Hurricane Generated Wave Loading on Coastal Bridges

LTRC Research Project

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Ocean Engineering Associates., Inc.

Presentation Outline

- Introduction
  - Hurricane damage to roadways and bridges
- Storm surge and wave atlas for Louisiana Coastal Waters
  - Approach
    - Storm hindcasts
    - Extreme value analyses
  - Presentation of results

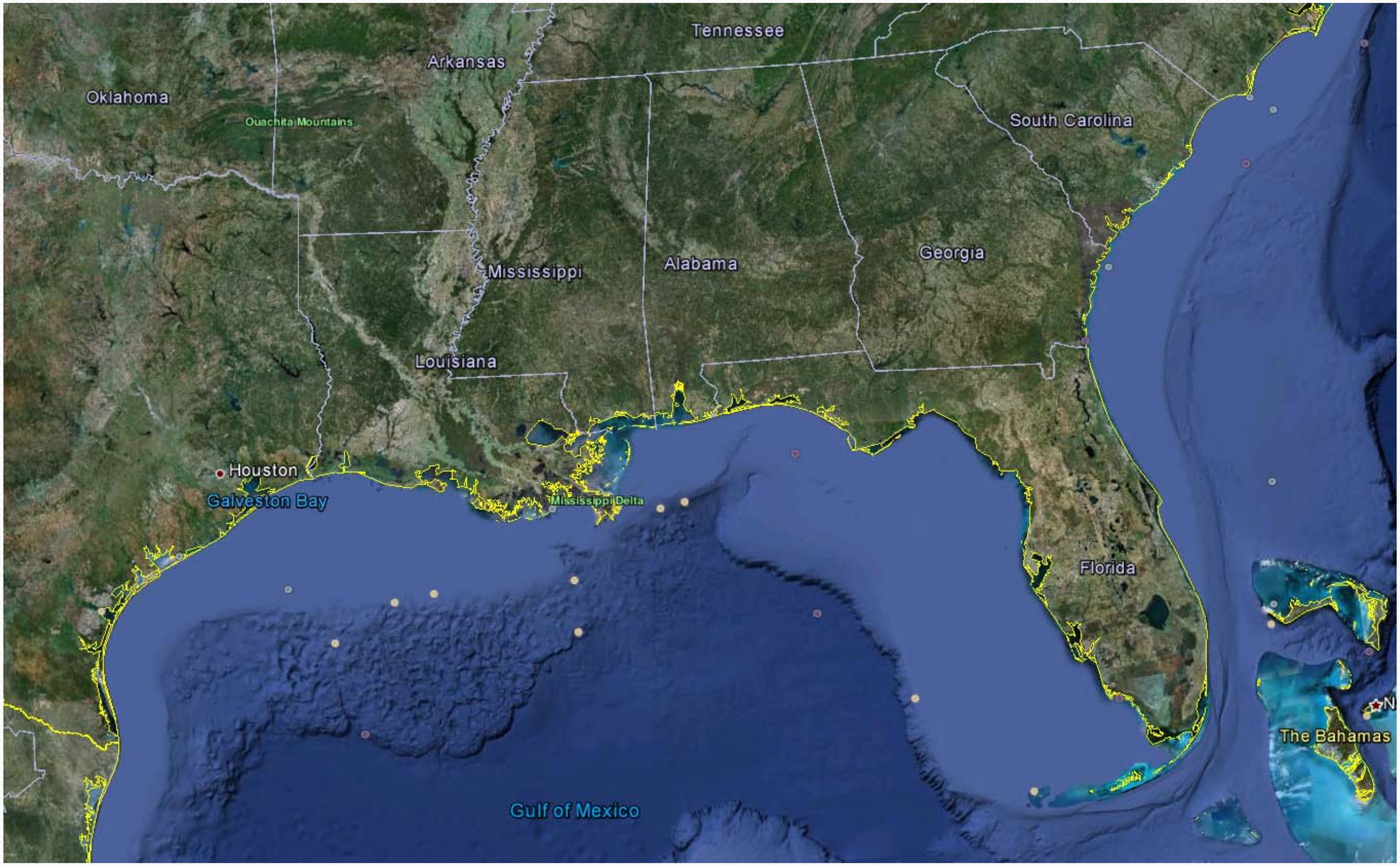
Presentation Outline (cont.)

- Surge/Wave loading on coastal bridges
  - Initial screening
  - Met/Ocean parameters
  - Structure parameters
  - Force – Moment calculations AASHTO code
  - Vulnerability
- Future design challenges
- Summary

Introduction

- Hurricane damage to transportation
  - Hurricane Ivan (2004)
    - I-10 Escambia Bay Bridge
    - Santa Rosa Island
  - Hurricane Katrina (2005)
    - US-90 Biloxi Bay Bridge
    - US-90 Saint Louis Bay Bridge
    - I-10 Lake Ponchartrain

