Exploring the Impacts of Hurricanes and Cold Fronts on the Morphological Evolution of the Wax Lake Delta, LA

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Introduction

Hurricanes and winter cold fronts both cause deposition and erosion on the Louisiana wetland coast. Unknown is the importance of these extreme events on the morphological evolution of a river-dominated delta. We apply Delft3D to investigate the influences of hurricanes and cold fronts on the Wax Lake Delta (WLD, Fig. 1). WLD is low-elevated, fast prograding and vulnerable to coastal disturbances. The delta is exposed to frequent cold fronts in winter (20 – 30 times per year) and episodic hurricanes in summer and autumn (16 major hurricanes potentially affected this area between 1941 and 2008).

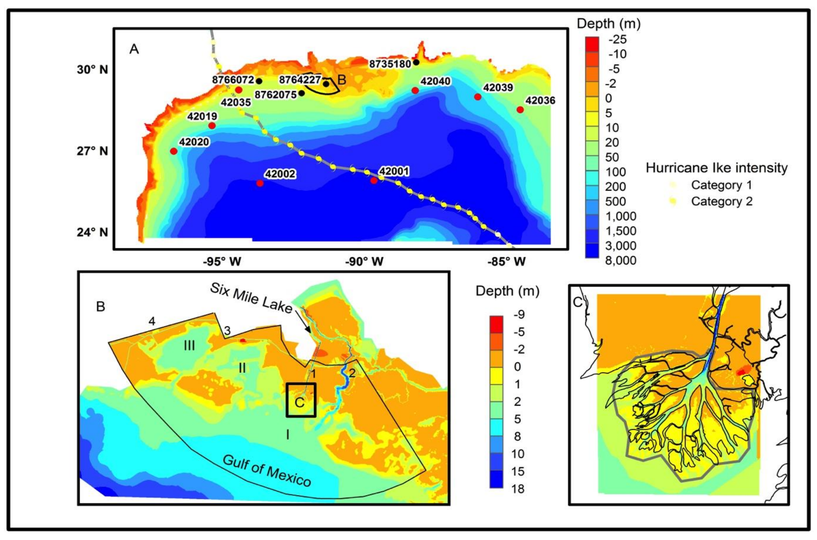


Fig. 1. Bathymetry and topography of model domains: A) Gulf of Mexico domain, with the track of Hurricane Ike. B) and C) show the detailed bathymetry and topography of the Atchafalaya and the Wax Lake Delta domains. The grey line in C) defines the area of interest for the sediment balance.

Method and Model Validation

The hydrodynamic model system Delft3D (flow, wave, and morphology) is applied to 2 hurricanes in 2008 (Gustav and Ike) and 11 cold fronts during 2008 – 2009 season (29 events with available winds out of 41 events, Fig. 2). Results are compared with observed storm surges and wave parameters (Fig. 3, 4). The model captures both the storm surges and wave fields during hurricane and cold front events.

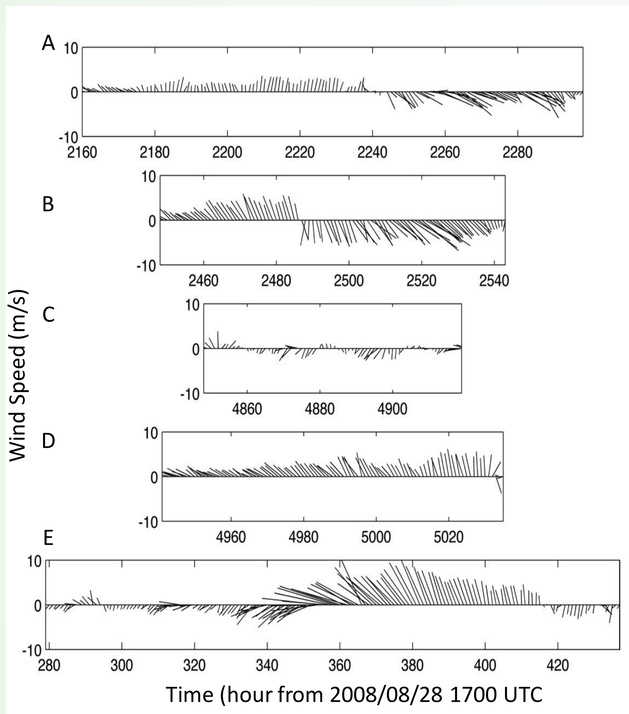


Fig. 2. Wind structures: A) typical cold; B) strong cold front; C) minor cold front with offshore winds; D) cold front with onshore winds; E) Hurricane Ike.

