NC STATE UNIVERSITY

Hurricane Wave and Storm Surge Forecasting for the Carolina Coast

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Lecture Series: *Triangle Physical Oceanography*
23 September 2014

About Me

North Carolina State University

- Civil, Construction, and Environmental Engineering
  - Assistant Professor: 08/2013 to present

CCEE Department, Mann Hall, NCSU

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University of Texas at Austin

- Institute for Computational Engineering and Sciences
  - Research Associate: 09/2012 to 07/2013
  - Postdoctoral Researcher: 11/2010 to 08/2012

University of Notre Dame

- Civil Engineering and Geological Sciences
  - Graduate Researcher: 08/2005 to 10/2010

University of Oklahoma

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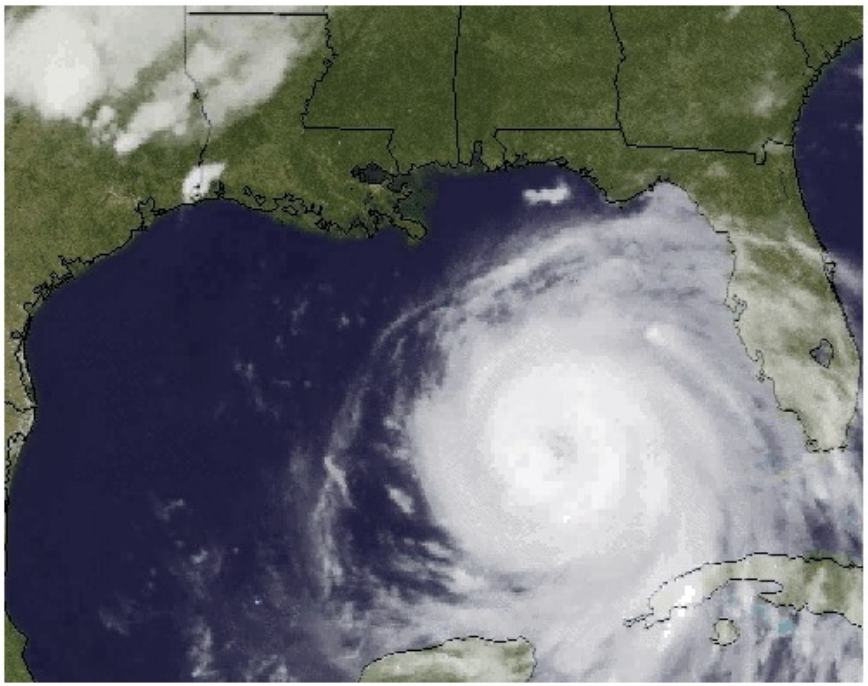
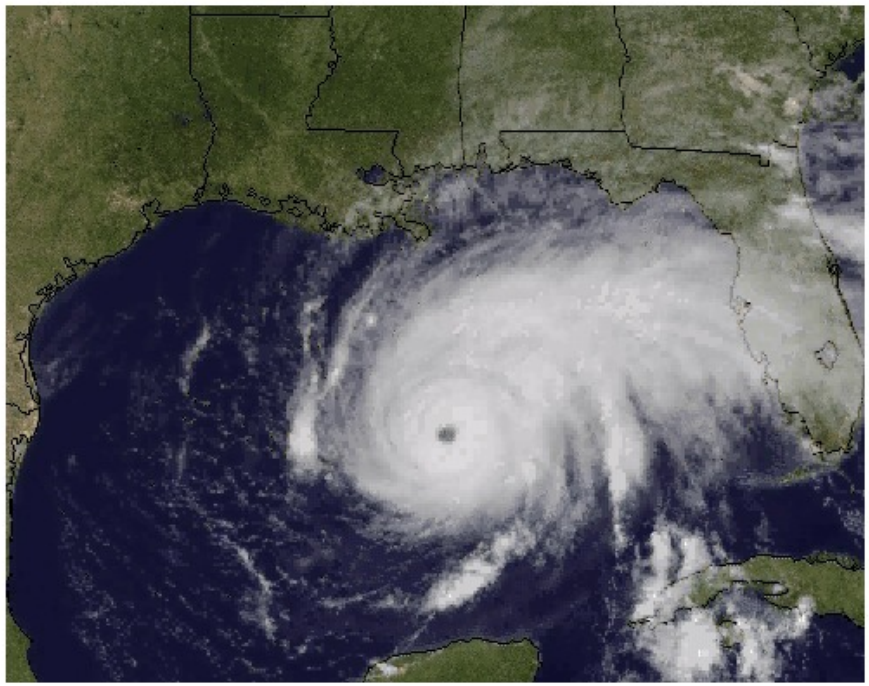
Hurricane Season 2005

Impacts on Southern Louisiana

Katrina: 08/28 - 08/29

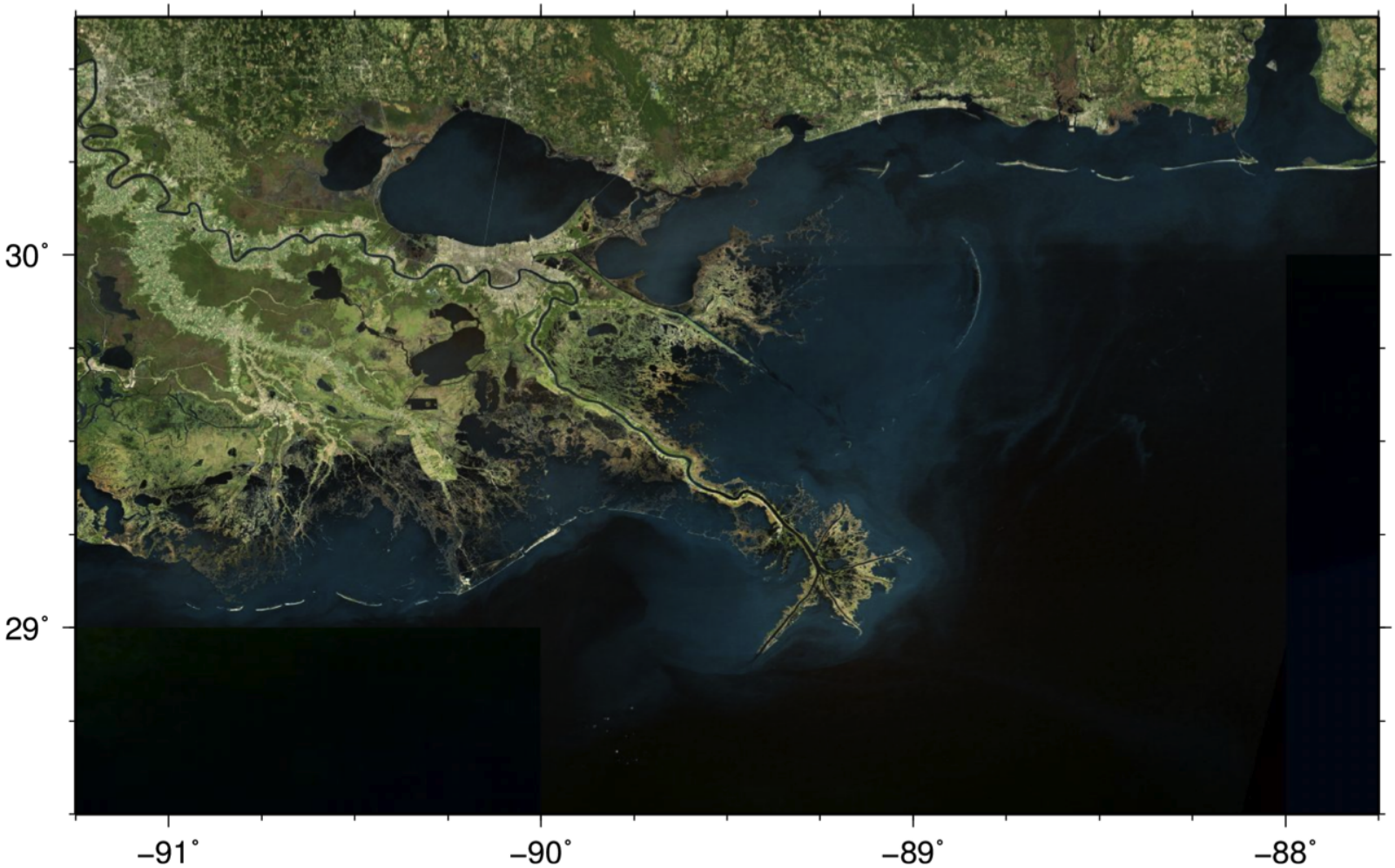


Rita: 09/22 - 09/24



Hurricane Season 2005

Flooding of New Orleans



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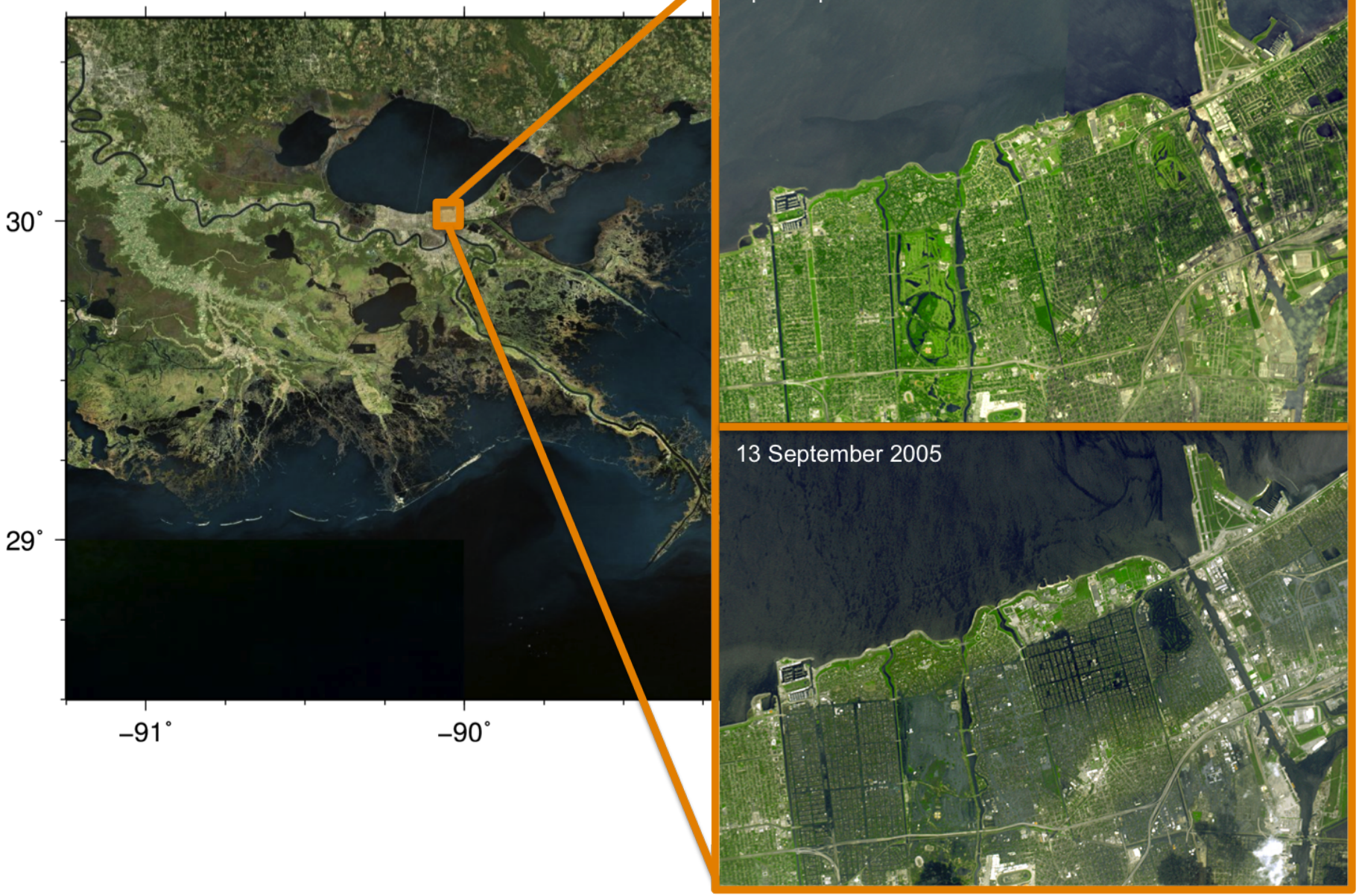
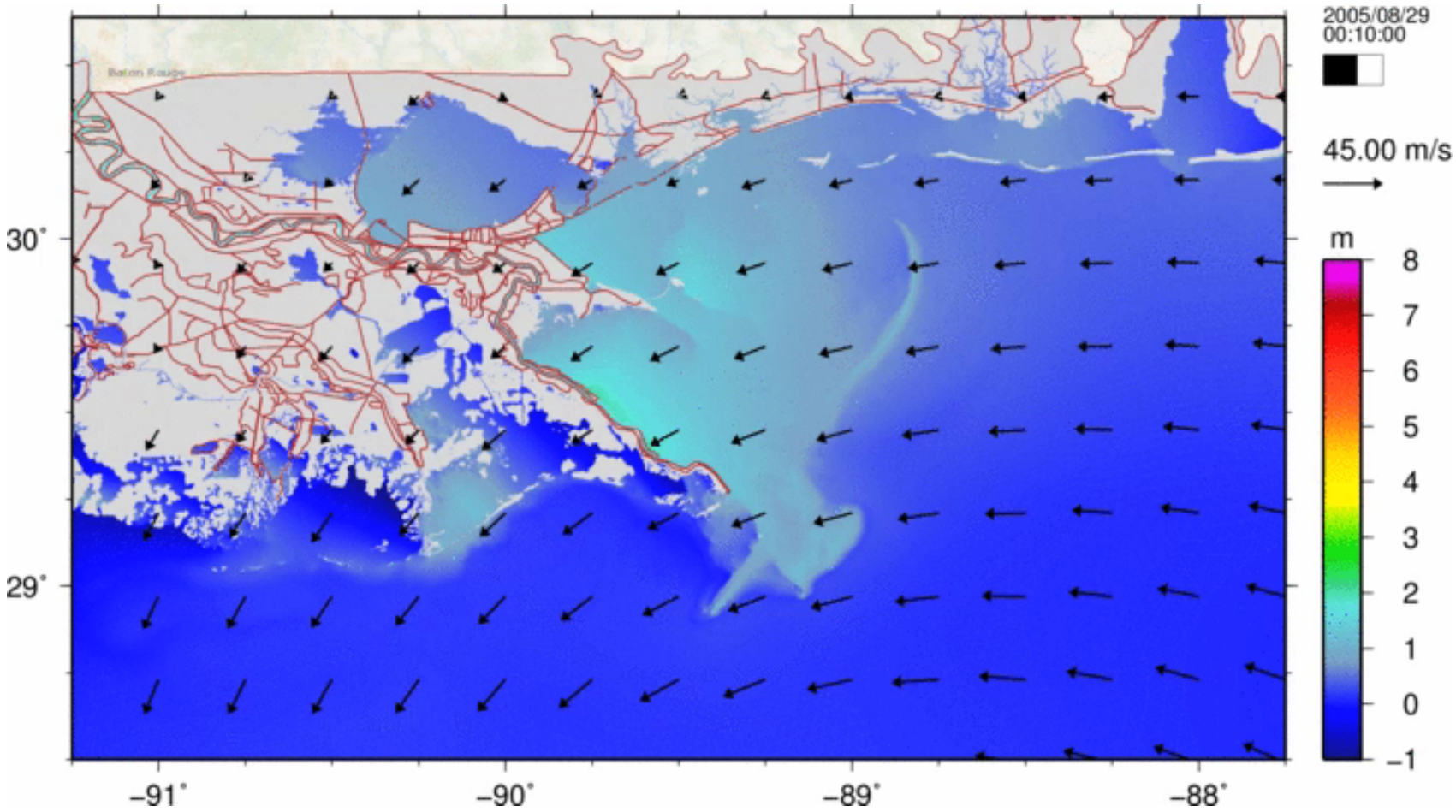