Gulf of Mexico States



Bridge Failures

I10 Bridges over Lake Pontchartrain
New Orleans, LA

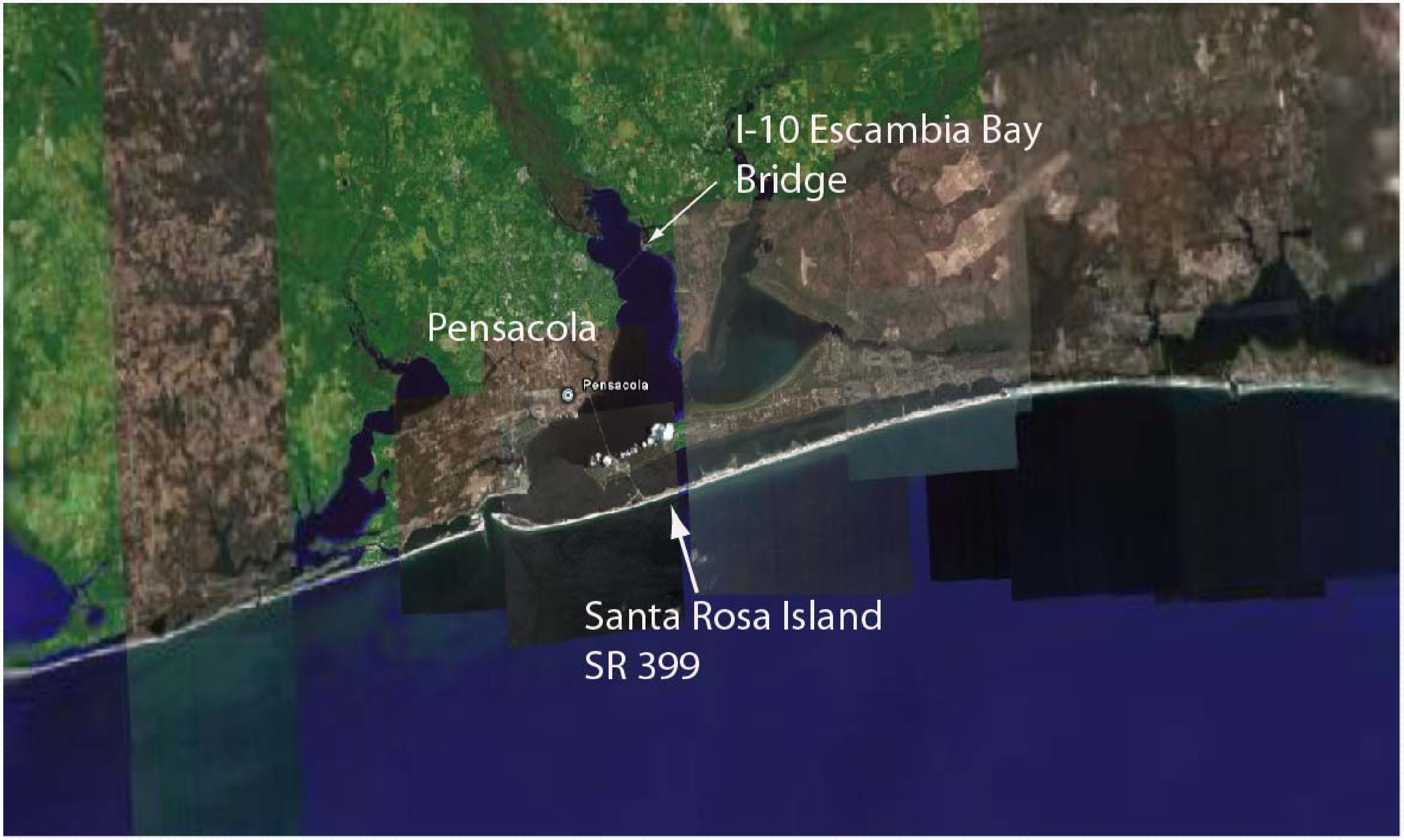
Bridge Failures

Pensacola, FL

Bay Saint Louis, MS

Biloxi, MS

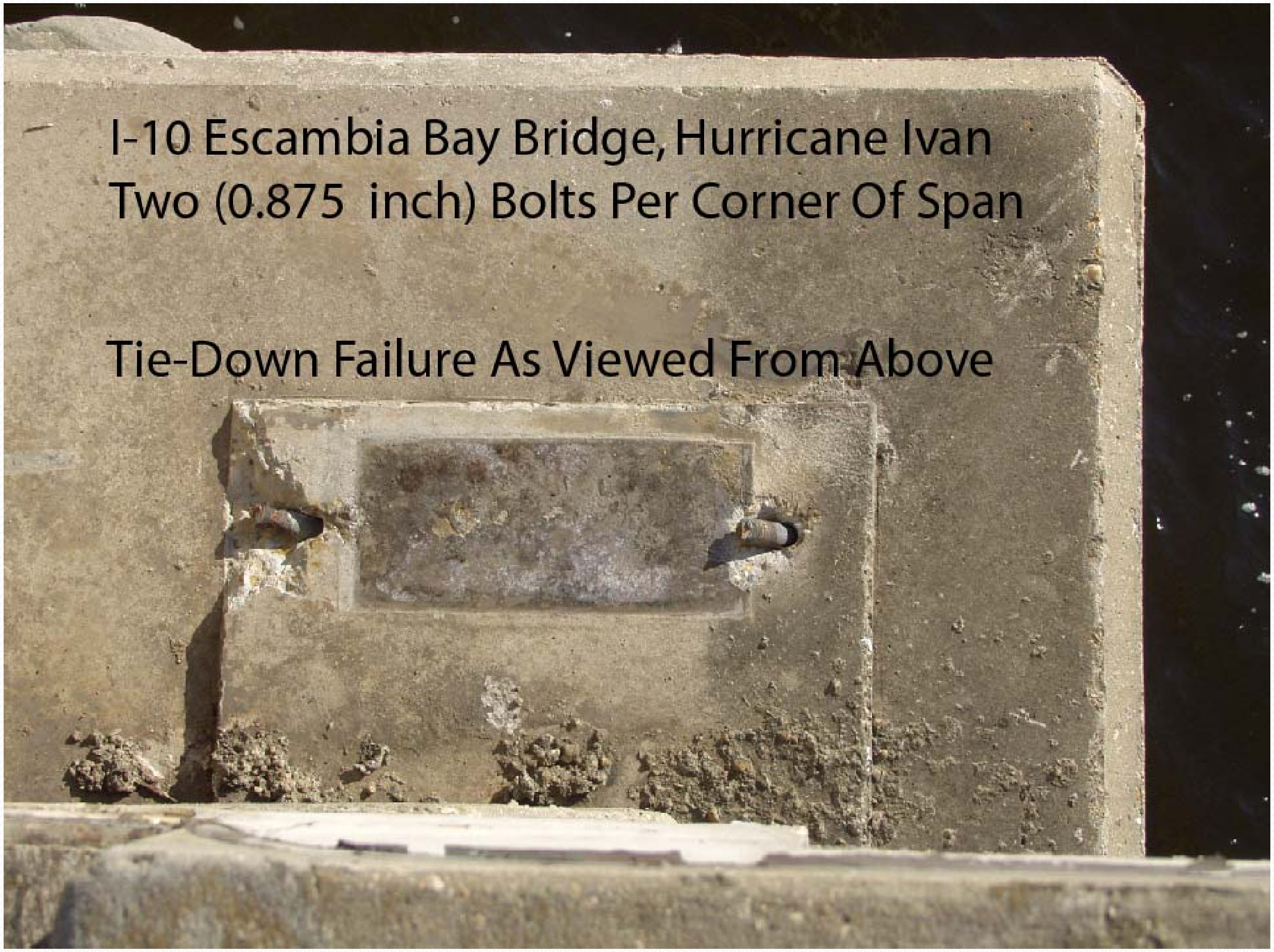
Biloxi, MS

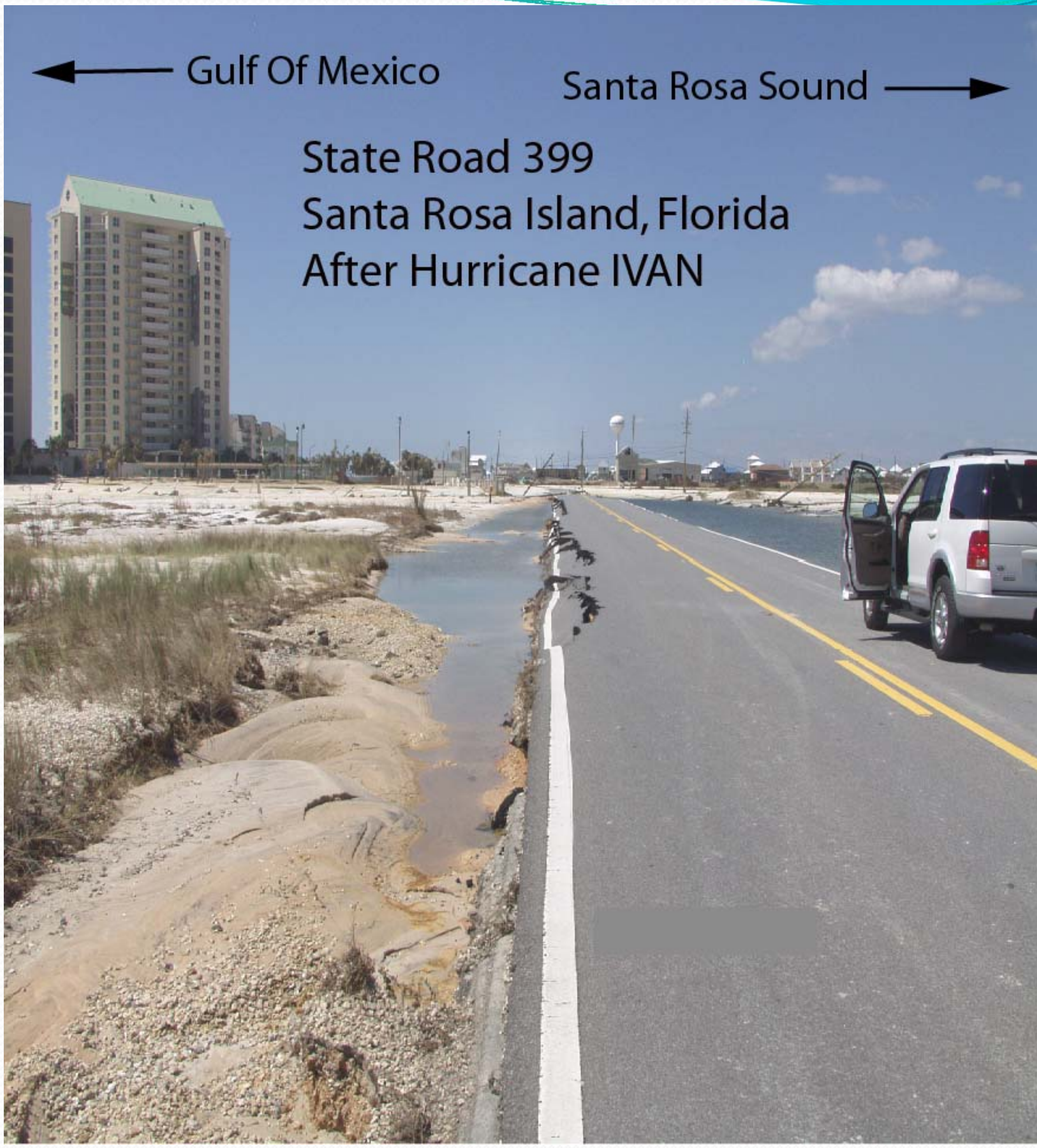

I-10 Escambia Bay Bridge
Pensacola
Pensacola
Santa Rosa Island
SR 399

I10 – Escambia Bay Bridge
East Abutment, West Bound Lane

Bridge Failures

I10-Escambia Bay Span Tie-Down



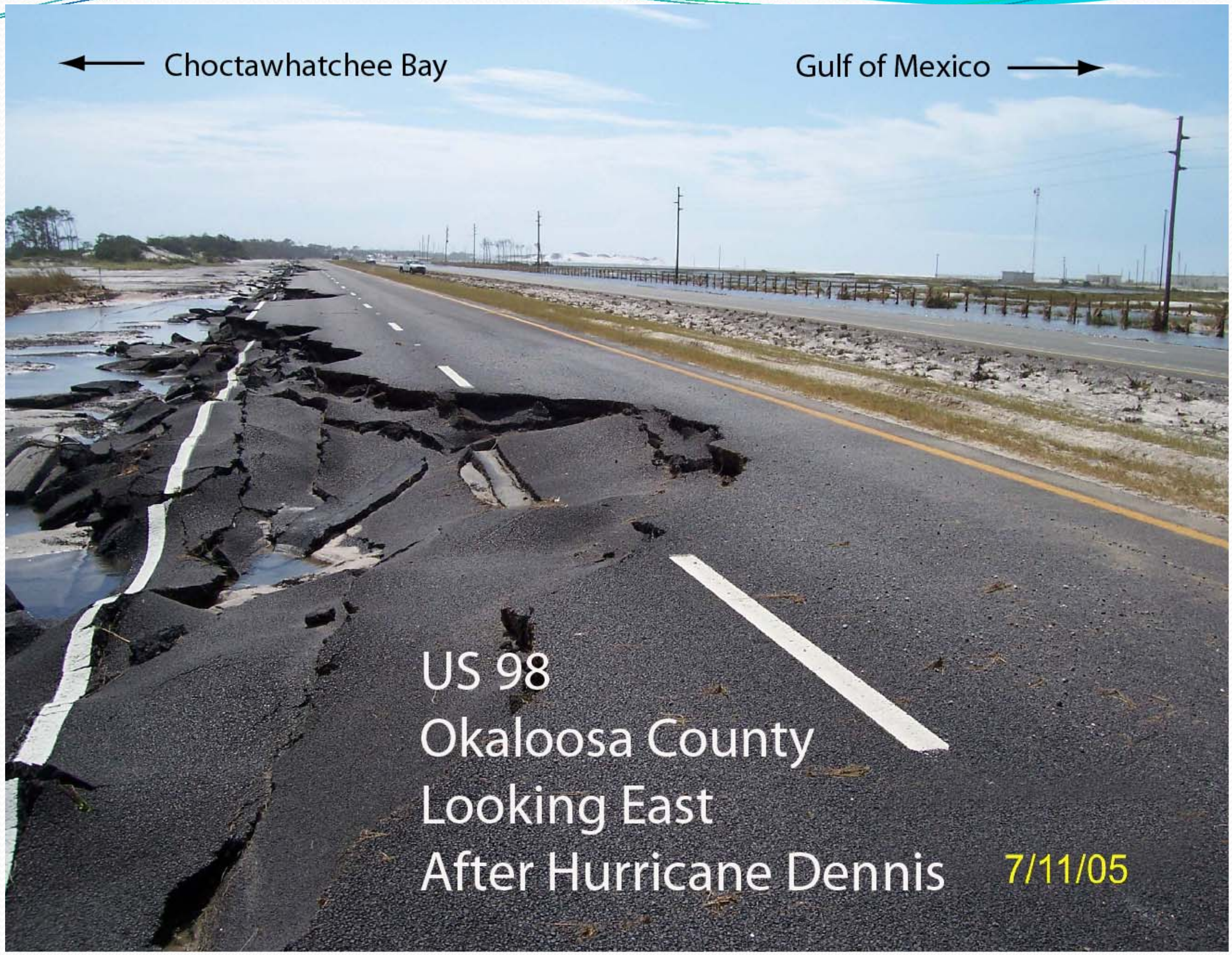

Gulf Of Mexico
Santa Rosa Sound
State Road 399
Santa Rosa Island, Florida
After Hurricane IVAN


