Non-linear Interaction between Cold Front Induced Storm Surge and Tides in a Shallow Bayhead Delta

Sajjad Feizabadi[1], Chunyan Li[1], and Matthew Hiatt[1]

[1]Department of Oceanography & Coastal Sciences and Coastal Studies Institute, Louisiana State University

February 15, 2024

Abstract

Atmospheric cold fronts are frequently occurring perturbations to the northern Gulf of Mexico coastal region. Given the low-lying elevations in this region and the connectivity between distributary channels and deltaic wetlands, the nonlinear interplay between the cold frontinduced storm surge and tidal oscillations are likely important hydrodynamic processes regulating circulation and sediment dynamics. This study uses the Delft3D Flexible Mesh numerical modeling suite to assess the water level fluctuations resulting from the non-linear interaction between cold front induced storm surge and tidal oscillations in Wax Lake Delta (WLD) between December 2022 and January 2023. The WLD is a small, dynamic sub-delta located in Louisiana, USA, known for its ongoing progradation. The primary focus of this study lies on analyzing two cold fronts that approach from the northwest direction. The results illustrate that within the shallow, vegetated wetland interiors with spatially-variable inundation, the water level fluctuations resulting from non-linear interaction can exceed four times the water depth, while the variations relative to the water depth in the relatively deep primary channels are insignificant. Analysis for two cold fronts from the northwest and further numerical experiments revealed that the water level variation response to the non-linear interaction between the cold front storm surge and tides is predominantly influenced by the intensity of the cold front and the magnitude of the tidal range. This study emphasizes the notable impact of the non-linear interaction between cold front and tide on water level variation, which, in turn, influences inundation extent, sediment transport, and ecological factors in the WLD.

AGU 2023, H51N-1280, San Francisco

Link: https://agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1293693

Non-linear Interaction between Cold Front Induced Storm Surge and Tides in a Shallow Bayhead Delta

Sajjad Feizabadi [a], Chunyan Li [a], Matthew Hiatt [a]

[a] Department of Oceanography & Coastal Sciences and Coastal Studies Institute, Louisiana State University, Baton Rouge, LA, USA