Hurricane Season 2005

Katrina on 29 August

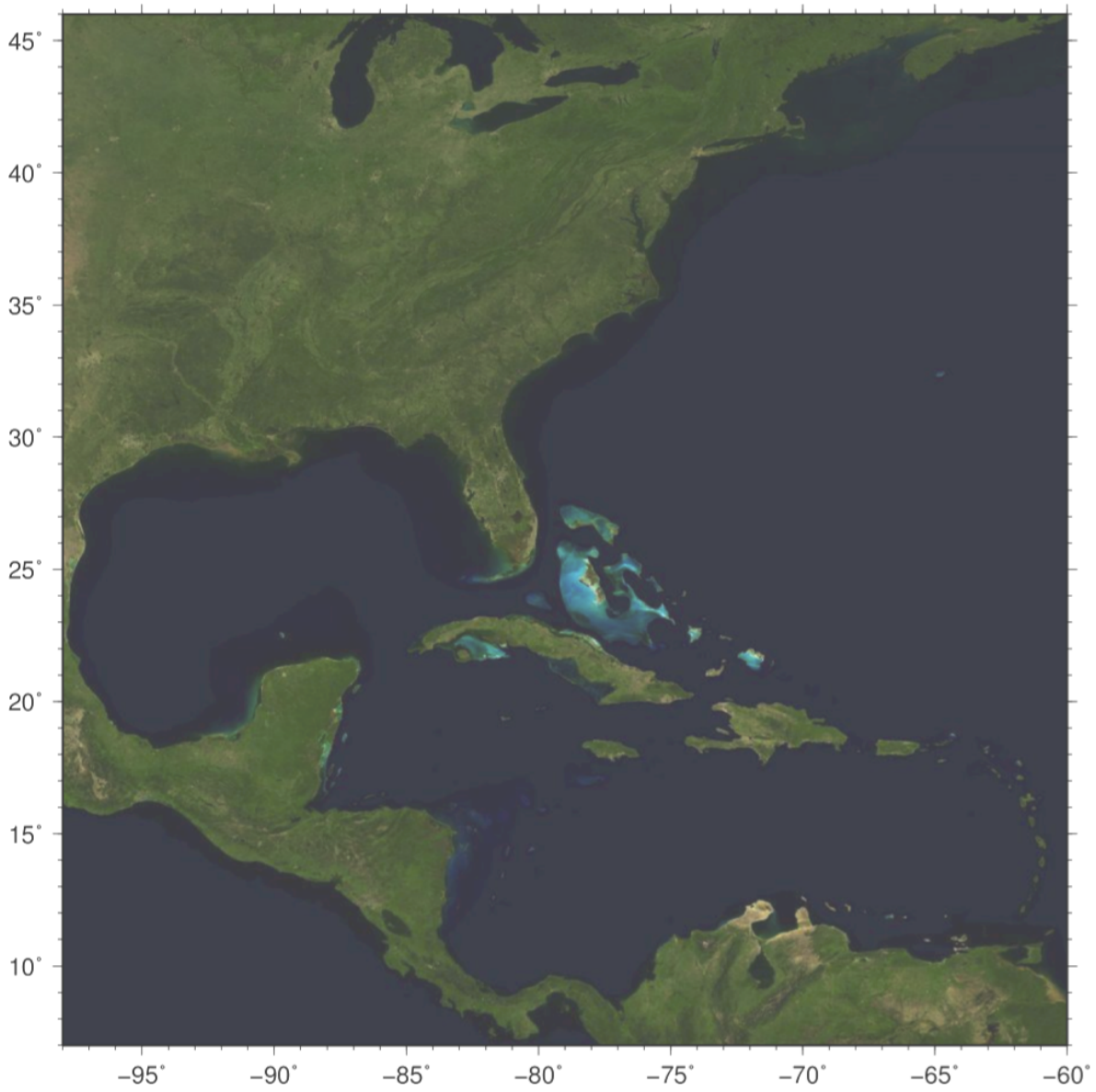


S Bunya, JC Dietrich, *et al.* (2010). A High-Resolution Coupled Riverine Flow, Tide, Wind, Wind Wave and Storm Surge Model for Southern Louisiana and Mississippi: Part I Model Development and Validation. *Monthly Weather Review*, 138(2), 345-377.

JC Dietrich, *et al.* (2010). A High-Resolution Coupled Riverine Flow, Tide, Wind, Wind Wave and Storm Surge Model for Southern Louisiana and Mississippi: Part II Synoptic Description and Analysis of Hurricanes Katrina and Rita. *Monthly Weather Review*, 138(2), 378-404.

Wide Range of Spatial Scales

Gulf and Atlantic Coasts



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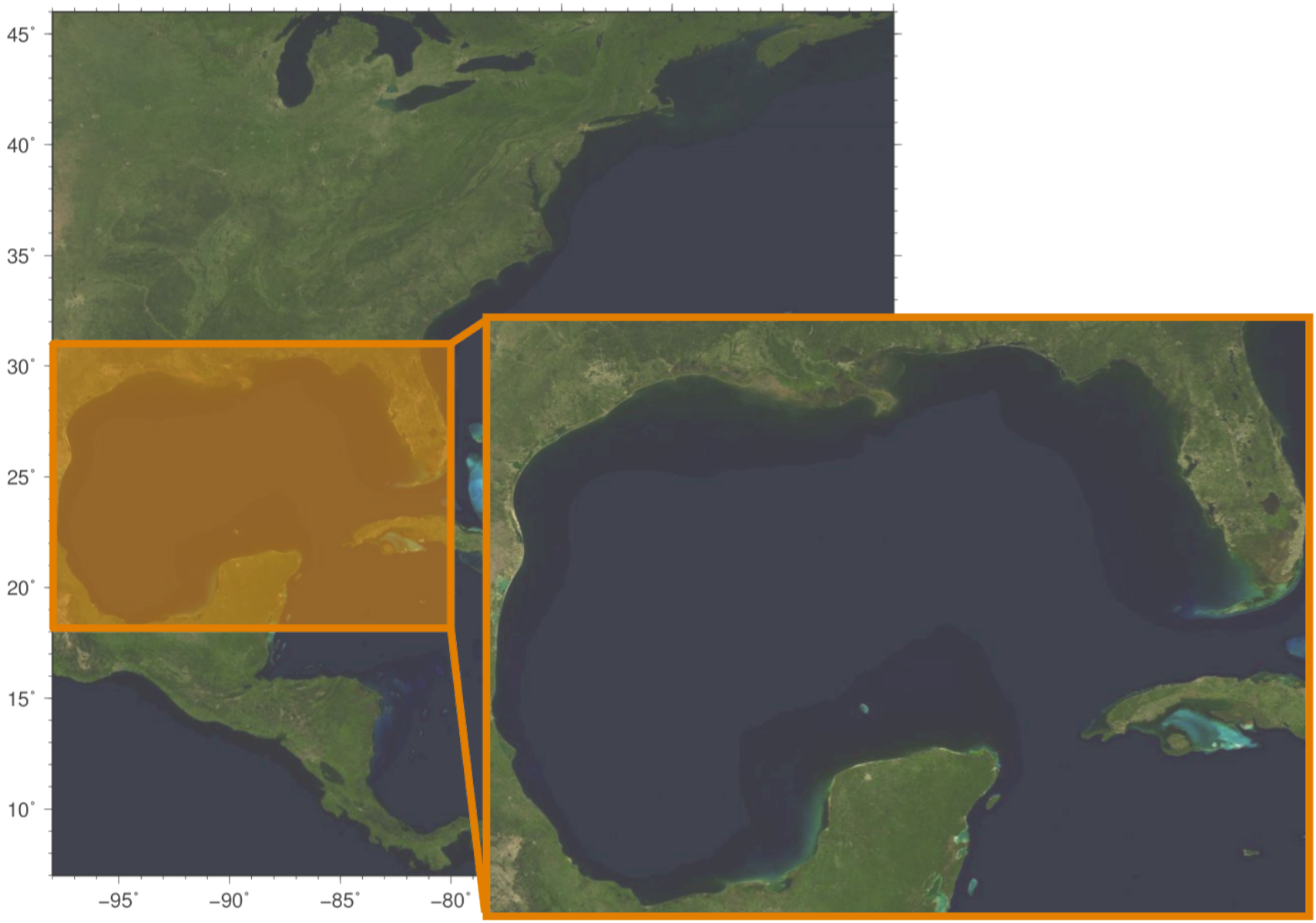
Gulf and Atlantic Coasts



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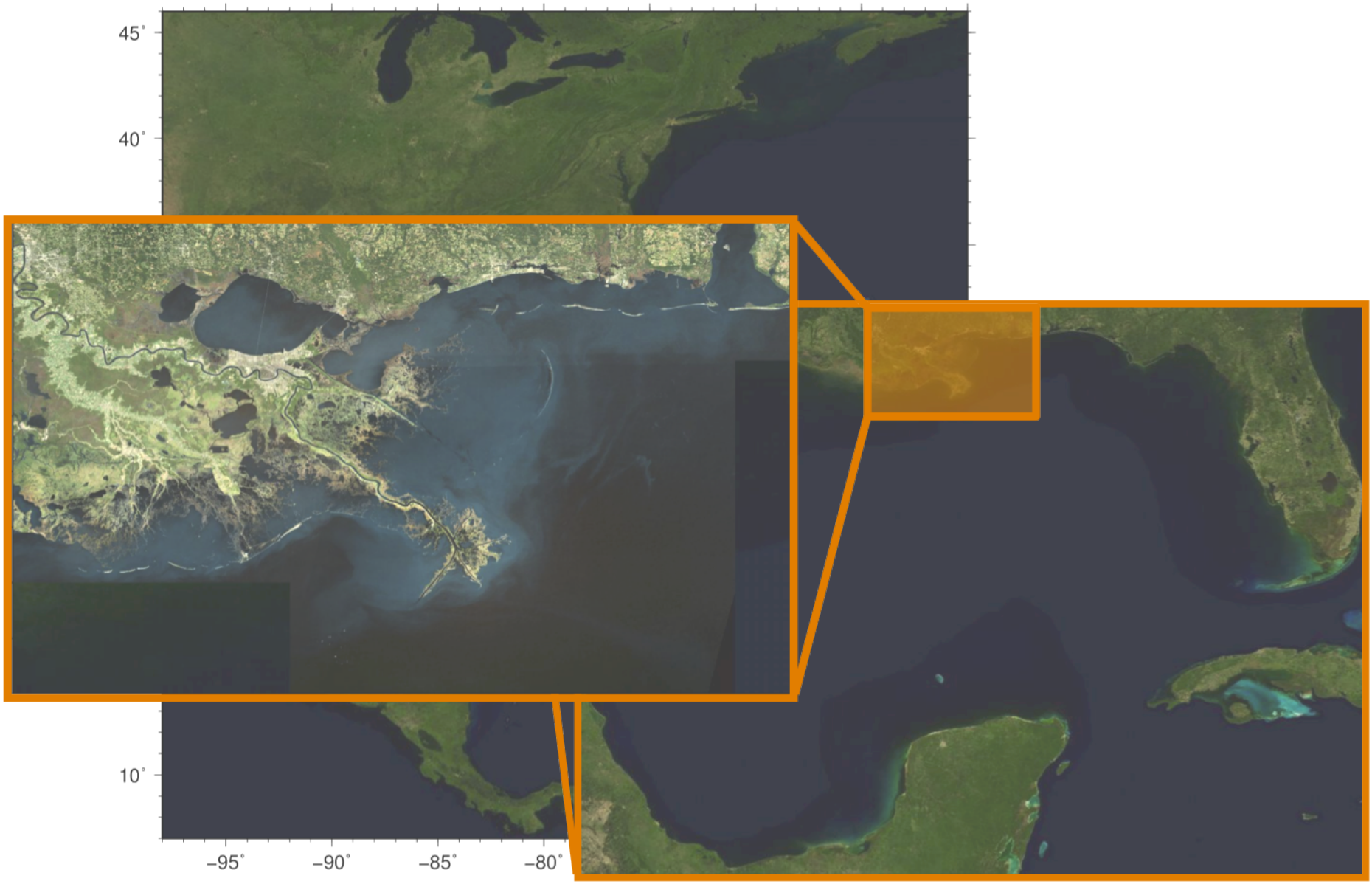

