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Impacts of historic morphology and sea level rise on tidal hydrodynamics in a microtidal estuary (Grand Bay, Mississippi)

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ABSTRACT

This study evaluates the geophysical influence of the combined effects of historic sea level rise (SLR) and morphology on tidal hydrodynamics in the Grand Bay estuary, located in the Mississippi Sound. Since 1848, the landscape of the Mississippi Sound has been significantly altered as a result of natural and anthropogenic factors including the migration of the offshore Mississippi–Alabama (MSAL) barrier islands and the construction of navigational channels. As a result, the Grand Bay estuary has undergone extensive erosion resulting in the submergence of its protective barrier island, Grand Batture. A large-domain hydrodynamic model was used to simulate present (circa 2005) and past conditions (circa 1848, 1917, and 1960) with unique sea levels, bathymetry, topography and shorelines representative of each time period. Additionally, a hypothetical scenario was performed in which Grand Batture Island exists under 2005 conditions in order to observe the influence of the island on tidal hydrodynamics within the Grand Bay estuary. Changes in tidal amplitudes from the historic conditions varied. Within the Sound, tidal amplitudes were unaltered due to the open exposed shoreline; however, in semi-enclosed embayments outside of the Sound, tidal amplitudes increased. In addition, harmonic constituent phases were slower historically. The position of the MSAL barrier island inlets influenced tidal currents within the Sound; the westward migration of Petit Bois Island allowed stronger tidal velocities to be centered on the Grand Batture Island. Maximum tidal velocities within the Grand Bay estuary were 5 cm/s faster historically, and reversed from being flood dominant in 1848 to ebb dominant in 2005. If the Grand Batture Island was reconstructed under 2005 conditions, tidal amplitudes and phases would not be altered, indicating that the offshore MSAL barrier islands and SLR have a greater influence on these tidal parameters within the estuary. However, maximum tidal velocities would increase by as much as 5 cm/s (63%) and currents would become more ebb dominant. Results of this study illustrate the hydrodynamic response of the system to SLR and the changing landscape, and provide insight into potential future changes under SLR and barrier island evolution.

1. Introduction

SLR has the potential to alter astronomic tidal hydrodynamics by increasing tidal ranges, tidal prisms and inundation, as well as changing current velocities and circulation patterns (French, 2008; Leorri et al., 2011; Hall et al., 2013; Valentim et al., 2013). Within estuaries, tidal asymmetries and resulting sediment transport patterns may be fundamentally altered if rising seas increase channel depths or alter the volume of water stored in the intertidal zone (Friedrichs et al., 1990). In addition, changes in coastal topography can influence the hydrodynamic response under SLR (Bilskie et al., 2014; Passeri et al., 2015). Changes in tidal hydrodynamics have important implications for navigation, fisheries, coastal flooding, and the evolution of the coastline. However, the complexities in coastal processes make determining the future impacts of SLR and coastal topography a difficult task. Evaluating historic changes in hydrodynamics under a changing landscape coupled with SLR can provide insight as to how water levels and currents may change in the future.

The marine dominant Grand Bay estuary is one of the few remaining coastal marsh environments in Mississippi. Over the past century, the estuary has undergone natural and anthropogenic induced landscape changes including the diversion of the estuary's sediment source and the erosion of its protective barrier island, Grand Batture. As a result, Grand Bay's marshes are being eroded

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away faster than any other marsh in the state (Mississippi Department of Marine Resources, 1999). The fate of the estuary depends on scientifically informed managerial decisions regarding factors such as SLR and changes in coastal morphology. This research examines the geophysical influence of SLR and historic morphology on tidal hydrodynamics. A high resolution large-domain hydrodynamic model was used to simulate present (circa 2005) and past conditions (circa 1848, 1917, and 1960) with unique sea levels, bathymetry, topography and shorelines that represent the conditions at those times. Additionally, a hypothetical scenario was performed in which Grand Batture Island exists under 2005 conditions to observe the influence of the island on tidal hydrodynamics. Changes in variables such as harmonic constituent amplitudes, phases and current velocities were examined. Comparison of past and present conditions illustrates the tidal hydrodynamic response of the system to SLR and the changing landscape. This yields a better understanding of the function of coastal morphology and the role of SLR on tidal hydrodynamics, while providing insight into potential future changes.

