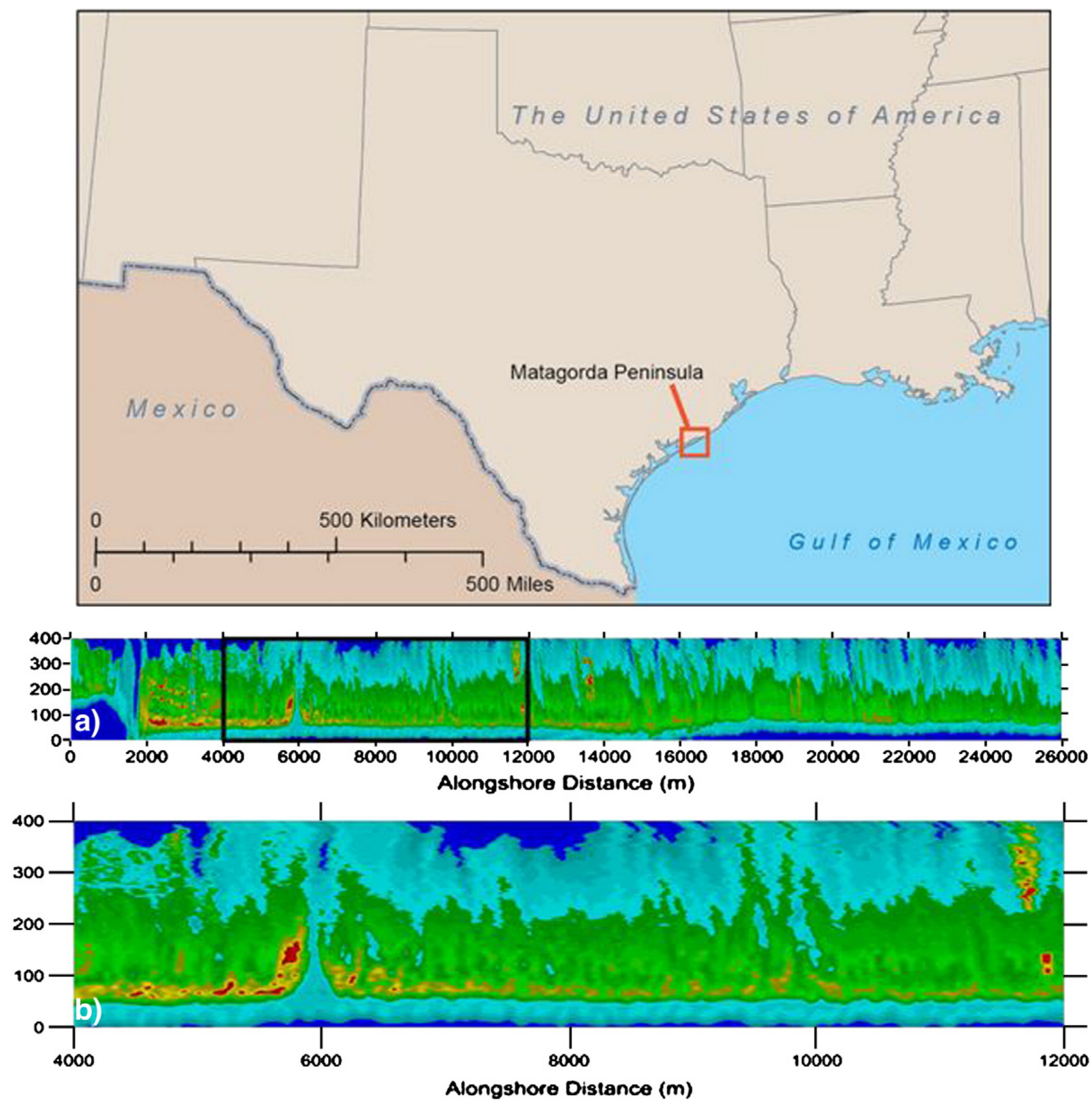

Fig. 1. (a) Location of Matagorda Peninsula, a low-lying and narrow transgressive barrier spit that separates Matagorda Bay from the Gulf of Mexico along the northeast coast of Texas. Also shown is (b) the LiDAR surface for the entire length of Matagorda Peninsula and (c) the LiDAR surface for the modeling area.