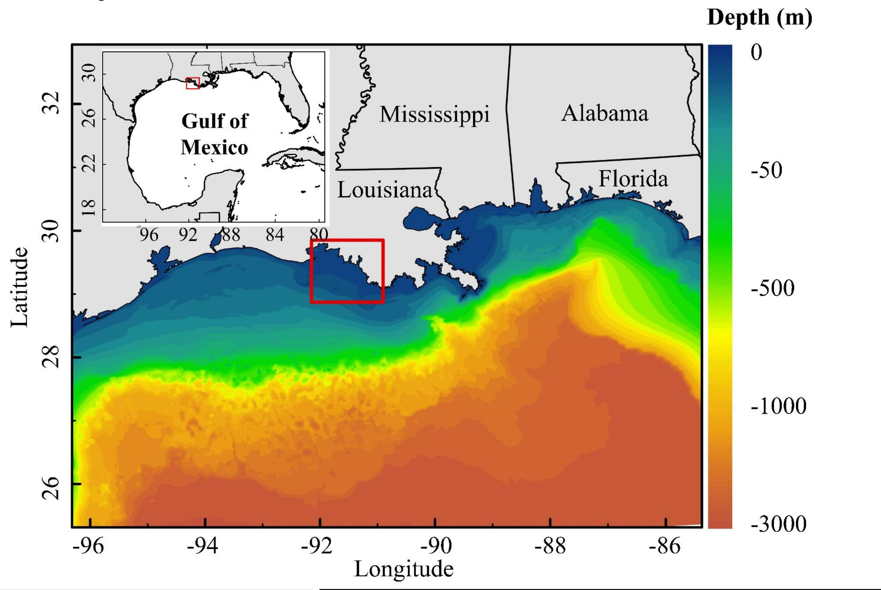
H51N-1280

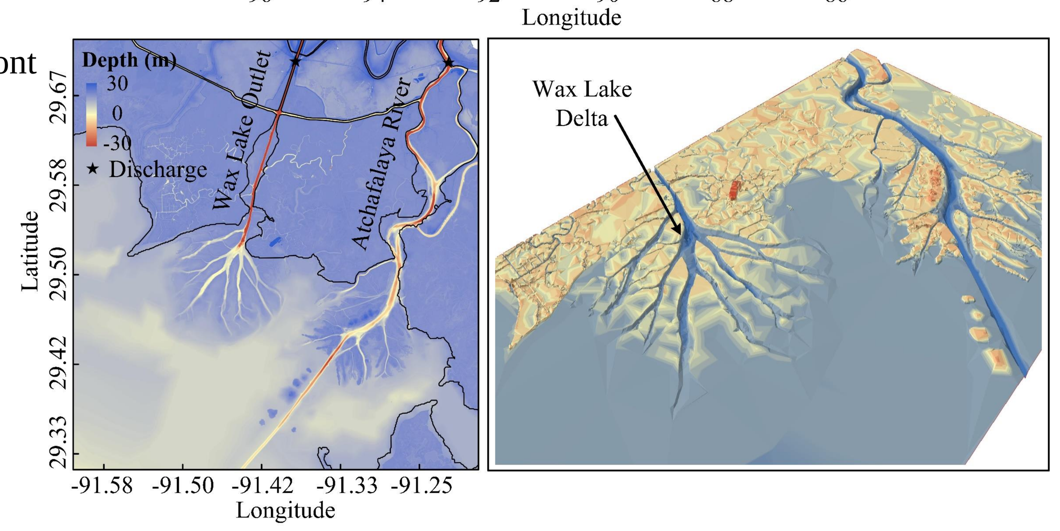
Introduction

This study aims to assess the water level fluctuations resulting from the non-linear interaction between cold front-induced storm surge and tidal oscillations in Wax Lake Delta (WLD). The WLD is a very shallow delta with a high elevation-to-depth ratio and thus high non-linearity.

Wax Lake Delta:

- is a prograding and river-dominated delta situated in the Atchafalaya Basin,
- with annual flow rate of 2,500 m^3s^{-1} and peak flows exceeding 5,000 m^3s^{-1},
- receives approximately 10-12% of the total discharge from both the Mississippi and Red Rivers,
- encounters an average of 41 ± 5 cold front passages every year with an average interval of 3-7 days from September through the subsequent May.





Methods

Preliminary Diagnosis of Non-linearity:

Hypothesis 1: Different cold fronts result to different non-linearity.

Hypothesis 2: The role of tidal amplitude is fundamental in non-linearity. Model results are used to diagnose and verify hypothesizes.

Tool - Model:

Delft3D Flexible Mesh

Time:

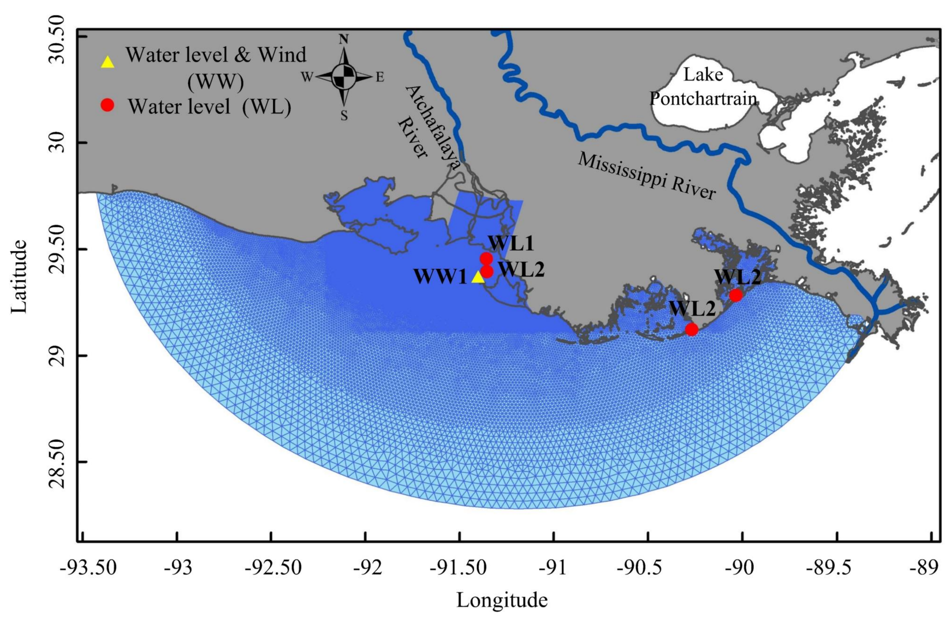
from December 2022 to January 2023

Grid Model:

consists of 1,542,859 grid cells, raging from 5000 m to 30 m.

