Hydrodynamics and Sediment Dynamics in a Receiving Basin for Sediment Diversion: a Case Study in Barataria Bay, Louisiana, USA

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HYDRODYNAMICS AND SEDIMENT DYNAMICS IN A RECEIVING BASIN FOR SEDIMENT DIVERSION: A CASE STUDY IN BARATARIA BAY, LOUISIANA, USA

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science

in

The Department of Oceanography and Coastal Sciences

by

Guandong Li
B.S., Shandong University of Science and Technology, 2017
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Abstract

Barataria Bay is a receiving basin of Mid-Barataria Sediment Diversion in Louisiana, USA. In this region the data of sediment transport and hydrodynamics are scarce but important for the design and planning of sediment diversion to be implemented in near future. Four-months bottom boundary layer observation was conducted to study winter and spring hydrodynamics and sediment dynamics in the bay. Hourly waves, tides, currents and bottom suspended sediment concentration were measured using multiple optical and acoustic sensors attached to two tripod platforms. High-temporal resolution data indicated that during winter, salinity at northern bay was mainly controlled by northerly wind during cold fronts, and tidal currents kept southern bay salinity high during the same period. In spring, frequent pervasive southerly winds and the westward shelf transport of flooding freshwater from Southwest Pass of Mississippi River Delta lowered the salinity in southern bay. Density spectral analysis showed that wind-driven currents played the most important role in generating wave-current combined shear stress that triggered bottom sediment resuspension. Style-Glenn 1-D boundary layer model was also applied for sediment flux calculation. During the cold front passages sediment transport directions generally rotated and its magnitudes changed greatly when southeasterly wind shifted to intensified northwesterly wind. Southerly pre-front winds facilitated wetland sedimentation by transporting sediment to the northern bay during high water level conditions such as flooding spring tides. Conversely, northerly winds during cold fronts could dominate over bidirectional tidal currents and led to southward net sediment transport and eventual sediment loss in the bay. Timing of diversion openings, orientation of receiving basins, dominant wind directions and water levels should be considered in the planning and management of future sediment diversions in coastal areas.
Chapter 1. Introduction

1.1. Background: The areas along coastal zones support about three quarters of global population, but only occupies 5 percent of the Earth’s landmass (Vörösmarty et al., 2009). River deltas within these zones are the most common landform and crucial for civilization and agriculture development in human history. However, both natural and anthropogenic factors have drastic impacts on large-river estuaries between continents and oceans which are important for material flux transport and further influence global marine biogeochemistry (Bianchi and Allison, 2009). Sediment-laden river discharge around the world contribute billions of tons of suspended sediment to the ocean yearly (Milliman et al., 1983). Sediment transport and deposition which are controlled by waves, currents, tides, etc. play an essential role in deltaic evolution and landscape change. In order to better understand how deltas and coastal zones are affected and the driving mechanisms of sediment transport, observations of hydrodynamics and sediment dynamics are very much needed.

Instrumented bottom tripods have provided abundant in-situ sediment transport data since the first deployment in a tidal channel in Puget Sound, WA in 1965 (Cacchione et al., 2006). Tripods data shed light on the understanding of near-bottom flows in coastal ocean and provide useful data for sediment transport and shelf circulation models’ validation and development. Based on a 5-year tripod dataset collected on the Eel River continental shelf, Guerra et al. (2006) stated that waves, river discharge and currents alone are insufficient to resuspend or accumulate large quantities of sediment in the continental shelf. In fact, river floods and storm events played important roles in sediment resuspend and transport in this study area. According to the same data sets and spectral analysis of the tripod data, Ogston et al. (2004) reported that sediment resuspension was primarily exerted by near-bed flows and sediment transport was sorted to
suspended load and fluid mud. Additionally, in the along-shelf direction, winds and very-low frequency mesoscale eddies were dominated and bottom sediment transport flux had northerly and southerly excursion, while the annual net transport near the tripod site was zero. Along East Coast of United States, Butman and Folger (1979) designed and deployed the bottom tripod instrument systems on Georges Bank in both middle and south Atlantic Bight. Based on the observational results, they believed that bottom sediment resuspensions on George bank and New Jersey continental shelf were mainly triggered by surface waves, tides currents and storms. In addition, fine sediment could be transported 10-20 km alongshore in the mid-shelf region during a winter storm event. Warner et al. (2012) reported that during cold front, the net sediment transport in Long Bay of South Carolina were northeastward mainly induced by northeastward wind, and net sediment flux was northeastward as well due to larger fetch when the winds were northeastward during warm front passage. Southwestward net sediment flux was generated during the passage of low-pressure system with strong winds, waves and currents to the north. Coastal studies also were conducted in continental shelf within north Gulf of Mexico using tripod observations. Beside hydrodynamics, meteorological factors (i.e. cold front passage, storm and hurricane) have been studied extensively because of wind-induced wave can greatly influence sediment resuspension and transport within bottom boundary layer (BBL). Jaramillo et al. (2009), for instance, suggested that near-bed sediment transport processes triggered by frontal swell activities could contribute to the formation of clinoform stratigraphy of muddy Atchafalaya subaqueous deltas. Also, a high concentration fine-sediment bottom layer was formed during post-front period which could effective attenuate wave energy over the muddy inner shelf inhibits erosion at the coast (Kineke et al., 2006). Muddy bed state cycle of dilation during energetic storm was proposed by Sahin et al. (2012), and without sediment-carrying waterfront, bed density increased during erosion phase
and decreased during deposition which was indicated by vertical sediment exchange between water column and the bed.

The Mississippi Deltaic Plain (MDP) is a dynamic coastal system. During the past 6000-7000 years, six delta lobes have been formed around the coastal Louisiana (Day et al., 2007). However, the modern Balize Mississippi Delta is facing a drowning threat due to natural and anthropogenic factors like sea level rise, subsidence and insufficient sediment supply (Blum et al., 2009). Eustatic sea level rise rate was 3.3±0.4 mm yr⁻¹ from 1993 to 2009 which were mainly contributed by thermal expansion of sea water and water mass input from land ice melt and land water reservoirs (Nicholls et al., 2010). Kolker et al. (2011) reported that long-term local subsidence rates in coastal Louisiana were 7.59 ± 0.23 mm yr⁻¹, indicated by long-term tide-gauge record at Grand Isle, Louisiana. Levee and dam construction significantly lowered the sediment load in the Mississippi and Atchafalaya river system.

