Exploring hydrodynamics to examine the impact of hurricanes on the morphological changes of deltaic wetlands: the Wax Lake Delta, Louisiana

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Objective

Wetlands act as a first buffer zone for the inland against coastal storms. Accordingly, wetlands get (partial) inundated, causing morphological changes. In this study we examine the hydrodynamic impact of hurricanes to determine morphological changes of wetlands during extreme events.

Introduction

Hurricanes and associated winds, waves and surges pose a threat to nearby coastal zones, humans and their properties. Coastal wetlands have been acknowledged to play an important role in protecting the inland against hurricane disasters. By doing so, hurricanes can significantly affect wetlands morphology. Accompanied salinity expansion may also influence fauna survival rates of wetlands, especially for the freshwater species, making wetlands more vulnerable to near-future large climatic events. To better understand the impact of hurricanes on deltaic wetlands, we apply Delft3D to the Wax Lake Delta under various scenarios.

Study area: the Wax Lake Delta (WLD)

The WLD, a typical river-dominated deltaic system, belongs to the Mississippi River Delta System. It is low-elevated, fast prograding delta and vulnerable to coastal disturbances. The delta is exposed to winter storms and hurricanes. Freshwater wetlands are widely distributed, as the fresh river input dominates the study area under normal conditions. The strong hydrodynamics and corresponding salinity changes during Hurricane Rita (2005) significantly impact the wetlands of WLD.

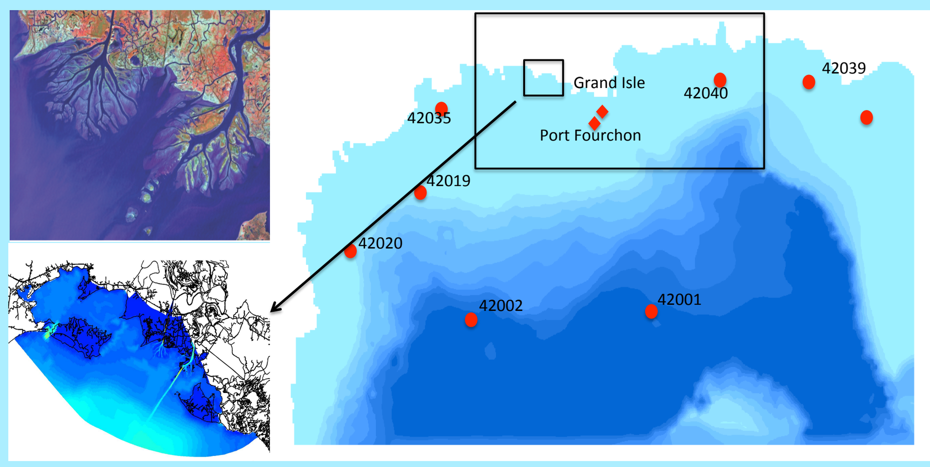

Fig. 1. Nested model area. The right figure shows the biggest modeled area (GoM); the two small black boxes show smaller modeled areas. Red dots indicate NOAA wave buoys stations, red diamond points show water level observation stations. Upper left shows the Landsat image of the Atchafalaya-Wax Lake Delta System and the lower left shows the bathymetry of the WLD model

Method

We applied a numerical model Delft3D (flow, wave, and morphology) (Lesser, et al., 2004). Model setup:

- Domain: three nested spatial domains (GoM, Mississippi, and Atchafalaya, Fig. 1)
- Case study: hurricane Rita (2005, highest wind: 285 km/h)
- Aboveground 3D plants: represented as cylinders
- Root impact: simulated by increasing bed shear stress for erosion
- Individual factor's impact: numerical experiments (see table 1, based on hurricane Rita)
- Residual current and sediment transport: low frequency filter method

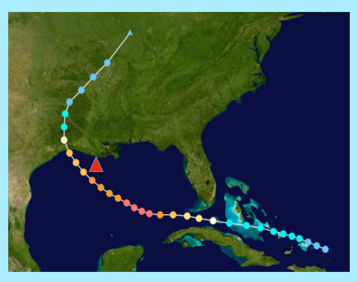

Fig. 2. Hurricane Rita Track

Hurricane Tracks		River		Waves		Vegetation	
Direct landfall	Side hit	River input	Non river	SWAN coupled	No wave	Aboveground	Aboveground and roots
EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8

Table 1. Parameter settings for numerical experiments

Model validation

We compared simulations with observed water level and wave parameters (Fig. 3). The comparison show that the model is able to capture the storm surges of hurricane events, and produce realistic wave fields.