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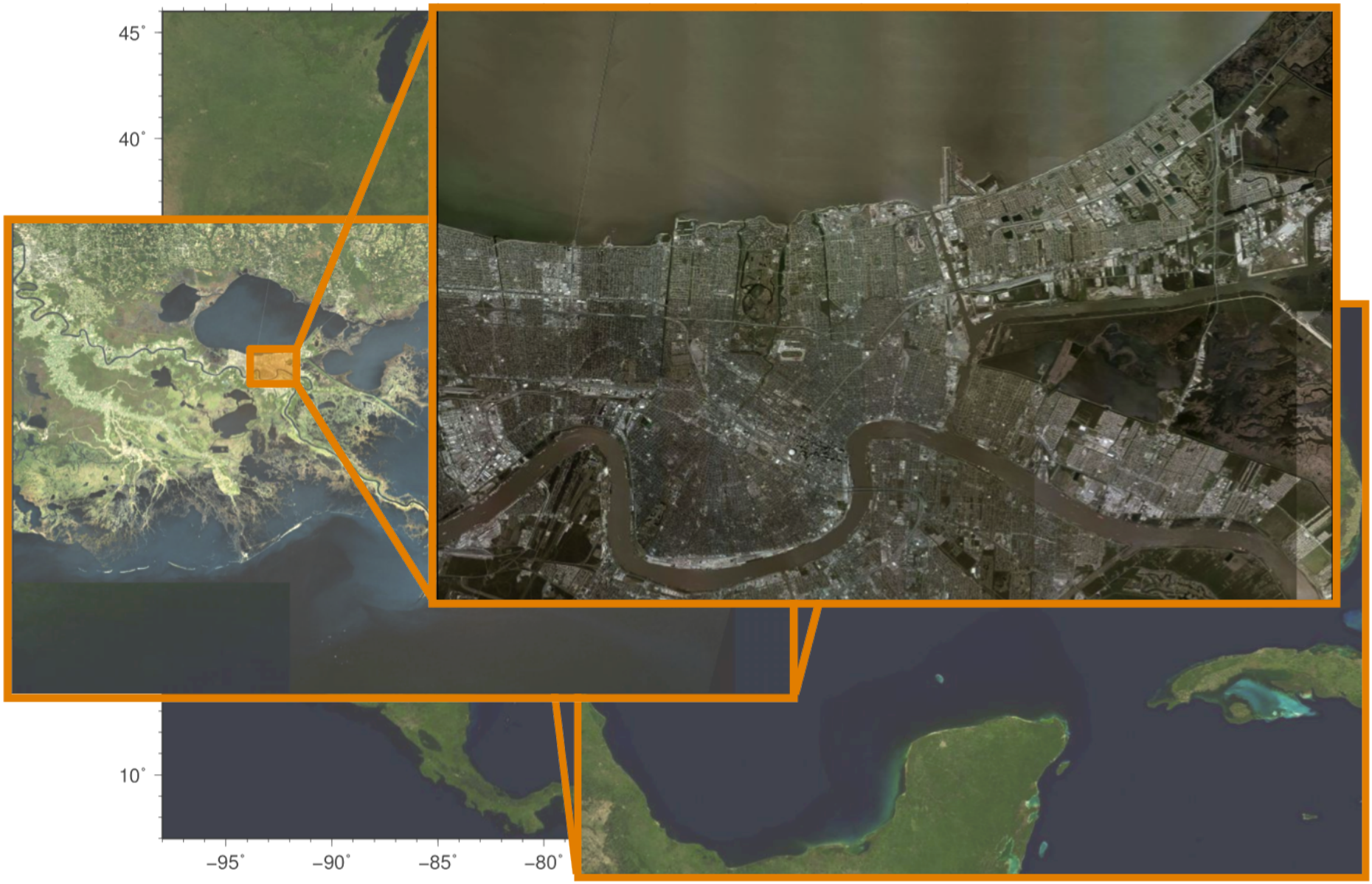
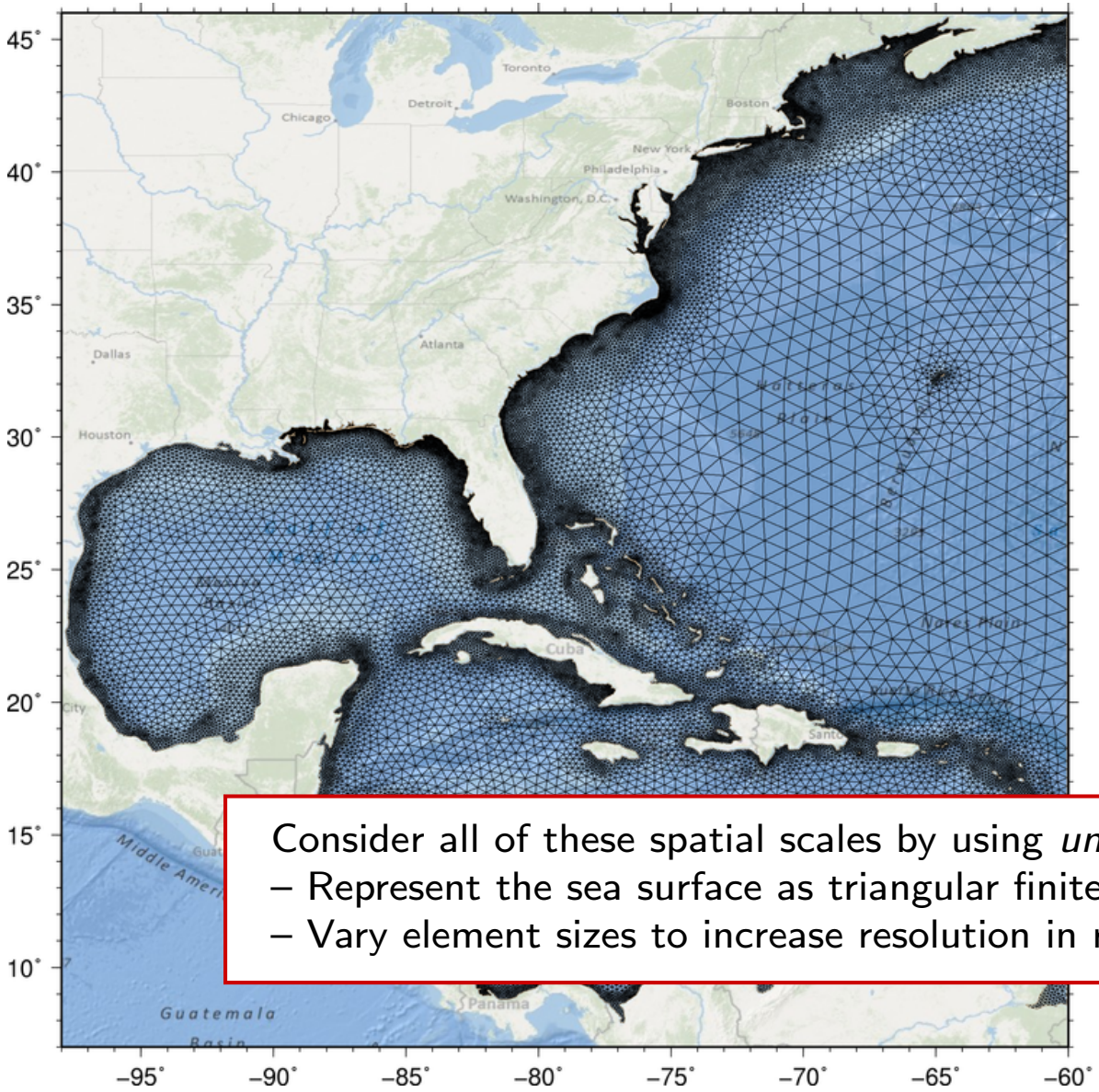


Wide Range of Spatial Scales

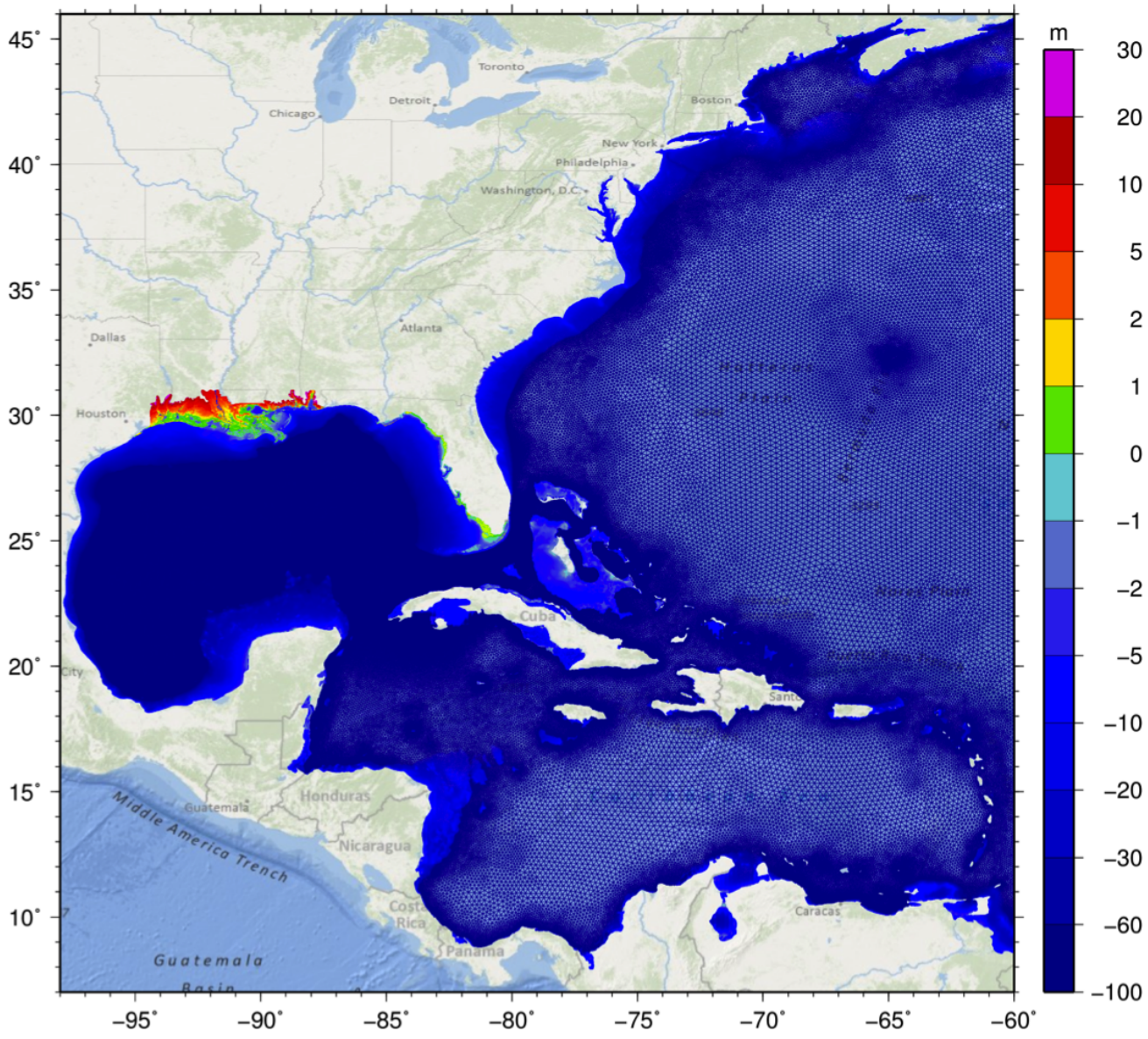
Unstructured, Finite-Element Meshes



Consider all of these spatial scales by using *unstructured meshes*:
- Represent the sea surface as triangular finite elements
- Vary element sizes to increase resolution in regions of interest

Wide Range of Spatial Scales

SL16 Mesh for Southern Louisiana



Wide Range of Spatial Scales

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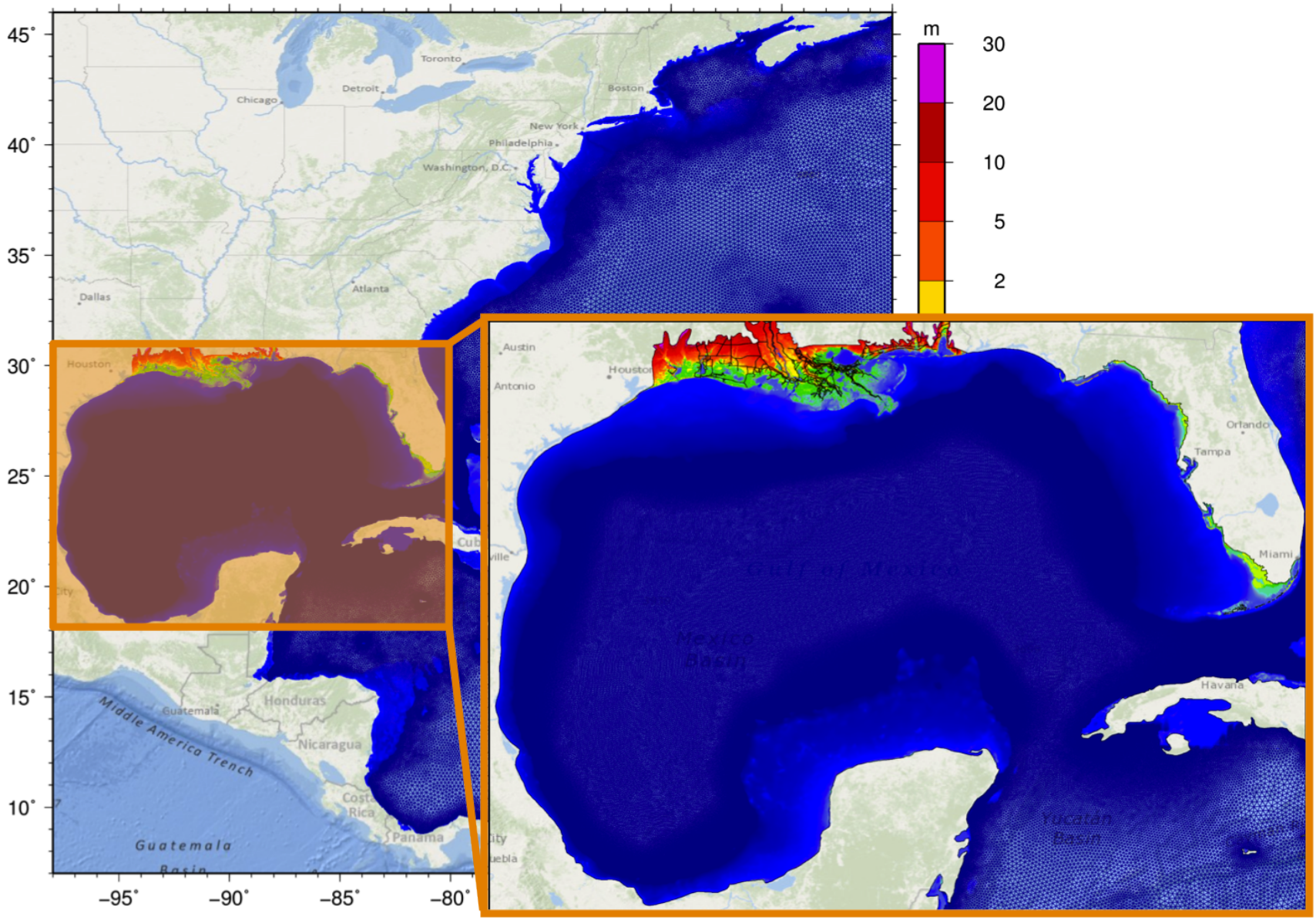