Wetlands are the most common land type within MDP and they are crucial for human beings because they provide services including habitats for coastal species, protections against river floods, storm surges and hurricanes, water purification, amenities and recreational opportunities (Woodward et al., 2001). According to an analysis result by Dogwood Alliance, an environmental nonprofit organization located at North Carolina, the total wetland services’ worth in Louisiana is 79.4 billion U.S. dollars which containing recreation services, food supplements, water supply, etc. (Dogwoodalliance.org, 2019). However, wetland loss drastically influenced coastal community by threaten the Louisiana coastal economics, environment, ecology, and even human safety during flooding or hurricane events. Although Louisiana occupies 40% wetlands in the United States, 80% wetland losses of the nation is currently occurring in Louisiana (USGS, 2018). In order to protect wetland and slow down the land loss, Coastal Protection and Restoration
Authority (CPRA) of Louisiana proposed multiple coastal restoration and protection methods including sediment dredging for barrier island restoration, reconnecting river and adjacent basin for sediment diversion, etc. Previous studies show a list of sediment dredging projects in Ship Shoal (Liu et al., 2019; Xue et al., 2019), Sandy point (Obelcz et al., 2018; Wang et al., 2019), Raccon Island (Oconnor, 2017), and Peveto Channel (Robichaux et al., 2020) in offshore Louisiana. Wang et al., (2019) collected sedimentary cores and sub-bottom seismic data in Lower Breton Sound and found top sedimentary facies of root-rich soft mud, organic-rich peat and massive mud are likely to be eroded away before sediment diversion is in operation. With the help of numerical model and field data collected near Myrtle Grove, Louisiana, Meselhe et al., (2012) stated the sediment-water ratio at a diversion is controlled by diversion channel alignment and orientation and placing the intake on top of a sand bar increases the amount of sand diverted.

1.2. Sediment Diversion: Sediment diversion is one of the efficient coastal restoration methods which is designed to reconnect the river to receiving basins through manmade channel and then delivery sediment-load river water to the basin to build new land. The Mid-Barataria Sediment Diversion was proposed in both 2012 and 2017 Costal Master Plans (CPRA, 2012, 2017) and this diversion is expected to reintroduce the Mississippi River to Barataria Basin through a manmade channel near Myrtle Grove, Louisiana. The environmental impact statement of Mid-Barataria Diversion which could avoid or minimize adverse impacts or enhance the quality of the human environment is currently underway. This project is scheduled to be permitted in 2022 and the construction will start once the permitting and design process is completed. How does this large diversion project impact salinity, hydrodynamics, sediment dynamics and ecology has been a topic interesting to many scientists, engineers, coastal managers and decisions makers in Louisiana and around the world.
1.3. **Barataria Bay Setting:** Barataria Basin, located in the southeast Louisiana, south of the city of New Orleans, is an interdistributary bay that is bordered by Bayou Lafourche to the west and the Mississippi River main channel to the east. It is a roughly triangle-shaped drainage basin which occupied more than 6,000 km² (Fig. 1.1a). Barataria Bay is the southern part of Barataria Basin. It has several barrier islands bounded to the south and multiple tidal inlets between the barrier islands, connecting the Barataria Bay to northern Gulf of Mexico. To the north, the Barataria Bay is surrounded by wetlands and marshes where contain Lake Cataouatche, Lake Salvador and Little Lake (Barbé et al., 2000; Duncan et al., 2004; Li et al., 2010). The average depth of this bay is roughly 2 m (Das et al., 2012) whereas the water depth near the inlets and channels can reach tens of meters. Diurnal tide is dominant, and the tidal range is approximately 0.35 m near the mouth during spring tide and decrease gradually northward. Average salinity ranges from zero to 35 during different physical conditions. The main fresh water sources are from man-made freshwater diversion to the north (Davis Pond Freshwater Diversion, Fig. 1.1a), rainfall, stream runoff, the Gulf Intracoastal Waterway and some possible seepage from the Mississippi River channel. In addition, due to the clockwise gyre in the Louisiana Bight which is west of Mississippi Delta (Fig. 1.1a), the Mississippi River water could some time enter the bay through multiple tidal inlets which then lowers the salinity of the bay (Li et al., 2010).
Barataria Bay has experienced severe wetland loss in past 40 years. Natural and anthropogenic processes made such land loss even worse. Because of the high economic value of this ecosystem in term of fishery, mineral resources, as well as environmental services, many
studies have been carried out on sediment transport. By taking water samples and in-situ observations, Barbé et al. (2000) concludes that tidal activities in Barataria Bay have minor impacts on sediment transport and that sediment fluxes were significantly affected by synoptic climate conditions, especially during winter cold fronts. Booth et al. (2000) obtained similar conclusions based on the result of a newly-designed wind-driven resuspension model. According to their model, 4 m s\(^{-1}\) of wind is a threshold that could induce 50 % of the bottom sediment resuspension. Over fall and winter seasons, 80 % of wind speeds are higher than this threshold. As a result, during fall, winter and early spring, bottom sediment resuspension events are most frequent and intensive. In addition, the size of water body (i.e., fetch) also plays an essential role in marsh edge erosion and the sediment in the open water could be eroded and transported during weak wind summer. In 2008 summer, 24h continuously ADCP survey and water sampling were performed by Li et al. (2011) within the 600-m wide Barataria Pass (the largest tidal inlet of Barataria Bay) and 13 ~ 19 days residence time of whole water body in the bay was detected. This period might reduce to 2 days during winter cold front passages or hurricane events.

