NC STATE UNIVERSITY

Recent Progress in Coupling Baroclinic Flow onto the Louisiana-Mississippi Shelf

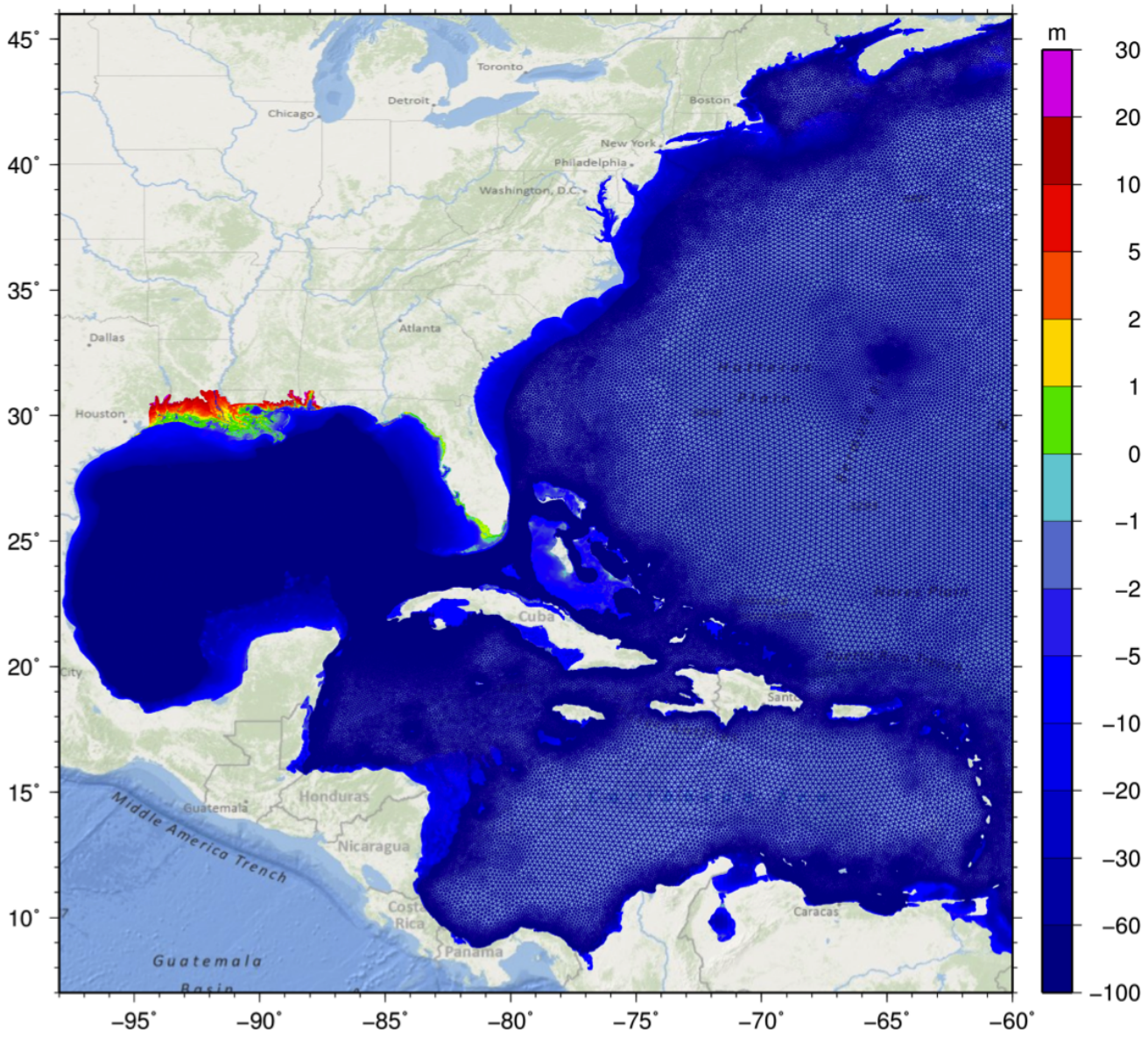
Casey Dietrich[1], Clint Dawson[2], Hamid Arabshahi[2]

[1]Civil, Construction, and Environmental Engineering, NC State University

[2]Institute for Computational Engineering and Sciences, University of Texas at Austin

CARTHE All-Hands Meeting
Coconut Grove, Florida
03 October 2013

Coastal Flooding with ADCIRC – Unstructured, Finite-Element Meshes



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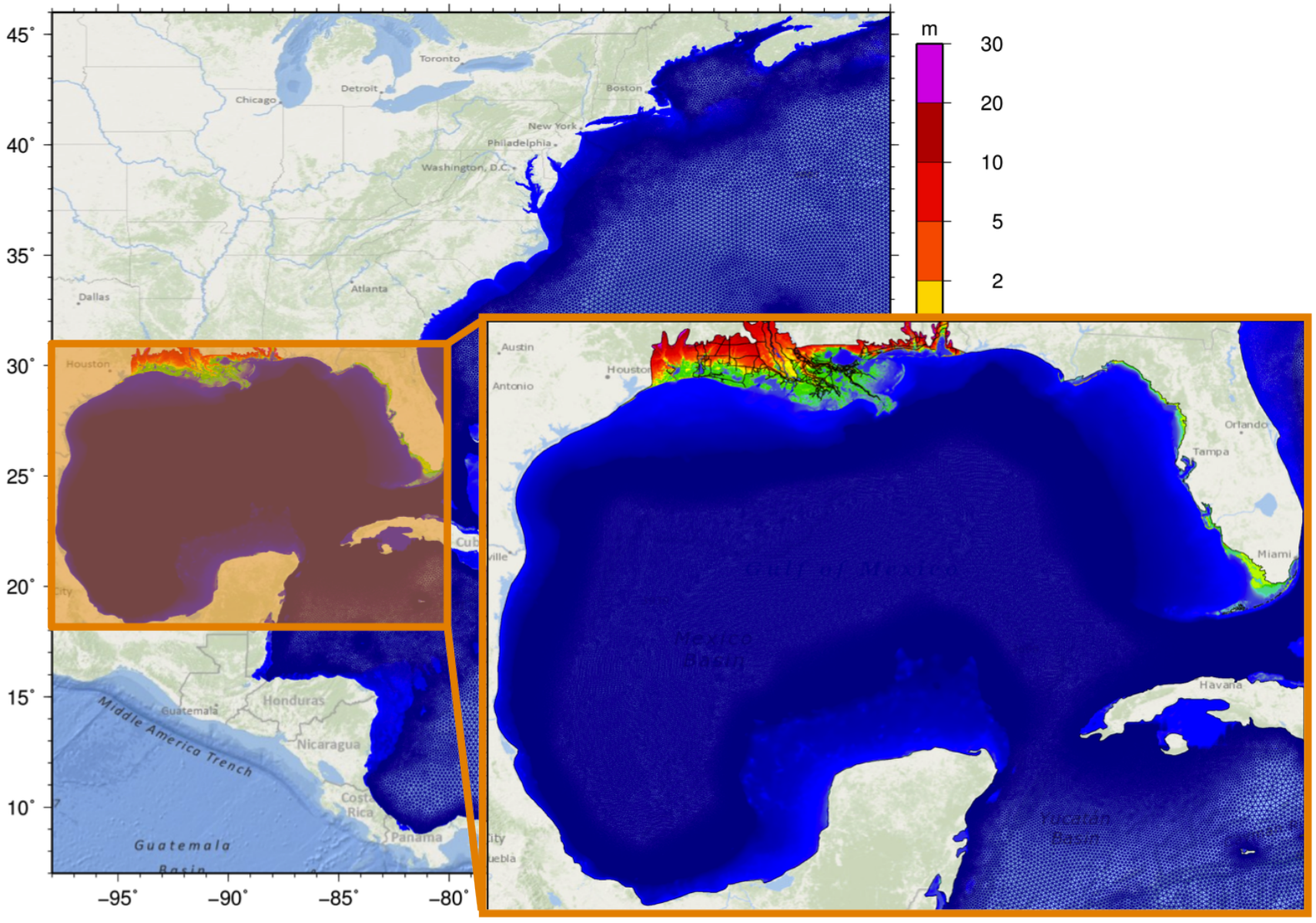