Gulf Of Mexico
Santa Rosa Sound
State Road 399
Santa Rosa Island, Florida

Bridge Failures

Bridge Failures

Bridge Failures



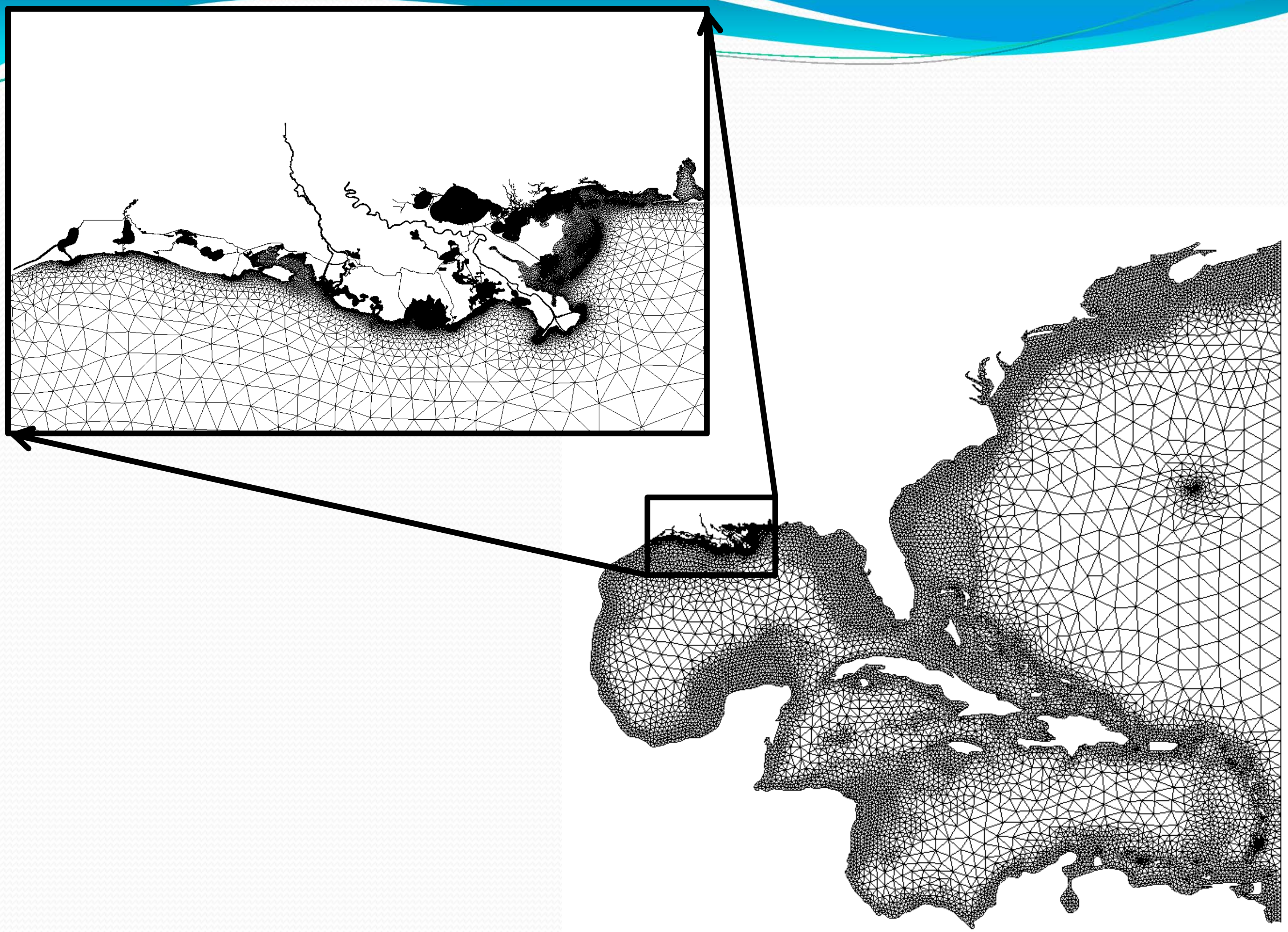
Choctawhatchee Bay
Gulf of Mexico
US 98
Okaloosa County
Looking East
After Hurricane Dennis
7/11/05

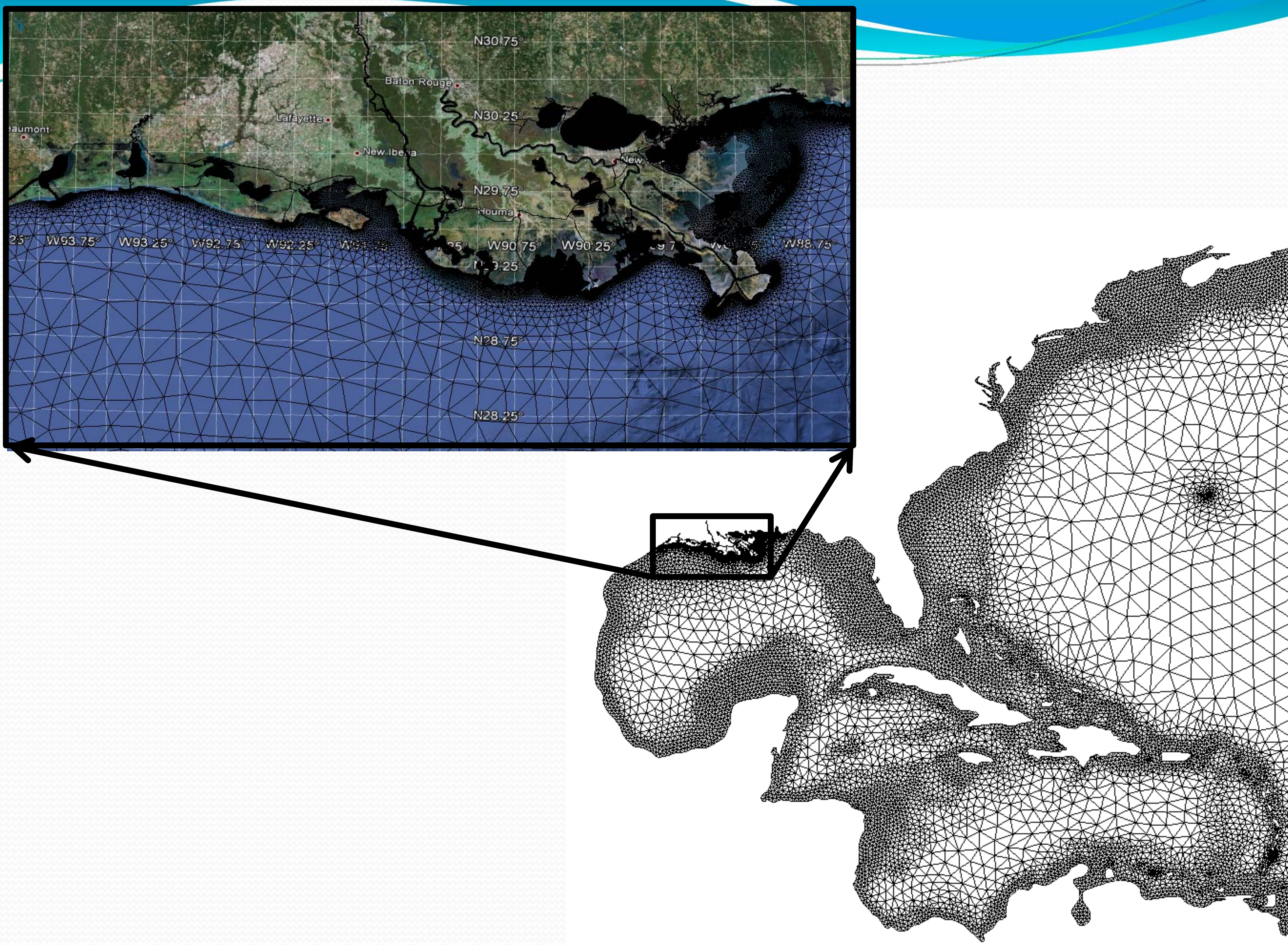

Gulf of Mexico
Choctawhatchee Bay
US 98
Okaloosa County
Looking West
After Hurricane IVAN

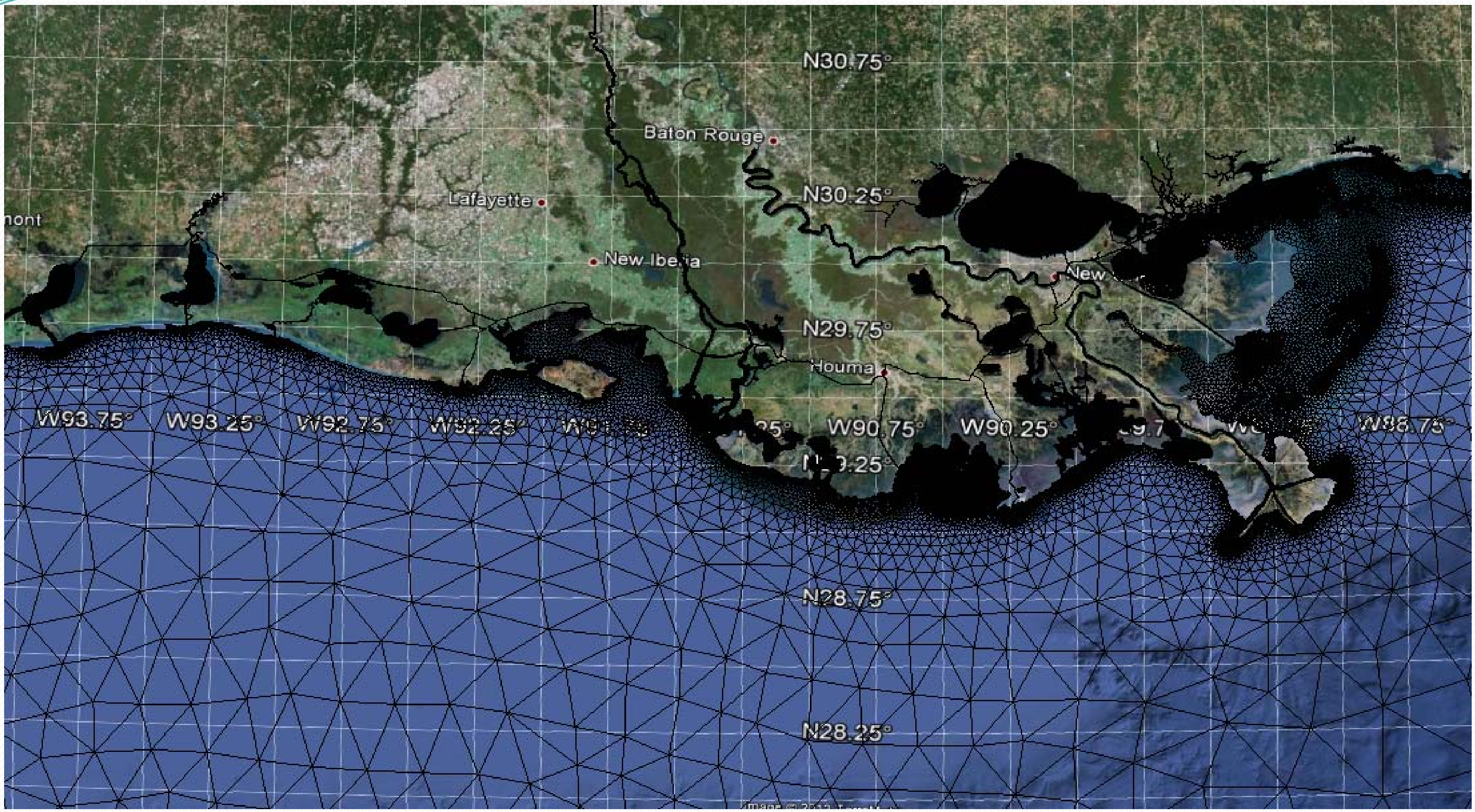
Prototype Wave Forces

Storm Surge/Wave Atlas

- Purpose
  - To provide water level, depth-average current and wave information for design frequency storm events
- Approach
  - Develop hydraulic-wave model mesh for Louisiana Coastal Waters
  - Acquire wind and pressure fields for ~ 50 of the most severe tropical storms and hurricanes that have impacted Louisiana over the past 154 years




N30.75°
Baton Rouge
N30.25°
Lafayette
New Iberia
N29.75°
Houma
W93.75°
W93.25°
W92.75°
W92.25°
W90.75°
W90.25°
W88.75°
N28.75°
N28.25°