1.4. Motivations and Scientific Questions: Although Barataria Bay was studied extensively in the past 40 years, no detailed time series studies were conducted for sediment dynamics and hydrodynamics within BBL in Barataria Bay yet. The objectives of this study are: (1) to identify how tides, currents, waves, river and wind impact sediment resuspension and transport; (2) to quantify the sediment transport flux and direction in the bay; (3) to understand the dominant shear stresses driving sediment resuspension and transport, such as wave-induced shear stress, current-induced shear stress, or the combination of two; (4) to explore how physical and meteorological parameters affect salinity distribution over the bay.
Chapter 2. Methods

2.1. Data Collection: Davis Pond diversion’s discharge data were obtained from U.S. Geological Survey (USGS) water-level sensor station near Boutte, Louisiana (LA), USA; this discharge is the main freshwater input of Barataria Bay. Mississippi River discharge data were downloaded from USGS Belle Chasse station (BC). Temperature and salinity data were obtained from two USGS stations: Barataria Waterway S of Lafitte, LA (BWS) and Barataria Pass at Grand Isle, LA (BGI). Hourly wind data collected at 9.3 m above mean sea level at station GISR1-8761724 of Grand Isle, LA, were downloaded from the National Data Buoy Center of National Oceanic and Atmospheric Administration (NOAA).

Two instrumented tripods were deployed in Barataria Bay to study the hydrodynamics and sediment dynamics. Their locations are shown at Fig. 1.1b. One tripod was deployed near the northern Barataria Bay (BBN) and the other near southern Barataria Bay (BBS). Four sensors were deployed on each tripod, including OBS (Optical Backscatter Sensor) 3A manufactured by Campbell Scientific, ADV (Acoustic Doppler Velocimeter) Ocean from Sontek, seabird HydroCAT-EP, and wave gauge made by Ocean Sensor Systems, Inc. There were two observational periods. The first observation period was from 13 December 2018 to 5 February 2019 and was defined as ‘winter’. The second observation period was from 8 March 2019 to 5 May 2019 which was defined as ‘spring’. All sensors and sampling parameters for the two deployment periods were shown at Table 1.

2.2. Data analysis methods: Wave data were analyzed with the Ocean Wave Analyzing Toolbox (OCEANLYZ) developed by Karimpour and Chen (2017). ADV current data were de-spiked before analyzing currents (Goring et al., 2002; Wahl et al., 2003; Wang et al., 2018). The current-induced shear stress near the bay bottom was calculated using the Turbulent Kinetic
Energy (TKE) method following Eqs. (1)-(2) (Kim et al., 2000; Soulsby and Dyer, 1981). In Eq. (1), $u'^2$, $v'^2$, and $w'^2$ are the mean square of the velocity fluctuations in northward, eastward and upward directions. In Eq. (2), $\tau$ is the bed shear stress and $C_1$ (-0.20) is a proportionality constant. Here the equations were based on the linear wave theory Eqs. (3)-(6) to calculate wave induced shear stress (Wright, 1995; Xu et al., 2016). In Eq. (3), $u_{bmax}$ is maximum wave orbital velocity near the bed, $a_w$ is wave orbital excursion amplitude, $f_w$ is wave friction factor, $k_b$ is effective roughness, $\rho$ is water density and $\tau_w$ is wave-induced shear stress. In Eq. (7), $\tau_{cw}$ is wave-current combined shear stress, where $\tau_w$ was calculated from Eq. (6) and $\tau_c$ from Eq. (1)-(2) (Soulsby, 1995; Yang et al., 2019).

Table 2.1. Sampling parameters and observational periods at tripod stations BBN and BBS

<table>
<thead>
<tr>
<th>Station</th>
<th>Coordinates</th>
<th>Sensor</th>
<th>Sampling Frequency (Burst Duration/Interval)</th>
<th>Sensor Height above Bed (cm)</th>
<th>Observational Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBN</td>
<td>Latitude 29°25.225’ N&lt;br&gt;Longitude 89°56.642’ W</td>
<td>Wave Gauge</td>
<td>10 Hz (1200 s/60 min)</td>
<td>37/38</td>
<td>13 December 2018 ~ 5 February 2019/ 8 March ~ 5 May 2019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OBS 3A</td>
<td>1 Hz (30 s/60 min)</td>
<td>32/33</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HydroCAT</td>
<td>1/1800 Hz (1800 s/60 min)</td>
<td>32/32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADV-Argonaut/ ADV-Ocean</td>
<td>0.2 Hz (120 s/60 min)&lt;br&gt;1/1800 Hz (1800 s/60 min)</td>
<td>37/42</td>
<td></td>
</tr>
<tr>
<td>BBS</td>
<td>Latitude 29°20.663’N&lt;br&gt;Longitude 89°56.450’ W</td>
<td>Wave Gauge</td>
<td>10 Hz (1200 s/60 min)</td>
<td>22/22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OBS 3A</td>
<td>1 Hz (30 s/60 min)</td>
<td>23/23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HydroCAT</td>
<td>1/1800 Hz (1800 s/60 min)</td>
<td>23/24</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADV-Ocean</td>
<td>8 Hz (256 s/60 min)</td>
<td>38/39</td>
<td></td>
</tr>
</tbody>
</table>

HydroCAT-EP turbidity data were calibrated for suspended sediment concentration (SSC) in a mixing chamber at Sediment Dynamics Lab (SDL) at Louisiana State University using local
seafloor sediments collected at BBN and BBS sites in different deployment periods. Quadratic regression models for two sensors in different periods were shown in Figs. S1, S2, S3 and S4 of supplementary materials.

$$E = \frac{(u'^{2} + v'^{2} + w'^{2})}{2}$$  \hspace{1cm} (1)

$$|\tau| = C_1 E$$  \hspace{1cm} (2)

$$u_{bmax} = \frac{\pi H}{[T \sinh(2\pi h/L)$$]  \hspace{1cm} (3)

$$a_w = \frac{H}{[2 \sinh(2\pi h/L]}$$  \hspace{1cm} (4)

$$f_w = \exp[5.213(k_b/a_w)^{0.194} - 5.977]$$  \hspace{1cm} (5)

$$\tau_w = 2\rho f_w u_{bmax}^2/(3\pi)$$  \hspace{1cm} (6)

$$\tau_{cw} = \tau_c[1 + 1.2(\tau_w/(\tau_c + \tau_w)^{3.2})]$$  \hspace{1cm} (7)

$$A_m = U_{bmax} \ast T/2\pi$$  \hspace{1cm} (8)

$$Q_s = \int_0^2 U_z C_z dz$$  \hspace{1cm} (9)

$$\varphi = -\log^d \frac{1}{2}$$  \hspace{1cm} (10)

Local sediment samples from BBN and BBS were collected during two tripods’ deployment, and further used for grain size analysis at LSU. The analysis was conducted using Beckman-Coulter laser diffraction particle size analyzer (Model LS 13 320) and followed the method described by Xu et al. (2014). Grain sizes’ unit were converted to the logarithmic unit $\varphi$ from unit in mm by using the equation Eq. (10) from Folk (1966). Results were shown in Fig. S5 that sediment at BBS were sand dominant while the sediment at BBN station were muddier. Overall grain size distribution for entire Barataria Bay was displayed as Fig. S6 and the data
were downloaded from usSEABED database. The grain size setting indicated the same result that the bay was muddy at northern part and sandy at southern part.