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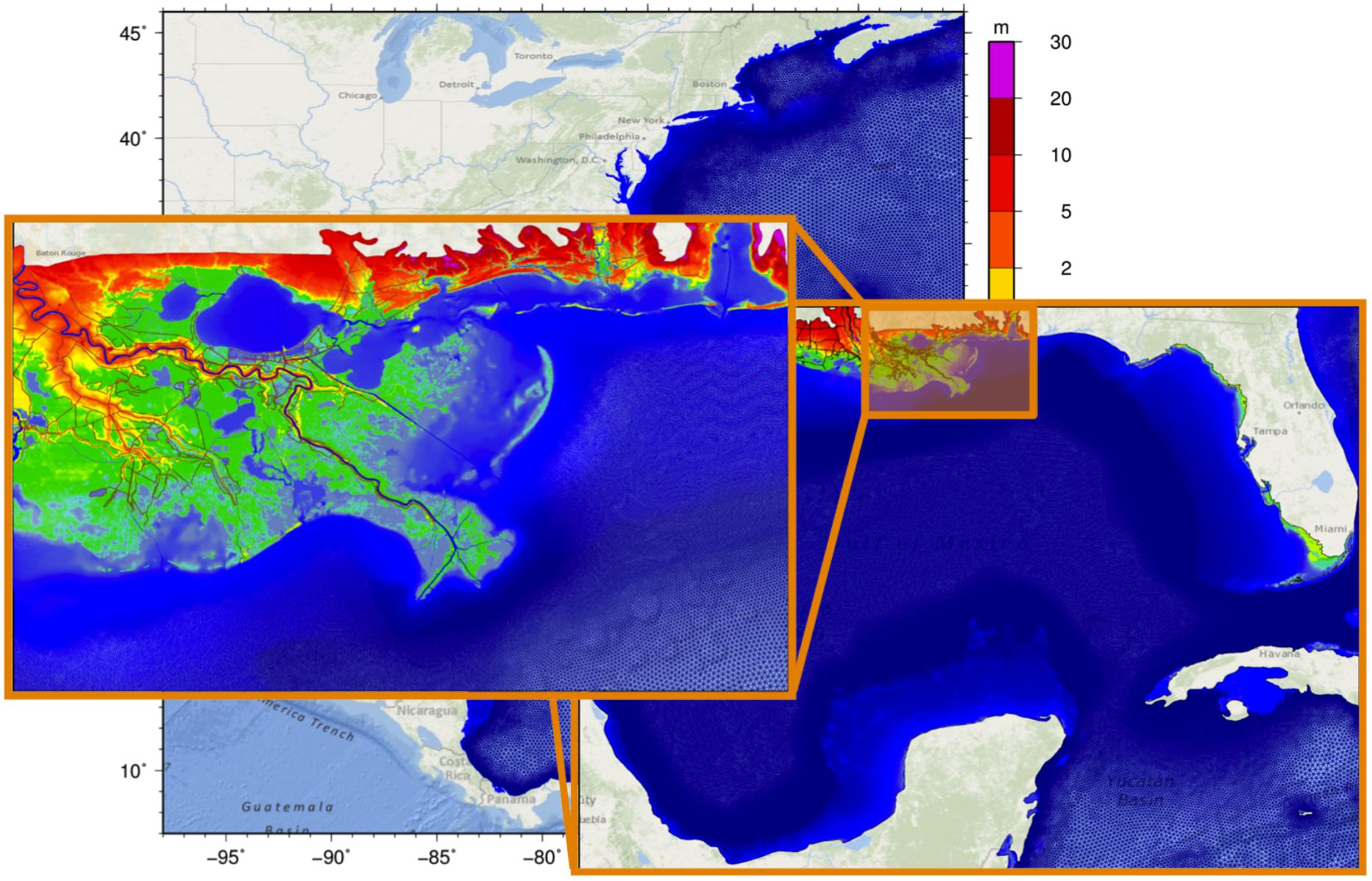

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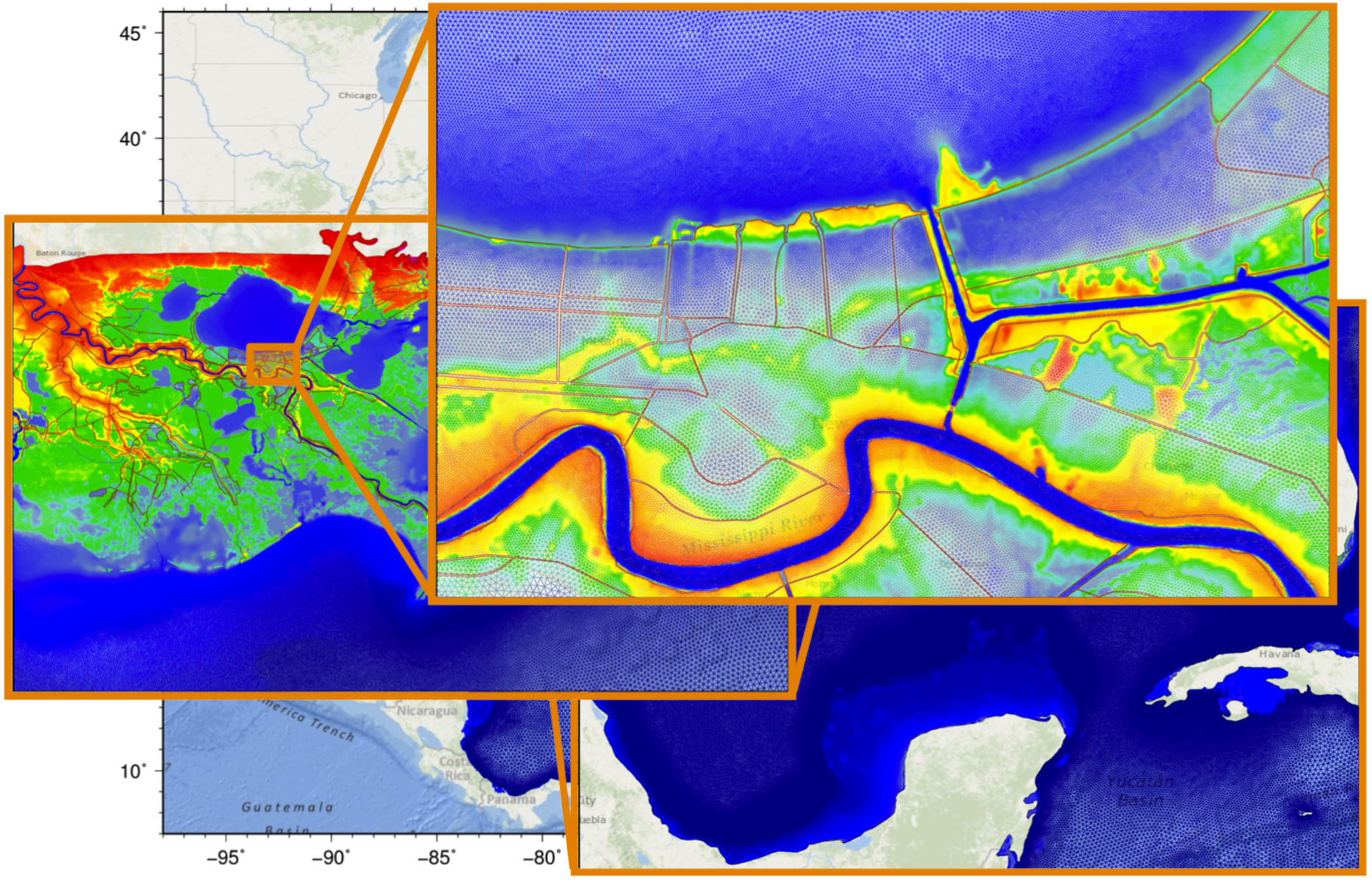
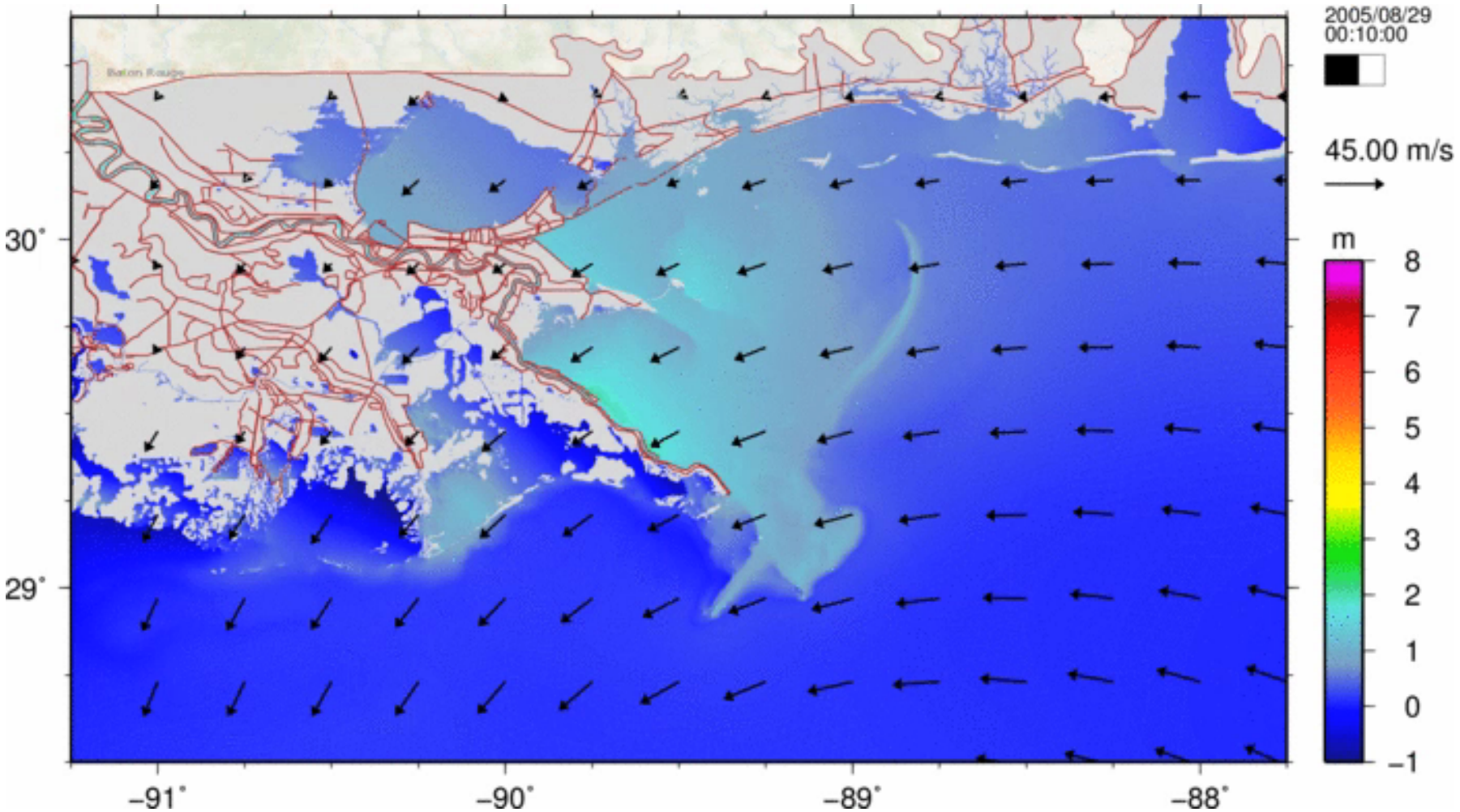


Coastal Flooding with ADCIRC – Katrina on 29 August 2005



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.