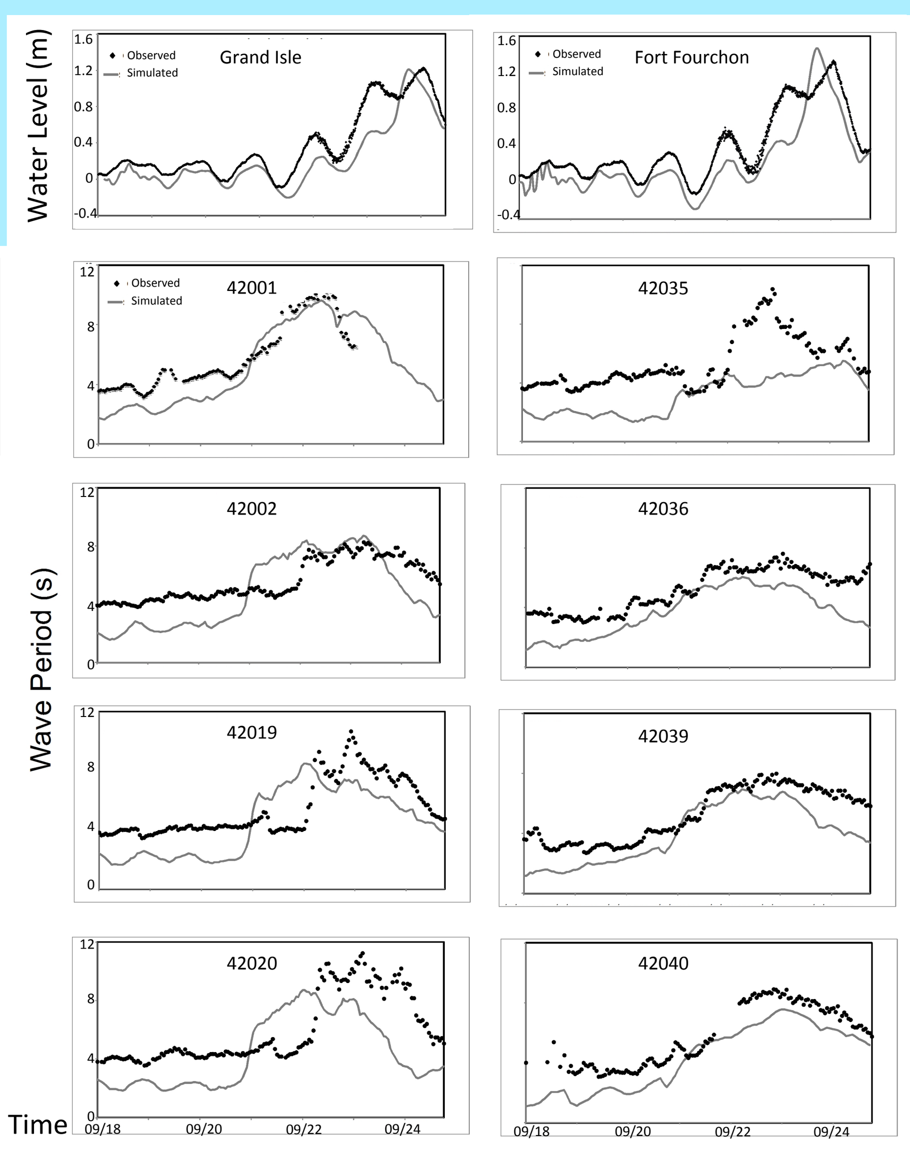
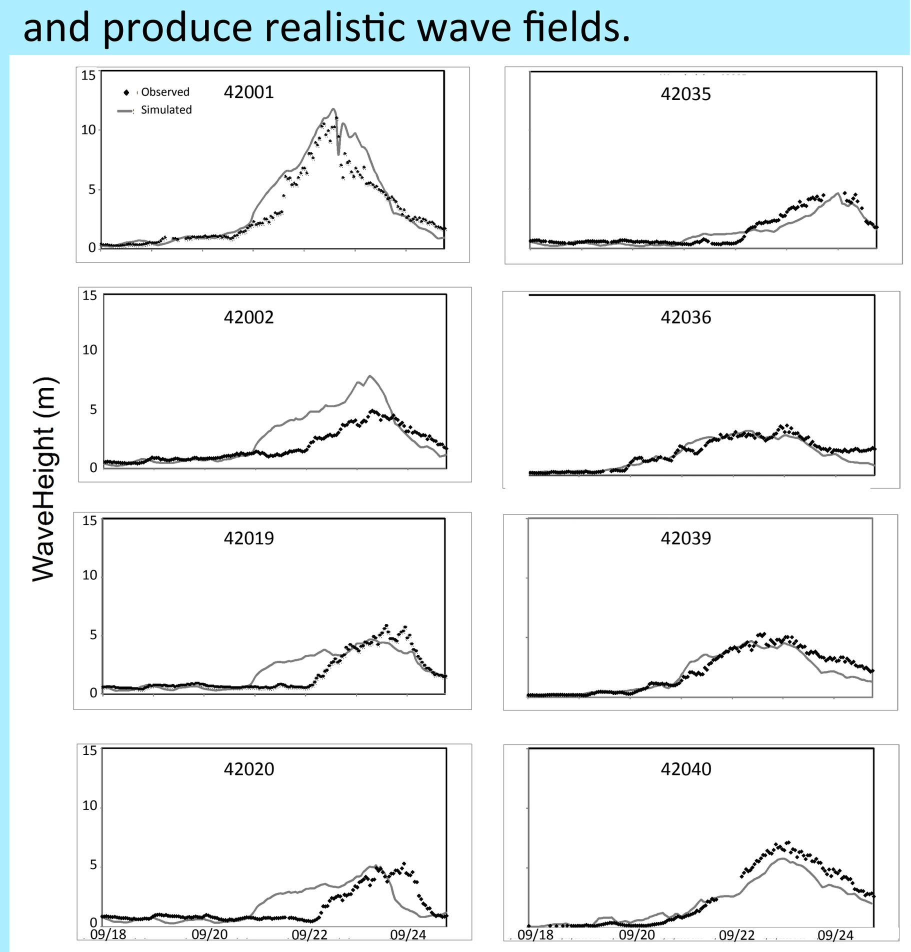