2. Study domain

The Grand Bay estuary is located within the Mississippi Sound at the MSAL border in the northern Gulf of Mexico (Fig. 1). The estuary is comprised of two bays (Point aux Chenes Bay and Grand Bay), bayous, and marsh shorelines. The bays are shallow with average water depths ranging from 0.5 m to 1.8 m, and up to 3.0 m at the tidally scoured entrance to Point aux Chenes Bay (Peterson et al., 2007). The estuary supports recreational and commercial fisheries with an abundance of marine life including shrimp, crabs and oysters (Eleuterius and Criss, 1991). This portion of the Gulf of Mexico is a diurnal, microtidal environment. The offshore MSAL barrier islands (namely Cat Island, Ship Island, Horn Island, Petit Bois Island and Dauphin Island) define the boundary between the Mississippi Sound and the Gulf of Mexico. Three of the barrier island inlets have been modified and connected to mainland ports via navigation channels: Mobile Ship Channel at the inlet to Mobile Bay, Pascagoula Channel at Horn Island Pass, and Gulfport Ship Channel at Ship Island Pass. In addition, the dredged Gulf Intracoastal Water Way (GIWW) navigation channel extends east to west through the Mississippi Sound.

Historically, the Escatawpa River flowed south–southeast and emptied into the Mississippi Sound at Grand Bay, creating a delta that encompassed the entire estuary and was sheltered by Dauphin Island. At this time, erosion was limited due to weak tidal and wave forces within the Sound, and was typically counteracted by sediment deposited by the Escatawpa River. However, prior to 1848 (exact time unknown) the river diverted its course and became a tributary of the Pascagoula River, which terminated the direct sediment supply to Grand Bay (Eleuterius and Criss, 1991). During the period of 1740–1766, a hurricane bisected Dauphin Island, creating an inlet and a new island called Petit Bois (Otvos, 1979). By 1848, waves and currents in Grand Bay had shaped deposited deltaic sediments into the Grand Batture Island, an elongated barrier island that sheltered the estuary from northerly directed waves (Eleuterius and Criss, 1991). Dredging of the navigation channels began in the mid-1800s. By 1857, the Mobile Ship Channel was in place; as early as 1880, construction began on the Pascagoula Channel, and in 1899, the Ship Island Pass began.

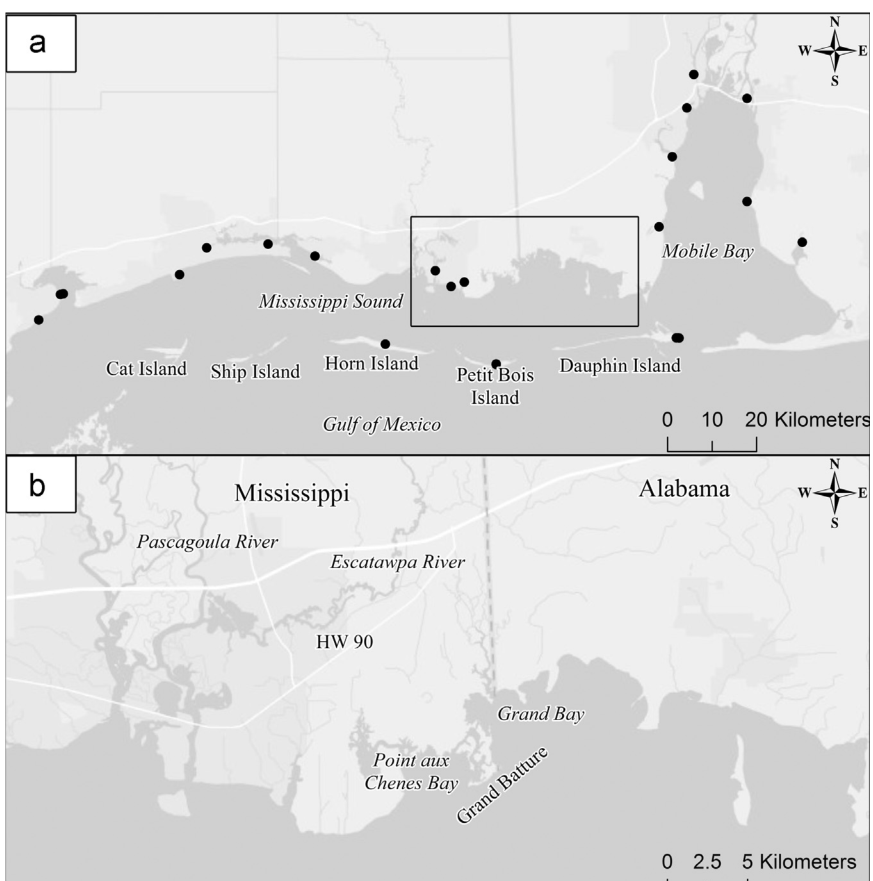

Fig. 1. (a) Present day Mississippi Sound study area; (b) zoomed in inset of Grand Bay estuary; black dots indicate locations of NOAA gauge stations used for model validation.