Style-Glenn 1-D bottom boundary model (here defined as ‘SG model’) was used to compute potential sediment flux in the bay at two tripod stations (BBN, BBS). This model was based on Glenn-Grant (1987) BBL model and updated by Style and Glenn (2000). Style and Glenn (2000) introduced 3-layers eddy viscosity profiles that made the model continuous in the eddy viscosity at the top of the wave boundary layer. The model was designed for time-series input data including time, wave orbital velocity, wave excursion amplitude, mean current velocity, height above bed current was measured, and angle between wave and current. Wave orbital velocity was calculated from wave height data based on Eq. (3). Wave excursion amplitude was calculated using Eq. (8), where \( \text{Am} \) is the amplitude, \( \text{Ubmax} \) is the maximum bottom wave orbital velocity and \( \text{T} \) is peak wave period. Mean current velocity was computed from ADV-Ocean data file which contained hourly current average data in north and east directions. Depth-integrated sediment flux \( Q_s \) was calculated using Eq. (9), where \( z \) is water depth, \( U_z \) is current velocity at \( z \) height and \( C_z \) is sediment concentration at \( z \) height. Both \( U_z \) and \( C_z \) were computed by SG model to better calculate depth-integrated sediment flux. The unit of sediment flux was calculated to be \( \text{g s}^{-1} \text{m}^{-1} \), which is gram of sediment transported through a cross-section area which is one meter wide and about 3.5 m deep (depending on water depths at each of two tripods).
Chapter 3. Results

3.1. River Discharge: The Mississippi River discharge was relatively stable over two months based on observational data downloaded from Belle Chasse station. No flooding event was found during this period. The river discharge kept a stable level between $2.5 \times 10^4$ to $2.8 \times 10^4$ m$^3$ s$^{-1}$ in winter 2018. Discharge from Davis Pond freshwater diversion didn’t change much either and it kept steady around $33$ m$^3$ s$^{-1}$ (Fig. 3.1a).

Fig. 3.1. Time series results for winter observation, 2018-2019: (a) river discharge at USGS stations at Davis Pond and Belle Chasse, LA; (b) wind direction and speed from USGS station at Barataria Pass, LA; (c) wave height (calculate from wave gauge); (d) wave-current combined shear stress (calculate from wave gauge and ADV-Ocean); (e) bottom suspended sediment concentration.
During spring season, Mississippi River discharge dropped slowly from $3.5 \times 10^4$ to $2.9 \times 10^4$ m$^3$ s$^{-1}$ during 14 March to 15 April 2019, and then increased after 20 April 2019. Discharge data at Davis Pond freshwater diversion kept at a stable level, and average water discharge was about 35 m$^3$ s$^{-1}$ (Fig. 3.2a).

**3.2 Wind and Wave Conditions:** Meteorological data displayed clear seasonal patterns and multiple cold fronts were found during winter and spring observation periods. Here we defined cold fronts as a period that wind speed > 5 m s$^{-1}$, lasting more than 1 day and the wind direction rotated from south to north in a short time. The period with wind speed increasing without wind direction changing was named as pre-frontal period. Cold front period started from wind direction changing and ended when wind speed was lower than 5 m s$^{-1}$. Post-front period was defined as wind direction changed again with wind speed lower than 5 m s$^{-1}$. In winter, there were two wind conditions, including northerly wind with speed > 5 m s$^{-1}$ (cold front) and southerly pervasive wind with speed < 5 m s$^{-1}$ (Fig. 3.1b). Multiple cold front events were observed during the winter season, most of them came from north-northwest with wind speed > 10 m s$^{-1}$ and the others came from north-northeast with wind speed < 10 m s$^{-1}$. The cold front events normally started with southwest wind and then shifted to northwest or northeast revealed low-pressure centers to the north passed from west to east. In spring observation, the overall wind speeds were lower than winter observation (Fig. 3.2b).

In winter and spring observations, eight cold front events were selected and labeled with grey shaded areas (P1 to P8). Multiple criteria were applied during these selections, including covered the cold front passage with high wind speed (>8 m s$^{-1}$), high-SSC events occurred
concurrently and well corresponded among wind speed, significant wave height at both stations, wave-current combined shear stress and SSC events.

Wind-generated waves were normally induced by wind blowing and the higher the wind speed the higher the wave height. In winter observation, wave height in Barataria Bay varied from 0 to 1 m (Fig. 3.1c). The differences of wave heights occurred between BBN and BBS station were generally less than 0.1 m. However, in spring observation, wave height at BBN station varied from 0 to 1.1 m and was higher than that at BBS station which varied from 0 to 0.8 m, especially during cold front passages from northeast (Fig. 3.2c).