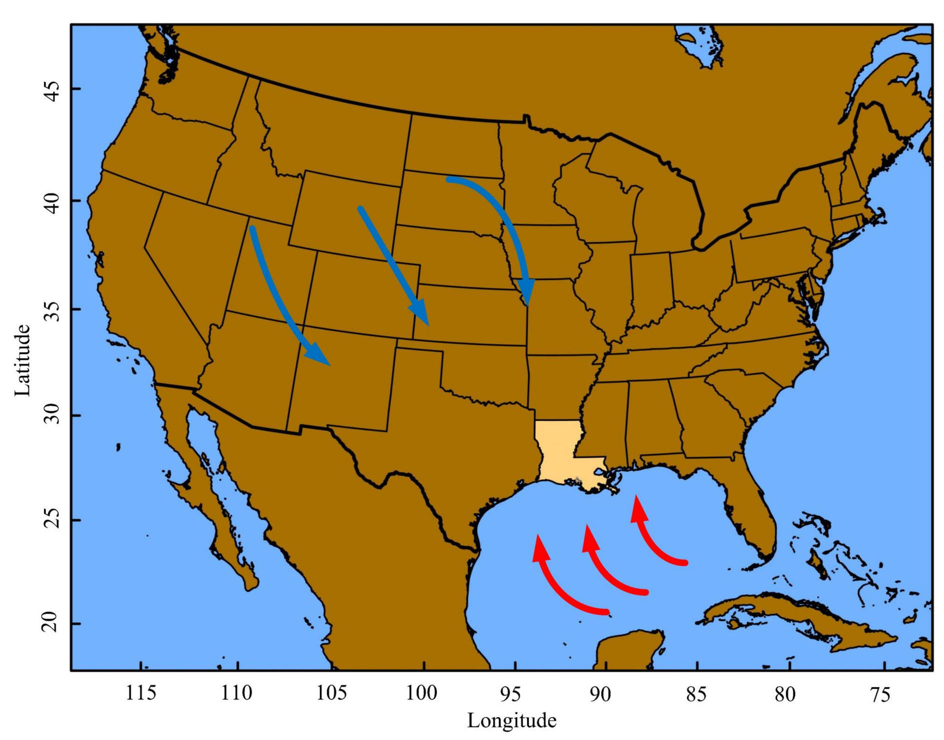
Validation & Calibration:

Five water level stations



Cold Front:

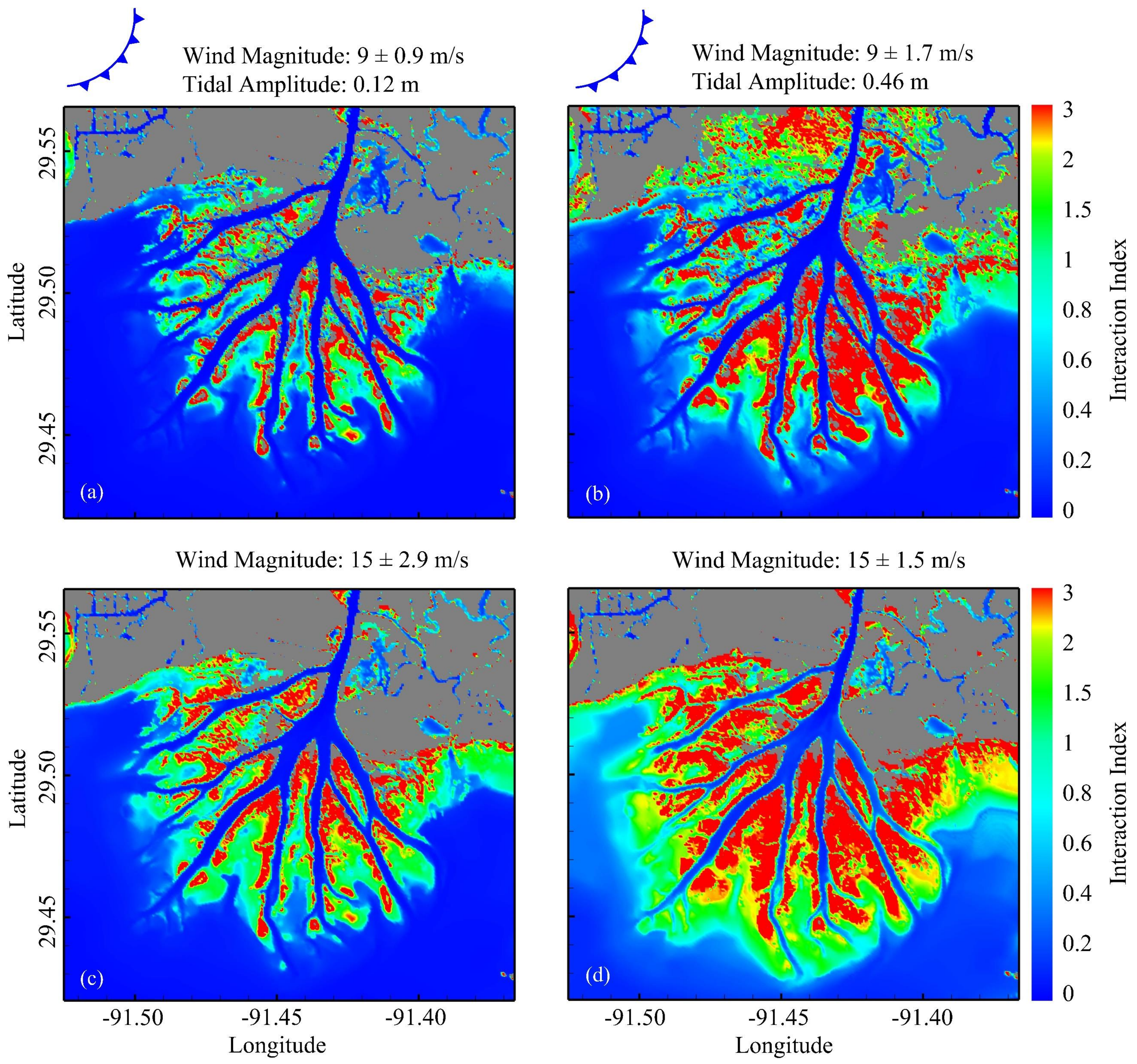
- First cold front:
  - Northwesterly
  - from 12/22/2022 to 12/24/2022
  - average speed: 10.4 ± 2 $m\,s^{-1}$
- Second cold front:
  - Northwesterly
  - from 01/13/2023 to 01/14/2023
  - average speed: 9.1 ± 0.9 $m\,s^{-1}$



Results

Actual Cold Fronts: the non-linear interaction between two northwesterly cold front-induced storm surge and tidal oscillations