DWH Rapid Response – Surface Oil Transport

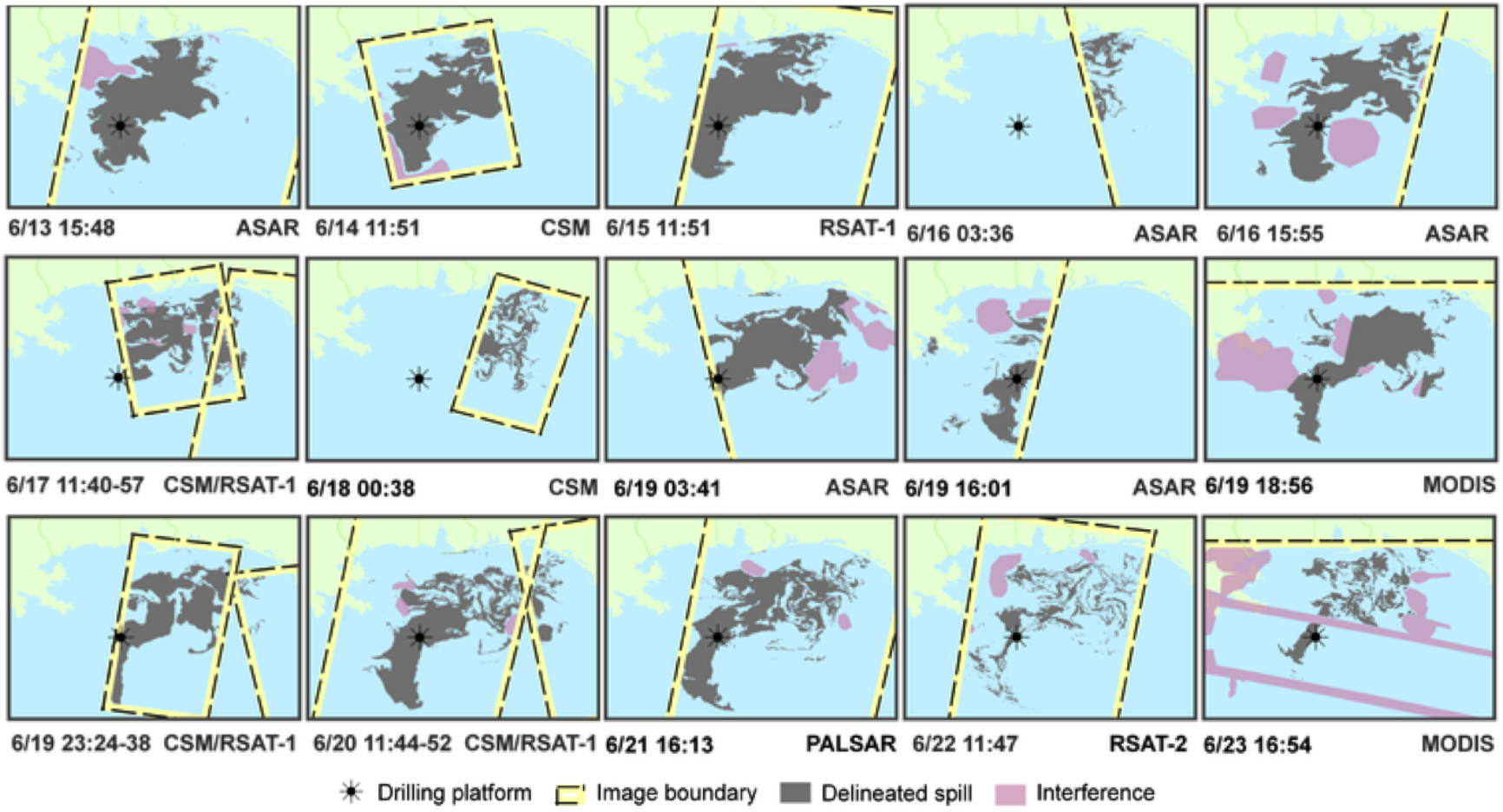
Initial response was built into the ADCIRC Surge Guidance System

- Used operational, 2D, barotropic version of ADCIRC
- Considered surface transport of oil as Lagrangian particles
  - Wind fields from WRF-NAM (`nomads.ncdc.noaa.gov`)
  - Initialize locations of the oil from NESDIS (`www.nesdis.noaa.gov`) as daily slick extents
  - Random-walk dispersion from Proctor *et al.* (1994)
  - Ability to combine the current velocities with some percentage (0-3%) of the wind velocities

Parallelized with hybrid OpenMP/MPI

- 11M particles were tracked on a 10M-element mesh using 256 cores on TACC Ranger in about **5.5 min/day**

DHW Rapid Response – Surface Oil Transport – 13-23 June 2010



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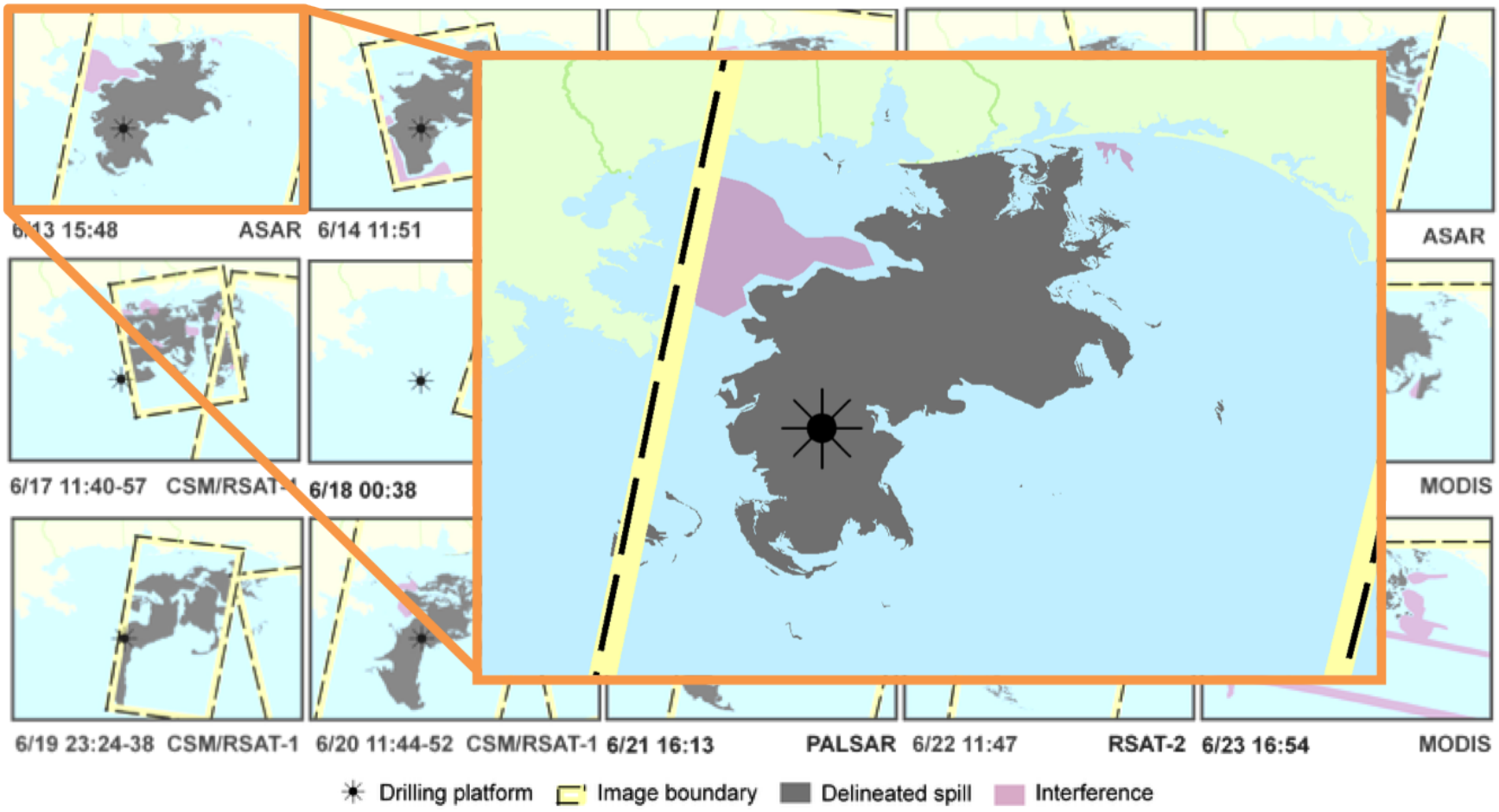