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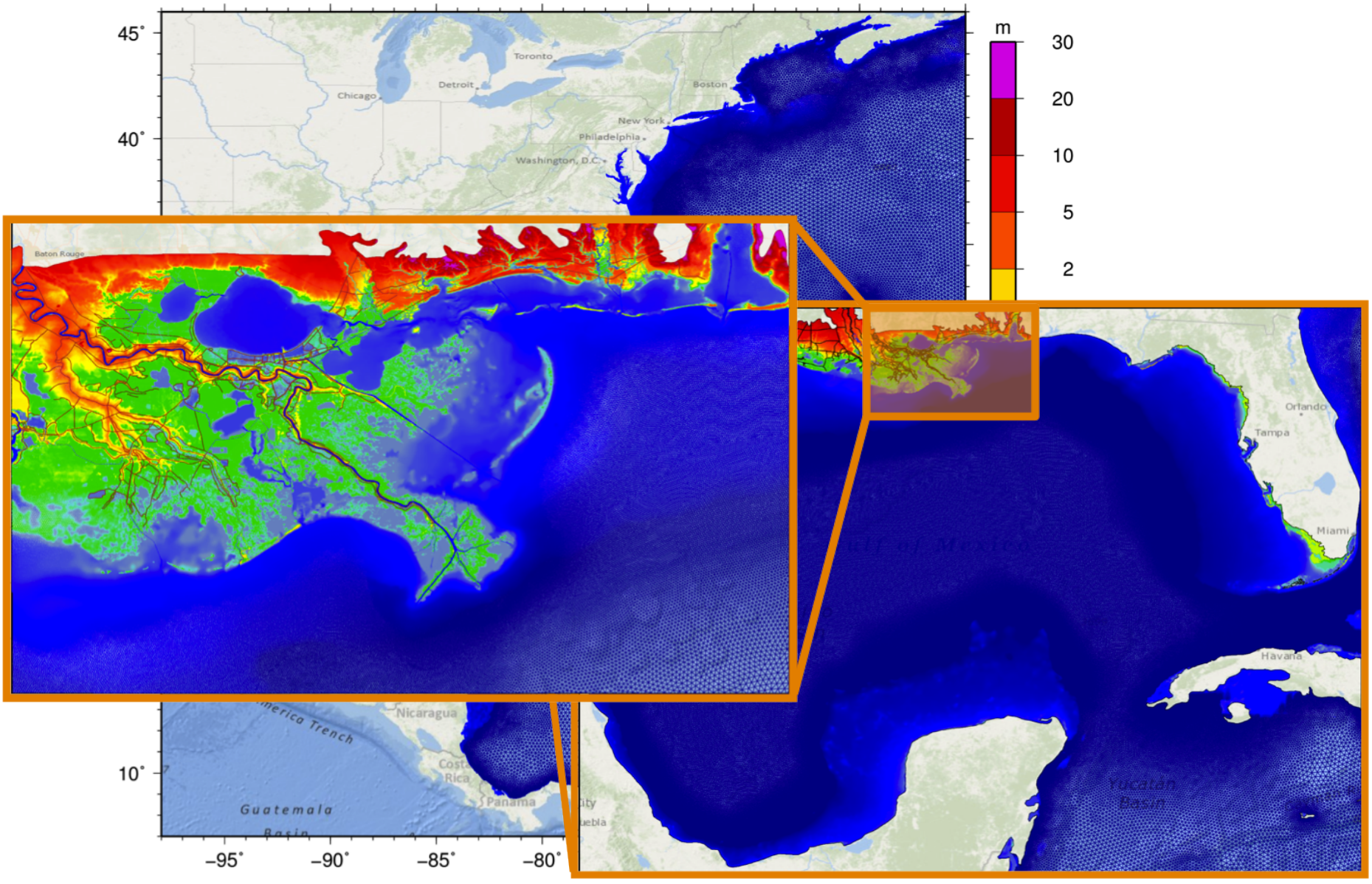

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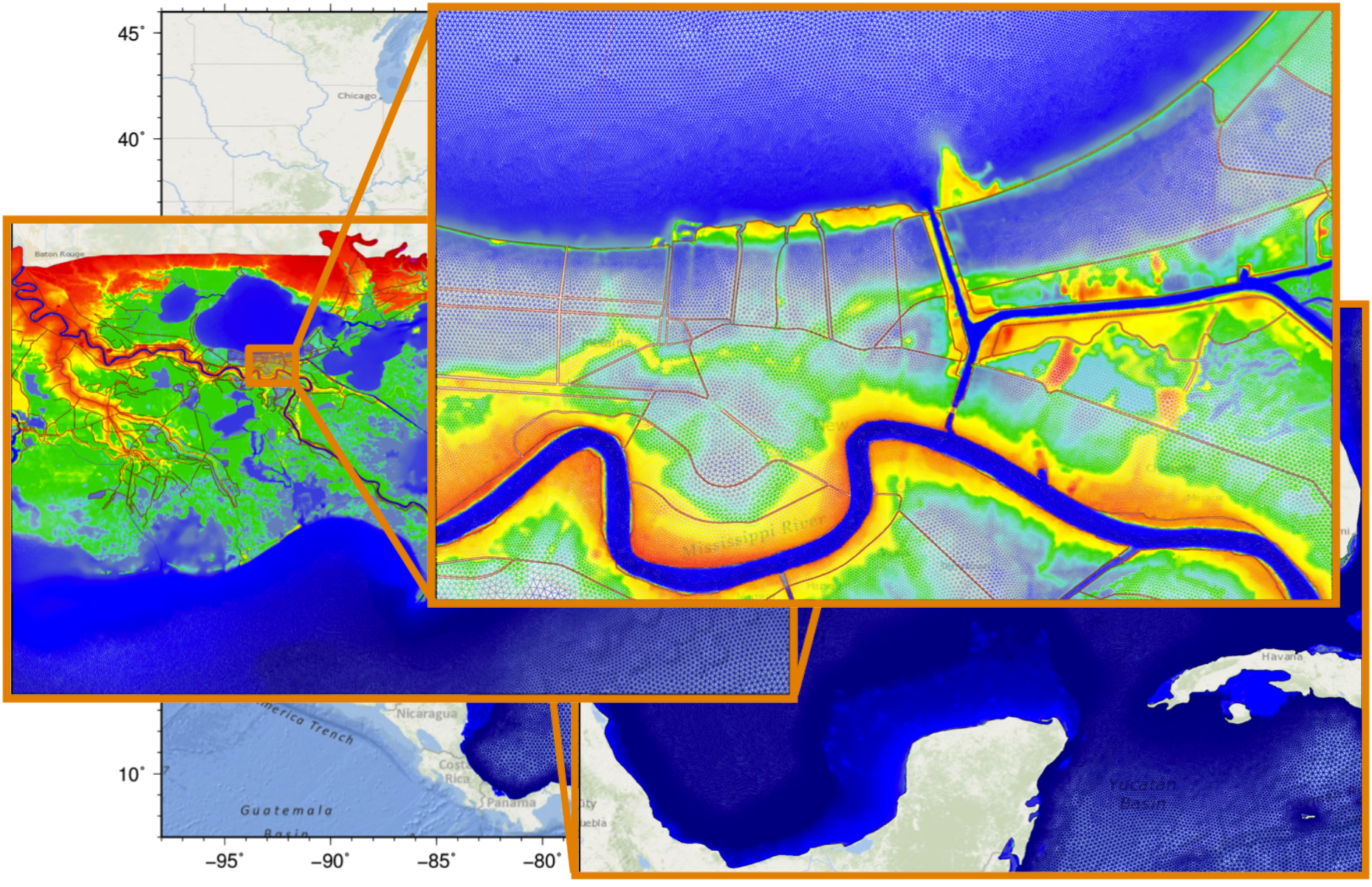


Waves and Storm Surge

Simulating WAves Nearshore (SWAN)

For short waves, we use SWAN

- Does not represent the phase of each individual wave
  - Conserved quantity is the action density $N(t, x, y, \sigma, \theta)$
  - Can be integrated to compute statistical wave properties

Solves the action balance equation:

$$\frac{\partial N}{\partial t} + \nabla_{\mathbf{x}} \cdot \left[(\mathbf{c}_g + \mathbf{U}) N \right] + \frac{\partial c_\theta N}{\partial \theta} + \frac{\partial c_\sigma N}{\partial \sigma} = 0$$

Solution methods in geographic (x, y) and spectral (σ, θ) spaces:

- Gauss-Seidel in geographic space
- Iterative solution of matrix system in spectral space

Waves and Storm Surge

ADvanced CIRCulation (ADCIRC)

For long waves, we use ADCIRC

- Does represent the phases of tides and/or storm surge

Solves the generalized wave continuity equation for water levels ζ:

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + \frac{\partial \tilde{J}_x}{\partial x} + \frac{\partial \tilde{J}_y}{\partial y} - UH \frac{\partial \tau_0}{\partial x} - VH \frac{\partial \tau_0}{\partial y} = 0$$

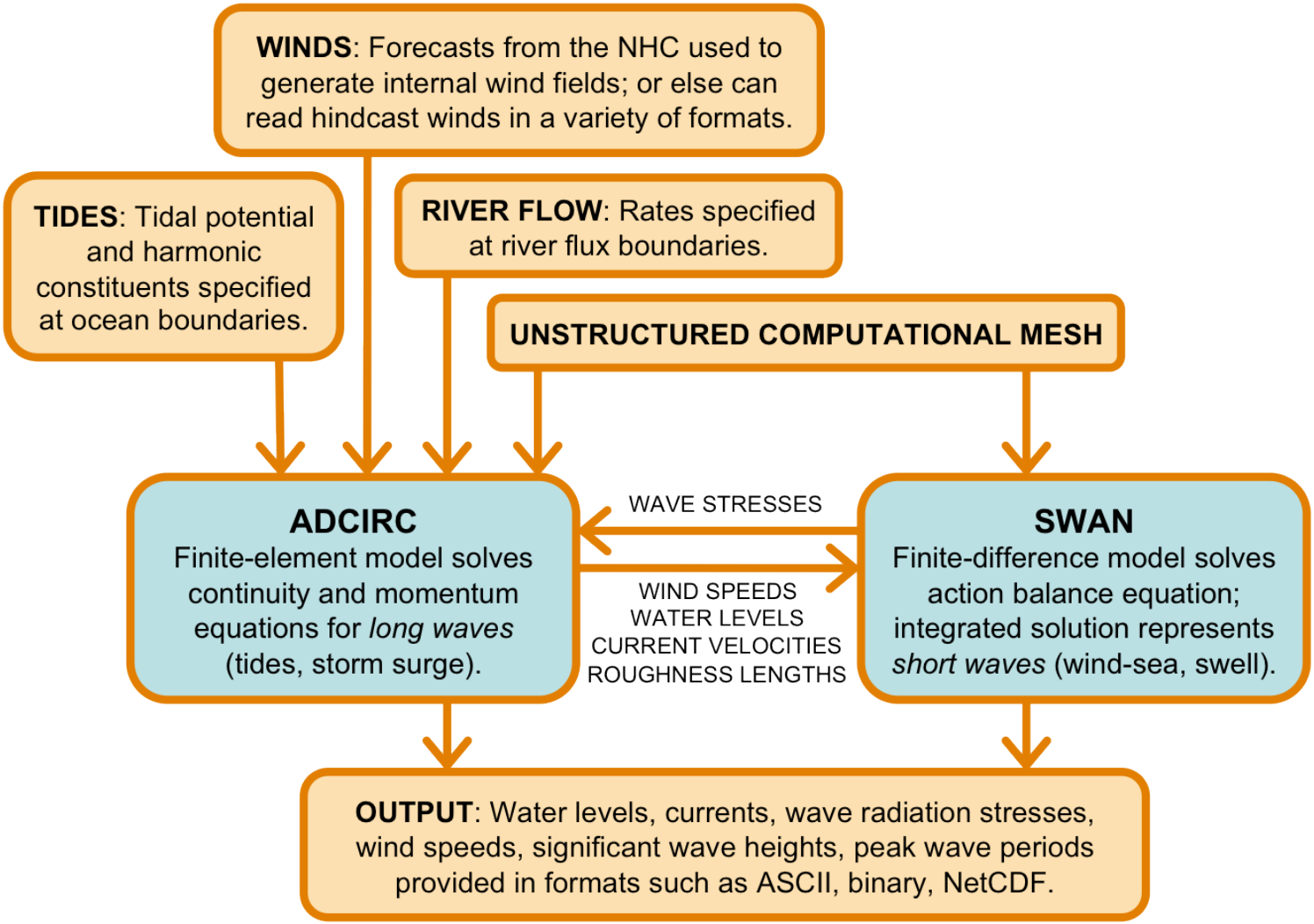
Solves the depth-averaged momentum equations for currents (U, V):

$$\frac{DU}{Dt} - fV = -g \frac{\partial}{\partial x} \left[\zeta + \frac{p_s}{g \rho_0} - \alpha \eta \right] + \frac{\tau_{sx} + \tau_{bx}}{\rho_0 H} + \frac{M_x - D_x}{H}$$

$$\frac{DV}{Dt} + fU = -g \frac{\partial}{\partial y} \left[\zeta + \frac{p_s}{g \rho_0} - \alpha \eta \right] + \frac{\tau_{sy} + \tau_{by}}{\rho_0 H} + \frac{M_y - D_y}{H}$$