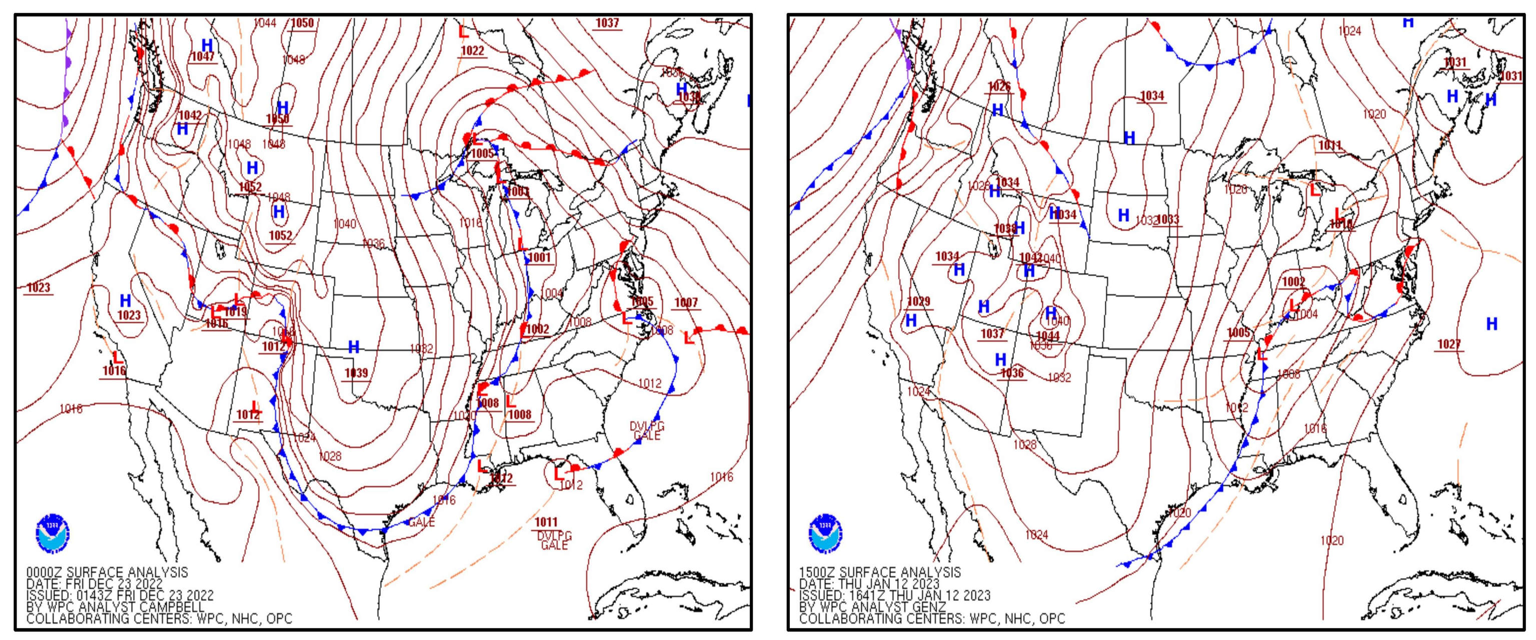
$$Interaction\ Index = \frac{Maximum\ amplitude\ of\ water\ level\ oscillation\ induced\ by\ non\_linear\ interactions}{Average\ Depth}$$



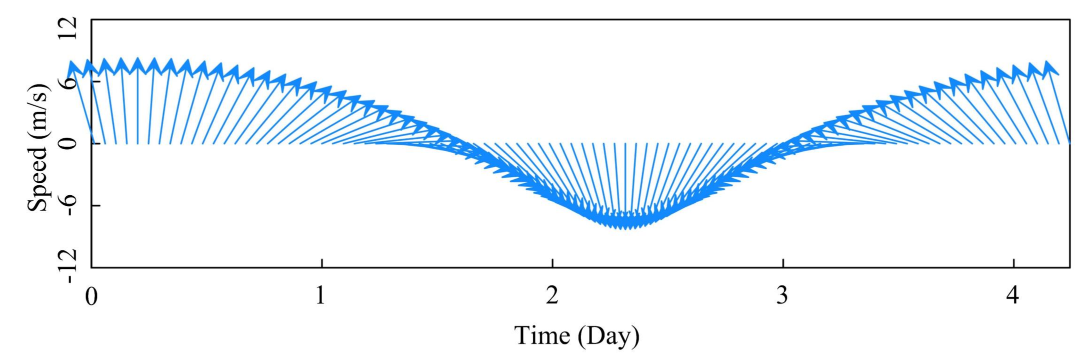
To establish a basis for comparison, the average wind velocities for two observed cold fronts were normalized to 9 m/s and 15 m/s, as shown in the above figure. The data reveals that the Interaction Index exceeds a threshold value of 4 in the shallow regions of the floodplains. In contrast to primary channels, where the Interaction Index is noted to be significantly lower.