Fig. 3. Comparison of modeled and simulated water level (m) at Louisiana, significant wave height (m) and wave periods (s) at NOAA buoys stations.

Results

Hydrodynamics during hurricane Rita

The WLD is a fast progradating system due to high fluvial sediment and a relatively weak oceanographic environment. That condition alter during hurricanes and winter cold fronts season. Table 2 and Figure 2 show the immense difference in water level (surges), velocity and significant wave height under normal and hurricane conditions.

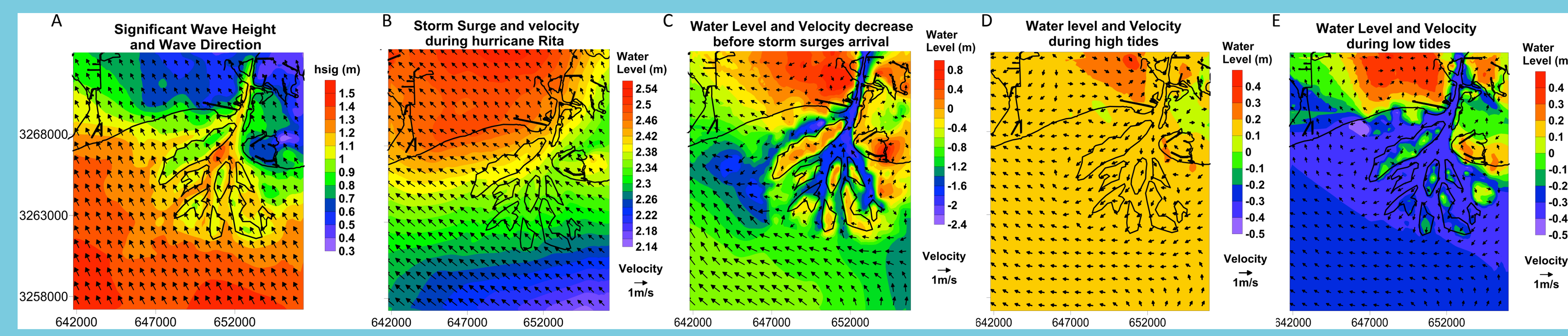

Fig. 4. A: significant wave height and direction; B: storm surge and velocity at the height water level point during hurricane Rita; C: water level and velocity at the lowest water level time point before storm surge; D and E show water level and velocity at the high and low tides conditions.