Tight Coupling of SWAN+ADCIRC

Flow Chart



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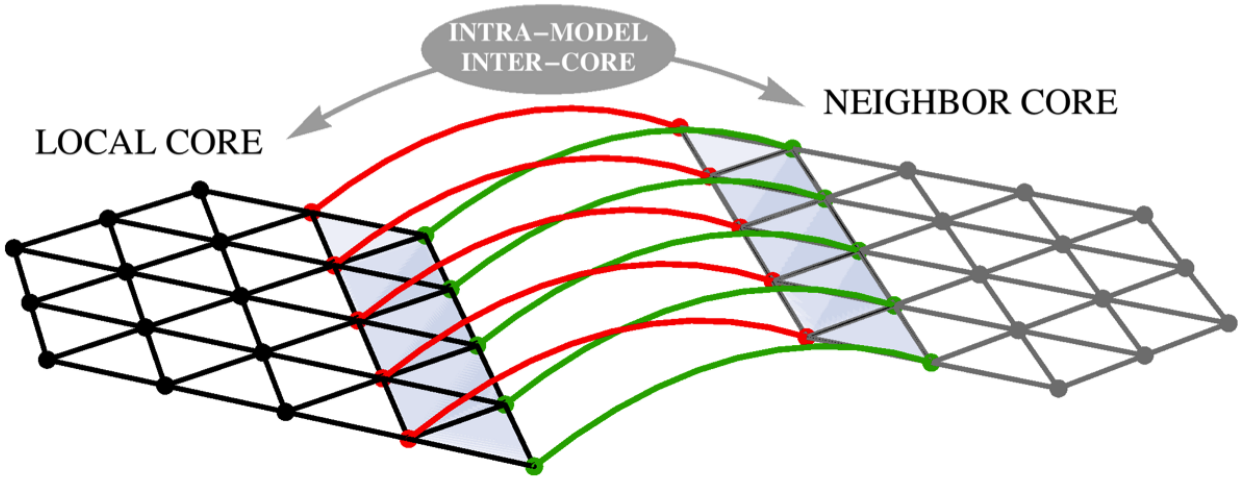
Tight Coupling of SWAN+ADCIRC

Parallel Communication

Communication between cores at sub-mesh boundaries



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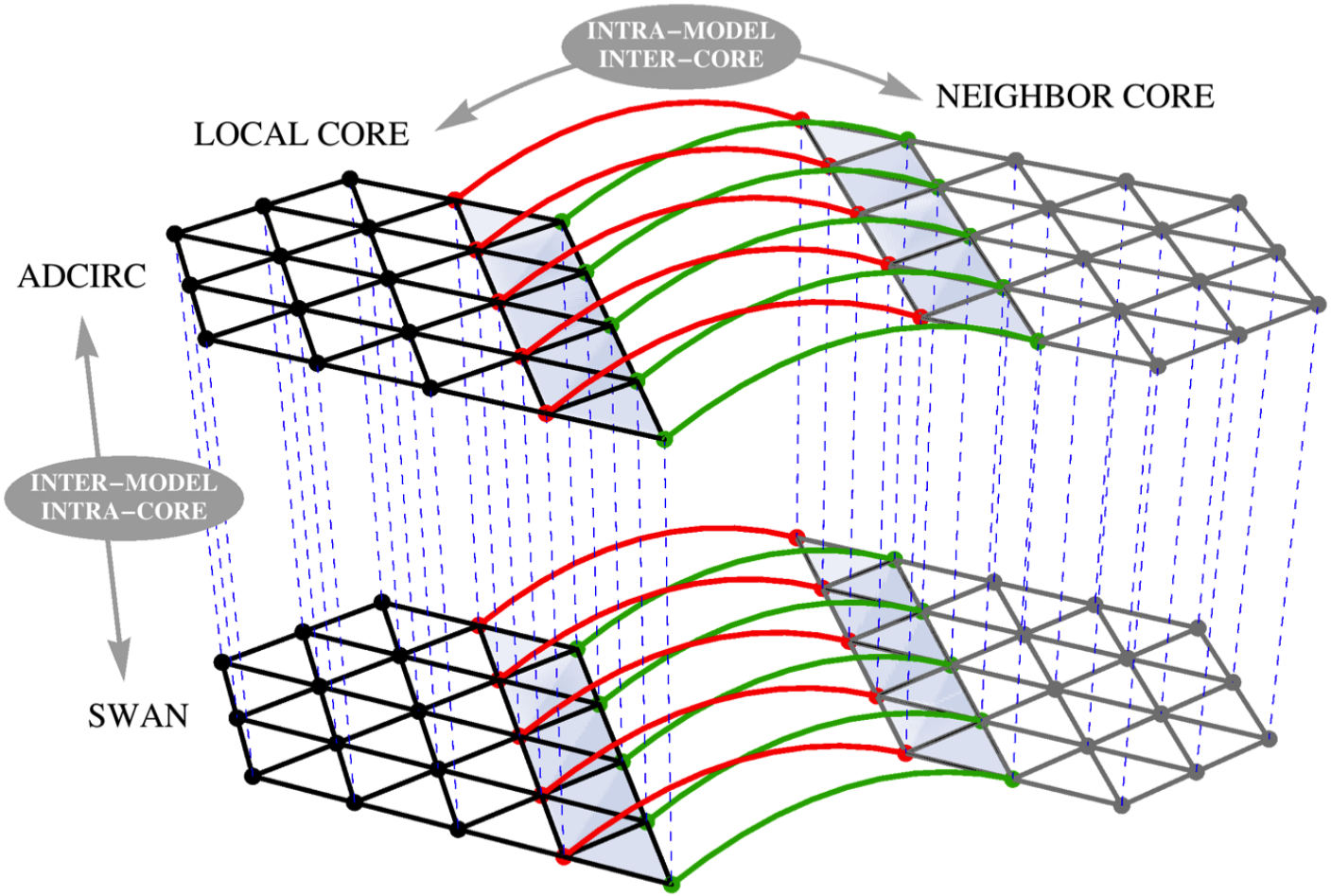
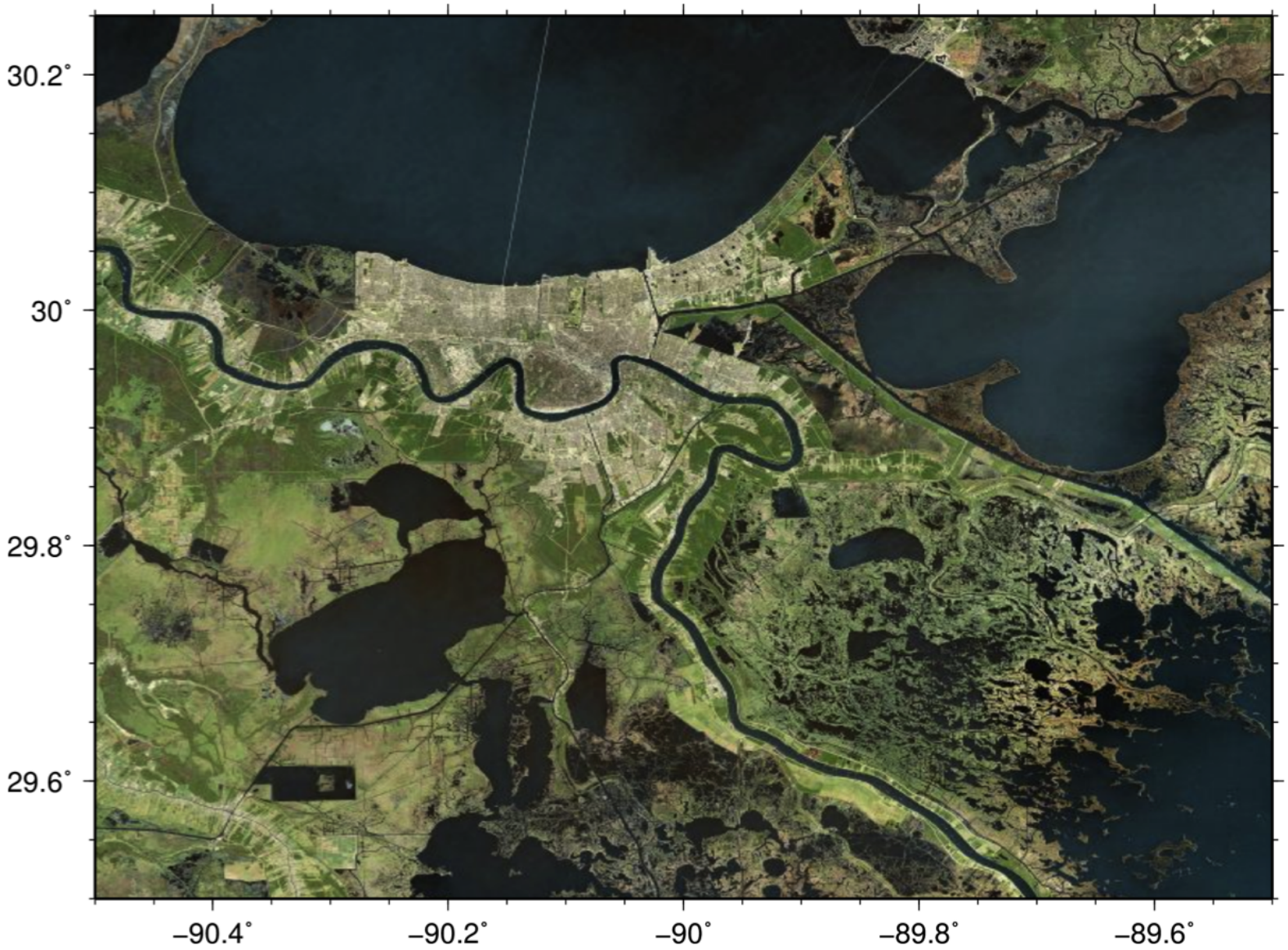


Validation for Hurricane Gustav (2008)

Near Flooding of New Orleans



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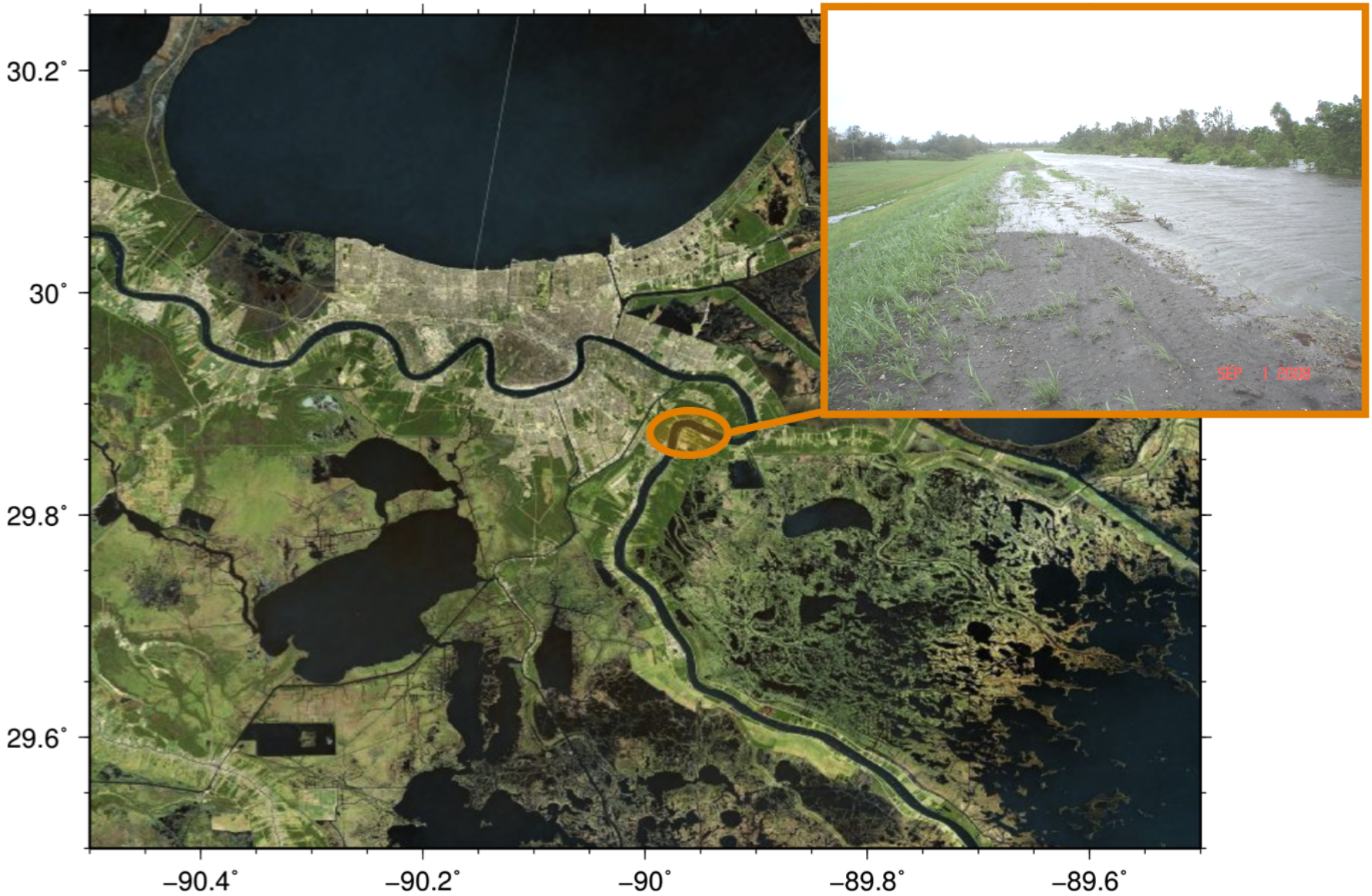

