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The potential for sea-level-rise-induced barrier island loss: Insights from the Chandeleur Islands, Louisiana, USA

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ABSTRACT

As sea level rises and hurricanes become more intense, barrier islands around the world become increasingly vulnerable to conversion from self-sustaining migrating landforms to submerging or subaqueous sand bodies. To explore the mechanism by which such state changes occur and to assess the factors leading to island disintegration, we develop a suite of numerical simulations for the Chandeleur Islands in Louisiana, U.S.A., which appear to be on the verge of this transition. Our results suggest that the Chandeleurs are likely poised to change state, leading to their demise, within decades depending on future storm history. Contributing factors include high rates of relative sea level rise, limited sediment supply, muddy substrate, current island position relative to former Mississippi River distributary channels, and the effects of changes in island morphology on sediment transport pathways. Although deltaic barrier islands are most sensitive to disintegration because of their muddy substrate, the importance of relative sea level rise rate in determining the timing of threshold crossing suggests that the conceptual models for deltaic barrier island formation and disintegration may apply more broadly in the future.

1. Introduction

Barrier islands are found on every continent except Antarctica and represent twelve percent of the world's coastline. As low-lying features, these landforms are dynamic over a range of temporal and spatial scales, and they are vulnerable to changing conditions. As sea level rises, storm activity increases or sediment-supply rates decrease, a barrier island will respond by migrating landward across the underlying substrate to higher elevations or by drowning and transforming into a subaqueous shoal (e.g., Penland et al., 1988) if there is no longer sufficient sand volume and relief above sea level to prevent repeated inundation during storms.

The conversion of landward migrating deltaic barrier islands into inner-shelf shoals is a well-recognized geomorphic threshold crossing, or state change — Penland et al. (1988) describe three different progressive states for islands that form at the edge of delta lobes: 1) barrier attached to an erosional headland, 2) transgressive barrier island arc and 3) inner-shelf shoal. Trinity Shoal, Outer Shoal and Ship Shoal, west of the modern Mississippi River delta, are examples of the transition from the second state to the third state (Penland et al., 1988). Given future predictions of accelerating sea level rise (e.g., IPCC, 2007) and increases in hurricane intensity (e.g., Knutson et al., 2010), the transition from landward-migrating barrier to inner-shelf shoal may no longer be restricted to sand-starved deltaic barrier islands.

To better understand the transition, we use the Chandeleur Islands in southeastern Louisiana U.S.A. — where changes have been occurring recently — and a modeling approach to suggest a mechanism for the island–shoal transition and to assess the likely timing of, and factors most influencing, island loss. To do this we develop a suite of model simulations to explore a comprehensive range of empirically-based geologic constraints and input parameters. Based on our testing of different combinations of these constraints and parameters we develop a "most-plausible" simulation, which we use to simulate barrier island behavior. From this simulation, we produce threshold crossing estimates that are most likely (of the simulations presented here) to represent future conditions. To account for uncertainties in parameter estimates, we use six additional simulations to consider the broader range of barrier island behavior that may occur. By carrying out additional simulations, we are also able to assess which factors are likely to be most important in determining the timing of threshold crossing.

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Previous work on this topic considered the evolution of subaerial morphology using aerial photo and subaerial lidar surveys (e.g., Sallenger et al., 2009). In a complimentary effort, here we model recent change in the context of longer-term evolution, and account for erosion of the entire shoreface profile and removal of sand through alongshore and cross-shore transport. As a result of our analysis, we also constrain the range of possible values for geologic variables important to the evolution of the Chandeleur Islands, allowing us to present a plausible scenario for past and potential future evolution of the northern portion of the barrier system.