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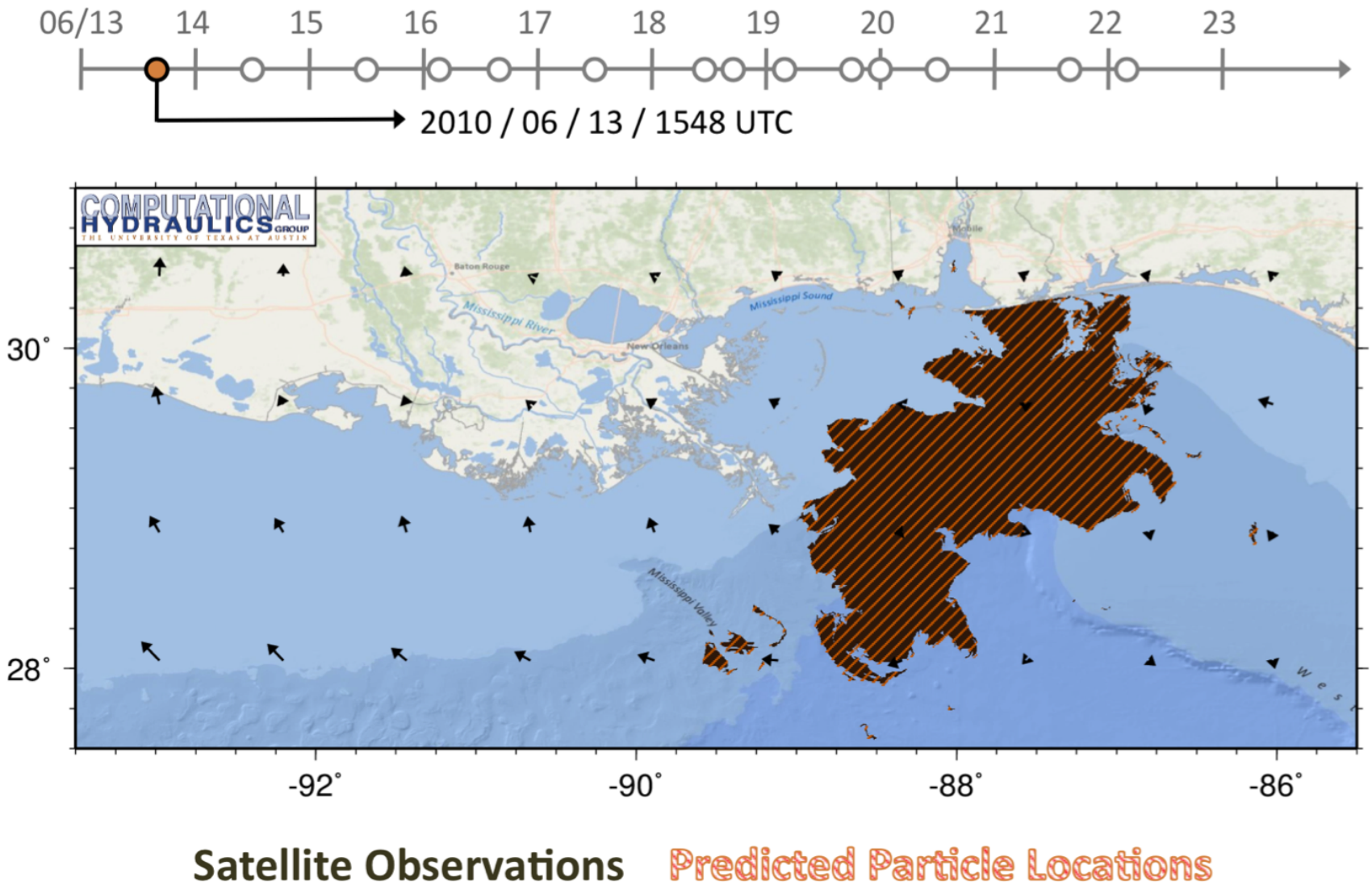


JC Dietrich, *et al.* (2012). Surface Trajectories of Oil Transport along the Northern Coastline of the Gulf of Mexico. *Continental Shelf Research*, 41(1), 17-47, DOI:10.1016/j.csr.2012.03.015.

Initial Coupling – HYCOM

Can we transport the oil from the sea floor to the beaches?

- For currents, need to consider 3D flow due to density gradients
- For oil transport, need source term, buoyancy effects, sink terms

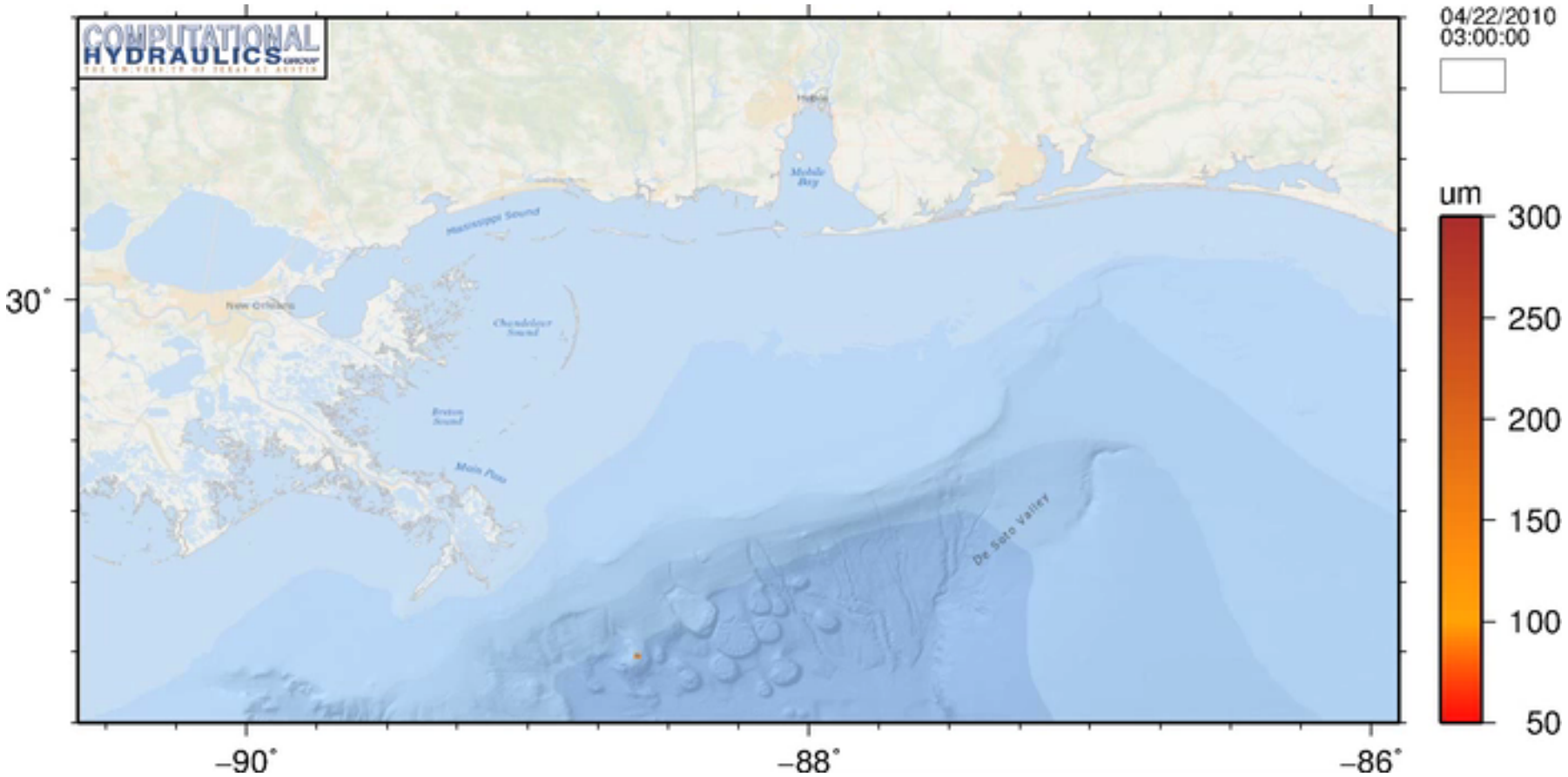
First attempt with the HYbrid Coordinate Ocean Model (HYCOM)

- Connect with existing expertise in CARTHE
- NRL operates a high-resolution forecast system for the Gulf
  - Horizontal resolution of $1/25^\circ$ (about 3.5km) with 20 vertical surfaces
  - Navy Coupled Ocean Data Assimilation (NCODA)
    - Satellite altimeter observations
    - Satellite and in situ sea surface temperatures
    - In situ vertical temperature and salinity profiles
  - Model results are available for download from hycom.org
    - Hourly output containing temperature, salinity, 3D currents, etc.
    - Output at standard Levitus depths (so fixed vertical layers in output)
- Use HYCOM model results as forcing to our oil transport