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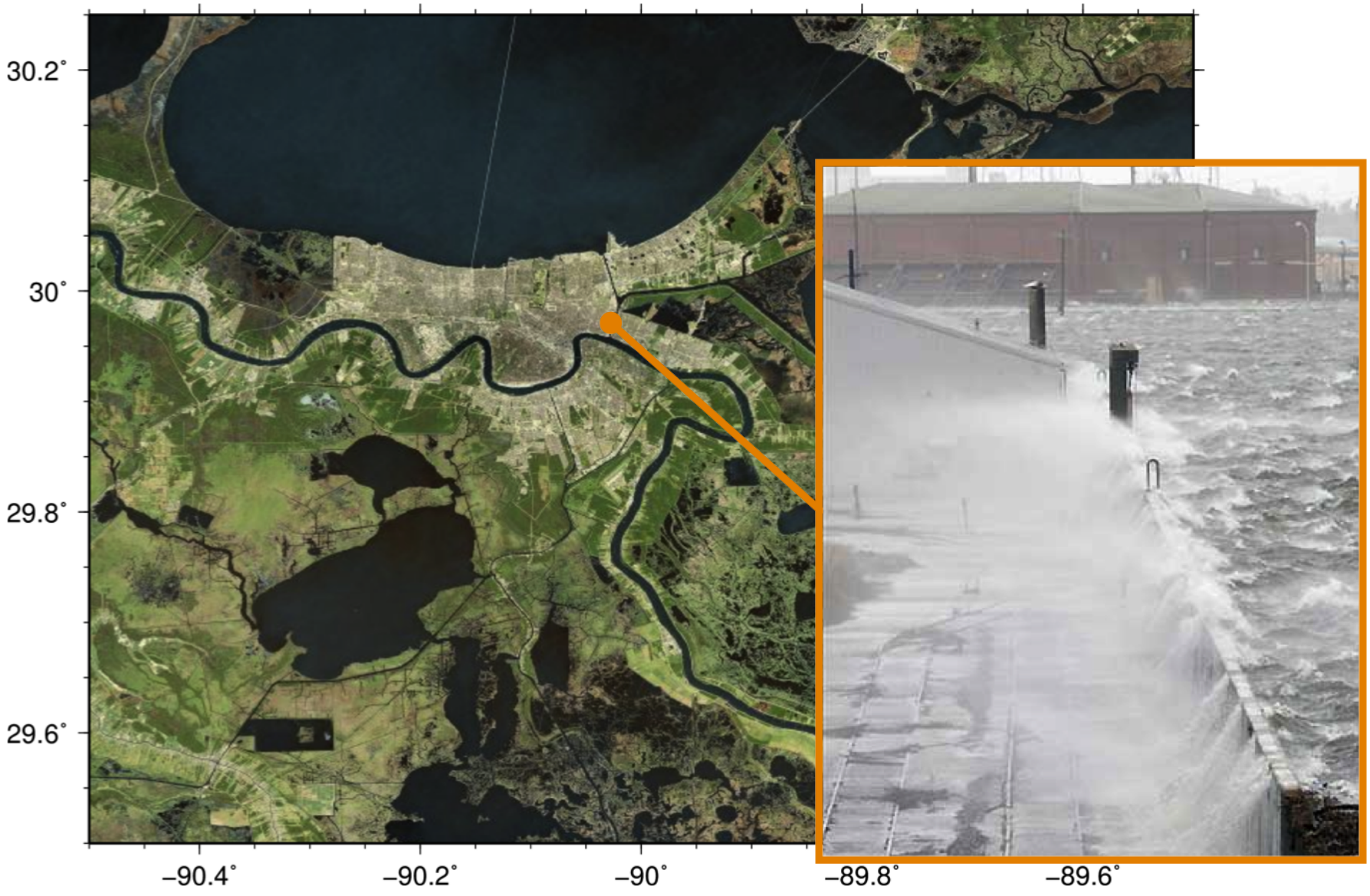
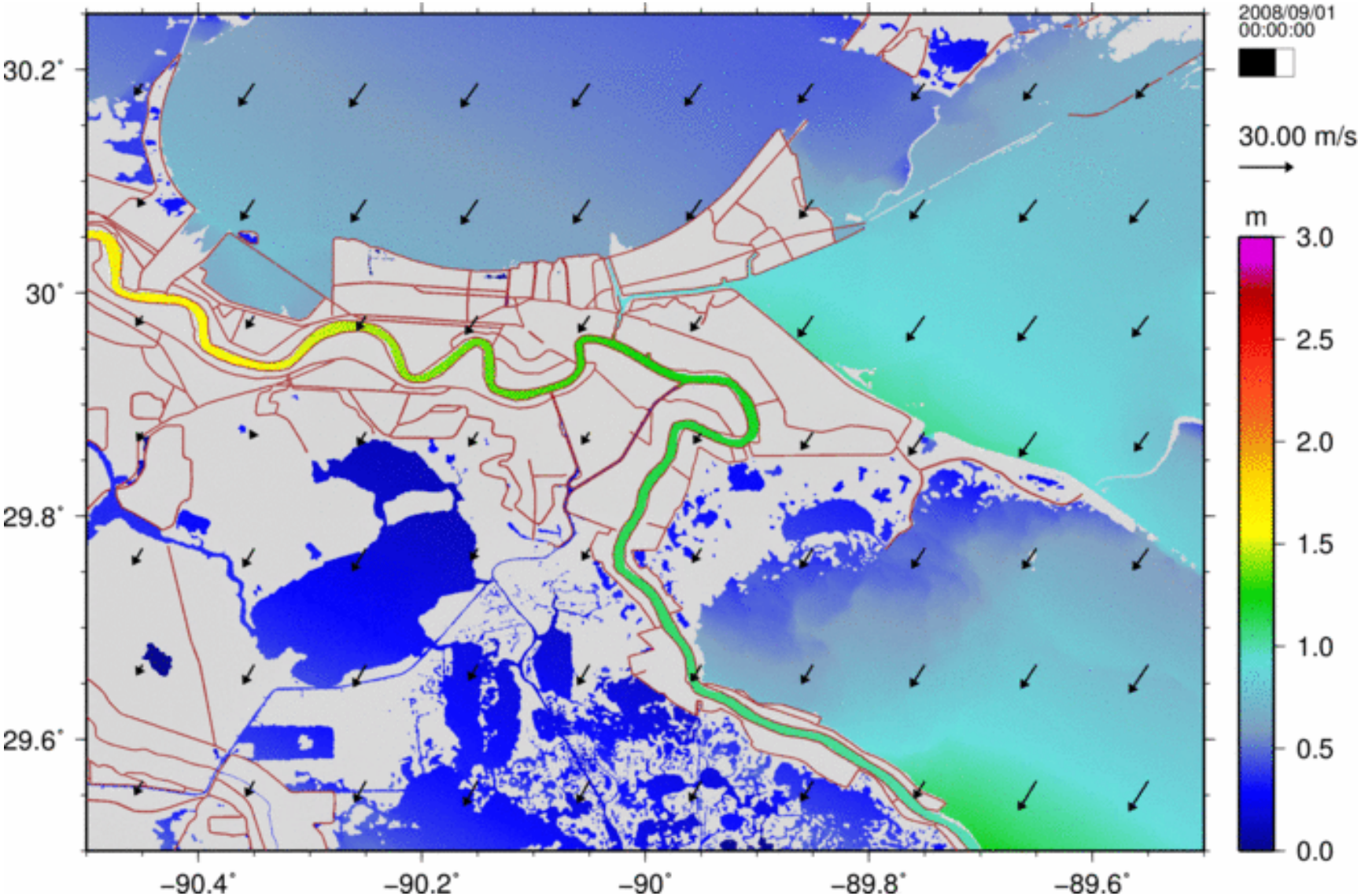


Validation for Hurricane Gustav (2008)

Day of Landfall



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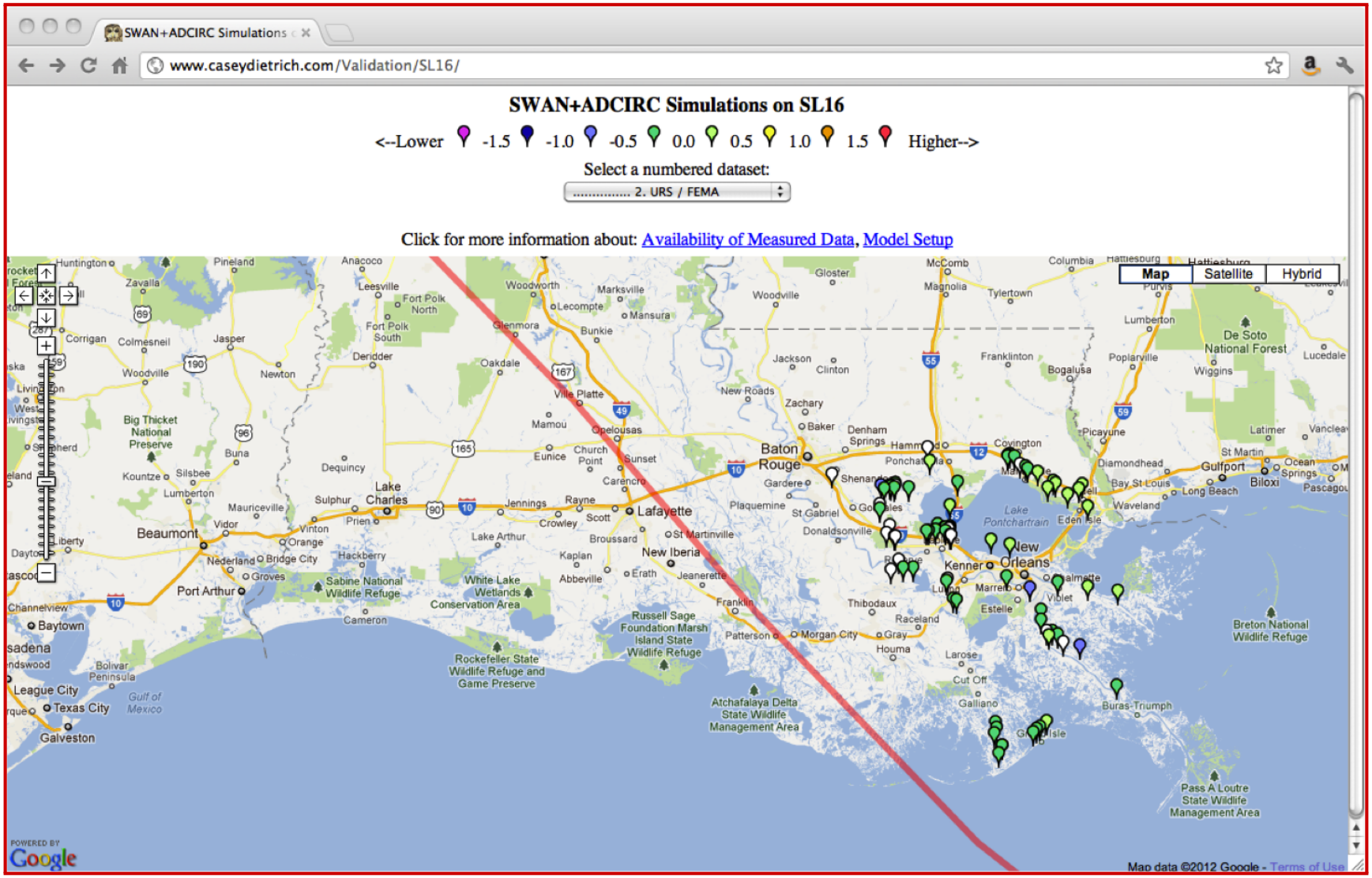
Validation for Hurricane Gustav (2008)

High-Water Marks



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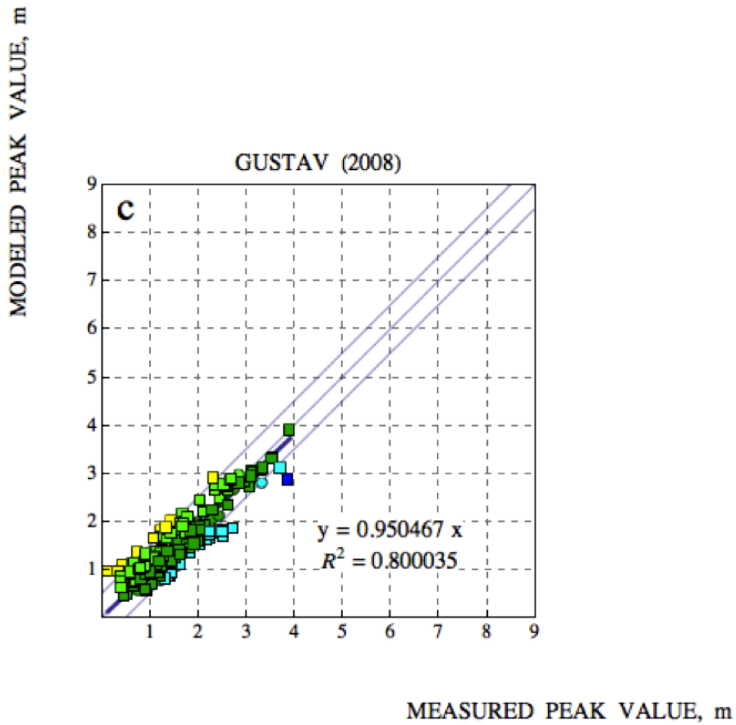

