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Dispersal of Mississippi and Atchafalaya sediment on the Texas–Louisiana shelf: Model estimates for the year 1993

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ABSTRACT

A three-dimensional coupled hydrodynamic-sediment transport model for the Texas–Louisiana continental shelf was developed using the Regional Ocean Modeling System (ROMS) and used to represent fluvial sediment transport and deposition for the year 1993. The model included water and sediment discharge from the Mississippi River and Atchafalaya Bay, seabed resuspension, and suspended transport by currents. Input wave properties were provided by the Simulating WAves Nearshore (SWAN) model so that ROMS could estimate wave-driven bed stresses, critical to shallow-water sediment suspension. The model used temporally variable but spatially uniform winds, spatially variable seabed grain size distributions, and six sediment tracers from rivers and seabed.

At the end of the year 1993, much of the modeled fluvial sediment accumulation was localized with deposition focused near sediment sources. Mississippi sediment remained within 20–40 km of the Mississippi Delta. Most Atchafalaya sediment remained landward of the 10-m isobath in the inner-most shelf south of Atchafalaya Bay. Atchafalaya sediment displayed an elongated westward dispersal pattern toward the Chenier Plain, reflecting the importance of wave resuspension and perennially westward depth-averaged currents in the shallow waters (<10 m). Due to relatively high settling velocities assumed for sediment from the Mississippi River as well as the shallowness of the shelf south of Atchafalaya Bay, most sediment traveled only a short distance before initial deposition. Little fluvial sediment could be transported into the vicinity of the "Dead Zone" (low-oxygen area) within a seasonal–annual timeframe. Near the Mississippi Delta and Atchafalaya Bay, alongshore sediment-transport fluxes always exceeded cross-shore fluxes. Estimated cumulative sediment fluxes next to Atchafalaya Bay were episodic and "stepwise-like" compared to the relatively gradual transport around the Mississippi Delta. During a large storm in March 1993, strong winds helped vertically mix the water column over the entire shelf (up to 100-m isobath), and wave shear stress dominated total bed stress. During fair-weather conditions in May 1993, however, the freshwater plumes spread onto a stratified water column, and combined wave–current shear stress only exceeded the threshold for suspending sediment in the inner-most part of the shelf.

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1. Introduction

1.1. Background

Large rivers play a key role in delivering freshwater, sediment, and nutrients to the ocean (Milliman and Meade, 1983; Milliman and Syvitski, 1992). Large-river deltas and associated coastlines are especially important interfaces between continents and oceans for material fluxes that globally impact oceanographic processes (Bianchi and Allison, 2009). The Mississippi River, the largest in North America, drains 41% of the continental United States before entering the northern Gulf of Mexico (Fig. 1A). The State of Louisiana contains about 40% of the nation's coastal and estuarine wetlands which are vital to recreational and agricultural interests, and is home to the state's $1 billion per year seafood industry (Stone and McBride, 1998). The Mississippi Delta, its associated wetlands and barrier islands developed over geological timescales in response to continuous accumulation of fluvial sediment and reworking by physical oceanographic processes

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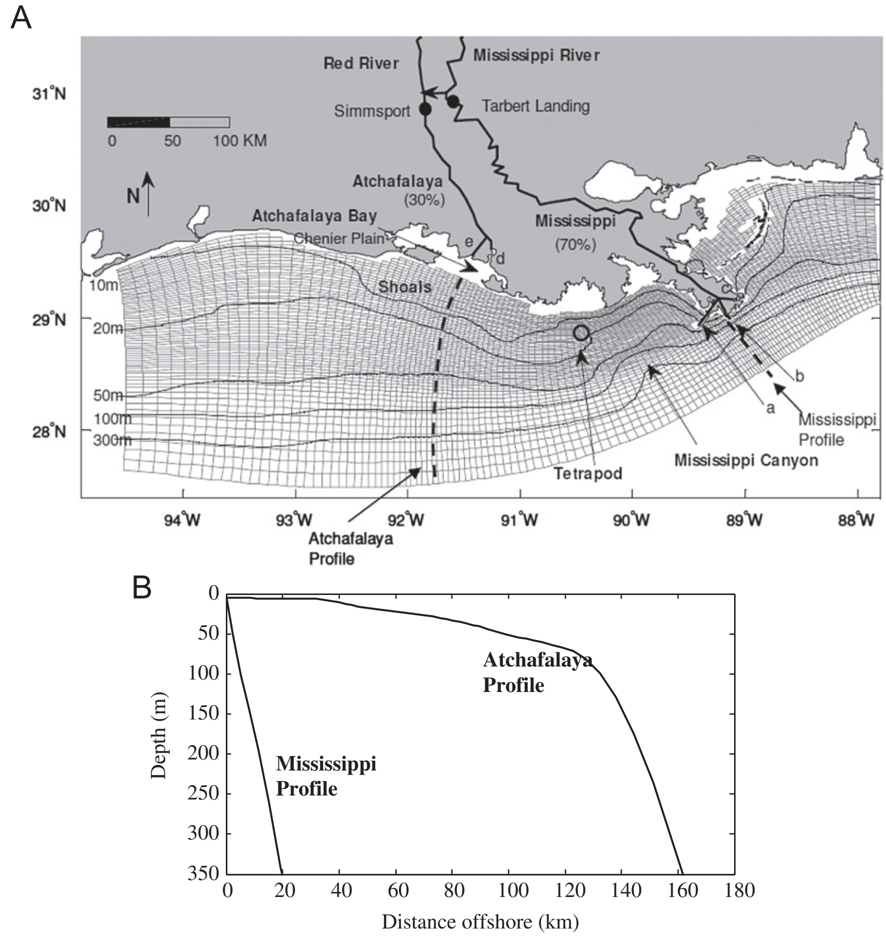