3.3. Shear Stress: The wave-current combined shear stress was controlled by both waves and currents. Shear stress fluctuated with wave height in winter period (Fig. 3.1d) and first half of spring period (Fig. 3.2d). Current-induced shear stress was generally higher than wave-induced shear stress both in winter and spring, which indicated that current played a more important role in wave-current combined shear stress composition (Fig. 3.5 and S. 7)

3.4. Suspended Sediment Concentration: Bottom suspended sediment concentration (SSC) fluctuated with $\tau_{cw}$ and significant wave height. Multiple high SSC events were observed during winter and spring periods. High SSC events were distinguished by suddenly increased SSC and normally the peak values were greater than 1 g L$^{-1}$. In winter, SSC in BBS station was always higher than BBN station in multiple high SSC events, such as in 21 December 2018 (P1), when the SSC in BBS and BBN station was 5 and 2 g L$^{-1}$, respectively (Fig. 3.1e). In spring, SSC at BBS station was still higher than BBN station, but lower than the SSC in winter period. On 16 March 2019 (P4), SSC in BBS station was 3.5 g L$^{-1}$, while SSC in BBN station was 1.5 g L$^{-1}$ (Fig 3.2e).
Due to biofouling, only half of the current data were in high-quality (even less in spring observation). Hence, we mainly focused on the high-SSC events at P1 and P4. In event P1, wind speed increased from 3 to 13 m s\(^{-1}\) within one day with wind direction changed from south to northwest, wave height at different station both increased from 0 to 0.7 m, concurrently the wave-current combined shear stress reached to 5.5 Pa and high-SSC indicated that bottom sediment started to resuspend. Interestingly, the SSC in BBS station were almost the double of BBN station and peak SSC occurred during the cold front passaged that reached to 4.5 g L\(^{-1}\). In

Fig. 3.2. Time series results for spring observation, 2019: (a) river discharge at USGS stations at Davis Pond and Belle Chasse, LA; (b) wind direction and speed from USGS stations at Barataria Pass, LA; (c) wave height (calculate from wave gauge); (d) wave-current combined shear stress (calculate from wave gauge and ADV-Ocean); (e) bottom suspended sediment concentration.
event P4, wind speed increased from 2 to 10 m s\(^{-1}\) within a half day along with the wind direction shifted from south to northeast. Wave height increased from 0 to 0.9 m at BBN and from 0 to 0.5 m at BBS station. Although wave height at BBN were larger than BBS, the wave-current

![Graph A: Wind direction and speed from USGS stations at Barataria Pass, LA]

![Graph B: Salinity from BWS, BBN, BBS, BGI stations]

![Map C: Schematic diagram of salinity distribution on 27 December 2018]

![Map D: Schematic diagram of salinity distribution on 21 January 2019]

Fig. 3.3. Processes and relationships between hydrological and meteorological forces and salinity in Barataria Bay with cold front passages in winter: (a) wind direction and speed from USGS stations at Barataria Pass, LA; (b) salinity from BWS, BBN, BBS, BGI stations; (c) schematic diagram of salinity distribution on 27 December 2018; (d) schematic diagram of salinity distribution on 21 January 2019.
combined shear stress at BBS were higher than BBN, which indicated strong bottom current had a strong impact on BBS station. Thus, SSC at BBS were higher than BBN, and reached a maximum at 2.5 g L$^{-1}$ during post-front period.
3.5. Salinity Variation: Salinity was dynamic at four stations (BWS, BBN, BBS and BGI) in both winter and spring observational periods (Fig. 1.1b). The minimum salinity difference among all four stations occurred on 27 December 2018 and 14 March 2019, with pervasive southerly-southeasterly wind (Figs. 3.3a, 3.3b, 3.4a and 3.4b). Under northerly-northwesterly wind condition on 21 January 2019, salinity at four stations decreased initially and then increased after cold front passage. The result also showed that salinity at BGI increased firstly, and salinity at the other three stations increased from south to north following a clear spatial sequence. The time lag among four stations regarding salinity change was roughly one day (Fig. 3.3b). During the cold front passage on 20 April 2019, wind came from west-northwest with a speed decreased from 10 to 8 m s\(^{-1}\) within one day. Salinity at two southern stations (BGI and BBS) started to increase while two northern stations (BBN and BWS) started to decrease together. The difference among 4 stations reached the maximum on 21 April 2019, respectively (Fig. 3.4b).

3.6. Periodicity Analysis: Wind speed and water level data from BGI station, as well as significant wave height and SSC data collected from BBN and BBS tripods in winter observational periods were used for spectral analysis. The spectral density analysis of wind speed had a peak power around 0.2-0.3 cycles/day, indicating a dominant periodicity of 3-5 days (Fig. 3.5a). The wave height and SSC had similar periodicities of 5-days at both BBN and BBS stations. However, wave height and SSC had the same weak periodicities of 1 day only at BBS station. The water level density spectral revealed two periodicities of 24 h and 25.8 h and a small peak was found around 0.2 cycles/day reflecting that water level had a 5-days periodicity as well.
Fig. 3.5. Spectrum density of winter (a) wind speed; (b) wave height; (c) tide (data downloaded from BGI station); (d) SSC.
Chapter 4. Discussion

4.1. Salinity Distribution in the Bay: Salinity in the bay is an important parameter for water quality and ecosystem (particularly to oysters) and is controlled by seasonal hydrological and meteorological conditions (Figs. 3.3 and 3.4). The Davis Pond freshwater diversion was set at the 30 m$^3$ s$^{-1}$ minimum flow during winter and spring observations and had relatively small impact on the salinity distribution over the bay (Figs. 3.1a and 3.2a). In addition, there was no direct water exchange between the Mississippi River channel and Barataria Bay, and the freshwater input to the bay was virtually eliminated by the flood protection levees along the Mississippi River. Although river discharge increased in spring observation, it did not seem to play a direct role in salinity variation over the bay in both observation periods.

Based on observation data, salinity generally increased under southernly wind in 2018-2019 (Fig. 3.3c). After the cold front passage on 21 December 2018, wind direction changed to the south or southeast and lasted for about 15 days. Southerly wind pushed salty seawater from northern Gulf of Mexico to the bay through multiple tidal inlets, increasing the salinity at northern station. On 27 December 2018, the salinity difference between BWS and BGI was only 3, reached the minimum in the entire winter observation. However, wind direction changed to the east on 29 December 2018 and brought a large amount of fresh water from ambient wetland and marshe into the bay, decreasing salinity of all four stations.

On 21 January 2019, the difference of salinity between BWS and BGI reached the maximum during winter observation. A strong cold front event carried the wind blowing from north and northwest, brought some water into the bay from wetland and low-salinity reservoirs, such as Lake Salvador at north, lowered the salinity at two northern stations, while two southern stations BBS and BGI kept high salinity levels (Fig. 3.3d). BBS station was located at northern
end of a tidal channel (Fig. 1.1b) which was influenced by strong tidal mixing. In other words, the high salinity condition at two southern stations were controlled by strong tidal currents, which moved saltwater from northern Gulf of Mexico to Barataria Bay through Barataria Pass and multiple other tidal inlets.