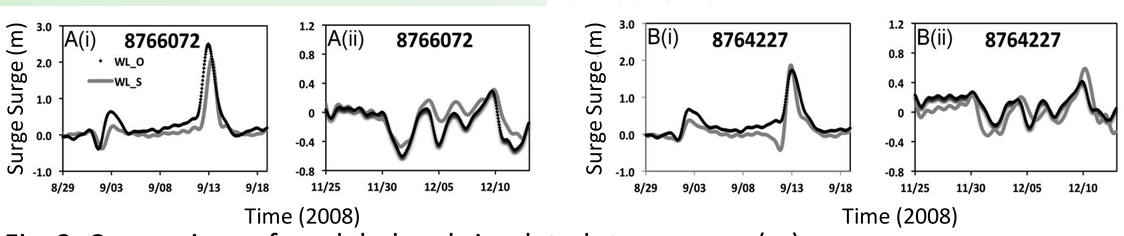


Fig. 3. Comparison of modeled and simulated storm surge (m).

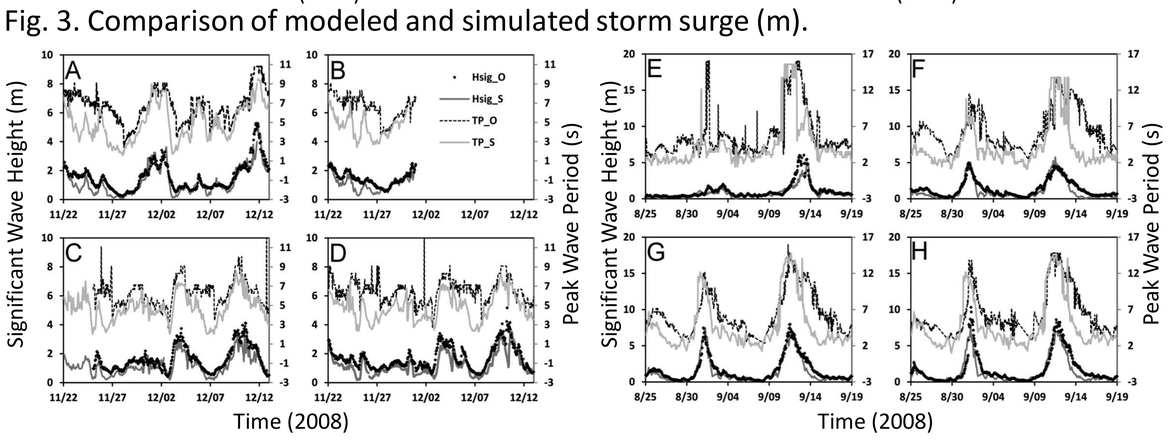
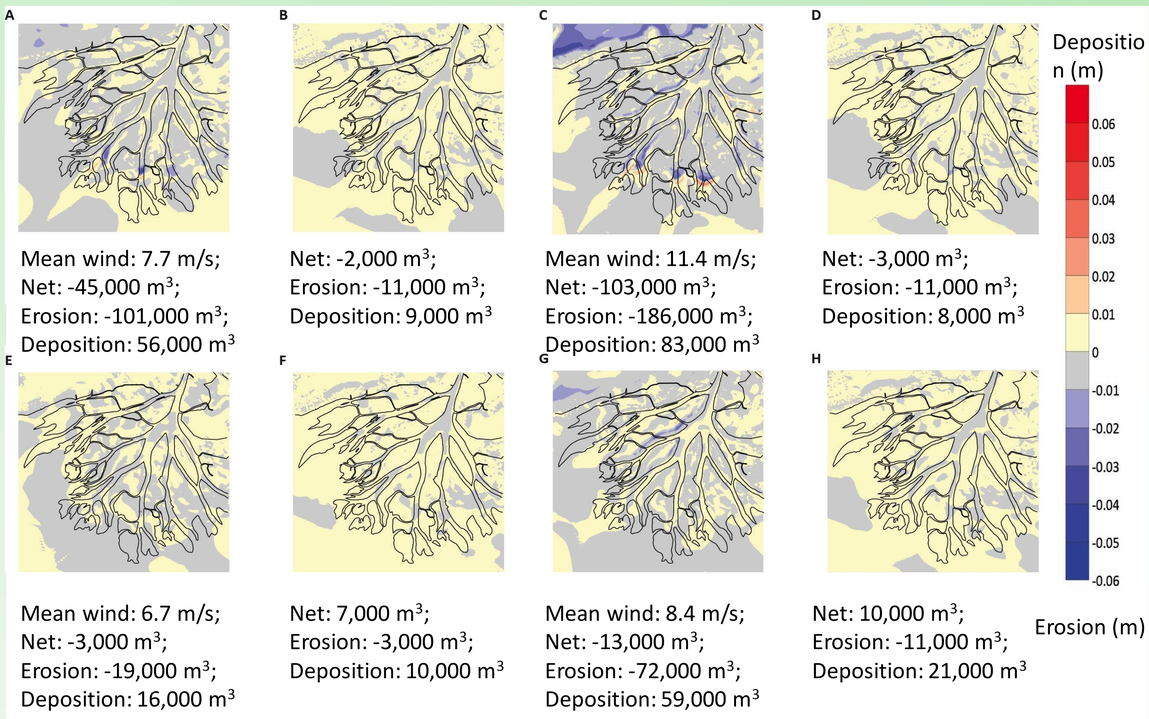