Fig. 1. (A) Curvilinear model grid for the Texas–Louisiana shelf. Isobaths contoured at 10, 20, 50, 100, and 300 m. The open circle is the tetrapod location for the LATEX sediment transport observation in spring, 1993 (Wright et al., 1997). Shown on the Mississippi Delta are Southwest Pass (a), South Pass (b) and Pass a Loutre (c). Both Atchafalaya (d) and Wax Lake (e) Deltas are being built in Atchafalaya Bay. (B) Bathymetric profiles south of the Mississippi Delta and Atchafalaya Bay. Locations of profiles shown as dashed lines in (A).

(e.g., waves and currents). Since the early Holocene ($\sim$8000 years BP), the Mississippi River has built six delta complexes, including the two most recent ones: the Balize (modern Mississippi Bird-foot Delta) and Atchafalaya–Wax Lake Deltas (Coleman et al., 1998).

The Atchafalaya has served as a distributary of the Mississippi since as early as the 1500s (Fisk, 1952), but the volume of diverted flow increased significantly during the past century when the Mississippi River begun to abandon the Balize course in favor of the Atchafalaya (Roberts, 1998). Since installation of a control structure in 1963, approximately 70% of the combined discharge of Mississippi and Red Rivers has entered the Gulf of Mexico through the modern Mississippi mainstem, while 30% went through the Atchafalaya (Meade and Moody, 2010; Fig. 1A). During the past two decades, the Mississippi and Atchafalaya carried an average of 115 and 57 Mt (Million tons)/year of sediment into coastal Louisiana, respectively (Meade and Moody, 2010).

The geomorphology of the areas offshore of the Mississippi and Atchafalaya Rivers differ. Though coastal morphological settings can greatly impact fluvial sediment dispersal, few recent studies have compared the sediment transport mechanisms or sediment accumulation patterns in the areas offshore of these two rivers. In response to high fluvial sediment discharge and relatively modest waves and tides, the Mississippi developed a river-dominated bird-foot shaped delta on the eastern Louisiana shelf (Fig. 1A). Near this prominent delta, high sediment supply has led rapid delta progradation, developing a narrow and steep shelf ($<$20 km wide south of the delta, a gradient of $\sim$0.4°, Fig. 1B). Along the western Louisiana shelf, however, the relatively young Atchafalaya River has been building bird-foot Atchafalaya and Wax Lake deltas inside the shallow and semi-enclosed Atchafalaya Bay (Fig. 1A). Because only a small portion of sediment from the Atchafalaya River can reach deep water (Allison et al., 2000), the modern sediment supply to the middle and outer shelf is minimal and the shelf south of Atchafalaya Bay is broad, smooth, and gently sloped ($\sim$200 km wide, a gradient of 0.02°) (Fig. 1B).

1.2. Physical oceanographic setting

Wind-driven low-frequency currents on the Texas–Louisiana shelf have distinct modes during summer (June–August) compared to non-summer periods (Cho et al., 1998). During the summer when winds are generally from the west and thus upwelling favorable, the fresh water introduced by the Mississippi and Atchafalaya Rivers combines with intense solar radiation, stratifying the shelf water column (Cochrane and Kelly, 1986); during the non-summer months, downwelling-favorable winds blow predominately from the northeast, enhancing westward currents (Rhodes et al., 1985). Tidal fluctuations in the area are diurnal or mixed diurnal types with amplitudes generally less than 0.4 m (Wright et al., 1997; DiMarco and Reid, 1998).

The northern Gulf of Mexico has low wave action except during storms (Curray, 1960). Typical deep-water waves show a range of wave periods averaging from 3 to 8 s with heights rarely