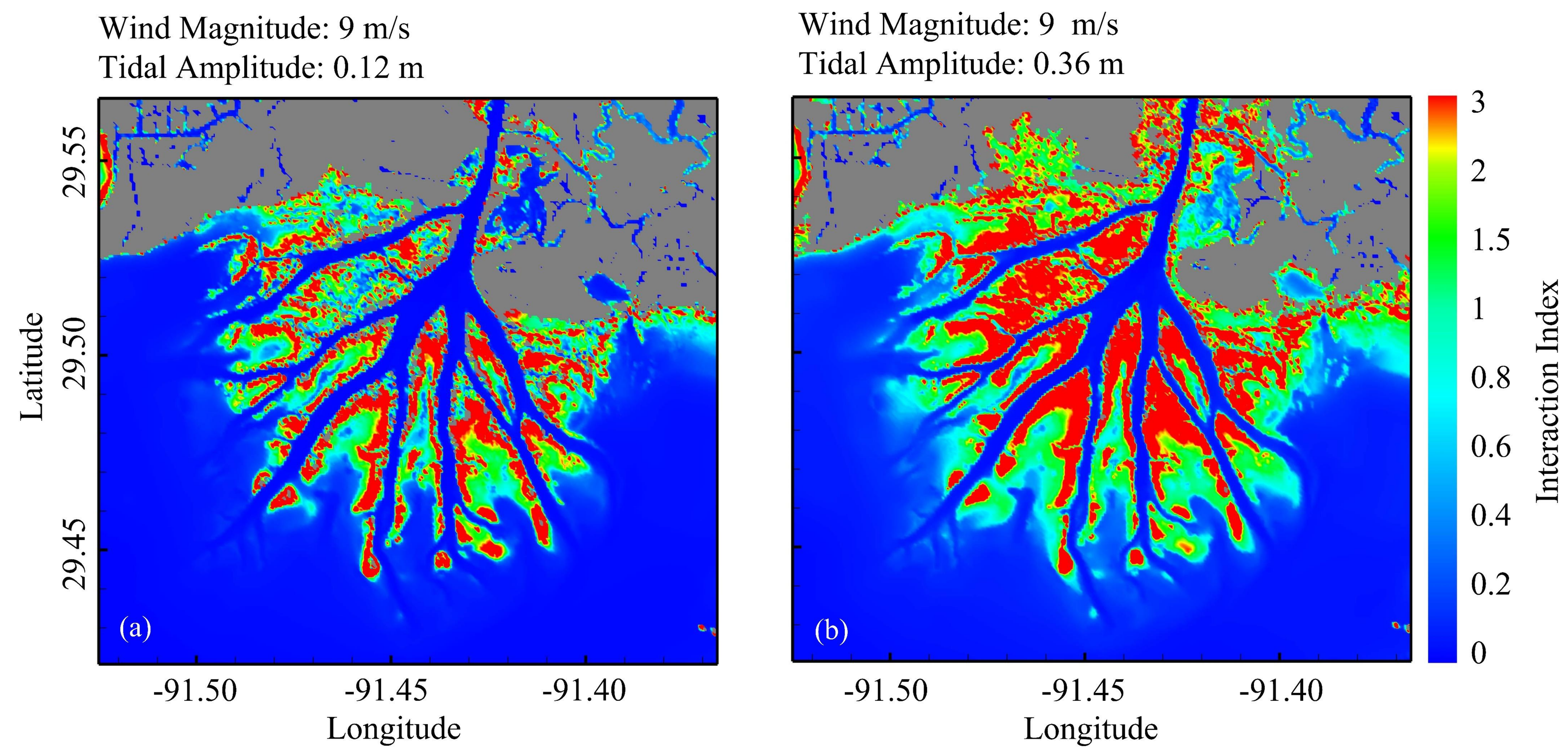
First Cold Front

Second Cold Front



Experimental Analysis: the non-linear interaction between an idealized cold front-induced storm surge and different tidal amplitudes,





The analysis of the interaction between an idealized cold front moving at a speed of 9 $m\,s^{-1}$ and two different tidal amplitudes, 0.12 meters and 0.36 meters, reveals that an increase in tidal amplitude correlates with a rise in the interaction index.

Conclusion

- The water level fluctuations resulting from non-linear interaction can exceed four times the water depth within the shallow wetland interiors, while the variations relative to the water depth in the relatively deep primary channels are insignificant. It represents the high non-linearity in shallow regions.
- The water level variation response to the non-linear interaction between the cold front storm surge and tides is predominantly influenced by the intensity of the cold front and the magnitude of the tidal range. Water level fluctuations exhibit a positive correlation with both the speed of cold fronts and the amplitude of tidal currents.
- Results emphasize the notable impact of the non-linear interaction between cold front and tide on water level variation, which, in turn, influences inundation extent, sediment transport, and ecological factors in the WLD.

Acknowledgment

This research was supported by the National Science Foundation (EAR-2023443), and partially supported by the Gulf of Mexico Coastal Ocean Observing Systems and NOAA Cooperative Agreement #NA16NOS0120018 and #NA21NOS0120092.