In spring observation, due to the Mississippi River flooding and south or southeast wind, westward current was produced in Louisiana Bight and a clockwise gyre could be generated (Fig. 1.1a), which transported a large amount of mixed water to the west along the coastline of Louisiana (Walker et al., 2005). Meanwhile, southerly wind pushed the mixed water into the bay, leading the salinity at two southern stations lower than northern stations (Fig. 3.4(c)).

Under westerly wind condition, salinity at two northern stations were decreased with freshwater input from westside wetland. At the same time, west wind could also bring saltier seawater to the south of Barataria Pass area, where was originally occupied by fresher water from the Mississippi River. After that, the saltier seawater could be transported into the bay mainly by tidal current and salinity then increased at two southern stations.

Our results showed that salinity at Barataria Bay seemed to be mainly controlled by three factors, wind, river and tides. In winter, the Mississippi River stage was low and had less impact on the salinity distribution over the bay. Frequent passages of cold fronts brought the wind blowing from north or northwest, moved some northern low-salinity reservoir southward and lowered salinity at two northern stations. Due to tidal activity and bottom topography near BBS and BGI station, the salinity at these two stations were not much affected by northerly or northwesterly winds. On the contrary, southerly or southeasterly wind in conjunction with tidal
current increased the salinity over the bay and decreased the salinity difference between southmost station (BWS) and northmost station (BGI).

In spring, the Mississippi River discharge increased and freshwater was delivered out of Southwest Pass of Mississippi Delta and transported to the west under southerly or southeasterly wind condition. In this circumstance, southerly or southeasterly wind increased salinity at two northern stations by push saltwater from the southern bay, and concurrently the wind also brought mixed water into the bay through tidal inlets and then lowered the salinity at two southern stations (BBS & BBN). Additionally, west wind played an important role in spring season which could help lower salinity at northern stations and increased salinity at southern stations.

4.2. Sediment Resuspension and Driving Forces: Spectral density analysis of SSC and wave height at both stations revealed that sediment resuspension and wave height had the same dominant periodicities of 12 days and 5 days (Fig. 3.5). Wind speed spectral analysis result indicated a dominant periodicity of 3-5 days, which corresponded with cold front periodicity (3-5 days) in winter well (Robert et al., 1989). With cold front passage, high wind speed increased wave height in the bay (Fig. 3.1b and Fig. 3.1c) and wave-induced shear stress drove the bottom sediment resuspension. The periodicity of 14 days for wave height and SSC might be associated with spring-neap tidal circle. Additionally, at BBS station, both SSC and wave height had the same periodicity of 1 day which was probably associated with diurnal tide. Based on the spectral density analysis result of water level, two high peaks were observed at 1 cycle/day and 1.08 cycle/day which could be affected by S1 and O1 diurnal tidal constituents. Hence, although tidal range in Louisiana coast normally less than a half
Fig. 4.1. Bottom shear stress in winter period at BBS station (wave-induced shear stress in blue lines, current induced shear stress in red circles).

In order to quantify the main driver of bottom sediment resuspension, besides spectral density analysis, wave-induced and current-induced shear stresses were calculated using linear wave theory and TKE methods. Current-induced shear stress was much higher than wave-induced shear stress though they were in same order of magnitude (Figs. 4.1 and S7). In P1 period, sediment resuspension event (high SSC) happened when SSC reached to 5 g L\(^{-1}\) and wave-current combined shear stress reached to 6 Pa concurrently (Fig. 3.1d and Fig. 3.1e). Wave-induced shear stress should have more impact on this sediment resuspension event based on spectral density analysis that both SSC and wave height had same dominant periodicity of 5 days. However, current-induced shear stress was as much as 5.5 Pa and wave-induced shear stress was only 1.2 Pa (Fig. 4.1), indicating that current-induced shear stress dominated wave-current combined shear stress in
winter observation. In addition, current-induced shear stress can be contributed by wind-driven current and tidal currents. During low-energy wind condition, tidal current was generally the main driver for current-induced shear stress and the shear stresses were normally lower than 0.5 Pa. However, during high-SSC events, current-induced shear stress could reach to 6 Pa indicated that wind-driven current played much more important role in current-induced shear stress. As a result, wind driven current combined with tidal current were the largest drivers of sediment resuspension at BBS station in winter observation. Although Barbé et al. (2000) stated that tidal activities had minor impacts on sediment transport over the bay, our results show that tidal current does play an essential role in sediment transport in southern Barataria Bay, especially the area close to tidal channel.

4.3. Sediment Transport Flux and Direction: Calibrated SSC data from HydroCAT were used for Style-Glenn (SG) model validation. The result indicated a good fit of SSC between model output and observation result at 21 cm and 22 cm above seabed at BBN station in winter and spring, respectively (Figs. 4.2b and 4.2d). All high SSC events were clearly captured by both sensor observation and SG model output in winter and spring at BBN station. Also, sediment profiles in water column were shown in Figs. 4.2a and 4.2c, which were associated with bottom sediment resuspension events in Figs. 4.2b and 4.2d. Model result also showed decent match with time series data at BBS station in both observational periods (S. 8).
Fig. 4.2. Style-Glenn bottom boundary layer model output and observation data at BBN station: (a) water level (1 m was added to the raw data for better view) and time series suspend sediment concentration in water column from model output in winter 2018; (b) benthic suspended sediment concentration at 0.21 m above the seabed (observation results are shown in red dot, while model outputs are shown in black line, grey dash line is the lower limit (0.322 g L\(^{-1}\)) ); (c) water level and time series suspend sediment concentration in water column from model output in spring 2019; (d) suspended sediment concentration at 0.22 m above the seabed (grey dash line is the lower limit (0.223 g L\(^{-1}\))).