	Water level (m)	Velocity (m/s)	Wave height (m)
Normal	+/- 0.5	0.5	0.5
Hurricane	+/- 2.5	1.5	1.6

Table 2. Comparisons of water level, velocity and wave height under normal and hurricane conditions

Salinity expansion and morphological changes

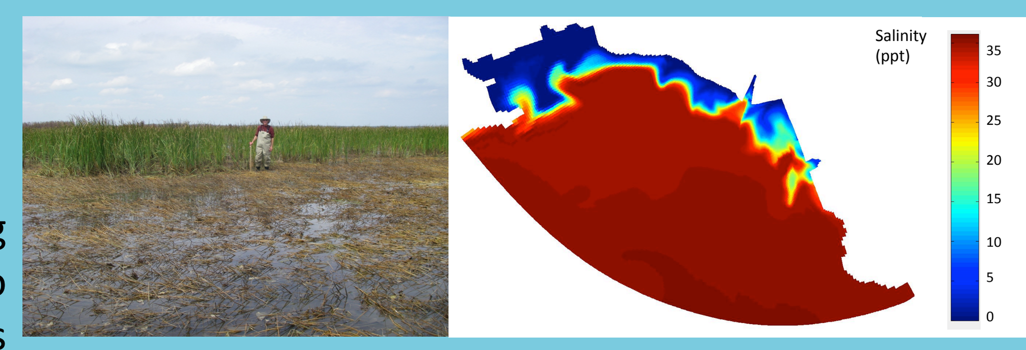

Fig. 5. Left: Freshwater wetlands devastation after hurricane Ike (2008); Right: Simulated saline water spreading during Hurricane Rita (2005).

The simulation results show that during Hurricane Rita, saline water spreads onto the coastal marshes, and expands upstream through the river channels and flooding of the wetlands. The salinity in the river channels decreases quickly after the surges due to fresh water input. However, saline water on the wetlands stays for a longer time, impacting the freshwater fauna survival rate (Fig. 5).

Figure 6 shows the morphological changes of the deltaic area after hurricane Rita. Channels are deposited and shallow islands are eroded, due to increased wave shear stress of shallow area. This pattern is opposite to the observed sedimentation pattern during river floods (Shaw and Mohrig, 2014).

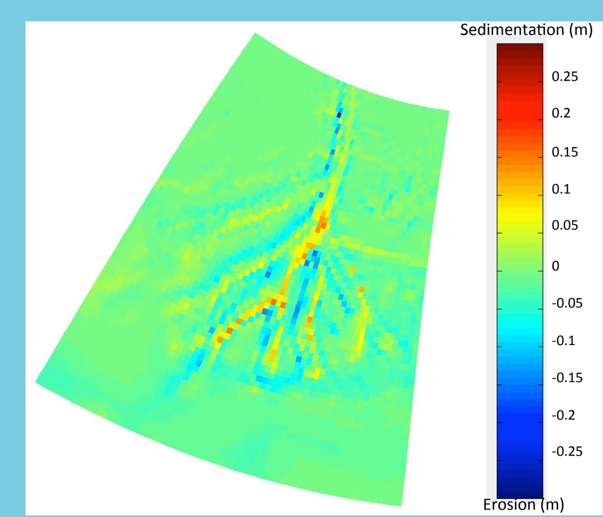

Fig. 6. Sedimentation-erosion pattern on the Wax Lake Delta area after Hurricane Rita.

Residual current and sediment transportation

The direction of residual current is towards northwest during hurricane Rita, following the wind direction (Fig. 7). The net sediment flux in/out of the deltaic area is acquired through calculating the net sediment flux at the four boundary profiles. The results show that 384,101 m^3 sediment flows into the deltaic area, which is 20 times the amount of averaged annual river sediment input during the same time period.

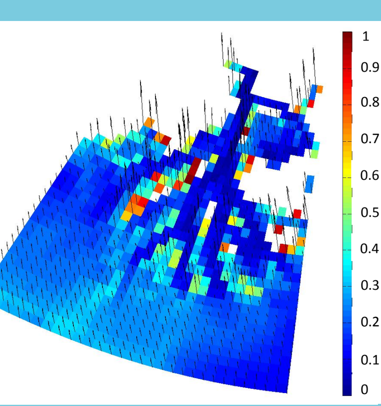

Fig. 7. Residual current (m/s) distribution on the deltaic area

Numerical experiments: hurricane tracks, waves, vegetation

The comparison of EX1 and EX2 shows that when a hurricane makes landfall at the study area more sediment is left on the delta (464,290 vs. 384,101 m^3). However, the residual current is lower compared to the side track (Fig. 8A, B). EX3 and EX4 show that the river acts negatively in transporting water and sediment during hurricane events (464,290 vs. 603,890 m^3, Fig. 8B,C). EX5 and EX6 demonstrate that waves play a significant role in forming the pattern of deposition in river channels and erosion on shallow islands (Fig. 8D). When aboveground vegetation is included in the simulation (EX7, Fig. 8E), the vegetated islands are less eroded, and there is less deposition in the channels. EX8 shows the impact of roots on protecting wetlands from erosion (Fig. 8F).

