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Case study

Shelf sediment transport during hurricanes Katrina and Rita

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ABSTRACT

Hurricanes can greatly modify the sedimentary record, but our coastal scientific community has rather limited capability to predict hurricane-induced sediment deposition. A three-dimensional sediment transport model was developed in the Regional Ocean Modeling System (ROMS) to study seabed erosion and deposition on the Louisiana shelf in response to Hurricanes Katrina and Rita in the year 2005. Sensitivity tests were performed on both erosional and depositional processes for a wide range of erosional rates and settling velocities, and uncertainty analysis was done on critical shear stresses using the polynomial chaos approximation method. A total of 22 model runs were performed in sensitivity and uncertainty tests. Estimated maximum erosional depths were sensitive to the inputs, but horizontal erosional patterns seemed to be controlled mainly by hurricane tracks, wave–current combined shear stresses, seabed grain sizes, and shelf bathymetry. During the passage of two hurricanes, local resuspension and deposition dominated the sediment transport mechanisms. Hurricane Katrina followed a shelf-perpendicular track before making landfall and its energy dissipated rapidly within about 48 h along the eastern Louisiana coast. In contrast, Hurricane Rita followed a more shelf-oblique track and disturbed the seabed extensively during its 84-h passage from the Alabama–Mississippi border to the Louisiana–Texas border. Conditions to either side of Hurricane Rita's storm track differed substantially, with the region to the east having stronger winds, taller waves and thus deeper erosions. This study indicated that major hurricanes can disturb the shelf at centimeter to meter levels. Each of these two hurricanes suspended seabed sediment mass that far exceeded the annual sediment inputs from the Mississippi and Atchafalaya Rivers, but the net transport from shelves to estuaries is yet to be determined. Future studies should focus on the modeling of sediment exchange between estuaries and shelves and the field measurement of erosional rates and settling velocities.

1. Introduction

Episodic events, such as river floods and hurricanes, happen over a relatively short period of time (hours to weeks), but can greatly modify the sedimentary record. However, our coastal scientific community has rather limited ability to predict the characteristics of strata produced by even well-observed modern-day events (Corbett et al., 2014). This is probably due to either the lack of field measurements or the damage of optical and acoustic sensors during energetic and extreme events.

It is well known that hurricanes drive energetic winds and generate currents and waves, both propagating toward the land. When the hurricanes reach continental shelves, seabed sediment is suspended to water column, causing the erosion on seabed. The seabed elevation difference between pre-hurricane level and the "deepest cut" is thus defined as "maximum erosional depth" (Fig. 1A), which is also called "bed scour" (Keen and Glenn, 2002). After making landfalls, hurricanes dissipate and sediment settles back to seabed or in coastal estuaries and wetlands. The seabed elevation difference between the deepest cut and post-hurricane level is thus defined as "post-hurricane deposit" (Fig. 1A and B). Net erosion/deposition is defined as the difference between pre- and post-hurricane levels. During the passage of hurricanes, some

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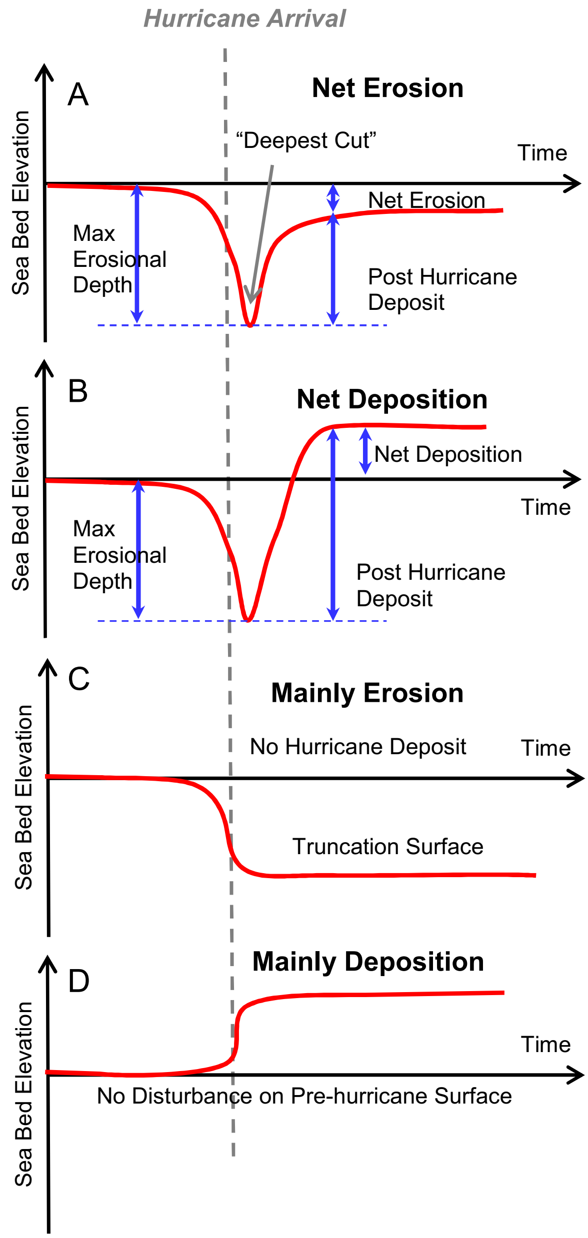