Initial Coupling – HYCOM

Release at wellhead and transport by buoyancy and 3D velocities

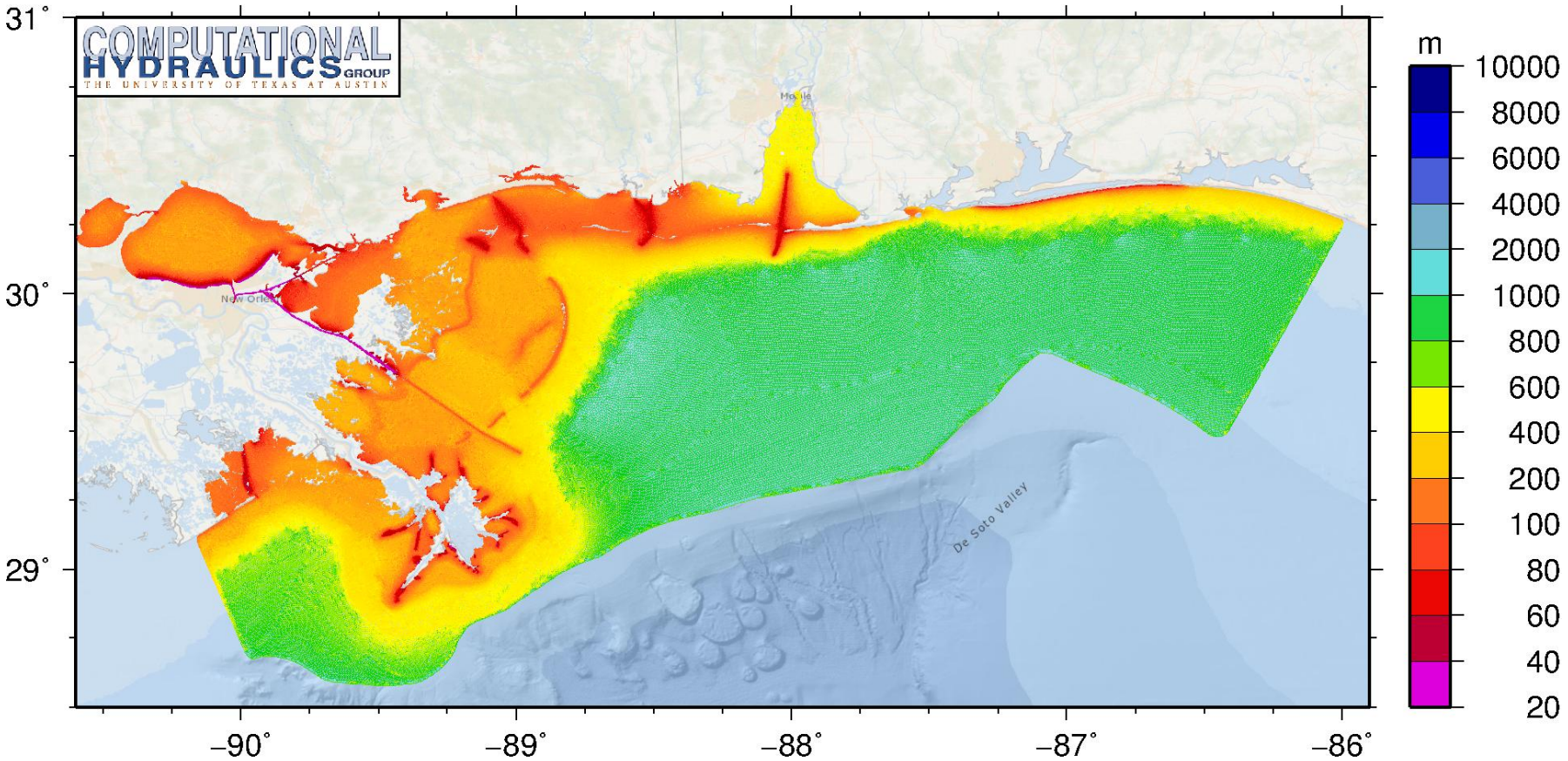
- Diameters assigned randomly in the range of **50μm** to **300μm**
- General movement is correct, but limited transport into nearshore



Initial Coupling – HYCOM+ADCIRC

Cut a small mesh with coverage of LA-MS shelf

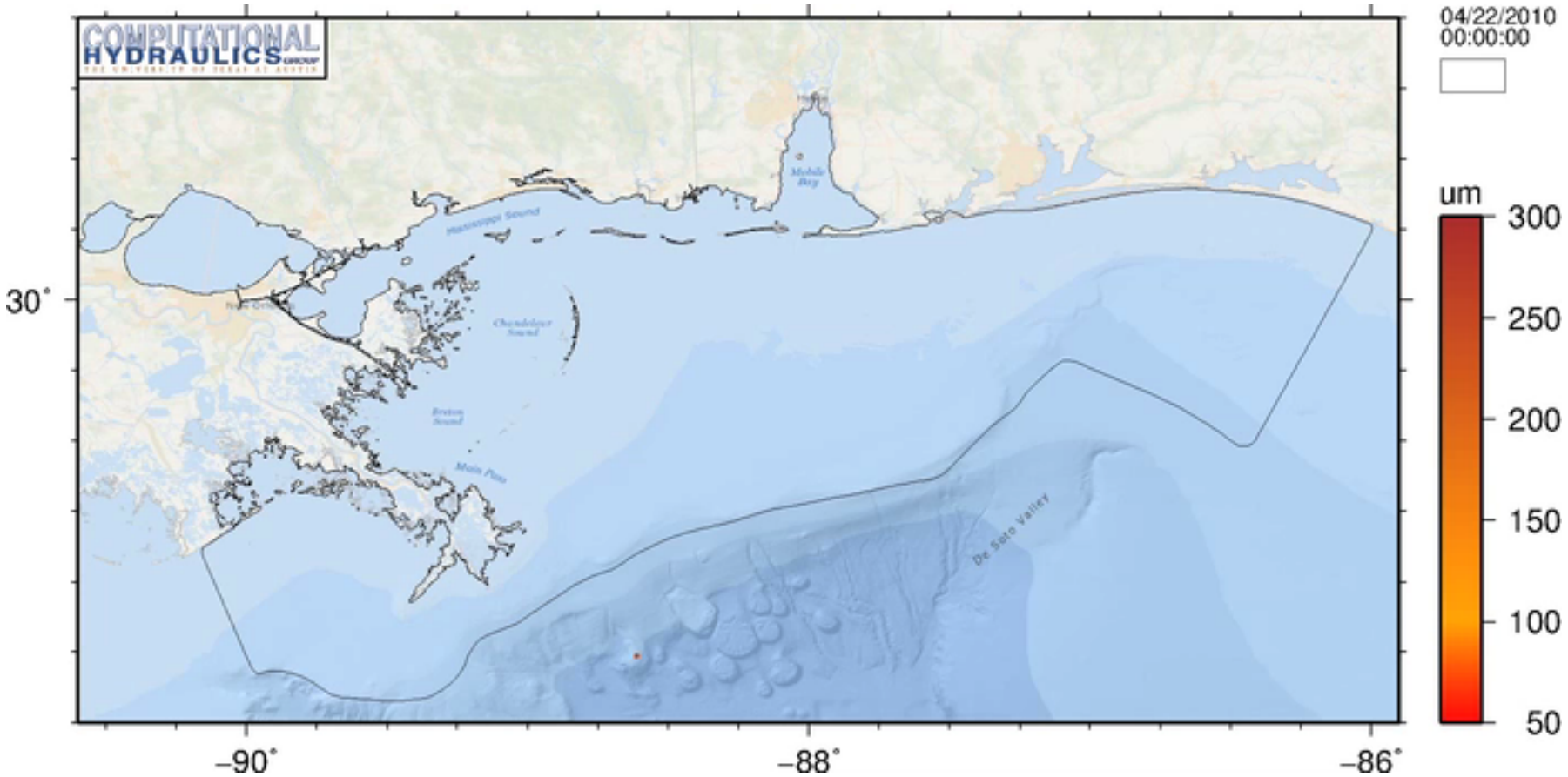
- Mesh spacings less than 1km on shelf, less than 200m in floodplains
- Element sizes range downward to minimum of 20m in channels, etc.