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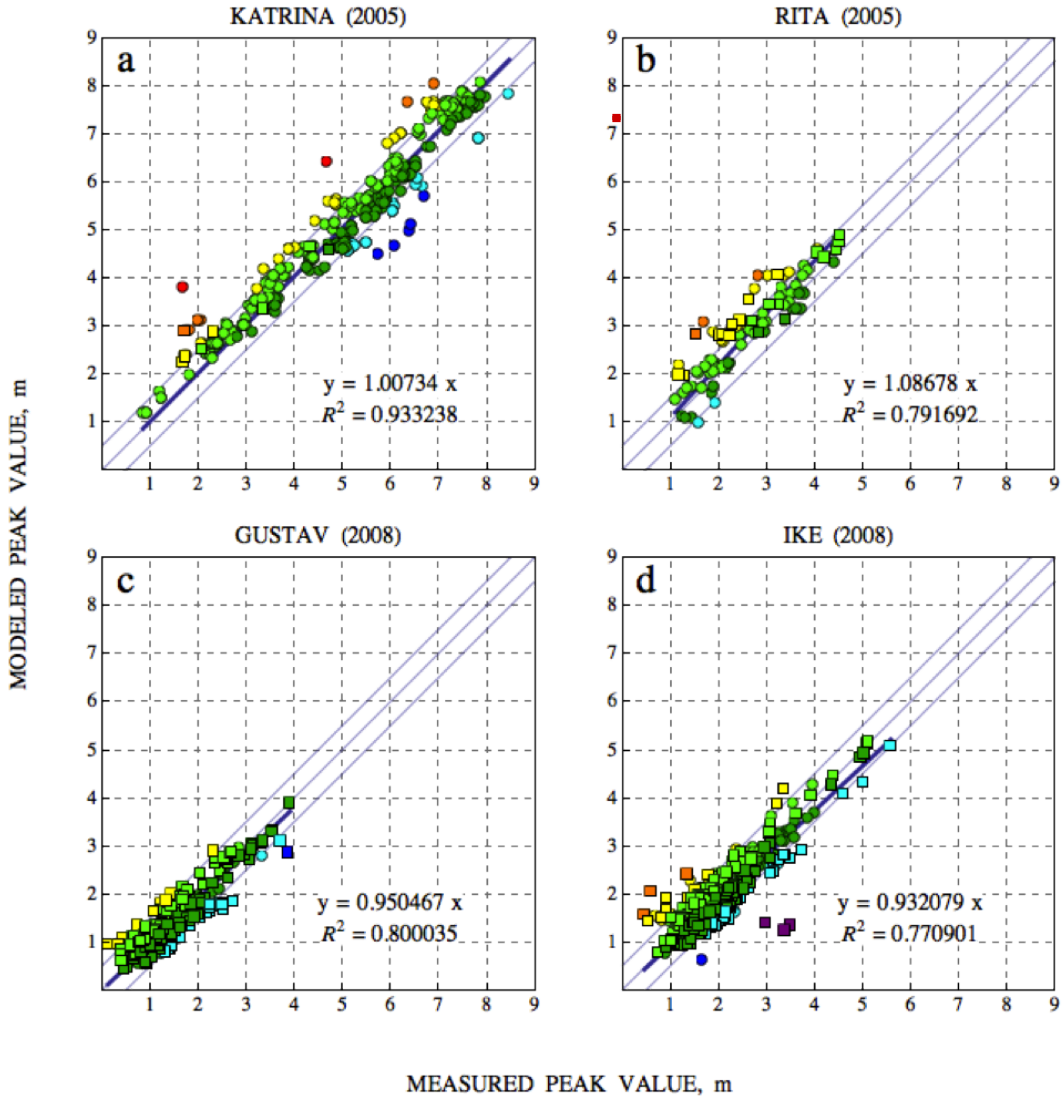

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ADCIRC Surge Guidance System (ASGS)

Introduction

SWAN+ADCIRC can be employed in real-time via the ASGS

- **Everything happens automatically**
  - Models are initialized, run and processed by Perl scripts

Wind fields from two sources:

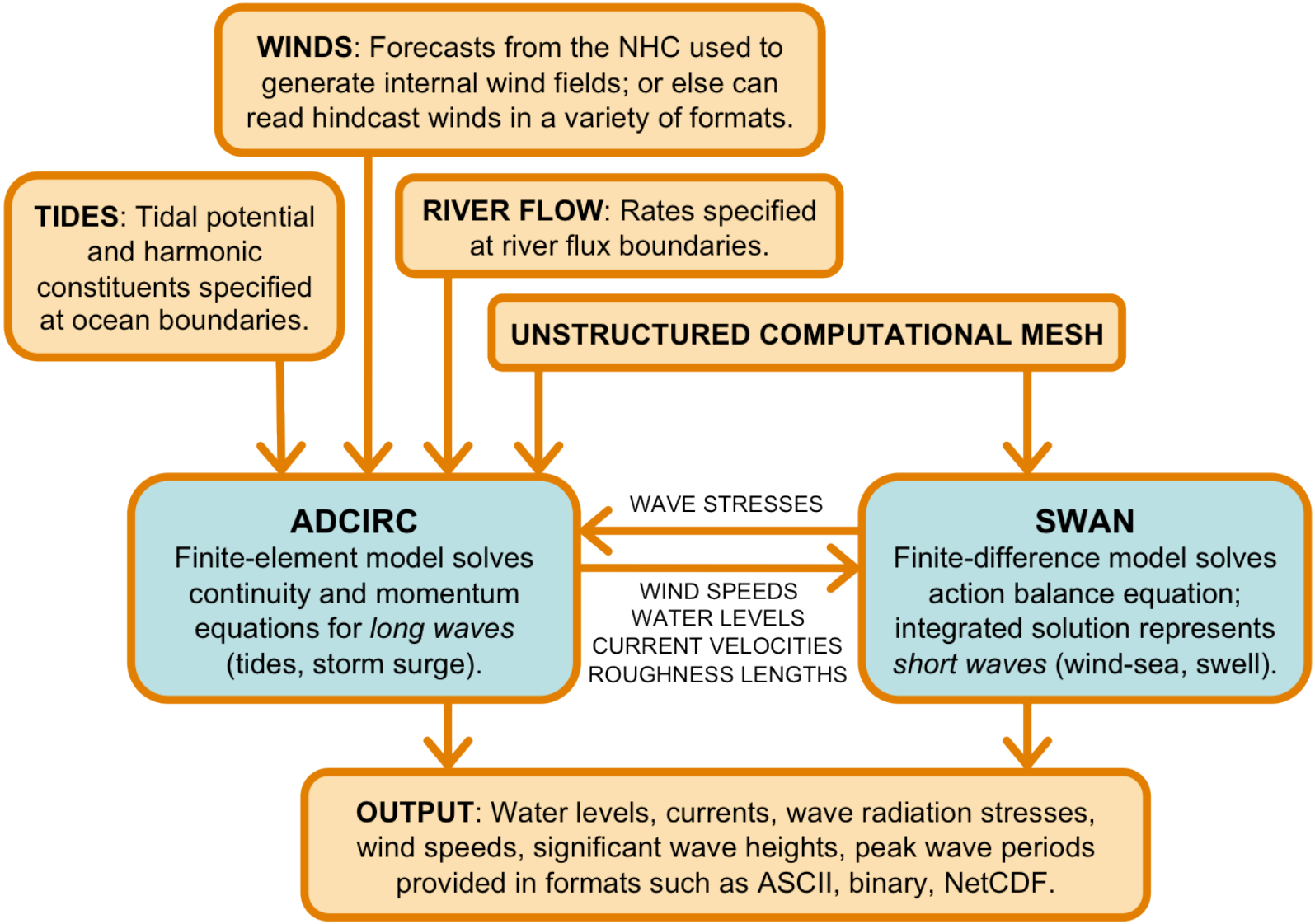
1. Under normal conditions:
   - Downloaded from NAM model output by NOAA/NCEP
   - Converted into format compatible with SWAN+ADCIRC
2. Under hurricane conditions:
   - Download advisories from NOAA/NHC
   - Generate wind field using parametric model (Holland, 1980)

Guidance can be shared in multiple formats:

- Raster images (JPG, PNG, etc.)
- Geo-referenced raster images (Google Earth, GIS)
- Web service (`coastalemergency.org`)

ADCIRC Surge Guidance System (ASGS)

Flow Chart



ADCIRC Surge Guidance System (ASGS)

Development Teams

University of North Carolina at Chapel Hill

- Provide forecasts for Carolina and surrounding states via Google Maps application (`nc-cera.renci.org`)
- Guidance during Irene (2011) prompted Coast Guard to shift operations to avoid flooding of operations center

Louisiana State University

- Provide forecasts for Louisiana and northern Gulf states via Google Maps application (`cera.cct.lsu.edu`)

University of Texas at Austin

- Provide forecasts for storms impacting Texas coastline; partnerships with Texas State Operations Center
- During Isaac (2012), guidance shared with NWS offices in Fort Worth, Tallahassee and Miami

Strengthening Guidance for North Carolina

Web-Based Guidance

In North Carolina, the guidance is available from the Coastal Emergency Risks Assessment (CERA) team:

- Shared via Web portal: `nc-cera.renci.org`

Updated often with new guidance:

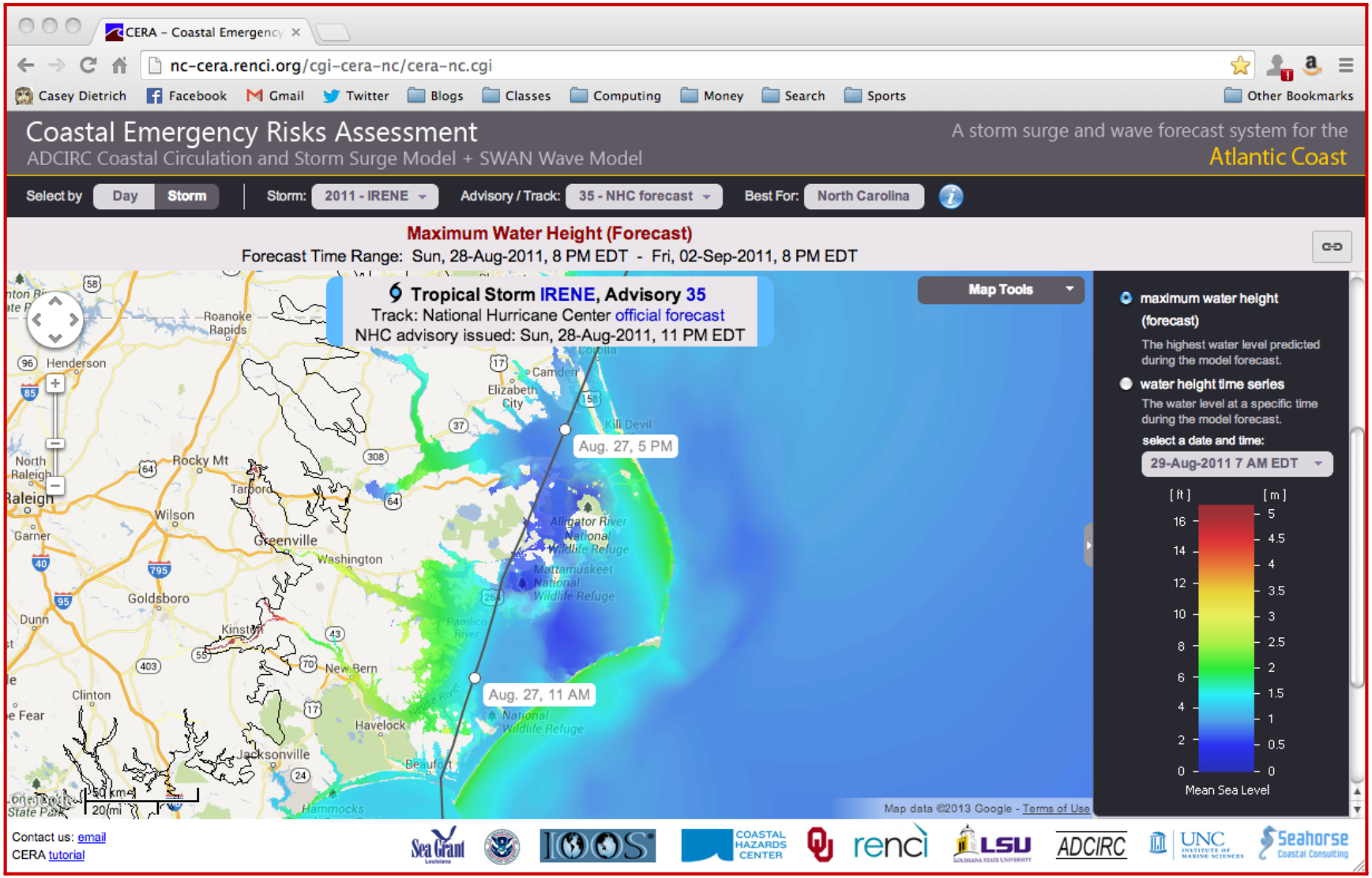
- Normal conditions with base meteorology from NOAA/NCEP
- Extreme conditions with storm advisories from NOAA/NHC

Guidance is interactive within Google Maps:

- View results as a time series or as maxima
- Select layers for:
  - Water levels (above MSL or above ground)
  - Waves (significant heights, peak periods)
  - Wind speeds
  - Hydrographs at NOAA/NOS gage stations

Strengthening Guidance for North Carolina

Example during Hurricane Irene (2011)



Strengthening Guidance for North Carolina

Expansion of Guidance to Other Formats

Some partners prefer guidance in other formats:

- Polygon-based formats:
  - Shapefiles and ancillary files for GIS
  - KML files for Google Earth
- These files can be overlaid with information from other sources

We developed Python-based scripts to convert SWAN+ADCIRC output

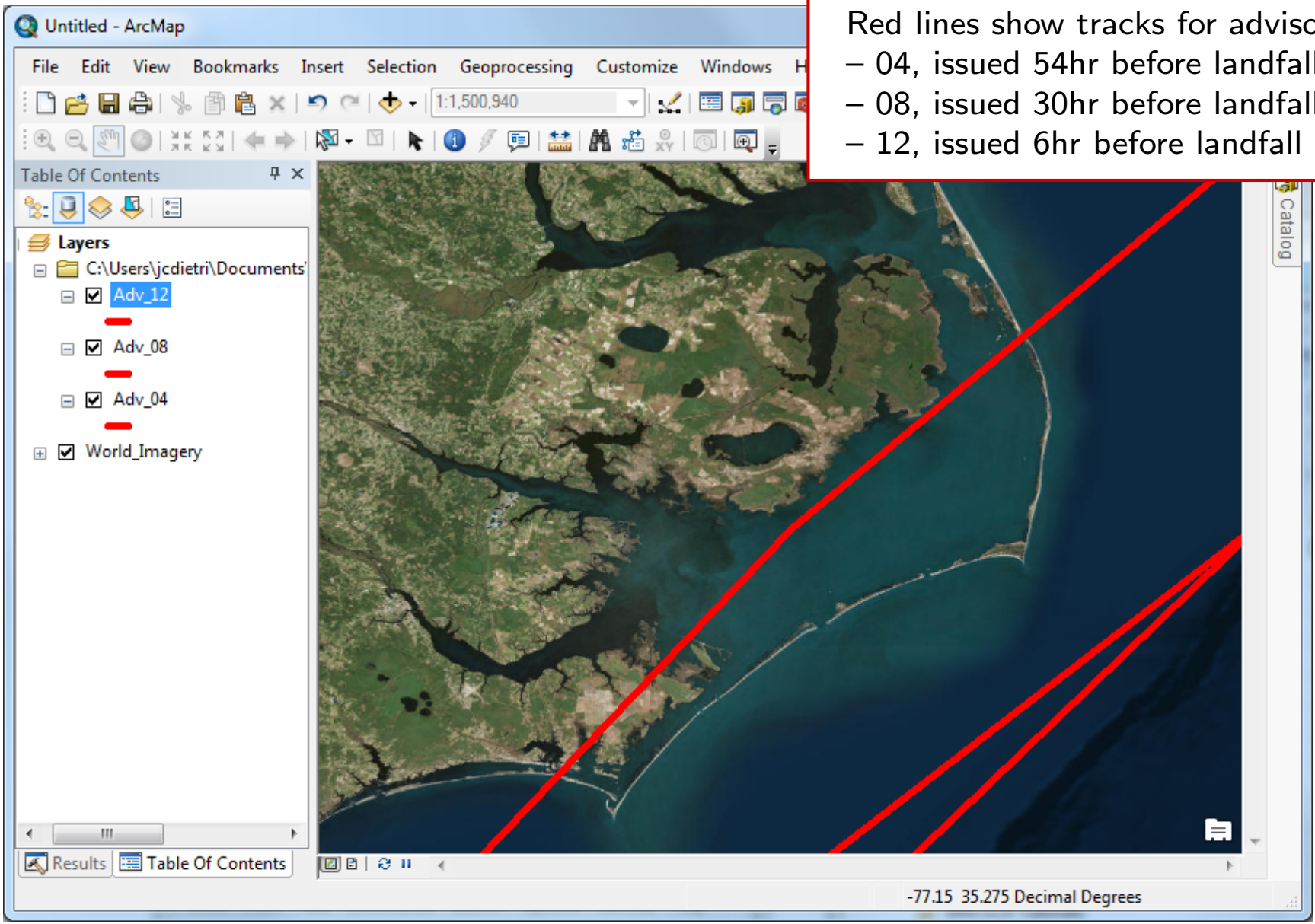
- Based on older scripts from BO Blanton, RA Luettich Jr
- Expanded to consider time series information, KML formats

