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Seabed erodibility variations on the Louisiana continental shelf before and after the 2011 Mississippi River flood

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ABSTRACT

Erodibility is critical to the sediment resuspension process but has not been measured systematically in large river-dominated muddy continental shelves before. During early summer of 2011, the Mississippi River experienced a major flood event. This flood provided a unique opportunity to examine how shelf seabed erodibility responded to a large river flood, and the ultimate fate of flood deposition is important to geological and biogeochemical processes (e.g., stratal formation, carbon sequestration).

A total of 106 sediment cores were collected on the Louisiana shelf during five cruises in 2010 and 2011, and a new dataset was used to evaluate the response of the seabed to the recent conditions. The localized flood deposit was mainly within tens of kilometers of river sources, and little sediment accumulated on the middle Louisiana shelf. Seabed erodibility was measured using a dual-core Gust Erosion Microcosm System. The erodibility of sediment collected in April 2011 exceeded that for August 2010 and August 2011. The springtime increase in erodibility seemed to be related to the recent presence of energetic waves that mobilized the seabed. Erodibility was highest on the inner shelf southwest of Atchafalaya Bay, intermediate on the middle shelf, lowest in the Mississippi Canyon, and highly variable on the Mississippi subaqueous delta. These spatial patterns were influenced by proximity to river sources, flood-deposit thicknesses, intensity of wave-driven bed stresses, and bioturbation. The flood-deposit thickness itself, however, was not sufficient to explain all the spatial variations of erodibility after the peak of the Mississippi flood. Comparing values to published data, the depth-varying erodibility on the Louisiana shelf was close to the "low erodibility" level for the York River of Virginia, and similar to the data collected from Baltimore Harbor in Maryland and the main stem of upper Chesapeake Bay. Our findings promote understanding of the resuspension of fluffy organic-rich layer at the water–sediment interface, which influences sediment oxygen demand on the Louisiana shelf. This dataset is also valuable to observational and modeling studies of large river sediment dispersal systems worldwide.

1. Introduction

Wright and Nittrouer (1995) identified four potential stages in the coastal dispersal of fluvial sediment: supply via river plumes, initial deposition, resuspension and transport, and long-term net accumulation. Critical to erosion from the seabed and the ultimate fate of fluvial sediment, resuspension depends on the seafloor erodibility which is defined as the measured propensity for sediment to be resuspended from the seabed (Grabowski et al., 2011). Sediment resuspension occurs when the bottom shear stress generated by currents and waves exceeds the critical shear stress for erosion, which may vary significantly in response to grain size changes, consolidation, dilation and biological processes (e.g., Sanford and Maa, 2001; Grabowski et al., 2011; Dickhudt et al., 2011; Lo et al., 2014). For depth-limited systems erodibility is characterized by the critical shear stress, which tends to increase as

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a function of depth into the seabed (Parchure and Mehta, 1985; Sanford, 2008). Several field studies of cohesive sediment erodibility have been done in estuarine and shelf environments. Widdows et al. (2000), for example, used annular flumes to measure intertidal sediment erodibility in the Humber Estuary of United Kingdom and found that biota can act as both sediment 'stabilisers' (benthic algal films) and 'destabilisers' (density of bioturbating clams). Andersen et al. (2005) reported that temporal variations in erodibility in the Rømø Bight of Denmark are highly influenced by biological activities in subtidal and intertidal sediments. Stevens et al. (2007) found that porosity, grain size and benthic organisms were important factors influencing erodibility on the western Adriatic shelf, Italy. Dickhudt et al. (2009) reported newly-formed, laminated sediments are associated with an ephemeral estuarine turbidity maximum in the York River estuary, Virginia; Dickhudt et al. (2011) further reported that compaction within the cohesive portion of the bed is better related to sediment erodibility than compaction of the bed as a whole.

Numerical models have been developed to study sediment settling, accumulation, and resuspension, often neglecting consolidation (e.g., Warner et al., 2008). Although some recent efforts accounted for cohesive seabed processes using field-based measurements of critical shear stress as a function of depth in the sediment (Sanford, 2008; Rinehimer et al., 2008), use of these methods has been difficult because of the paucity of erodibility data. Xu et al. (2011), for example, developed a numerical model for the northern Gulf of Mexico that included spatial grain size variation and river sediment supply, but it neglected bed consolidation processes. Inclusion of the cohesive effects requires the knowledge of the erodibility of the sediment bed, but to date these have been lacking for the northern Gulf of Mexico.