Fig. 4. Comparison of modeled and simulated significant wave height (m) and wave periods (s) at NOAA buoys stations.

Delta's responses to cold fronts and hurricanes

Both hurricanes and cold fronts cause erosion on the WLD (Fig. 5, 6). Morphological changes vary according to wind structures and speeds (Fig. 3, 5). Mean wind speed is critical in controlling sediment transport (Fig. 5) and abrupt water level variations favor sediment transport (Fig. 5). Hurricane Ike produced significant sediment transport within a short period (Fig. 6D). Winds and waves intensify residual currents and sediment transport (Fig. 6). Channels are dominated by deposition, distinct from the erosional pattern during the cold front (Fig. 5C) and river floods, demonstrating marine forces outweigh fluvial forces during Hurricane Ike. The strong downstream flow caused by fluvial forces and offshore winds produces significant erosion in channels and deposition at the delta front for both cold front 11 and Ike.



Mean wind: 7.7 m/s; Net: -45,000 m³; Erosion: -101,000 m³; Deposition: 56,000 m³
Net: -2,000 m³; Erosion: -11,000 m³; Deposition: 9,000 m³
Mean wind: 11.4 m/s; Net: -103,000 m³; Erosion: -186,000 m³; Deposition: 83,000 m³
Net: -3,000 m³; Erosion: -11,000 m³; Deposition: 8,000 m³
Mean wind: 6.7 m/s; Net: -3,000 m³; Erosion: -19,000 m³; Deposition: 16,000 m³
Net: 7,000 m³; Erosion: -3,000 m³; Deposition: 10,000 m³
Mean wind: 8.4 m/s; Net: -13,000 m³; Erosion: -72,000 m³; Deposition: 59,000 m³
Net: 10,000 m³; Erosion: -11,000 m³; Deposition: 21,000 m³

Fig. 5. Morphological changes and sediment balance during A) cold front **CF 9** including winds and waves; B) **CF 9** excluding winds and waves; C) **CF 11** including winds and waves; D) **CF 11** excluding winds and waves; E) **CF 20** including winds and waves; F) **CF 20** excluding winds and waves; G) **CF 21** including winds and waves; H) **CF 21** excluding winds and waves.

Model Uncertainty

36 simulations explore the uncertainty related to grain size, critical shear stress for mud erosion (Cr_{ERO}) and deposition (Cr_{SED}), using the Latin hypercube sampling method (Stein 1987). Spatial uncertainty follows the pattern of morphological changes: uncertainty is high where more morphological changes occur (Fig. 5, 6). Model uncertainty varies with the event magnitude; higher for Hurricane Ike than the cold front 11 (Fig. 6). Events should be evaluated for specific hydrodynamic conditions.