N30.75°
Baton Rouge
Lafayette
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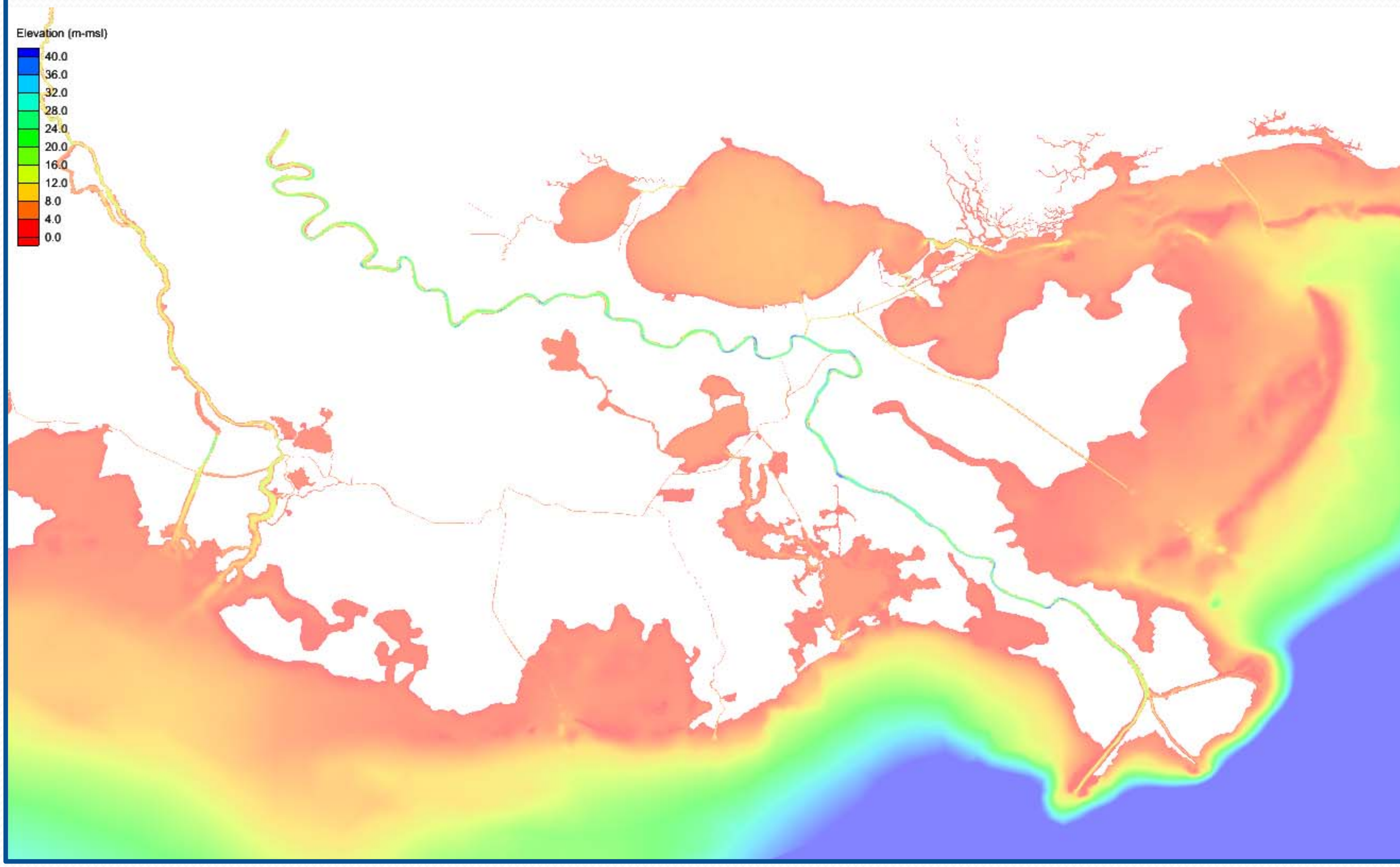
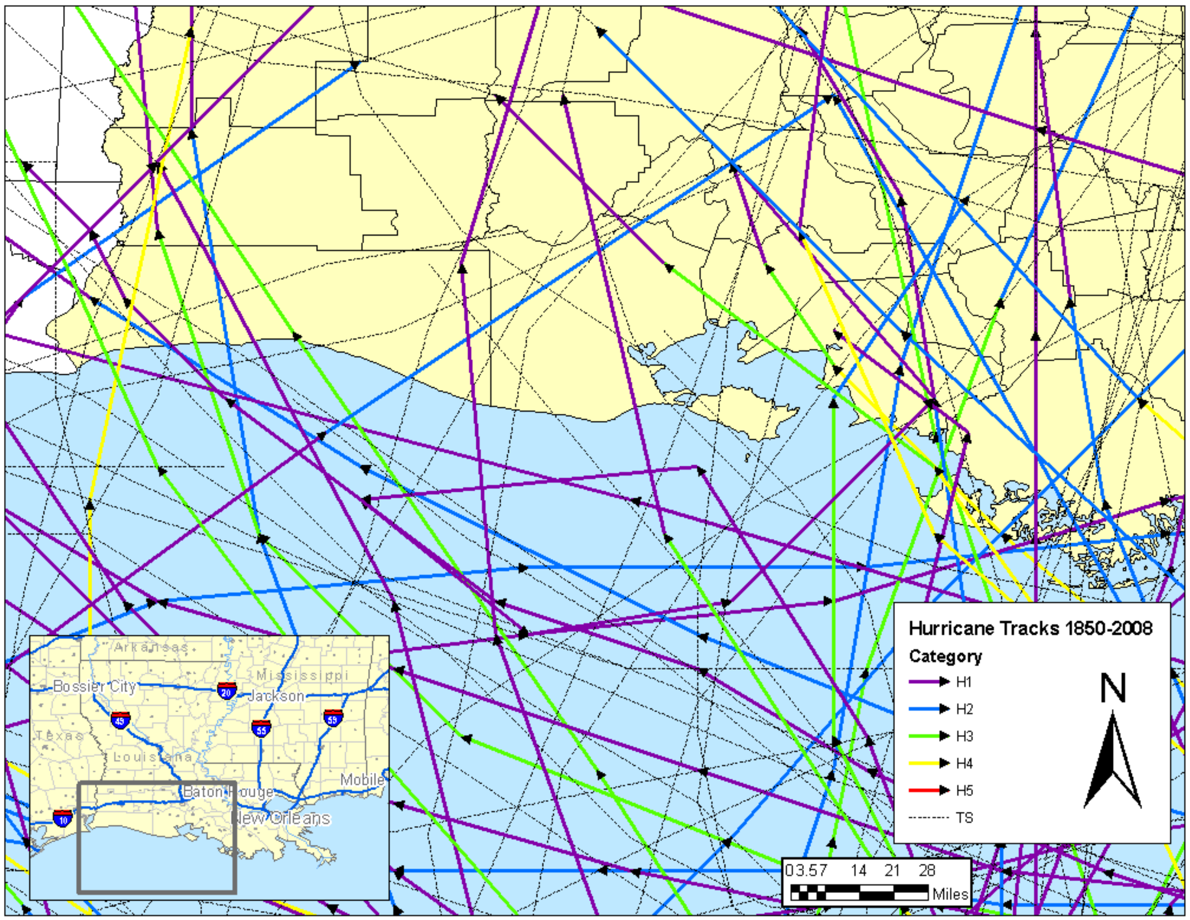

Elevation (m-msl)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0

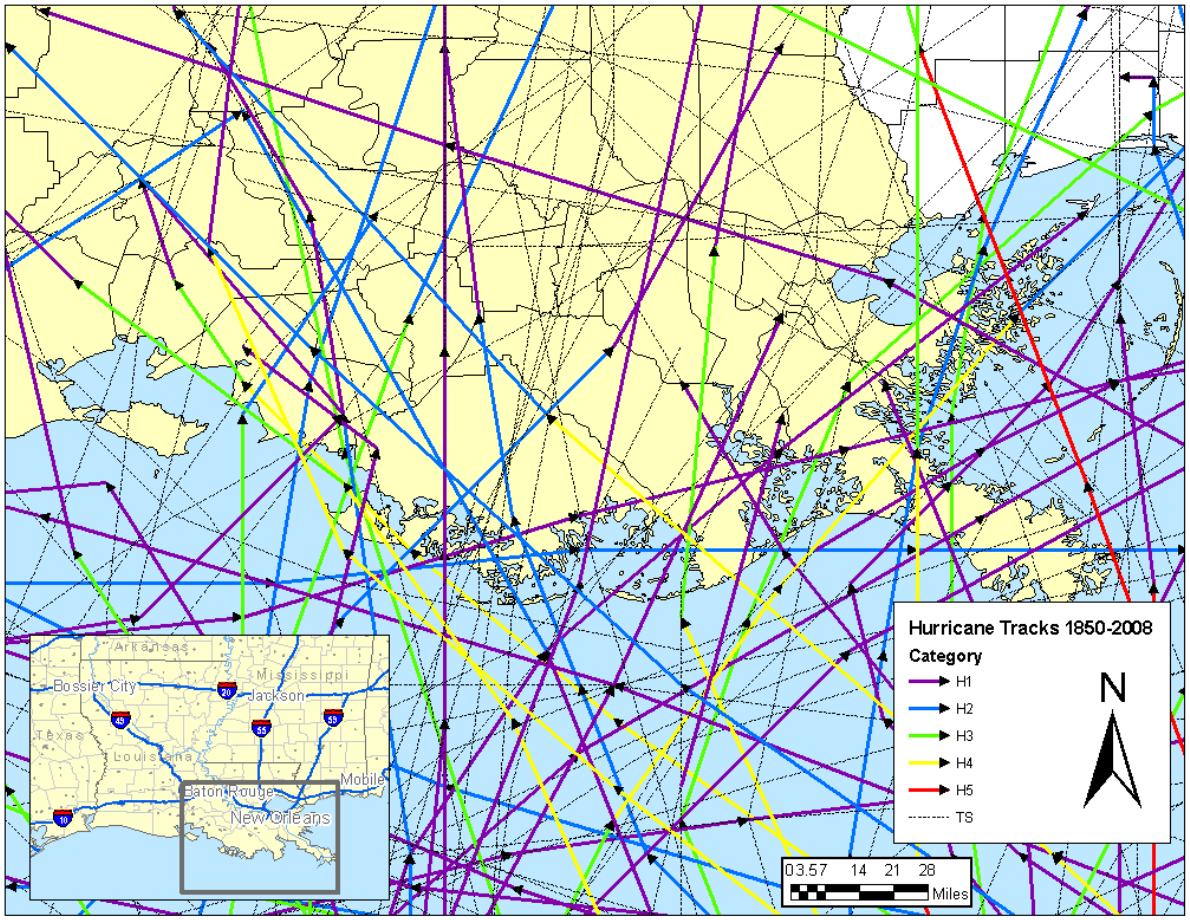
Storm Surge/Wave Atlas (cont.)