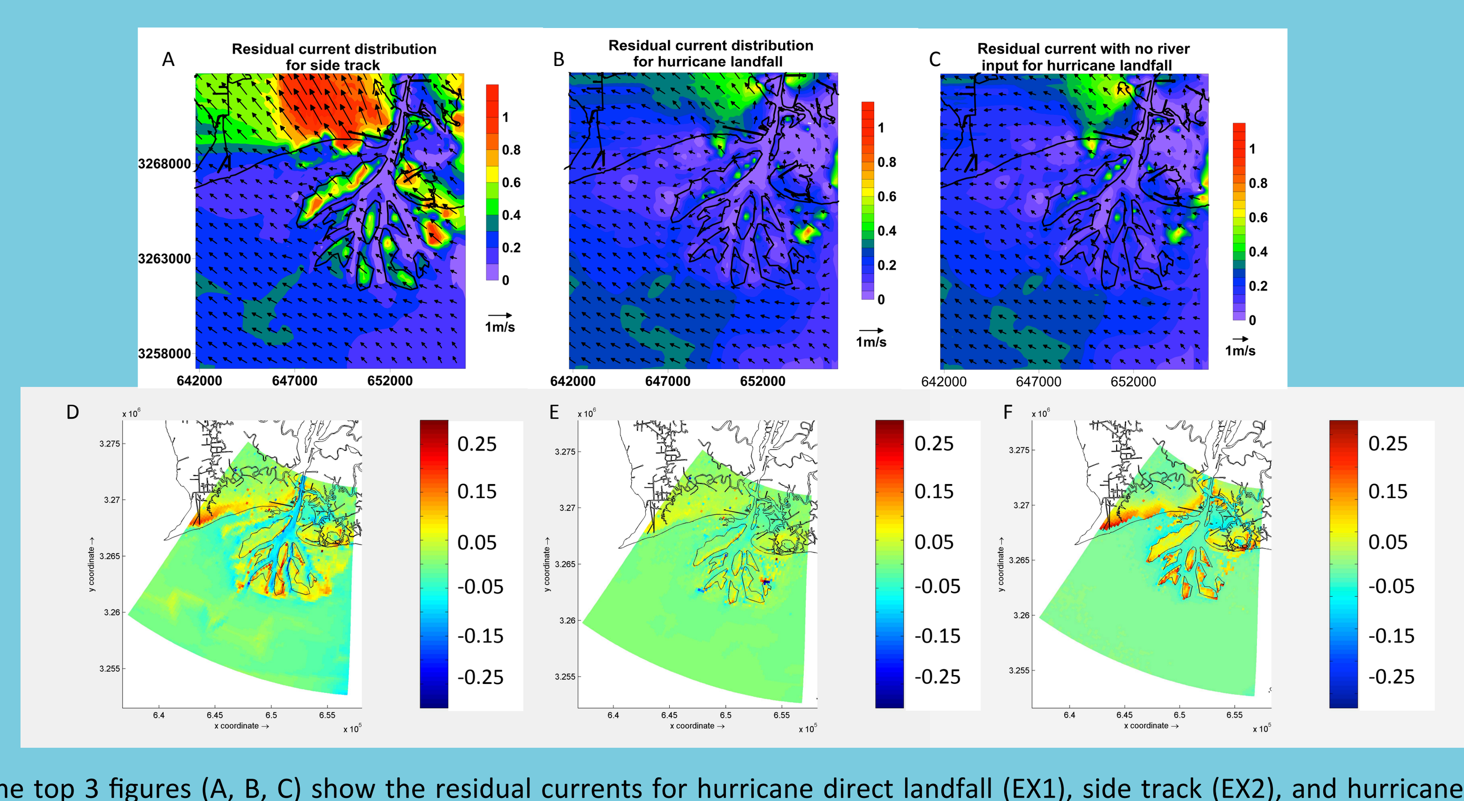

Fig. 8. The top 3 figures (A, B, C) show the residual currents for hurricane direct landfall (EX1), side track (EX2), and hurricane simulation based on EX1 without river input (EX4); the bottom 3 figures (D, E, F) show the sedimentation pattern influenced by waves (EX5-EX6), aboveground vegetation (EX7-EX2), and roots (EX8-EX2).

Conclusions

- Hurricanes produce extreme hydrodynamics on deltaic wetlands. For the WLD, shallow islands are eroded and deep channels are deposited, which is opposite to river floods.
- Residual current flows towards northwest and transports 384,101 m^3 sediment to the deltaic area, which is 20 times the amount of annual-averaged river sediment input over the same time span.
- Hurricanes spread saline water to the coastal zone, which might significantly influence the survival rate of wetlands fauna species.

Acknowledgements

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