Initial Coupling – HYCOM+ADCIRC

Initial attempt with coupling to HYCOM

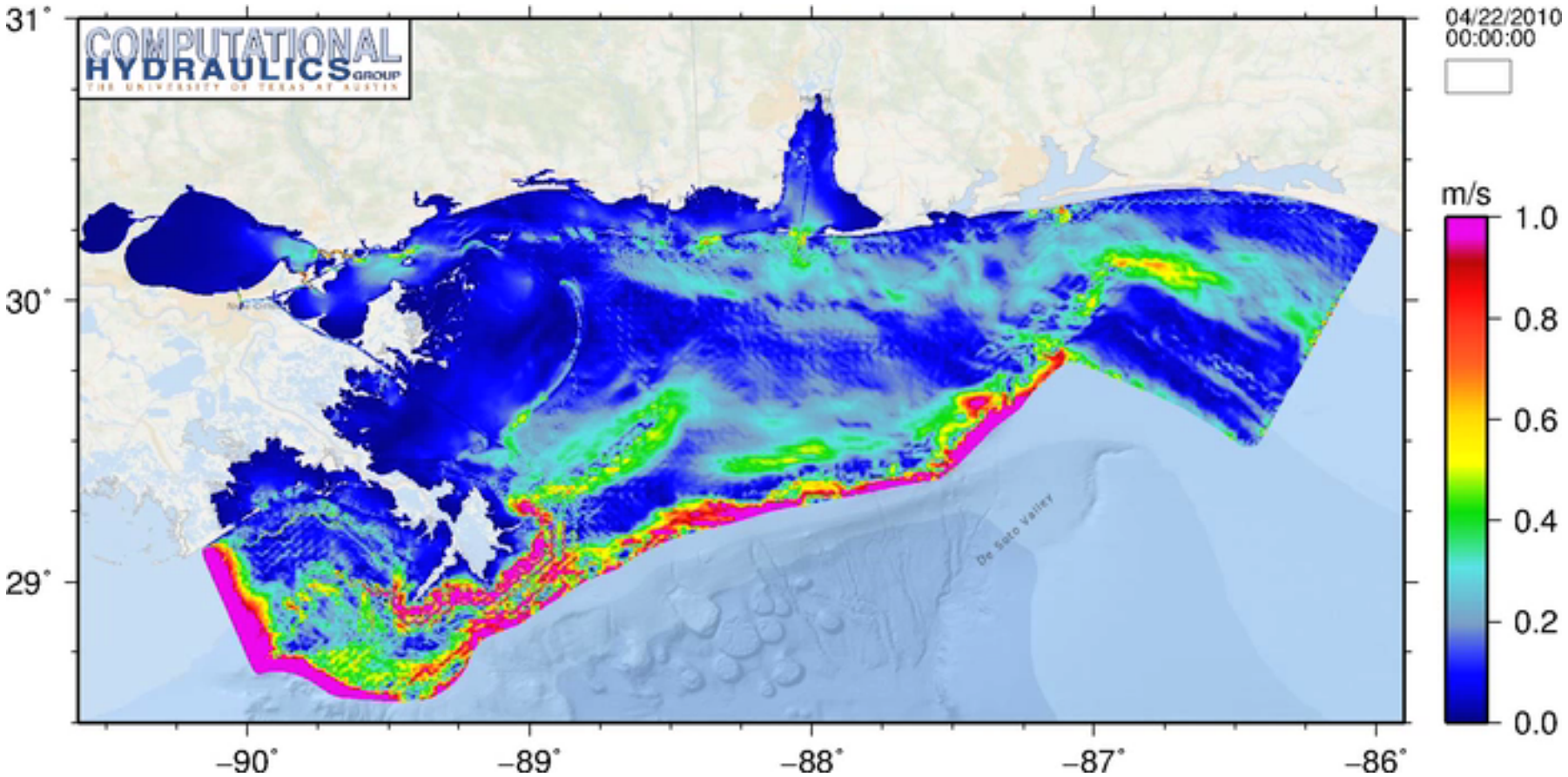
- Particles forced with ADCIRC currents only in its domain
- Obvious discontinuity in current fields at domain boundary



Initial Coupling – HYCOM+ADCIRC

Initial attempt with coupling to HYCOM

- Forced with tides at open boundary (no winds, waves, etc.)
- Spurious currents are generated along the shelf break, near boundary



Recent Progress – HYCOM+ADCIRC

How are we coupling with HYCOM?

- Initial conditions:
  - Sea surface heights
  - Horizontal currents (u, v) throughout the water column
    - ADCIRC calculates the vertical component w
  - Salinities
  - Temperatures
- Surface boundary conditions:
  - Heat fluxes
- Open ocean boundary conditions:
  - Sea surface heights
  - Salinities
  - Temperatures

Recent Progress – HYCOM+ADCIRC

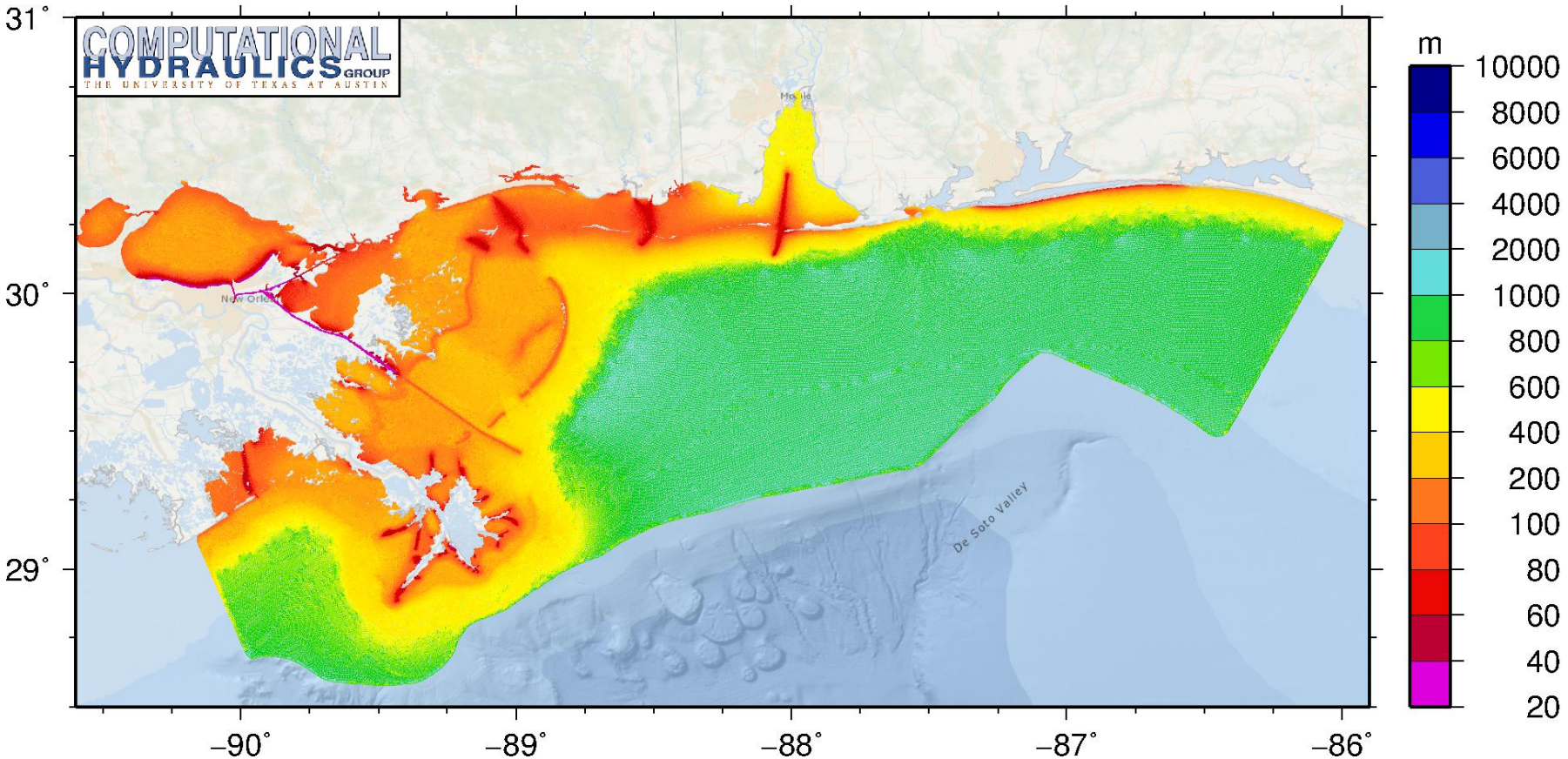
There were two obvious problems:

1. Interpolation was not "smooth"
   - Especially in regions with steep bathymetry
     - Mismatch between HYCOM fixed layers and ADCIRC sigma layers
   - When ADCIRC points extend below layers in the HYCOM output, should we extrapolate horizontally or vertically?
2. Currents at the open ocean boundary:
   - Calculated from tidal forcing with seven constituents
     - $(K_1, O_1, Q_1, M_2, S_2, N_2, K_2)$
   - Not using any information from HYCOM?
   - Utilize a flux boundary condition in baroclinic ADCIRC
     - Interpolate HYCOM velocities to ADCIRC boundary
     - Convert to normal fluxes
     - Apply in ADCIRC as normal fluxes as natural boundary condition, with no constraint on tangential flow

Recent Progress – HYCOM+ADCIRC – Flux Boundary

For testing purposes, coarsen the mesh ...

