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# Modeling hurricane-induced wetland-bay and bay-shelf sediment fluxes

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ABSTRACT

Hurricanes have long been recognized as a strong forcing in shaping the coastal morphology, especially by redistributing sediments among coastal wetlands, bays and inner continental shelves. However, the contribution of hurricane-induced sediment transport to the sediment budget of a shelf – bay – wetland system has not been evaluated using a physics-based numerical model. There is a particular confusion on how sediment transport to coastal wetlands contributes to sediment accretion in wetlands and thus wetland adaptation to sea level rise. In this paper, we present a coupled modeling system for hurricane winds, storm surge, waves and sediment transport on the Louisiana coast, and use it to investigate two fundamental questions: (1) How much sediment is transported and deposited on coastal wetlands during a major hurricane event like Hurricane Gustav (2008), and (2) where is the source of the deposited sediment on the wetland soil surface. Our model successfully reproduced the measured basin-averaged sediment accretion in the Terrebonne and Barataria Basins after Gustav, and estimated that Hurricane Gustav imported approximately 27 million metric tons of sediment on wetlands in that area. The estimated deposition was mainly made up of mud suspended from the coastal bays, and the contribution of this sediment to wetland deposition was 88.7% in Terrebonne Bay and 98.2% in Barataria Bay within the tested range of sediment properties. This paper demonstrates a useful tool to help understand how sediment dynamics in the coastal zone during hurricane events play a significant role in the sediment budget of a deltaic coast.

## 1. Introduction

The Mississippi River Delta Plain (MRDP) has the largest area of coastal wetlands in the contiguous United States, which serves multiple ecosystem functions including reduction of surge and waves during extreme events, habitat for fisheries and wildlife, and a valuable economic resource for agriculture and industry. It is widely recognized that intense hurricanes play a key role in shaping the morphology of coastal wetlands by redistributing a significant amount of sediment. Sediment accretion has been observed on the marsh surface after hurricanes and storms, and these processes are significant to maintaining marsh elevation relative to sea level rise and subsidence (Morgan et al., 1958; Chamberlain, 1959; Roberts et al., 1987; Rejmánek et al., 1988; Reed, 1989; Nyman et al., 1995; Cahoon et al., 1995; Turner et al., 2006; McKee and Cherry, 2009). On the other hand, hurricanes may have negative effects by eroding the edge of marshes and expanding the existing ponds and small lakes (McGee et al., 2006; Morton and Barras, 2011). There is a debate on the net effect of hurricanes on coastal morphodynamics. In order to understand the effects of hurricane on the large-scale sediment budget of a coastal system, it is necessary to identify the major source of sediment deposition on coastal wetlands and sediment fluxes across land and sea boundaries.

Considerable effort has been devoted to quantifying the contribution of hurricane-induced sedimentation. Turner et al. (2006). estimated that Hurricane Katrina and Rita brought in 131 million metric tons (MMT) of mineral material to the MRDP. Tweel and Turner (2012) developed a statistical model based on the sediment deposition data observed from Hurricanes Katrina (2005), Rita (2005) and Gustav (2008), and estimated that the annual deposition on the marsh surface from category 1 or higher hurricanes was 5.6 MMT. By chronostratigraphic assessment of 27 cores taken within the Breton Sound Basin, Smith et al. (2015). suggested the annual sediment accumulation caused by category 3 or higher

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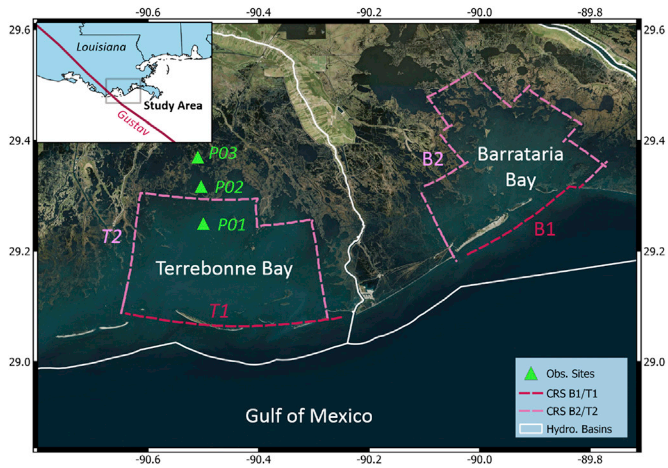


**Fig. 1.** Terrebonne Bay and Barataria Bay. P01/P02/P03 are the locations of model output points, T1&T2 are the cross sections in Terrebonne Bay, and B1&B2 are the cross sections in Barataria Bay.

hurricanes was only about 0.05 MMT in that area. Besides the large discrepancy between the existing estimates based on different methods, some obvious limitations exist in the above-mentioned studies: Firstly, the spatial distribution of sediment deposition in wetlands was predicted using a limited number of coring or sampling stations, and thus the effects of local bathymetry and man-made structures on sediment redistribution were not taken into account. Secondly, sediment deposition in the interior of wetlands is often associated with both local erosion and deposition, while most measurements didn't include the temporal variation of the marsh surface elevation and thus could not reproduce the erosional history of a storm event.