- Approach (cont.)
  - Acquire wind and pressure fields for 50 of the most severe tropical storms and hurricanes that have impacted Louisiana over the past 154 years
  - Will add additional storms if necessary

Hurricane Tracks West Louisiana Coast



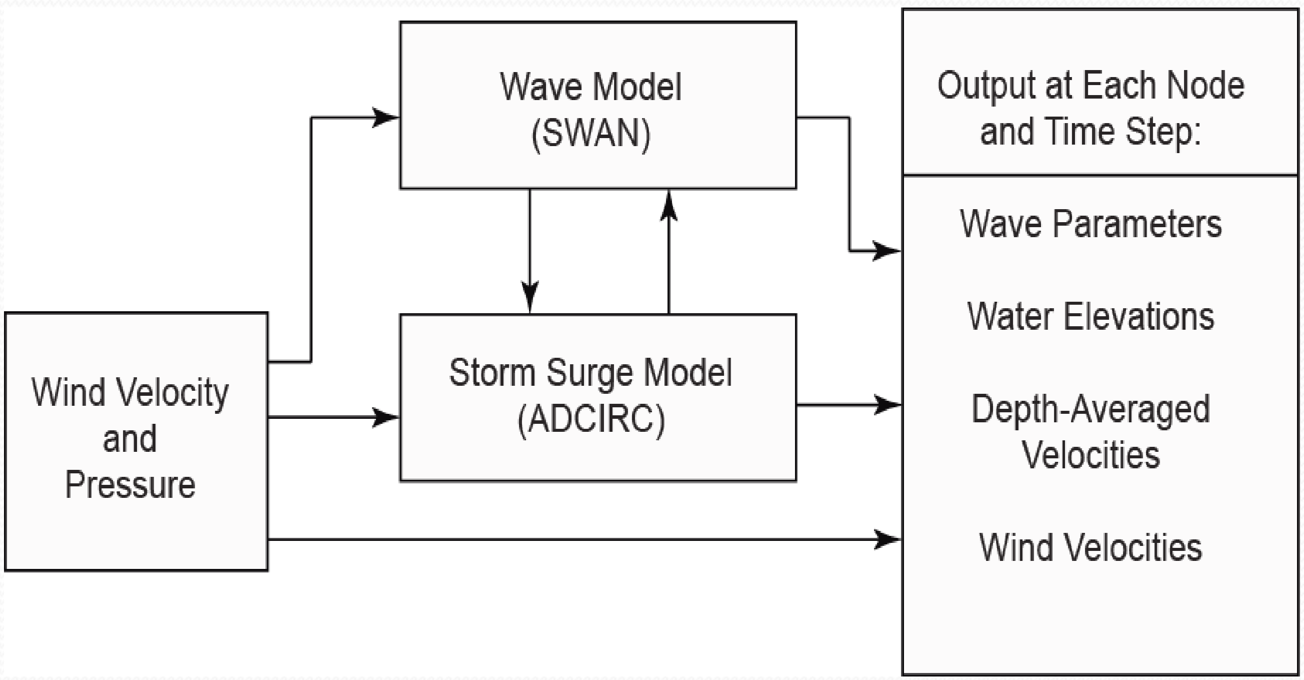
Hurricane Tracks
East Louisiana Coast



Storm Surge/Wave Atlas (cont.)

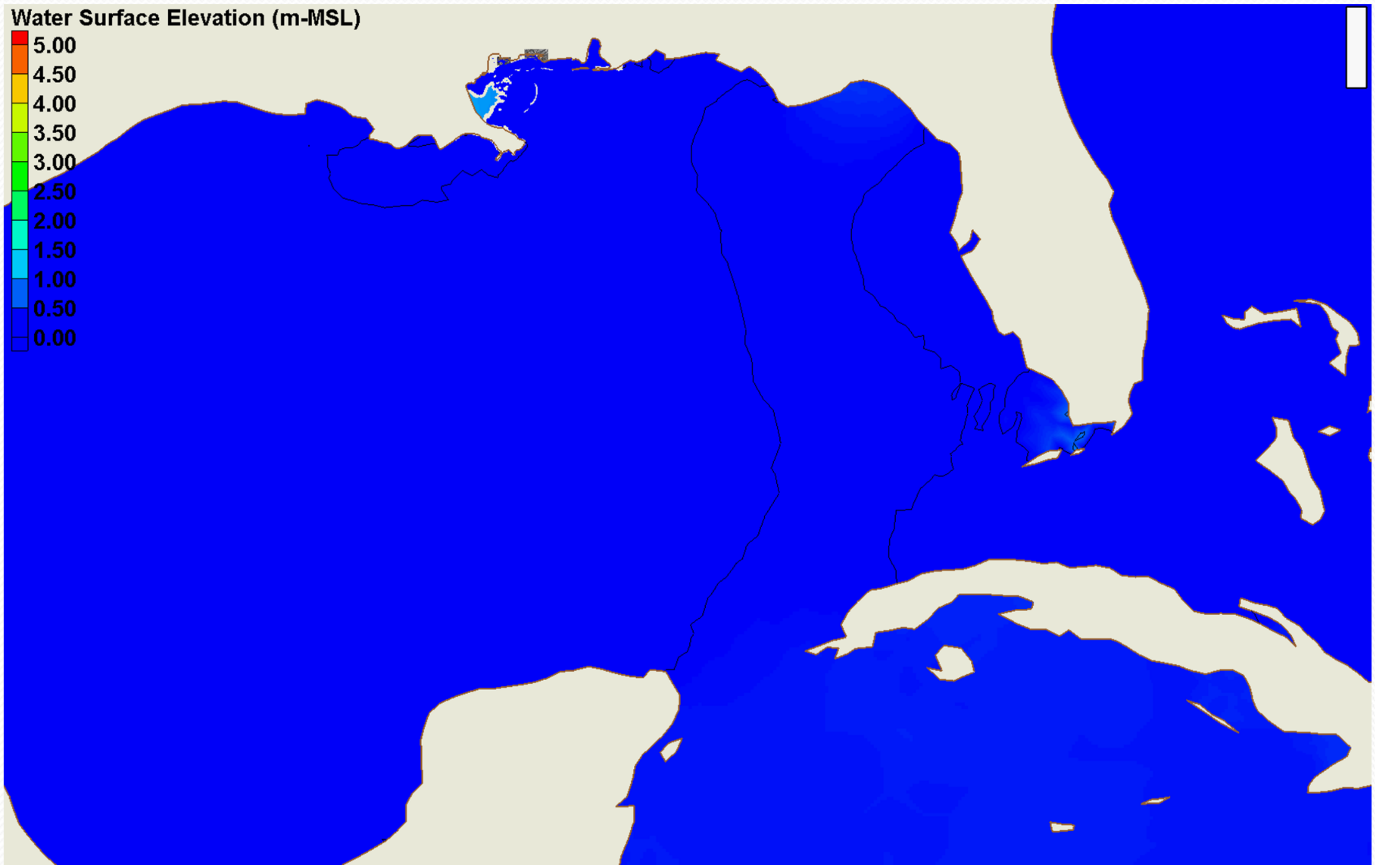
- Approach (cont.)
  - Adjust storm paths to right and left ½ degree (~55 km)
    - Total number of storms ~ 150
  - Run models

Hindcast Diagram



Storm Surge/Wave Atlas (cont.)

- Example hindcast – Hurricane Katrina



Storm Surge/Wave Atlas (cont.)

- Approach (cont.)
  - Perform extreme value analyses
    - Water elevations and associated wave heights
    - Wave heights and associated water elevations
    - Depth-averaged current speeds

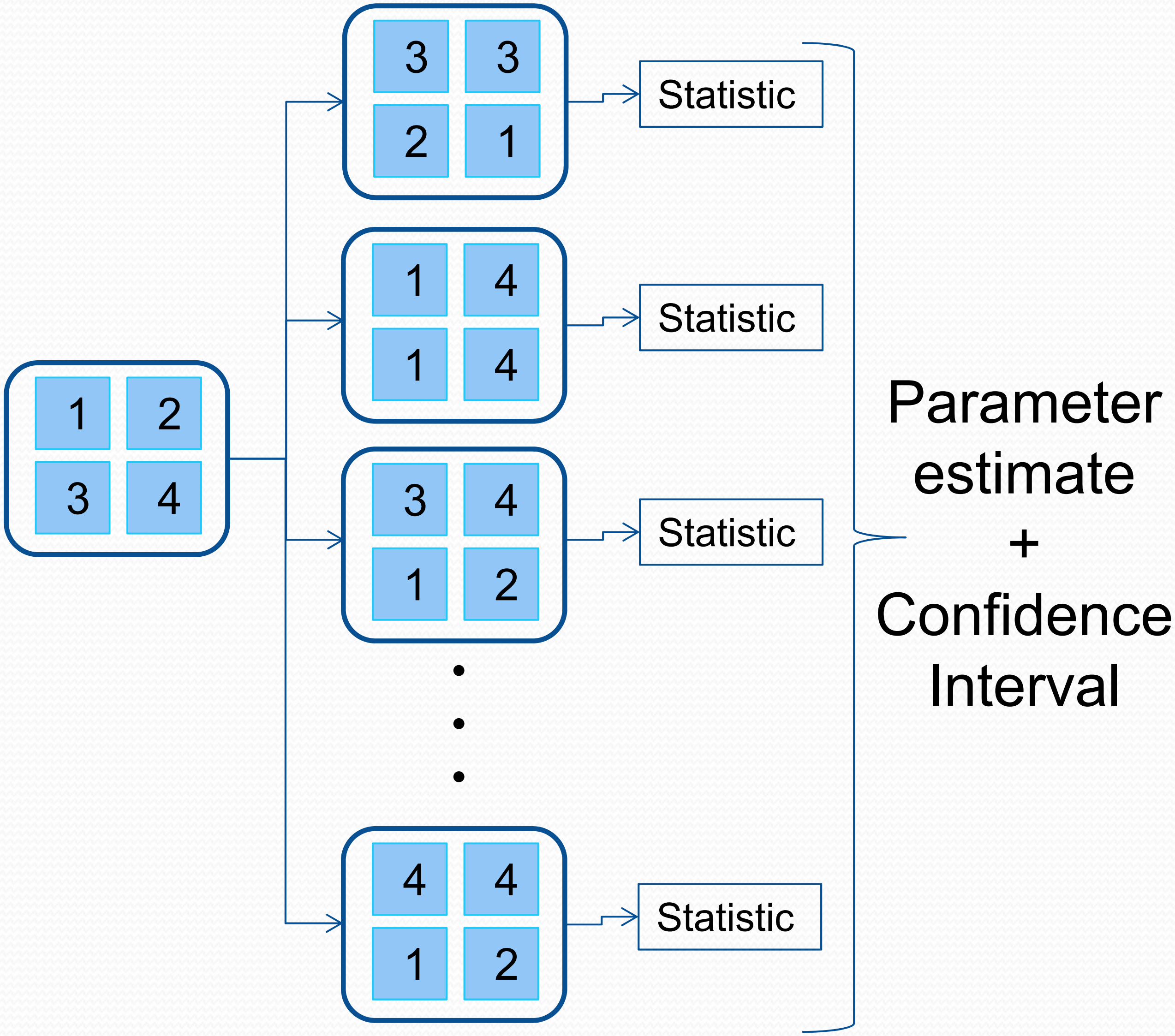
Storm Surge/Wave Atlas (cont.)

- Approach (cont.)
  - Data analyses
    - Extract data from solution files
      - Maximum water elevations
      - Wave heights at time of maximum water elevation
      - Maximum wave heights
      - Water elevation at time of maximum wave heights
    - Extreme value analysis
      - Obtain 100-Year maximum water elevation throughout study area
      - Obtain 100-Year associated wave heights throughout study area

Storm Surge/Wave Atlas (cont.)