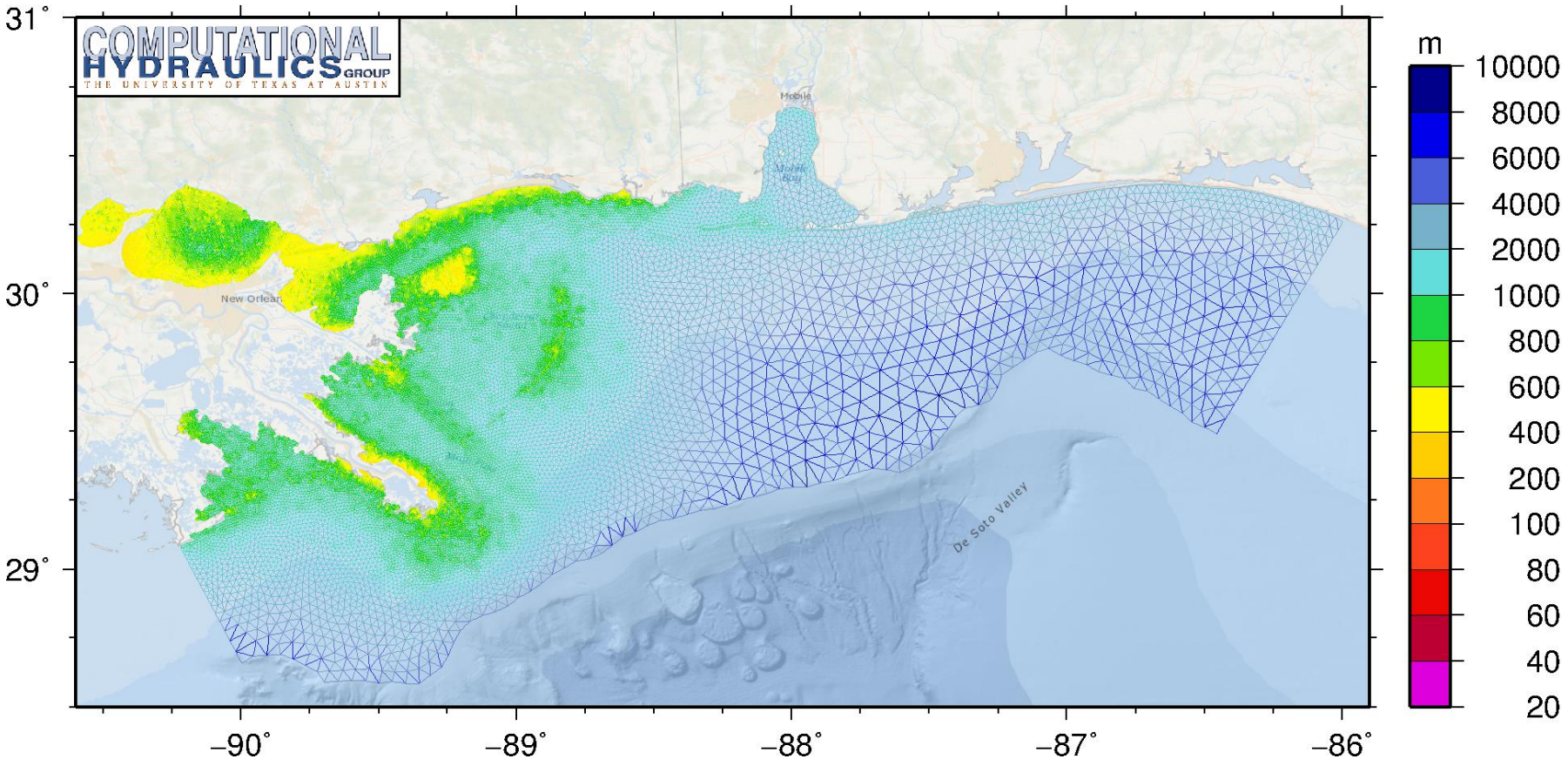
- Mesh spacings less than 1km on shelf, less than 200m in floodplains
- Element sizes range downward to minimum of 20m in channels, etc.



Recent Progress – HYCOM+ADCIRC – Flux Boundary

... to something more efficient

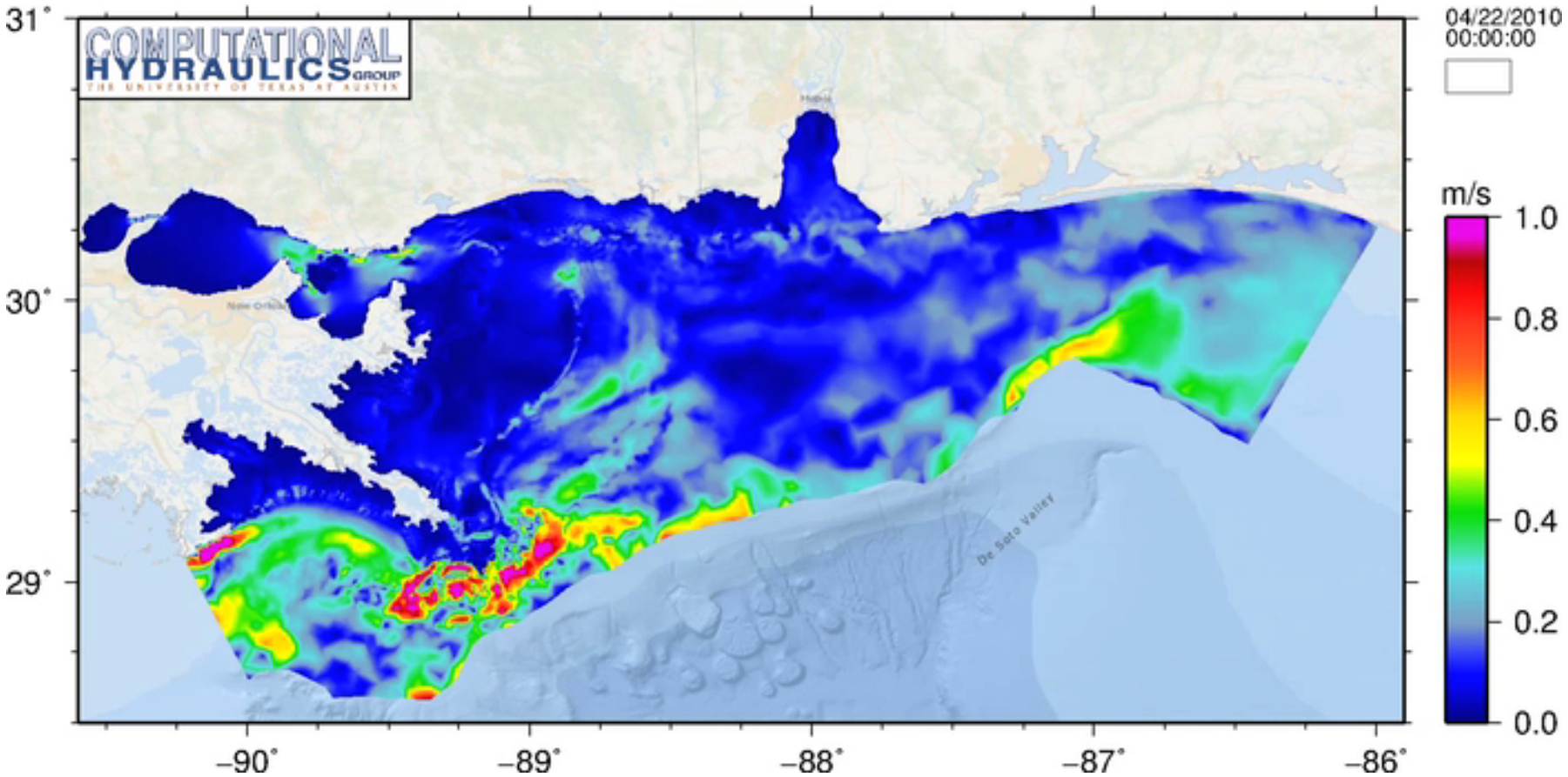
- Mesh spacings less than 10km on shelf, less than 1km in floodplains
- Element sizes range downward to minimum of 400m in channels, etc.



Recent Progress – HYCOM+ADCIRC – Flux Boundary

Surface velocities are improved significantly at boundary with HYCOM

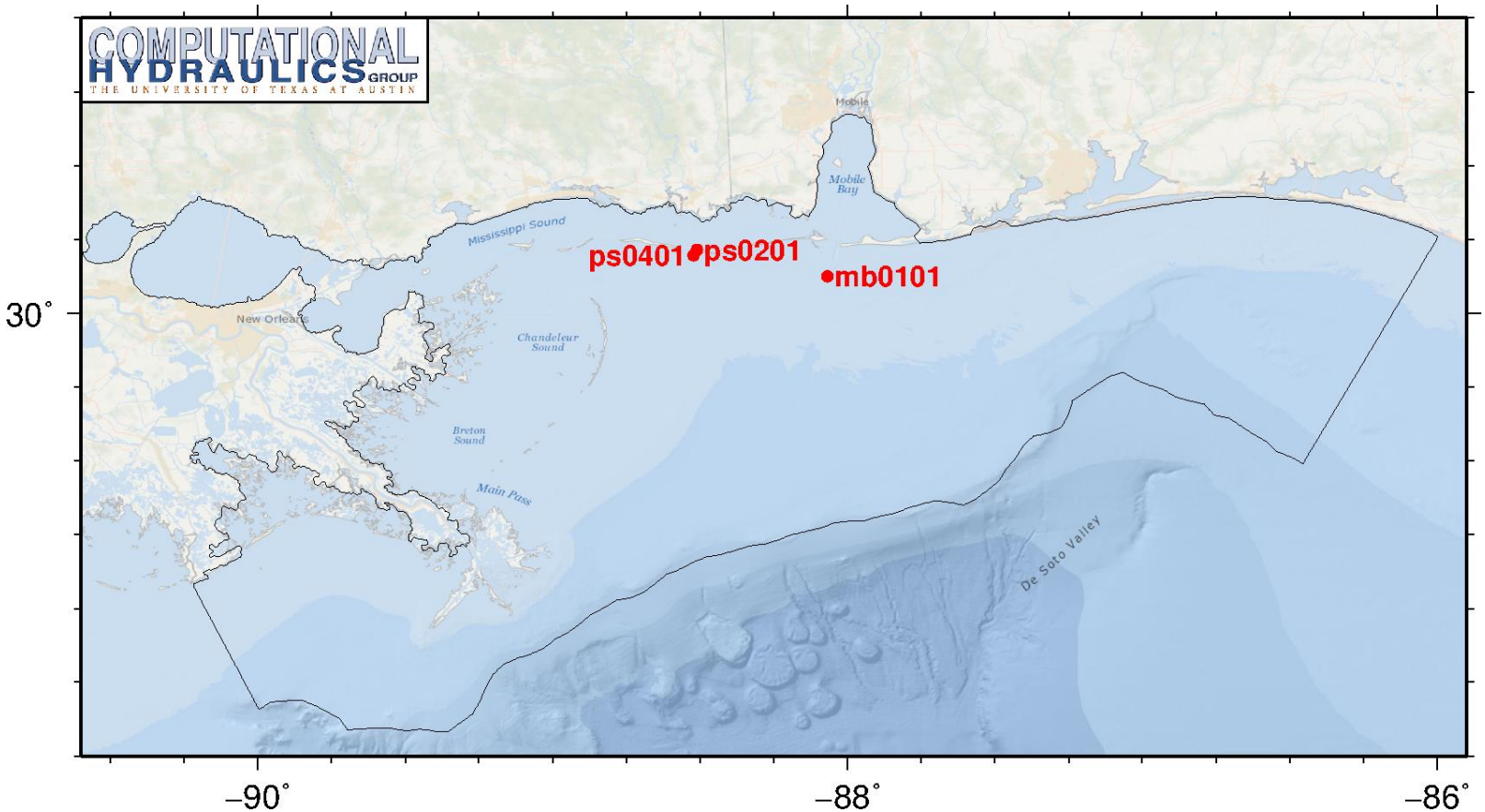
- Spurious currents are eliminated along the ocean boundary
- Large currents persist near Mississippi River delta



Recent Progress – HYCOM+ADCIRC – Flux Boundary

Validation of surface currents at selected NOAA stations:

- Stations near barrier islands of Mississippi and Alabama
- Some encouraging behavior, but velocities are still too small?