The source of sediment deposited in marshes during storm events includes onshore transport of marine material originating from the inner continental shelf or redistribution of local sediment in bays and estuaries of MRDP. These two sources imply different mechanisms of sediment balance and could lead to different wetland restoration strategies. A plausible hypothesis is that most deposition originates from the shallow lakes and open bays, where relatively large waves suspend sediment and the surge water moves suspended materials to the marsh surface (Chamberlain, 1959; Roberts et al., 1987; Rejmánek et al., 1988; Reed, 1989). There are few techniques available to identify the pathway of sediment transport in a typical coastal environment during an extreme event and test the dependency of these sources on sediment properties, vegetation coverage, and other local environmental factors.

Numerical models have been applied to simulate large-scale hydrodynamics, sediment transport and morphological changes for MRDP under hurricane conditions (Freeman et al., 2015; Warner et al., 2017; Xu et al., 2015; Yamashita et al., 2016). For instance, the seabed erosion and deposition on the Louisiana-Texas continental shelf after Hurricane Katrina and Rita were studied using a three-dimensional sediment transport model based on the Regional Ocean Modeling System (ROMS) (Xu et al., 2015), and the spatial pattern of sediment accretion and erosion at Sister Lake during Hurricane Rita was simulated using MIKE21/MIKE 3 (Freeman et al., 2015). However, little has been done to model the sediment transport and morphological processes in the entire coastal system, including the continental shelf, bays, lakes, and wetlands, and to quantify the sediment exchange at shelf-bay and bay-wetland borders. In the present study, we utilize a coupled modeling system based on Delft3D, including wind, surge, waves and sediment processes for the Louisiana coast (Liu et al., 2015). We apply the model to study the short-term impact of a hurricane on sediment dynamics in coastal wetlands with the following specific objectives: (1) estimate net sediment deposition in the coastal wetlands during a major hurricane event, (2) identify the major source of deposited sediment on the wetland surface, and (3) develop sediment budgets of coastal basins as result of cyclone effects on sediment redistribution. This paper is organized as follows. The study area, model setting and measurement data are described in section 2. The modeled hydrodynamic forcing during Hurricane Gustav is validated against measurements in section 3.1. The morphodynamics and a comparison with the measured post-hurricane accretion are presented in section 3.2. The hurricane-induced sediment flux, the deposition in coastal wetlands and the sediment balance in the coastal bays are analyzed in Section 3.3 and 3.4. A discussion about the model sensitivity and uncertainty is given in section 4. A summary of our findings is presented in section 5.

## 2. Methods

### 2.1. Study area and Hurricane Gustav

Our study area is the wetland-bay-shelf system of Terrebonne and Barataria Basins in the MRDP. The Terrebonne and Barataria Basins are located in south Louisiana, between the Mississippi River and the Atchafalaya River, open to the Gulf of Mexico to the south (Fig. 1). This region encompasses 1243 square kilometers of swamp and 4221 square kilometers of marshes, grading from fresh water marsh inland to brackish and salt marshes near the bays and the gulf. Severe marsh erosion and land loss occurred in these two coastal basins from 1932 to 2010 at 1092 square kilometers in Barataria and 1191 square kilometers in Terrebonne (Couvillion et al., 2011).

This region was impacted by multiple major hurricanes in the last decade, including Katrina and Rita in 2005, Gustav and Ike in 2008 and Isaac in 2012. In this paper, we chose Hurricane Gustav as an example because the availability of a large number of field observations following this storm. Hurricane Gustav (2008) was the first major hurricane tracking through the southeast Louisiana after Katrina (2005). Although Gustav was a category 2 hurricane when it made landfall on 1 September 2008, much weaker than Katrina, its size increased as it approached the Louisiana coast. The tropical-storm-strength winds impacted this region for 12–15 h and generated significant storm surge along the Louisiana coast.

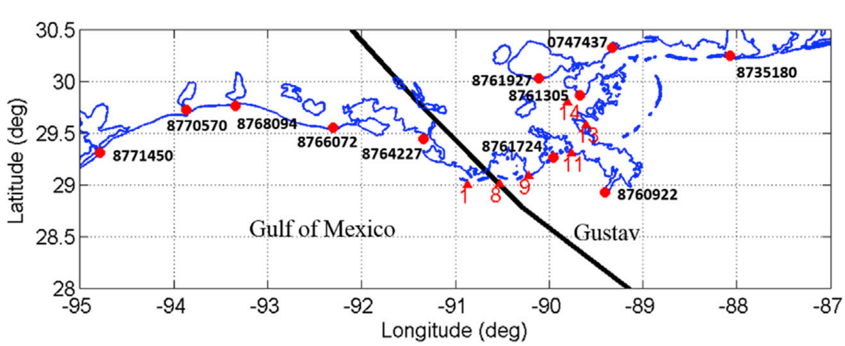


**Fig. 2.** The locations of NOAA tide stations (red dots) and wave gauges by Kennedy et al. (2010). (red triangles). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)