1.1. Study area

The Chandeleur Islands (80 km-long, and north–south trending) (Fig. 1), formed near the distal end of the St. Bernard Delta lobe following abandonment by the Mississippi River approximately 2000 years ago (e.g., Penland et al., 1985; Twichell et al., 2009b). At present, North Chandeleur Island comprises the northern two-thirds of the island system while the southern one-third consists primarily of smaller, even more dynamic islands. Estimates of average relative sea level rise rates (RSLRRs) in the region vary from a late Holocene

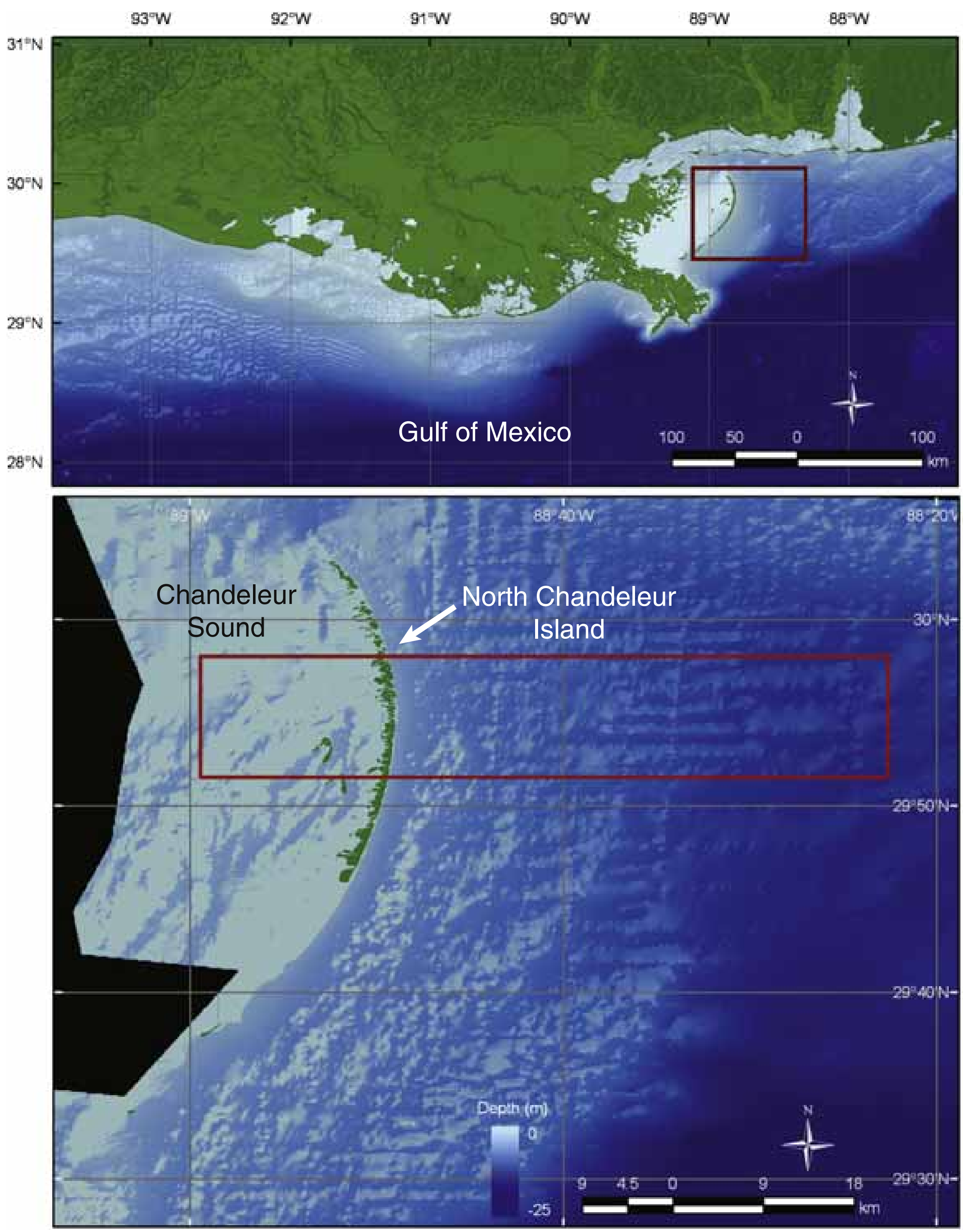

Fig. 1. The Louisiana–Mississippi Coastline (upper panel), Chandeleur Islands outlined in red. Close up of the Chandeleur Islands (lower panel) with the North Chandeleur Island study area outlined in red (bathymetry is from Miner et al. (2008) and topography from NOAA 1:80K medium resolution shoreline) (chart 11363. rev. Nov. 1991).