- Approach (cont.)
  - Data analyses (cont.)
    - Extreme value analysis (cont.)
      - Obtain 100-Year maximum wave heights throughout study area
      - Obtain 100-Year associated water elevations throughout study area
      - Both expected and 90% confidence values

Bootstrapping



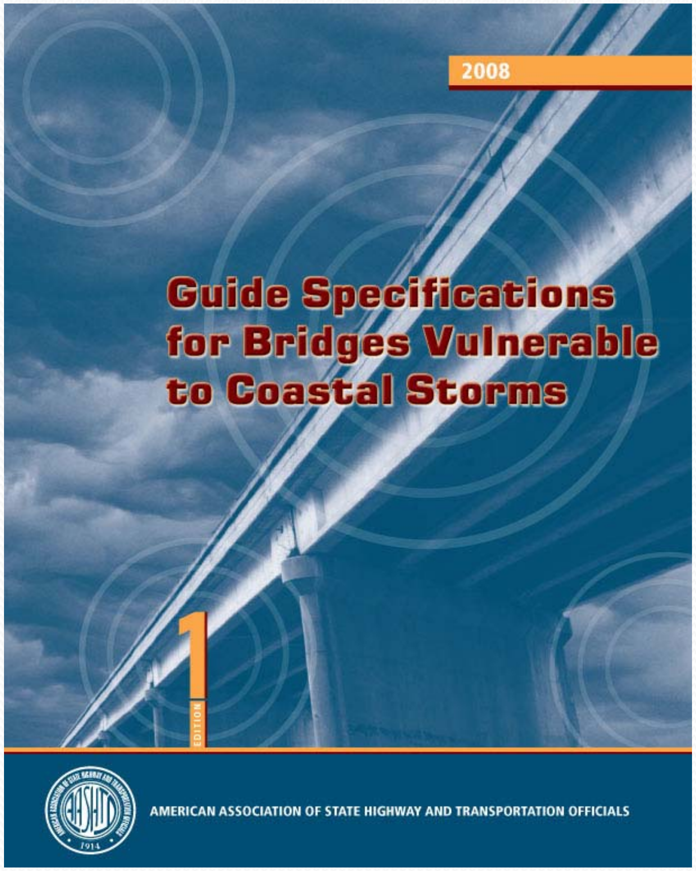
Statistical method that uses random sampling with replacement from a data set and analyzes each sample and predicts confidence intervals

Surge/Wave Atlas

- Propose to put results in GIS database and provide open source GIS reader
- Provides quick and easy, user friendly, access to the information

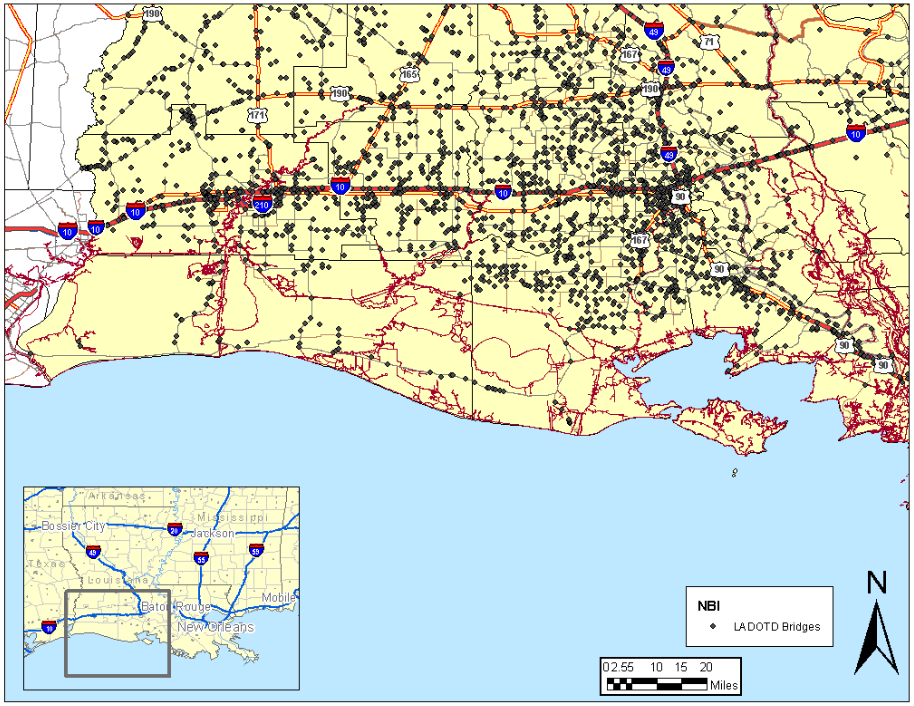
Surge/Wave Loading

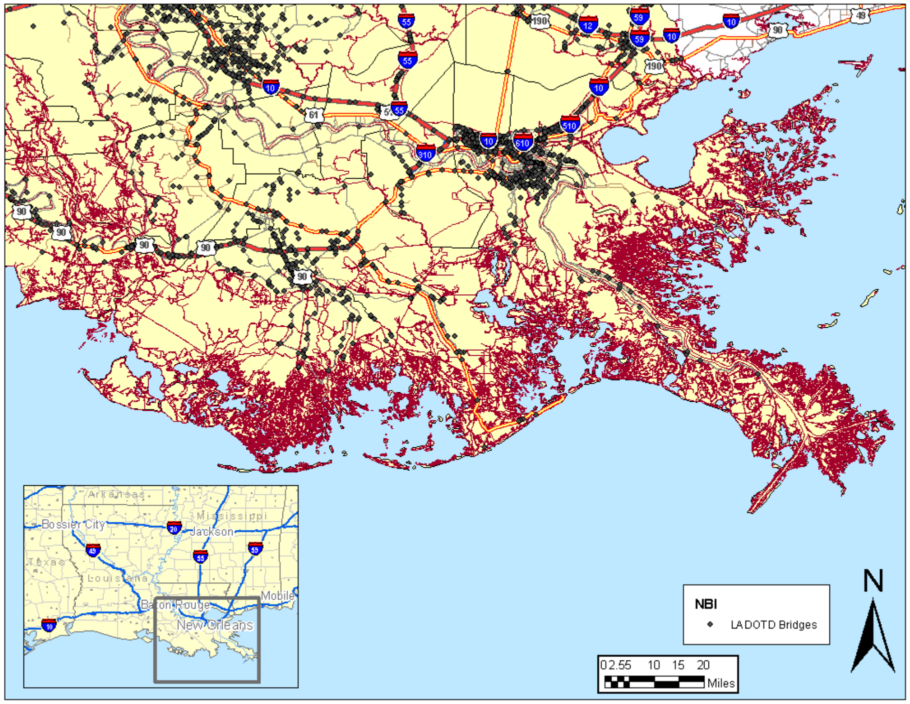
- AASHTO Code: "*Guide Specification for Bridges Vulnerable to Coastal Storms*"
  - Developed by: Modjeski and Masters with OEA, Inc. providing the surge/wave procedures and development of force & moment equations



Surge/Wave Loading on Bridges

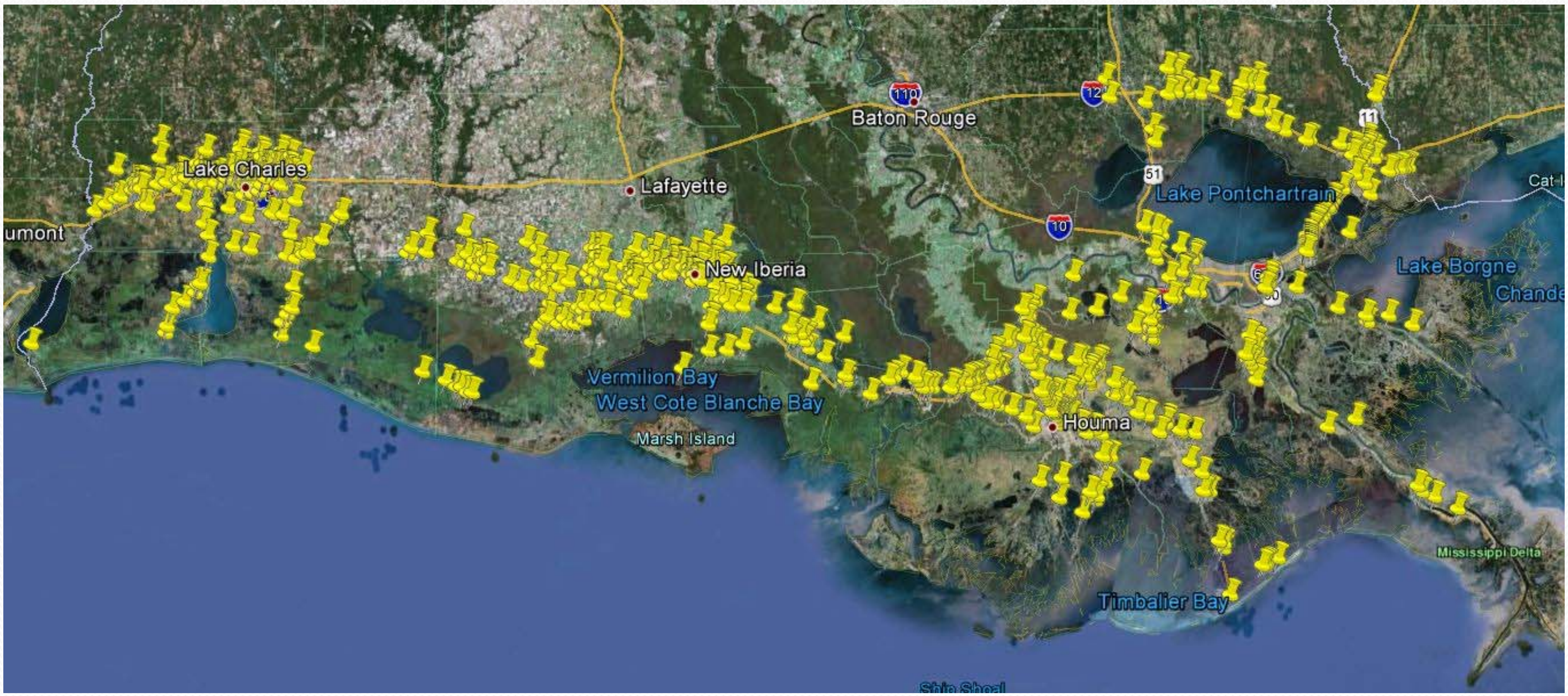
- Significant number of bridges in South Louisiana





Surge/Wave Loading on Bridges

- Initial list of bridges to be considered



Surge/Wave Loading on Bridges

- Final list of bridges to be analyzed

Information Needed to Compute Loads

- Design water levels and associated wave heights
- Design wave heights and associated water levels
- Superstructure design, dimensions, elevation, orientation
- Force and Moment predictive equations