To understand sediment transport flux and direction during cold front passage, schematic diagrams were used in Figs. 9 and 10. During P1 period, the cold front started from 19 December 2018 and ended at 24 December 2018, lasting 5 days (Fig. 3.1). Strong wind came from northwest, sediment was transported to the south and east at two stations that indicated sediment loss in the bay. At BBN station, eastward sediment flux was \(5.73 \times 10^5\) kg m\(^{-1}\), while southward sediment flux was \(22.2 \times 10^5\) kg m\(^{-1}\)(Fig. 4.3a). Water was in a lower level at this time (Fig. 4.2a), and weak
southerly wind lasted relative short period comparing with stronger pervasive northerly wind (Fig. 3.1). Thus, much more sediment-laden water was pushed to the south rather than to the north. However, at BBS station, southward flux was lower than BBN station, revealing that tidal current pushed sediment to the north near BBS station.

Fig. 4.3. Schematic diagram of sediment flux over cold front passages: (a) sediment flux at BBN and BBS station over winter cold front from 19 December 2018 to 24 December 2018. Wind direction and intensity are shown as green arrows at left up corner, fluxes are shown as brown arrows; (b) sediment flux at BBN and BBS station over winter cold front from 14 March 2019 to 19 March 2019, wind direction and intensity are shown as green arrows at left up corner, fluxes are shown as brown arrows.

Cold front P4 started from 14 March 2019 to 19 March 2019 and lasted 5 days (Fig. 3.2). During this period, wind came from northeast moved sediment to the southeast at BBN station while to the northwest at BBS station. Wind came from south initially and changed to the north after the wind speed reached to 10 m s\(^{-1}\) with the low water level condition (1.9 m water depth). Hence the net sediment flux during this period were southeastward at BBN station and northwestward at BBS station that probably indicated a clockwise sediment transport direction over the bay. As a result, strong northerly wind would facilitate sediment escape out of bay while
southerly wind together with tidal current could retain sediment in the bay, especially at BBS station.

Besides sediment flux during cold front events, cumulative sediment fluxes in winter and spring were calculated with the entire depth-integrated flux as well. Considering the shape of the bay, northward net sediment transport flux was beneficial to sediment retention in the bay, conversely, southward net sediment transport flux provided the opportunity for sediment escaping out of the bay which could lead to sediment loss. Hence, north-southward net sediment transport fluxes were our focuses during winter and spring. In winter, it displayed southeastward net sediment flux at BBS station and the net southward sediment flux was 152.9 MT m$^{-1}$ (Fig. 4.4c). At BBN station, net sediment flux was shifted from southeast to northeast (Fig. 4.4b) and net northward sediment flux was 13.16 MT m$^{-1}$. In spring, it showed net southwestward sediment flux at BBN station and net southwestward sediment flux at BBS station. Net southward sediment flux at BBN station was 2.88 MT m$^{-1}$

Most cold front events in winter began with southerly wind (southwesterly, southerly and southeasterly) and then shifted to northerly wind that moved sediment to the south, leading to possible sediment escape. However, if the pre-front southerly wind lasted long enough, such as the cold front events at P2 and P3, though the wind direction changed to the north finally, the sediment flux at BBN station was northward and kept the sediment in the bay. In spring observation, wind condition was normally weaker than in winter and wind initially came from southwest or southeast and then changed to the northwest and northeast, respectively. Under the wind blew from east to northeast condition, sediment fluxes at both stations were southeastward. When wind came from northeast sediment fluxes at BBN and BBS were southwestward, and flux at BBS station was higher than BBN station might be due to the longer fetch.
In winter observational period, high wind speed event (P1) with short pre-front period (several hours) moved the sediment to the south at both stations. However, longer pre-front period (one day) with southerly wind could make sediment transport to the north, even the dominant wind direction was northerly during two events at BBN station (P2 and P3). At BBS station, sediment fluxes were southward during P2 and P3, indicating that BBN station was sensitive to the duration of southerly pre-event wind than the BBS station. In addition, BBS station always lost sediment during strong northerly wind events in winter. Relative similar phenomenon was also observed during spring observation that short southerly pre-events wind

Fig. 4.4. (a) Winter wind direction and speed from USGS stations at Barataria Pass, LA; (b) winter deployment at BBN. Cumulative sediment flux for the entire water column (positive northward net transport in magenta line, positive eastward net transport in blue line); (c) winter deployment at BBS.
could not generate strong enough northward sediment flux that could counteract southward sediment flux induced by northerly wind during the events (P4 and P5). Even longer pre-event (2-3 days) southerly wind (P6) transported the sediment to the north at both stations during a lower high northerly wind speed event (wind speed < 10 m s\(^{-1}\)). Rotary sediment fluxes were captured during P7 and P8 (Fig. 4.5a). Sediment flux was northward initially with southwesterly pre-event wind and changed to the southeast with northwesterly wind. Although pre-event southerly wind lasted one and half day, longer period (two days) of northerly wind during the event transported sediment back to the south and made the sediment loss in the bay.

![Graphs showing wind direction and sediment flux](image)

**Fig. 4.5.** (a) Spring wind direction and speed from USGS stations at Barataria Pass, LA; (b) spring deployment at BBN. Cumulative sediment flux for the entire water column (positive northward net transport in magenta line, positive eastward net transport in blue line); (c) spring deployment at BBS.
Additionally, wind direction also affected water level over the bay. Under pre-front southerly wind condition, wind was blowing from south to north and piled up the water in the northern bay, thus increased the water level during P2 and P3 (Fig. 4.4) which was beneficial for sediment retaining to the northern marsh edge of Barataria Bay. Conversely, northerly wind pushed the water southward and lowered the water level in the bay, inhibiting any wetland sedimentation. Hence, long-lasting northerly wind would not only move sediment out of the bay but also decrease the water level, both of which cause possible sediment escape out of Barataria Bay (Fig. 4.4).

For the coastal bay with river direct input, such as Fourleague Bay, LA, Perez et al. (2000) illustrated that highest SSC events occurred with cold front passage and continuous source of sediment input from Atchafalaya River, while in spring season with highest river discharge, net sediment transport flux was exported to the Gulf of Mexico. Wang et al. (2018) also reported that sediment resuspension in Fourleague Bay was mainly caused by wind-driven waves and river discharge together with wind direction (especially wind speed > 3 m s⁻¹) dominated the direction of net sediment transport flux.