Our study area is the shelf off the Louisiana coast in the northern Gulf of Mexico, which receives a bulk of water and sediment discharge from the Mississippi and Atchafalaya Rivers. Being the home of approximately two million people, the Louisiana littoral zone supports the U.S.'s largest commercial fishery, supplies 90% of the nation's offshore oil and gas, and facilitates about 20% of the nation's annual waterborne commerce. Since the 1930s coastal Louisiana has lost over 4660 km^2 of land, diminishing wetland habitats, increasing flood risk, and endangering the coastal environment. This land loss is primarily associated with decreased sediment discharge from the Mississippi and Atchafalaya Rivers; relative sea level rise; levee construction; sediment dewatering and subsidence; withdrawals of water, oil and gas; and other natural and human activities (Day et al., 2007; Törnqvist et al., 2008; Blum and Roberts, 2009; Allison and Meselhe, 2010; Kolker et al., 2012). As a result, the rates and frequencies of sediment erosional/resuspension processes in wetlands and the nearby Louisiana continental shelf are critical to morphological evolution and the economic future of the State of Louisiana. Sediment resuspension and transport processes are also highly relevant to the land building of future large sediment diversions of Louisiana.

The primary goal of this study is to understand the spatial and temporal variations of seabed erodibility on the Louisiana shelf. The period of our study, from April 2010 to August 2011, included a major flood of the Mississippi River. Peak daily water and sediment discharge was observed in late May 2011 at Tarbert Landing and Simmesport stations on the Mississippi and Atchafalaya Rivers, respectively, and was nearly twice that of the 10-year mean daily discharge from 1991 to 2010 (Fig. 1A and B). This event provided a unique opportunity to examine how shelf

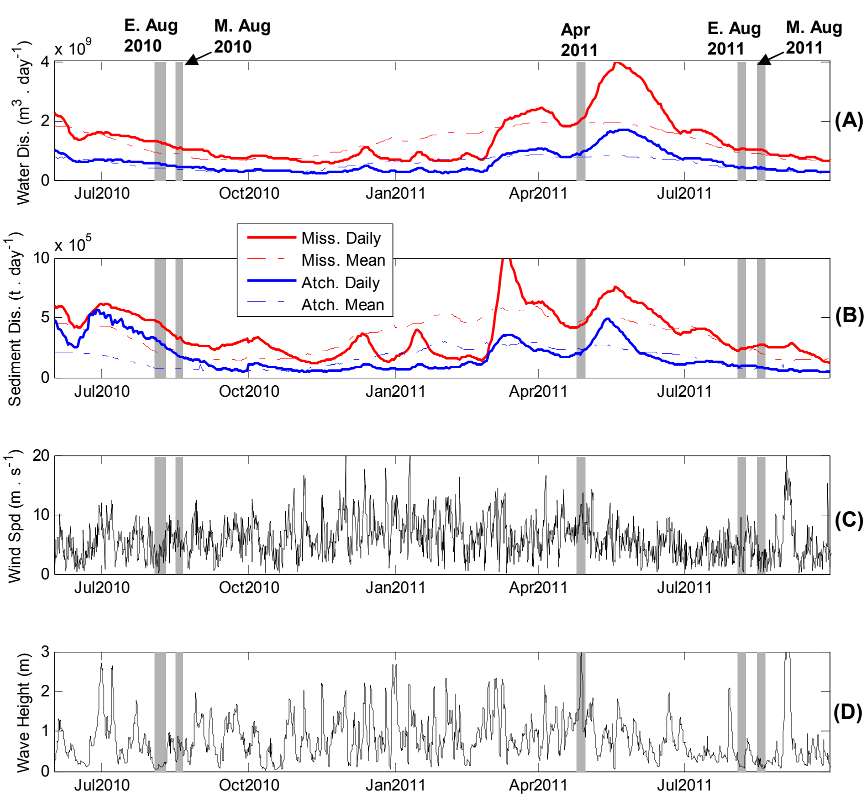

Fig. 1. (A) Daily water discharge of the Mississippi (at Tarbert Landing) and Atchafalaya (at Simmesport) Rivers from June 2010 to September 2011, with comparison of 10-year mean discharge from 1991 to 2010. (B) Daily and 10-yr mean sediment discharge of the Mississippi and Atchafalaya Rivers. See supplementary data in Allison et al. (2012) for the websites to access water and sediment discharge data. (C) Wind speed from BURL1C-MAN weather station near the Southwest Pass of the Mississippi Delta. D) Wave height at Station 10B based on WaveWatch III hindcast modeling data. See Fig. 7A for the locations of wind and 10B stations. Five gray bars identify periods of five research cruises conducted during early and middle August 2010, April 2011 and early and middle August 2011.