Fig. 1. Conceptual diagrams of four types of sea bed elevation changes during and after the arrival of a hurricane. Maximum erosional depth is defined as the change between pre-hurricane seabed surface and the "deepest cut" during the peak of a hurricane, and is also called bed scour. Post-hurricane deposition represents the difference between the sea bed elevation after the storm and the peak erosion during the storm. Net erosion or deposition represents the difference between the post-hurricane and pre-hurricane sea bed levels.

regions may experience erosion only (Fig. 1C), whereas other areas like costal bays/wetlands may have deposition only (Fig. 1D). Turner et al. (2006) reported that the major source of mineral sediment to Louisiana coastal marshes is from hurricanes, not river floods. Törnqvist et al. (2007), however, believed that there were an over-estimation of hurricane return periods and a lack of erosion measurements in the study of Turner et al. (2006). By now our coastal scientific community has not reached a consensus on sediment dynamics during hurricanes. No matter if rivers or hurricanes play a more important role in wetland sedimentation, it is the *net erosion/deposition* that actually impacts sediment budget, not the post-hurricane deposition, as shown in Fig. 1. Unfortunately it is well known that the erosional process is challenging to measure in sedimentary system. In some environments erosion can be measured using either the comparisons among repeated field surveys (e.g., Goff et al., 2010) or the numerical models (e.g., Xu et al., 2011).

In this study we focus on Louisiana continental shelf sediment transport during hurricanes. Hurricanes strike the Louisiana coast approximately once every three years, normally between May and November (Neumann et al., 1993). Based on an overview of hurricane impacts, Stone et al. (1997) found that hurricanes cause chronic erosion to Louisiana barrier systems, but sometime also generate considerable deposition in Louisiana's marshes and bays. They also reported that Hurricanes Audrey (1957) and Andrew (1992) formed 0.70 and 0.16 m of mixed organic and inorganic debris in Louisiana marsh areas, respectively. Goni et al. (2006) collected sediment samples in the inner shelf southwest of Atchafalaya Bay after Hurricane Lili (2002) and identified a storm layer up to 0.2 m thick; they also found fining-upward deposits to be composed of silty clays with a sandy basal layer. Keen and Glenn (2002) predicted bed scour on the continental shelf during Hurricane Andrew (1992) and simulated storm sedimentation on the sandy Ship Shoal (Fig. 2) of Louisiana shelf; they found that the bottom boundary layer was wave-dominated and bed scour was primarily by resuspension. Goff et al. (2010) found offshore sediment transport during Hurricane Ike (2008) and believed that shoreface sands appear to have been incised by the storm and advected offshore by the strong storm-surge ebb currents.

In this study we focus on Hurricanes Katrina and Rita, both of which happened in the year 2005. The economic and environmental damages caused by Katrina were over $40 billion of insured losses (Knabb et al., 2006). Hurricane Katrina formed as a tropical depression on August 23, 2005 over the Bahamas Islands. After passing the southern tip of Florida, it moved westward into the Gulf of Mexico where it gained strength to become a category five hurricane in August 28. Then it swept northward and made landfall on August 29 over the Mississippi River Delta (MRD) as a category four hurricane (http://www.csc.noaa.gov; Fig. 2). About three weeks later, Hurricane Rita formed as a tropical depression in the Caribbean Sea and headed westward into the Gulf of Mexico. On September 21 it became a category five hurricane and moved northwest toward the western Louisiana coastline, where it made landfall on September 24 at the Texas–Louisiana border as a category three hurricane (Fig. 2).

Multiple event-response studies have been performed in wetland, estuary and shelf areas after Hurricanes Katrina and Rita. Turner et al. (2006), for example, reported that more than 131 Million Tons (Mt) of post-hurricane sediment deposited in coastal wetlands when Hurricanes Katrina and Rita crossed the Louisiana coast; they identified several cm thick of sediment deposition on wetlands. Based on further data analyses, Tweel and Turner (2012) reported that sediment deposition on coastal wetlands was 68 and 48 Mt from Hurricanes Katrina and Rita, respectively. Using gain size, X-radiographs, and gamma-density data for sediment cores, Keen et al. (2006) found that Hurricane Katrina deposited a storm bed east of landfall on the Louisiana shelf with a maximum observed thickness of 0.58 m, which thinned to approximately 0.1 m about 200 km west of landfall; they also reported that the fining-upward bed is similar to event beds observed in both ancient and modern sedimentary environments. Based on a collaborative multi-institution rapid-response effort, Walsh et al. (2006) collected bathymetric and sediment core data in the MRD and reported the evidence of mud flow activities near the Mississippi subaqueous delta after two hurricanes. Goni et al. (2007) studied radionuclides, x-radiographs and stable isotopes by analyzing 1-cm thick slices in post-hurricane Katrina/Rita deposits and found that the post-hurricane layers was predominantly local sediments mobilized by the intense wave activity during the storms; they also believed that post-hurricane deposit thicknesses ranged