**4.4. Implication and Future Work:** Land loss was threatened by natural and anthropogenic factors globally. Sediment diversion reintroduces the sediment-laden river to adjacent basin to build new land and can be a useful method to save our coast. Our observational results indicated that wind and tide together played important roles in sediment transport. Before Mid-Barataria Bay sediment diversion is implemented, marsh edges erosion and Davis Pond freshwater diversion were two only sediment sources to the bay. At BBS station, northly wind had relatively small impact on southward sediment flux due to strong tidal current. Mississippi River plume could indirectly impact the salinity distribution over the bay when it is in a flooding
stage and the plume is impacted by south or southeasterly wind. In winter, wind-driven current and tidal current could affect salinity distribution and the salinity difference among four stations from north to south. Groundwater seepage from the Mississippi River channel to Barataria Bay was not measured in this study, but more data are needed to quantify the indirect impact of the Mississippi River on salinity in Barataria Bay. Additionally, our ADV data showed that local morphology, such as tidal channel, could strengthen tidal current and further influence the sediment dynamics in BBS station.

Hydrodynamics and sediment dynamics data in Barataria Bay are important for future diversion implementation. These data can help our scientific community to better understand when and how long the diversion should be open and what strategies can be used to maximize sediment retention. Timing of diversion openings, orientation of receiving basins, dominant wind directions and water levels should be considered in the planning and management of future sediment diversions in coastal areas. During pervasive southerly wind, high tide and high-water level conditions, the net sediment flux will be transported northward which is the best timing for sediment diversion opening in Mid-Barataria that would have the highest efficiency for sediment to be sustained in the bay. Our results also show the nonlinearity and complexity of sediment transport during events P1-P8; sediment transport directions and fluxes can change greatly from one cold front to another. Our data also can help to validate and calibrate numerical models which can then be used to better understand the temporal and spatial variations in the whole bay. Future field observations are still necessary even after sediment diversion implementation, and new data can be used to access the impact of diversion on water quality, hydrodynamics and sediment transport.
Chapter 5. Conclusions

Barataria Bay is a dynamic system and close interactions between hydrodynamics and sediment dynamics were observed from in-situ observational data. Multiple major findings were described below.

(1) Salinity at Barataria Bay was mainly controlled by wind pattern in winter, the minimum salinity difference among four stations occurred with pervasive southerly wind and the maximum salinity difference happened with strong northerly wind during cold front passage. In summer, freshwater released by Mississippi River could be transported to the west with Louisiana circulation during easterly wind condition, and then could be transported into the bay through tidal inlets and lowered the salinity at southern stations.

(2) Wind-driven current-induced shear stress played the most important role in bottom sediment resuspension during cold front events.

(3) With strong northerly wind during cold front passage, the bay kept losing sediment at both BBN and BBS stations. however, long-duration pre-front southerly wind could reverse this condition at northern station that would be beneficial for sediment retaining to the north with northward net sediment transport flux.

(4) Sediment transport direction could be rotary with strong pre-frontal southeasterly wind and multi-intensified northwesterly wind that shifted net sediment transport flux from northwestward to southeastward. More observational data are needed to study the nonlinearity and complexity of sediment transport in Barataria Bay.
Supplementary Materials

Before the first deployment, ADV-Ocean probe was accidentally broken and needed to be sent back to Sontek for repairs. Thus, an alternative ADV-Argonaut was used to replace ADV-Ocean. Based on the ADV-Argonaut measurement mechanisms, data collecting frequency was 0.2 Hz and sampling length was 2 minutes per hour. Because of memory space limitation, ADV-Argonaut cannot save burst details, and only 5-second averaged data could be stored on installed memory card. After repairing, ADV-Ocean sensors were used on both tripods during second deployment.

In addition, over the second half of spring observation, the current data were influenced by serious biofouling. Although we used 30 SNR (signal noise ratio) as a threshold for de-spiking, the data quality still weak and poor.

S. 1. Turbidity calibration by a quadratic regression model. x axis shows the turbidity in NTU and y axis shows the corresponded SSC in mg L\(^{-1}\). The regression model indicates the relationship between NTU and suspended sediment concentration at Barataria Bay North (BBN) station during first deployment period from December 10th 2018 to February 5th 2019.
S. 2. Turbidity calibration by quadratic regression model, x axis shows the turbidity in NTU and y axis shows the corresponded SSC in mg L\(^{-1}\). The regression model indicates the relationship between NTU and suspended sediment concentration at BBN station during the second deployment period from March 5th to May 5th 2019.

\[ y = 0.0196x^2 + 15.209x \]
\[ R^2 = 0.9571 \]

S. 3. Turbidity calibration by quadratic regression model, x axis shows the turbidity in NTU and y axis shows the corresponded SSC in mg L\(^{-1}\). The regression model indicates the relationship between NTU and suspended sediment concentration at Barataria Bay South (BBS) station during first deployment period from December 10th 2018 to February 5th 2019.

\[ y = 0.0626x^2 + 18.645x \]
\[ R^2 = 0.9883 \]
S. 4. Turbidity calibration by quadratic regression model, x axis shows the turbidity in NTU and y axis shows the corresponded SSC in mg L$^{-1}$. The regression model indicates the relationship between NTU and suspended sediment concentration at Barataria Bay South (BBS) station during the second deployment period from March 5th to May 5th 2019.

\[ y = 0.0375x^2 + 25.292x \]

\[ R^2 = 0.9821 \]

S. 5. Sediment grain size distribution at BBN and BBS station (analysis from in-situ sediment samples collections).
S. 6. Sediment grain size distribution in Barataria Bay. Data source: usSEABED.

S. 7. Comparison of wave-induced and current-induced shear stress at BBS in spring. Calculation was based on the method as Fig. 4.1.
S. 8. Style-Glenn bottom boundary layer model output and observation data at BBS station: (a) water level (1 m was added to the raw data for better view) and time series suspend sediment concentration in water column from model output in winter 2018; (b) benthic suspended sediment concentration at 0.21 m above the seabed (observation results are shown in red dot, while model outputs are shown in black line, grey dash line is the lower limit (0.322 g L\(^{-1}\)) ; (c) water level and time series suspend sediment concentration in water column from model output in spring 2019; (d) suspended sediment concentration at 0.22 m above the seabed (grey dash line is the lower limit (0.223 g L\(^{-1}\))).
References


Vita

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