Now sharing guidance in developmental formats with partners at NWS offices, state and local emergency management teams

- **Guidance products are generated and shared automatically**
- Goal – Integrate these products as downloads from NC-CERA

Strengthening Guidance for North Carolina

Maximum Water Levels during Hurricane Arthur (2014)

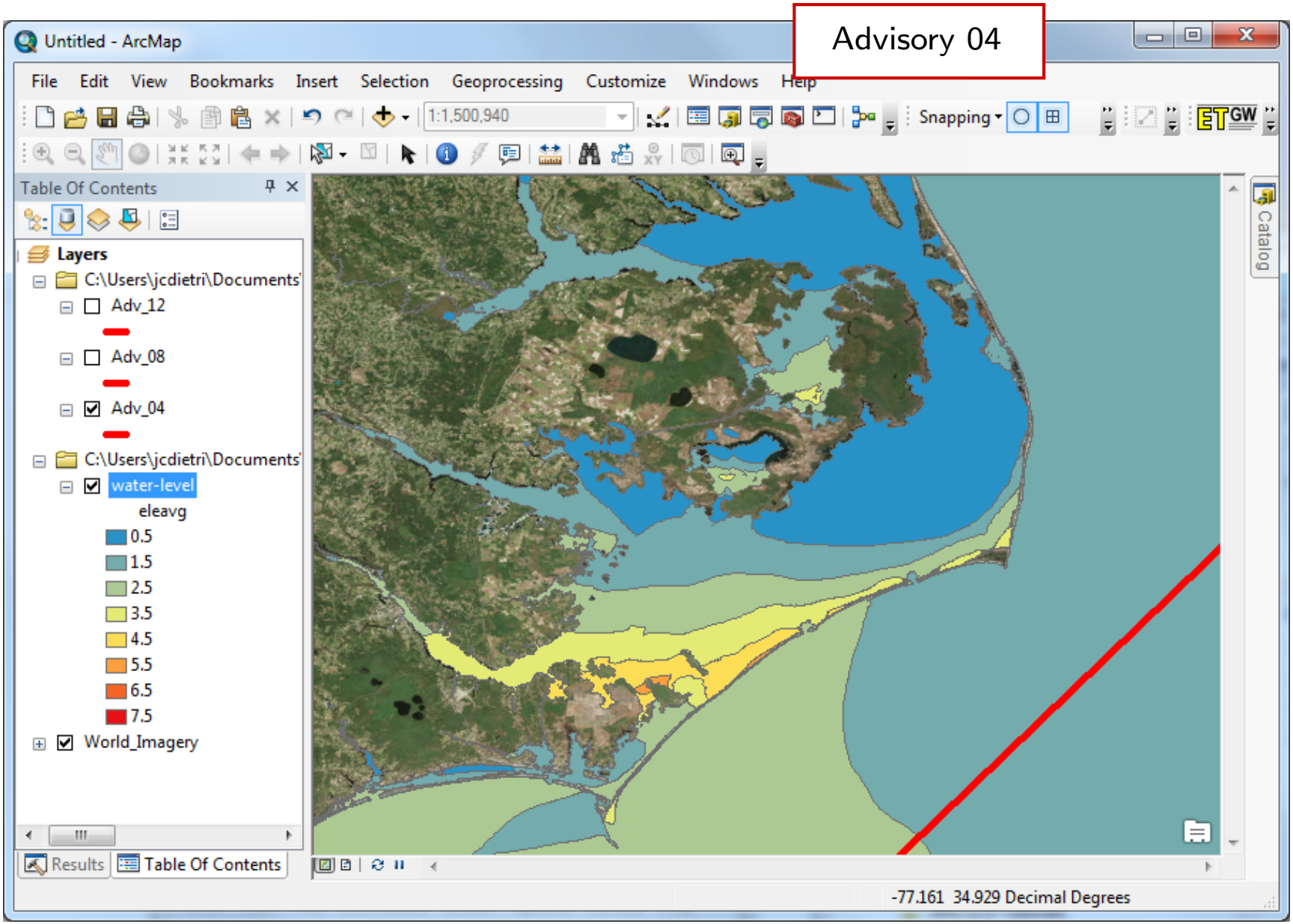


Red lines show tracks for advisories:

- 04, issued 54hr before landfall
- 08, issued 30hr before landfall
- 12, issued 6hr before landfall

Strengthening Guidance for North Carolina

Maximum Water Levels during Hurricane Arthur (2014)



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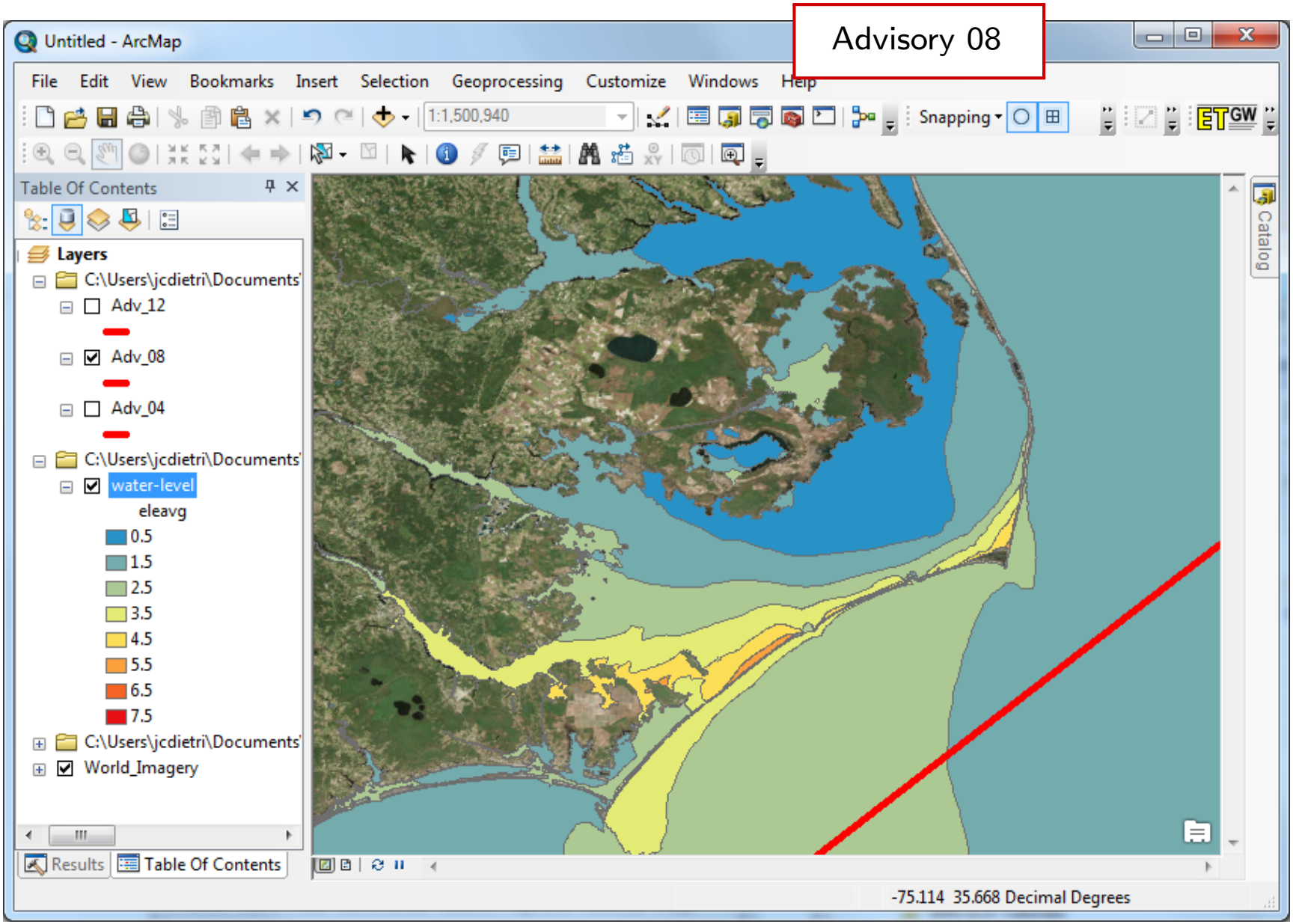

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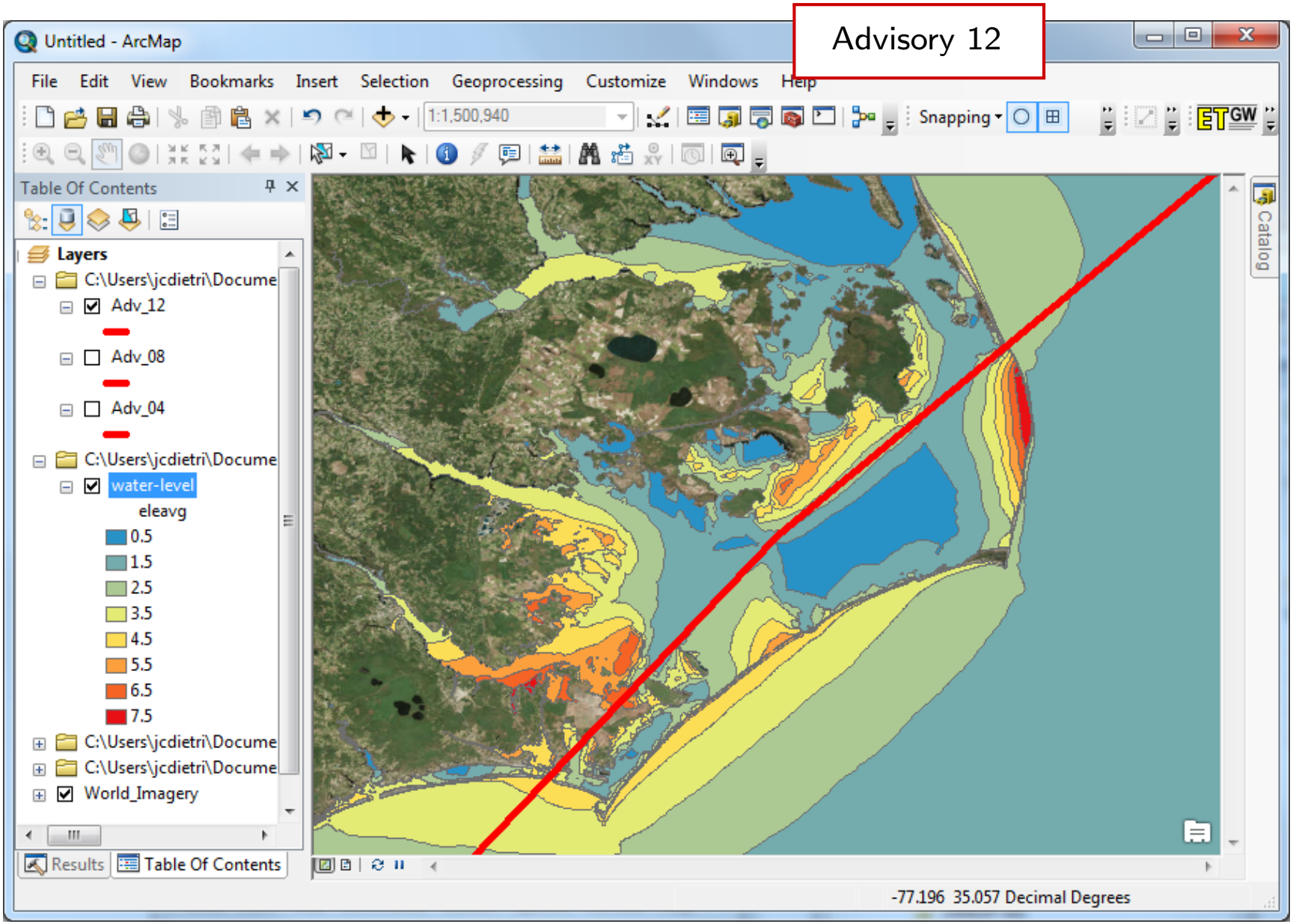

Summary

High-resolution models for southern Louisiana:

- Resolution varies from kilometers to meters in unstructured mesh
- Tight coupling of SWAN+ADCIRC
- Validation to wealth of measurement data

Real-time forecasting for Texas and North Carolina:

- Useful information despite track uncertainties
  - Arthur (2014) in NC
- CERA Web-based guidance for NC coast
- Expanding guidance to GIS and KML formats

Sea Grant North Carolina | COASTAL HAZARDS CENTER | ADCIRC | Seahorse Coastal Consulting | renci | UNC INSTITUTE OF MARINE SCIENCES | NC STATE