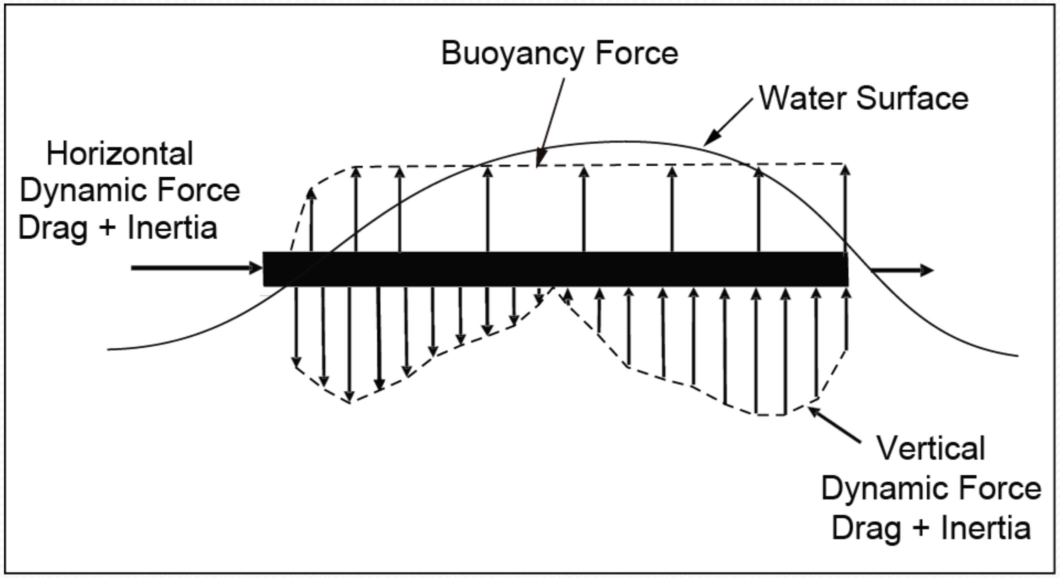
Needed Information

- Met/Ocean provided by surge/wave atlas
  - 100-year water elevation and associated wave height
  - 100-year wave height and associated water elevation

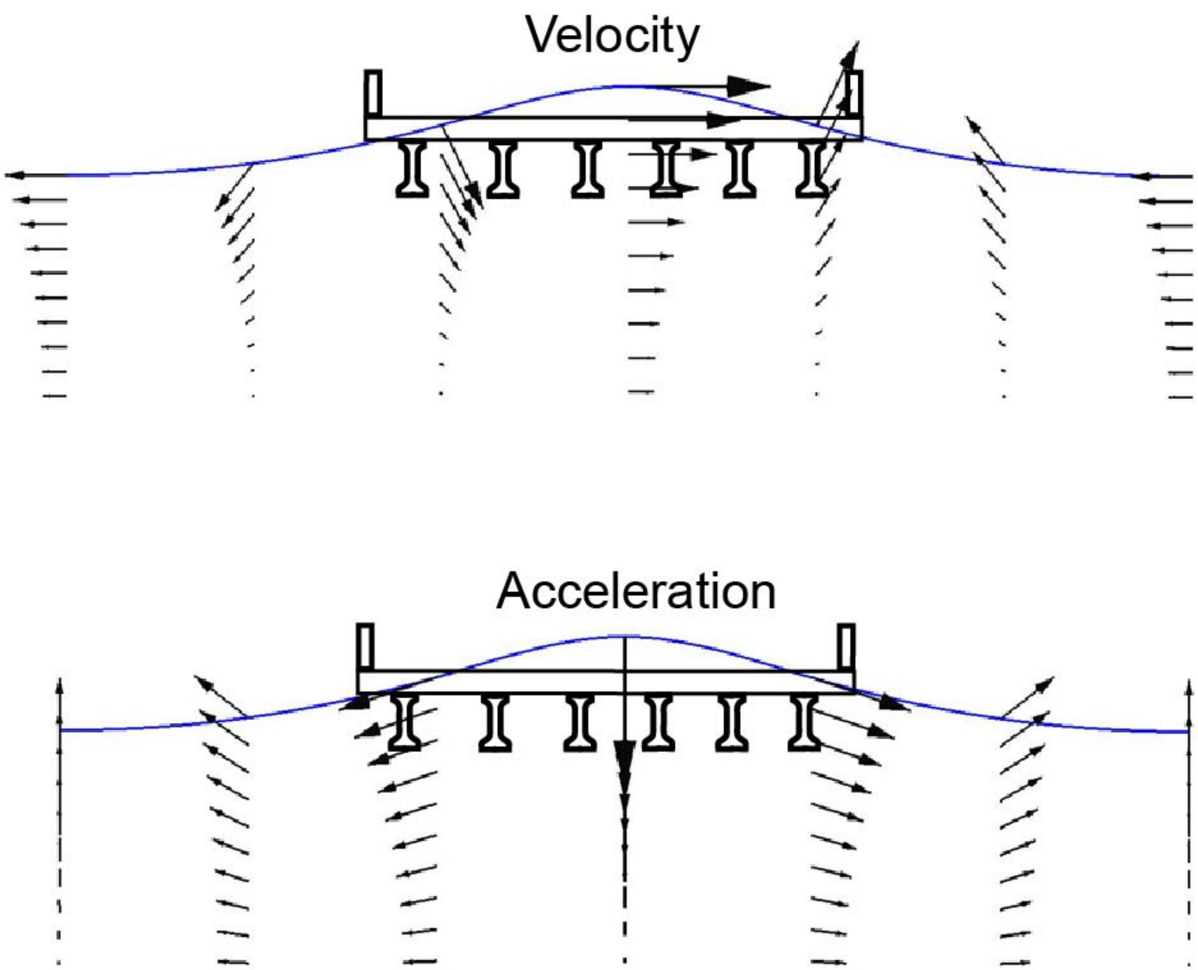
- Bridge superstructure information provided by LADOTD

Forces and Moments

- Forces and moments on bridge superstructures more complex than those on substructure
- Vary in both time and space as wave progresses past structure
- Moments, as well as, forces important



Water Motion in Waves



Example Wave Kinematics

Water Depth = 30 ft,
Wave Height = 10 ft,
Wave Period = 5 sec

Surge/Wave Forces

Horizontal and vertical forces

$$F_H = F_{Drag} + F_{Inertia} + F_{CAM} + F_{Slamming}$$

$$F_V = F_{Buoyancy} + F_{Drag} + F_{Inertia} + F_{CAM} + F_{Slamming}$$

Surge/Wave Forces

$$F_{Drag} = C_d \frac{1}{2} \rho L w V |V|$$

$$F_{Inertia} = C_{Inertia} \frac{d(m_e V)}{dt} = \left(C_{cam} \frac{dm_e}{dt} V + C_m m_e \frac{dV}{dt} \right)$$