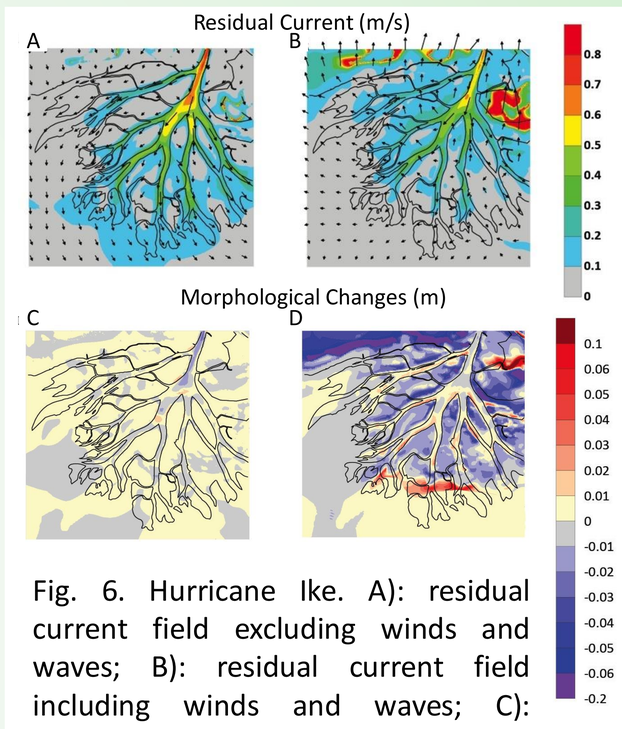


Fig. 6. Hurricane Ike. A): residual current field excluding winds and waves; B): residual current field including winds and waves; C): sedimentation-erosion pattern excluding winds and waves; D): sedimentation-erosion pattern including winds and waves.

Importance of Hurricanes and Cold Fronts on Morphology

11 events during the 2008 – 2009 season are simulated to analyze the statistical features of cold fronts and their influences on delta evolution. Simulations show winds and waves significantly increase sediment erosion and deposition; the rates of erosion and deposition are positively correlated to mean wind speeds; R^2 = 0.94 and 0.81 for erosion and deposition, respectively (Fig. 7A, 7B). We estimate that 1,900,000 m³ of sediment would be transported out of the WLD area during the cold front season, significantly more than the sediments removed by hurricanes (500,000 m³).

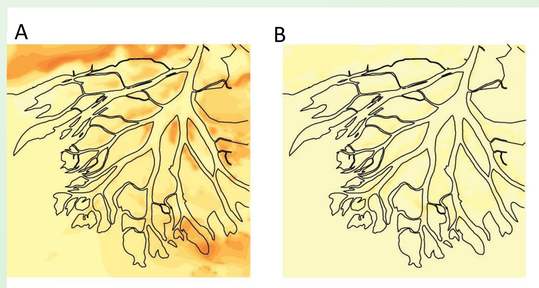


Fig. 7. Spatial distribution of model uncertainty during Hurricane Ike (A) or cold front event 11 (B).

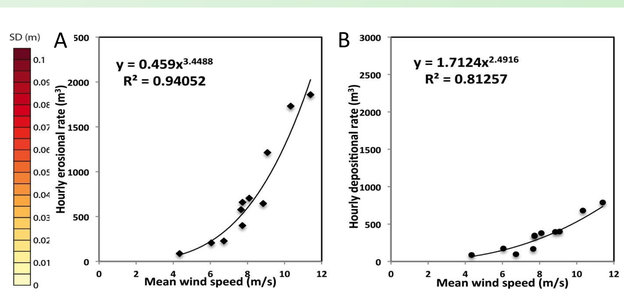


Fig. 8. Relationship between mean wind speeds (m/s) and hourly erosion and deposition caused by winds and waves.

Conclusions

Hurricanes and cold fronts cause erosion on islands; opposite to river floods. Hurricane Ike caused deposition in channels, distinct from the erosional pattern for river floods and cold fronts— winds & waves outweigh fluvial forces. Cold front erosion is caused by mean wind speeds and water level variations. Although hurricanes cause more sediment transport in a shorter time, frequent cold fronts are more critical in determining long-term morphological changes of the WLD system.

Acknowledgements

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