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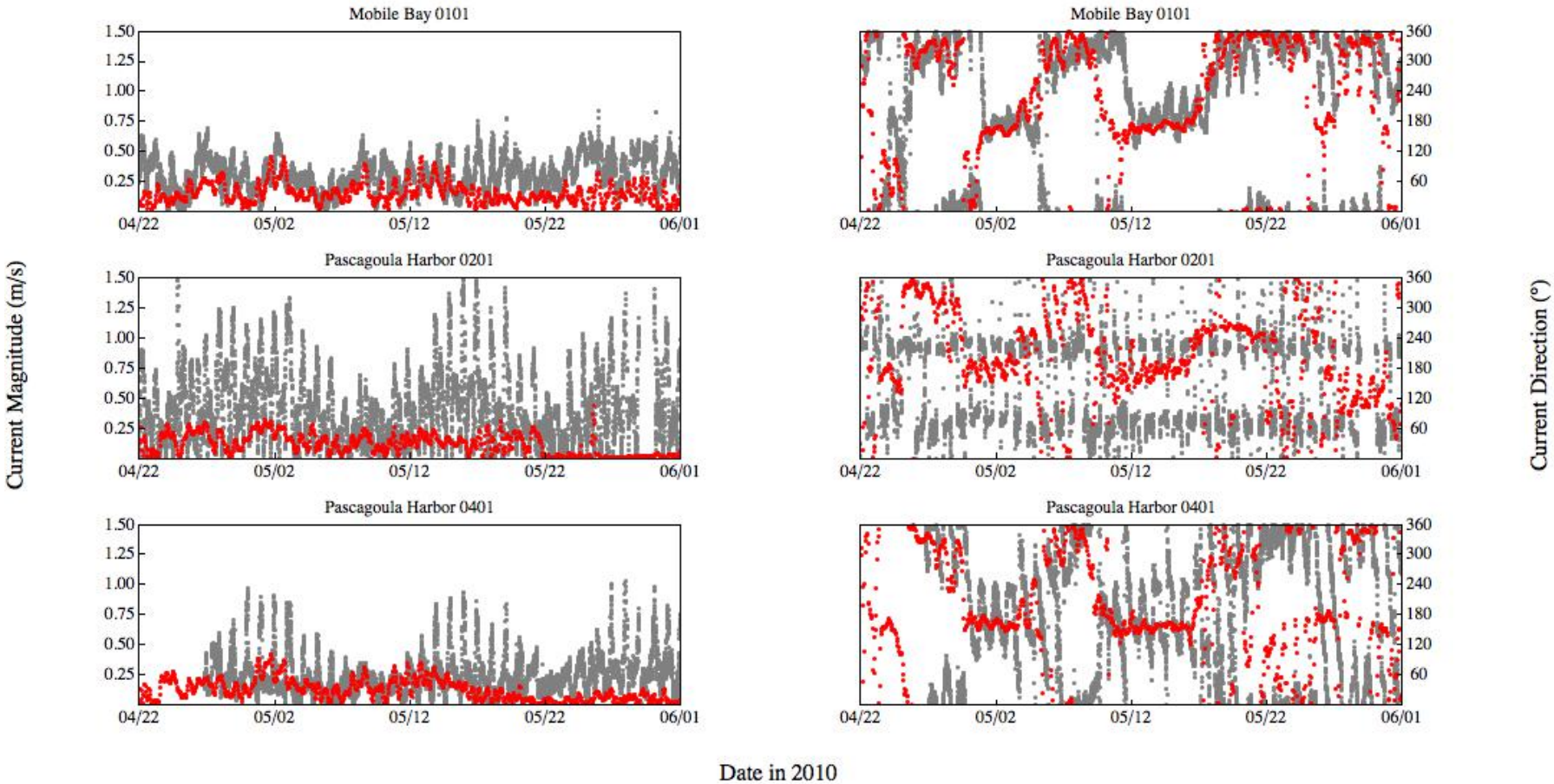
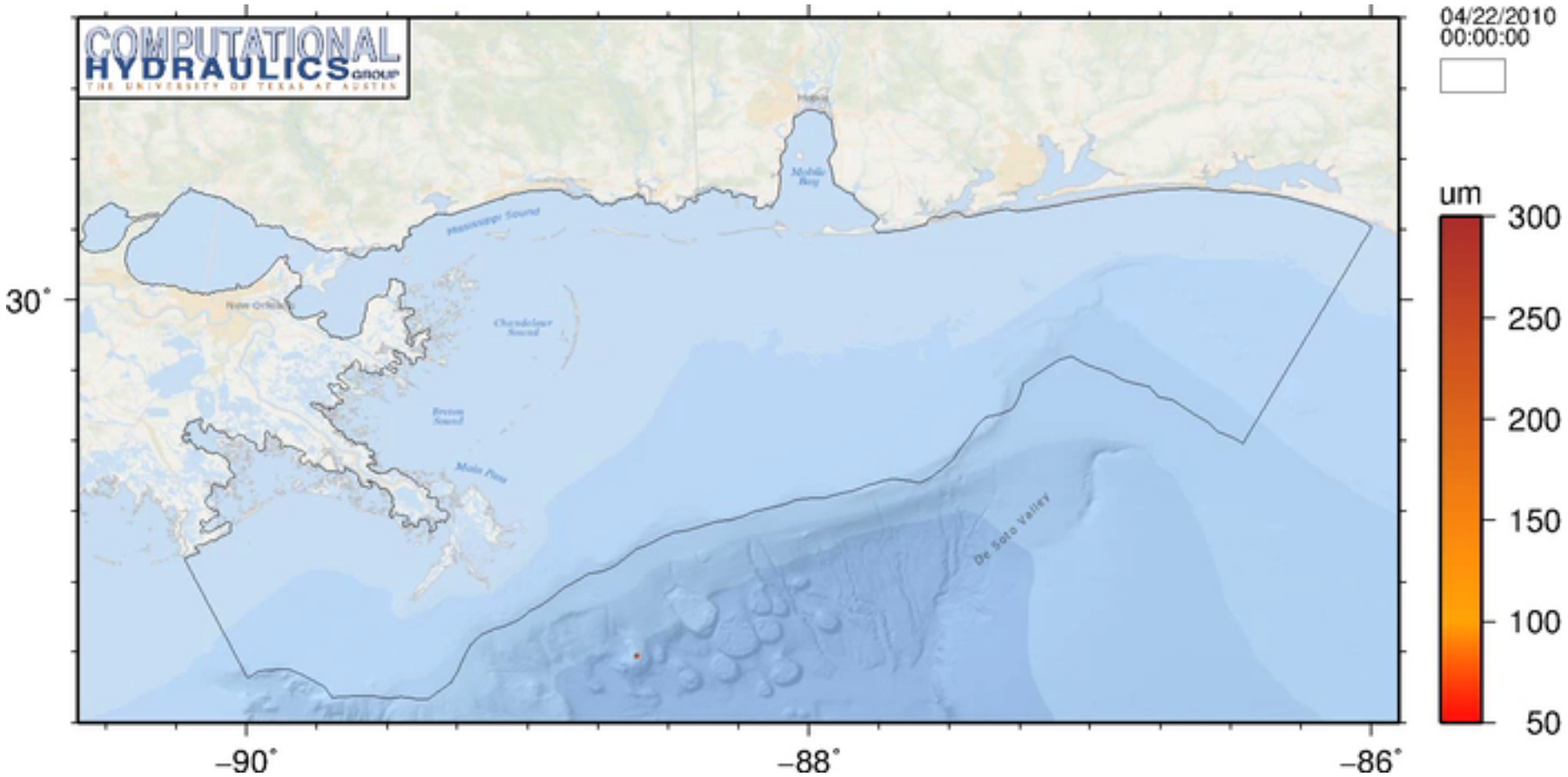


Recent Progress – HYCOM+ADCIRC – Flux Boundary

Transport occurs smoothly between models

- Particles no longer stick at open ocean boundary
- Less transport to Mississippi coast than with HYCOM?



Recent Progress – HYCOM+ADCIRC – Next Steps

Next steps for moving forward ...

- Return to testing with high-resolution mesh
- Add wave-induced currents through coupling to SWAN
  - Need wave information at boundary?
- Update tracking code to force particles with both velocity fields
- Connect to dispersion parameterizations from GLAD, SCOPE?
- Add sink terms for evaporation, biodegradation, etc.