$$F_{Buoyancy} = \rho g \forall$$

where $\forall$ = wetted volume

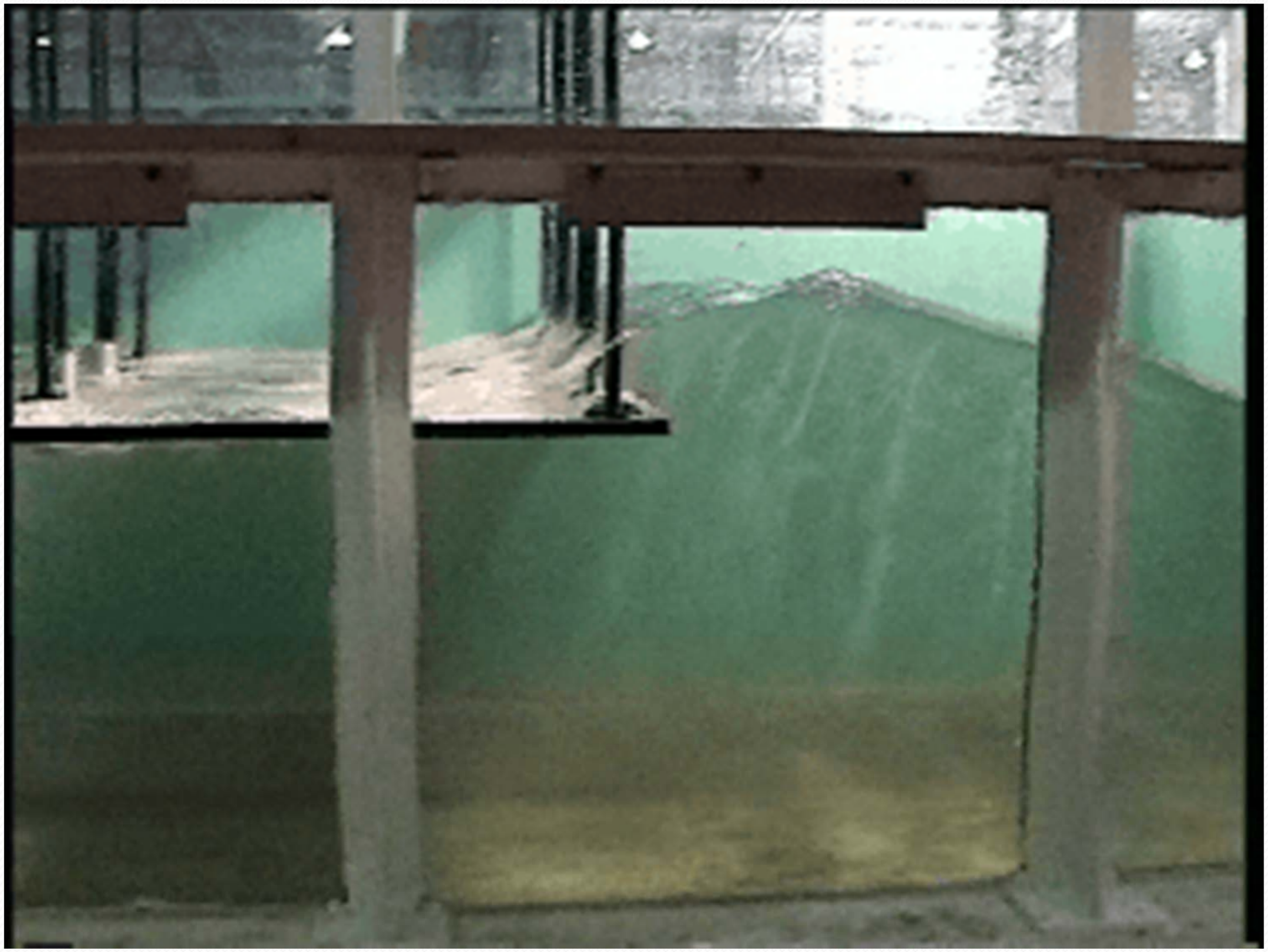
m_e = effective mass =

mass displaced + added mass = $m_e(t)$

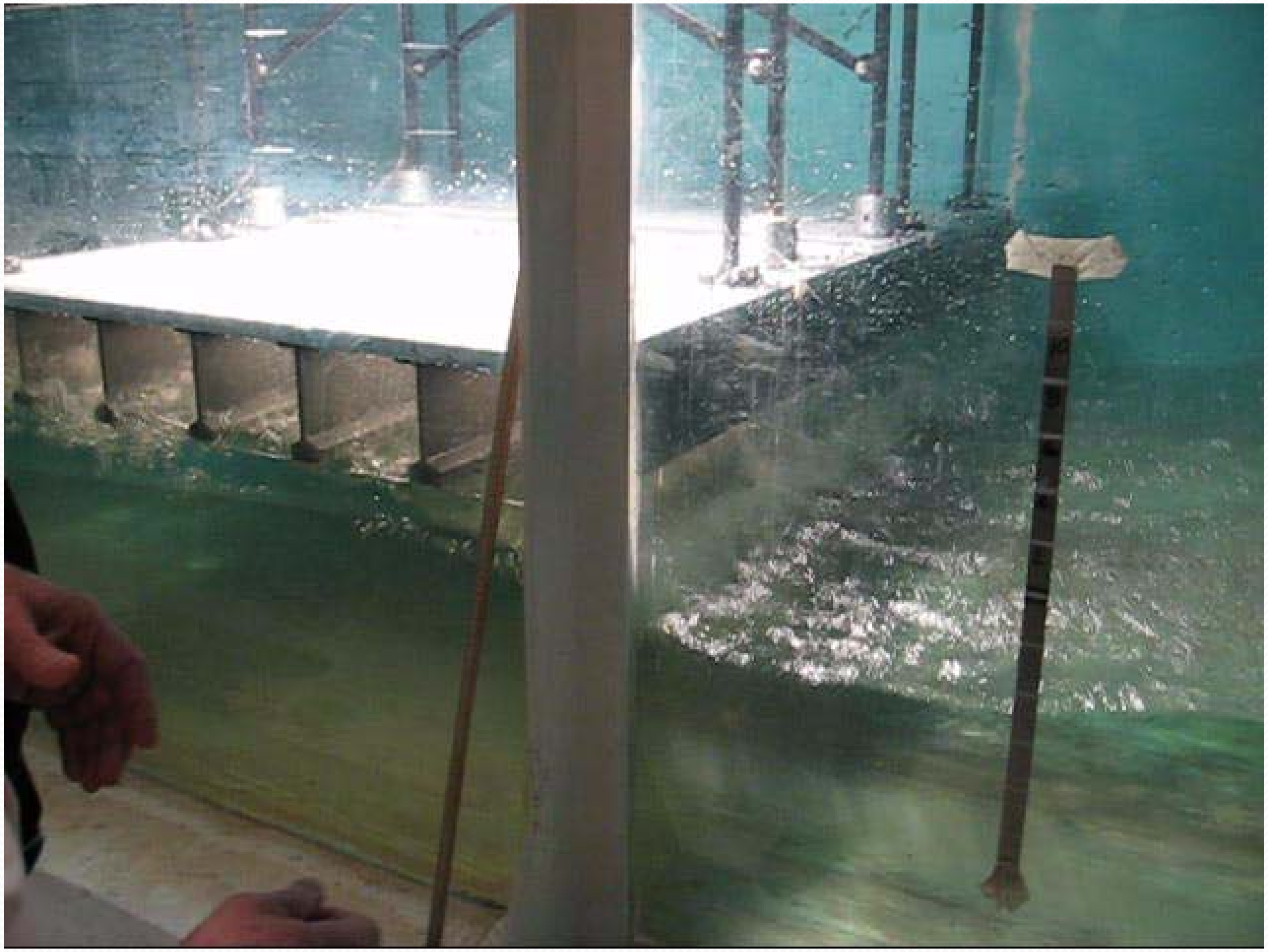
Determination of Coefficients

- Drag, inertia and change in added mass coefficients were determined by numerous wave tank tests

Wave Tank Tests



Girder Span Tests

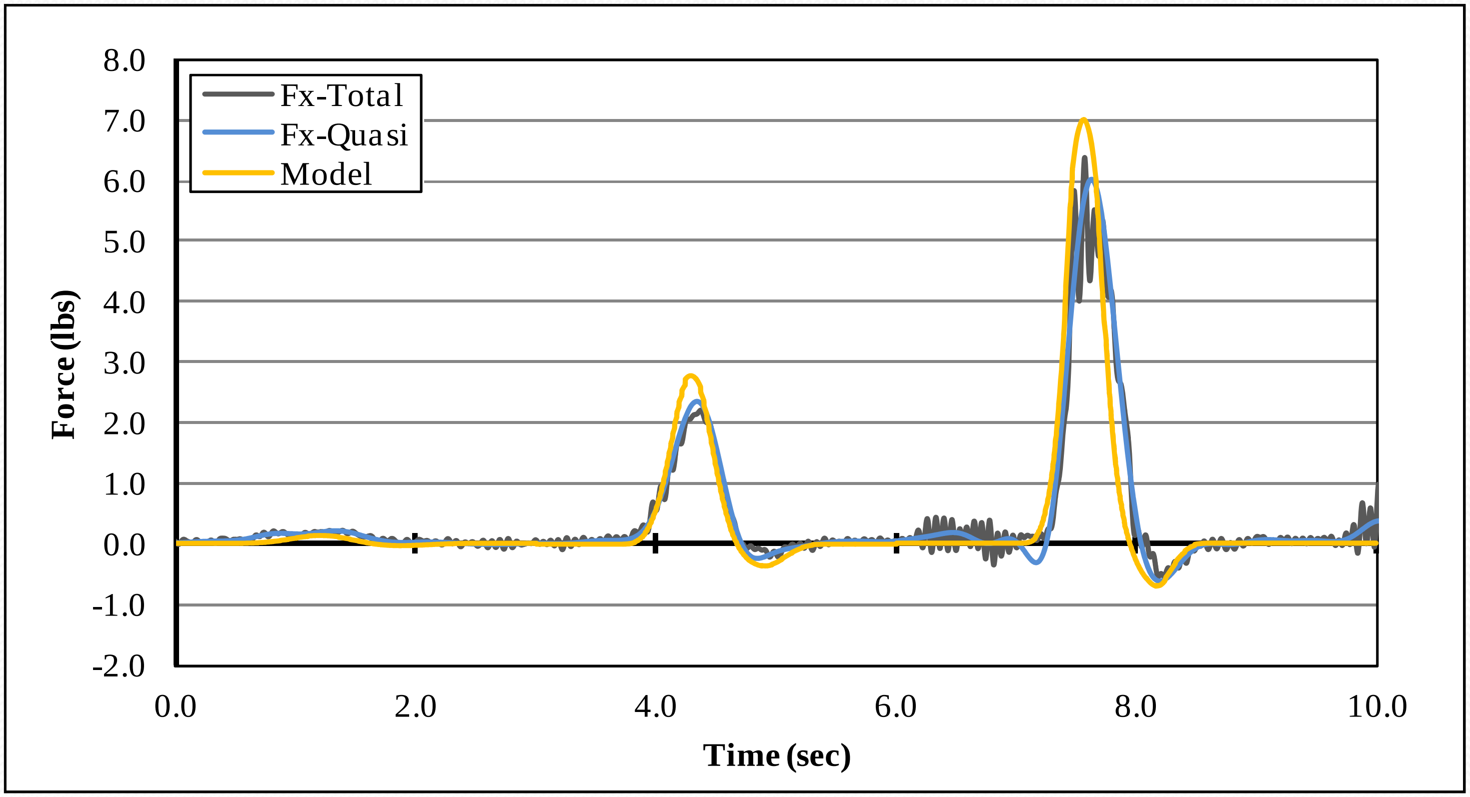


OEA, Inc.

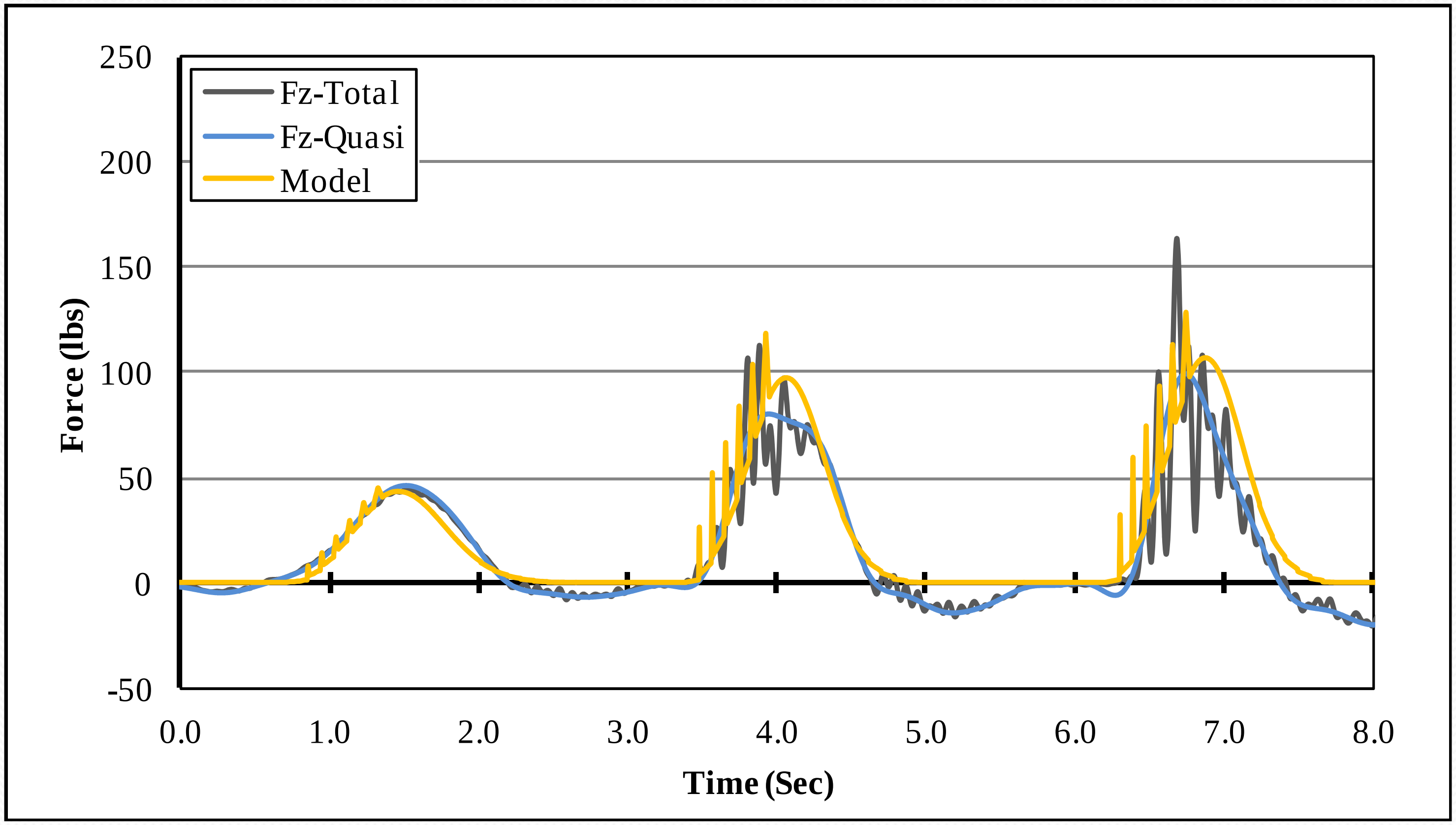
PBM

- Evaluates storm surge/save force and moment equations at each element and at each time step
- Has built-in nonlinear wave model to compute wave velocities and accelerations

Horizontal Force Comparison



Vertical Force Comparison



Future Design Challenges

- Climatological changes
  - Sea level changes
  - Storm frequencies and pattern changes
- Coastal land subsidence
  - Tectonics,
  - Holocene sediment compaction,
  - Sediment loading,
  - Glacial isostatic adjustment,
  - Anthropogenic fluid withdrawal, and
  - Surface water drainage and management

Summary

- Wave atlas provides significant met/ocean information that will be useful for analyzing existing and future bridges and coastal roadways in Southern Louisiana
- Assessment of the vulnerability of LADOTD coastal bridges to surge/wave loading provides information needed to:
  - Retrofit or modify
  - Contingency planning

Questions? Comments