Forecast Modeling for Hurricane Isaac

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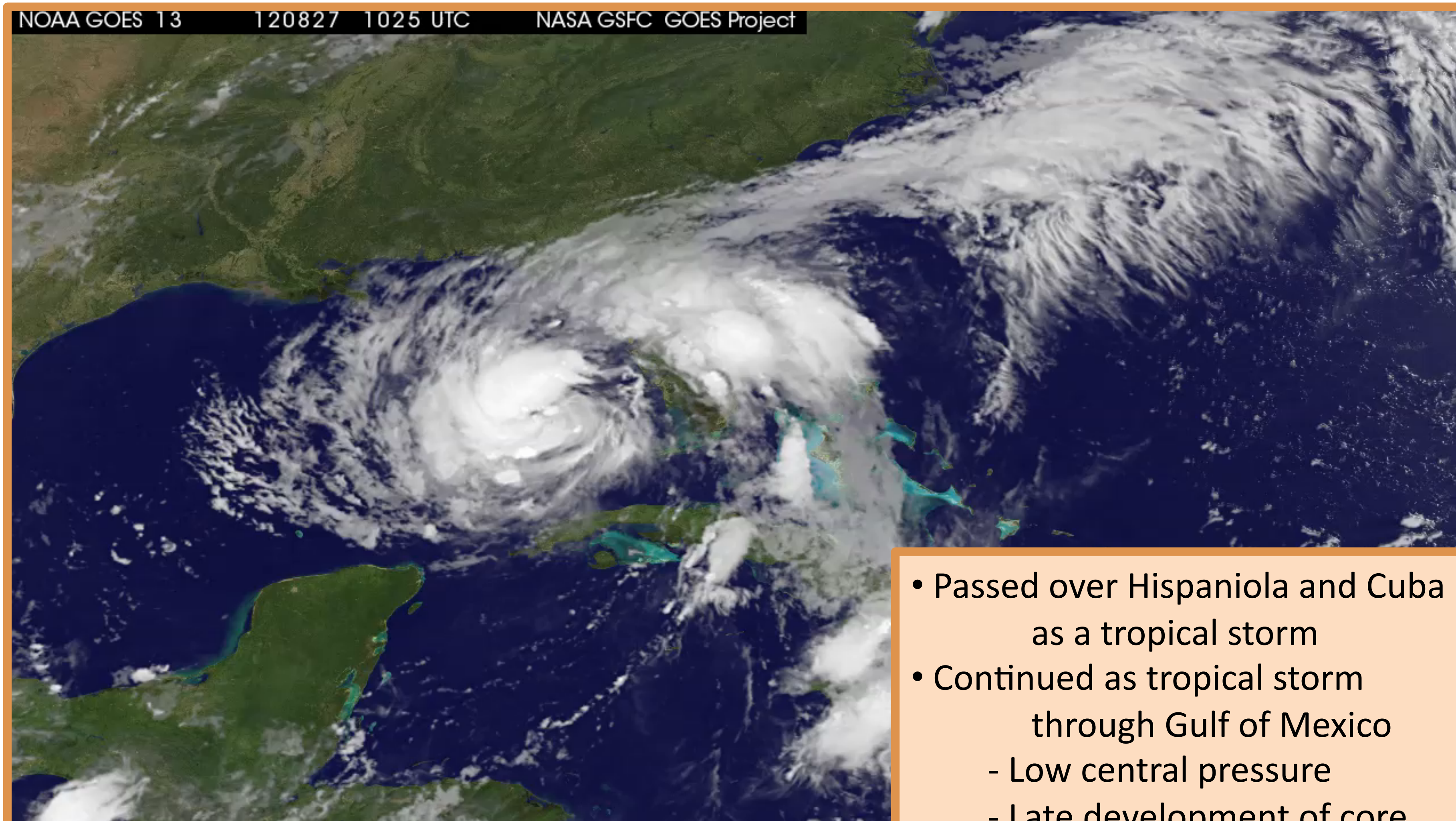
CARTHE All-Hands Meeting

Coconut Grove, Florida, 08 November 2012

1. Forecast Modeling for Hurricane Isaac
2. Oil Spill Modeling in the Nearshore

Isaac (2012) : Disorganized Movement across the Gulf



Movie Courtesy NASA

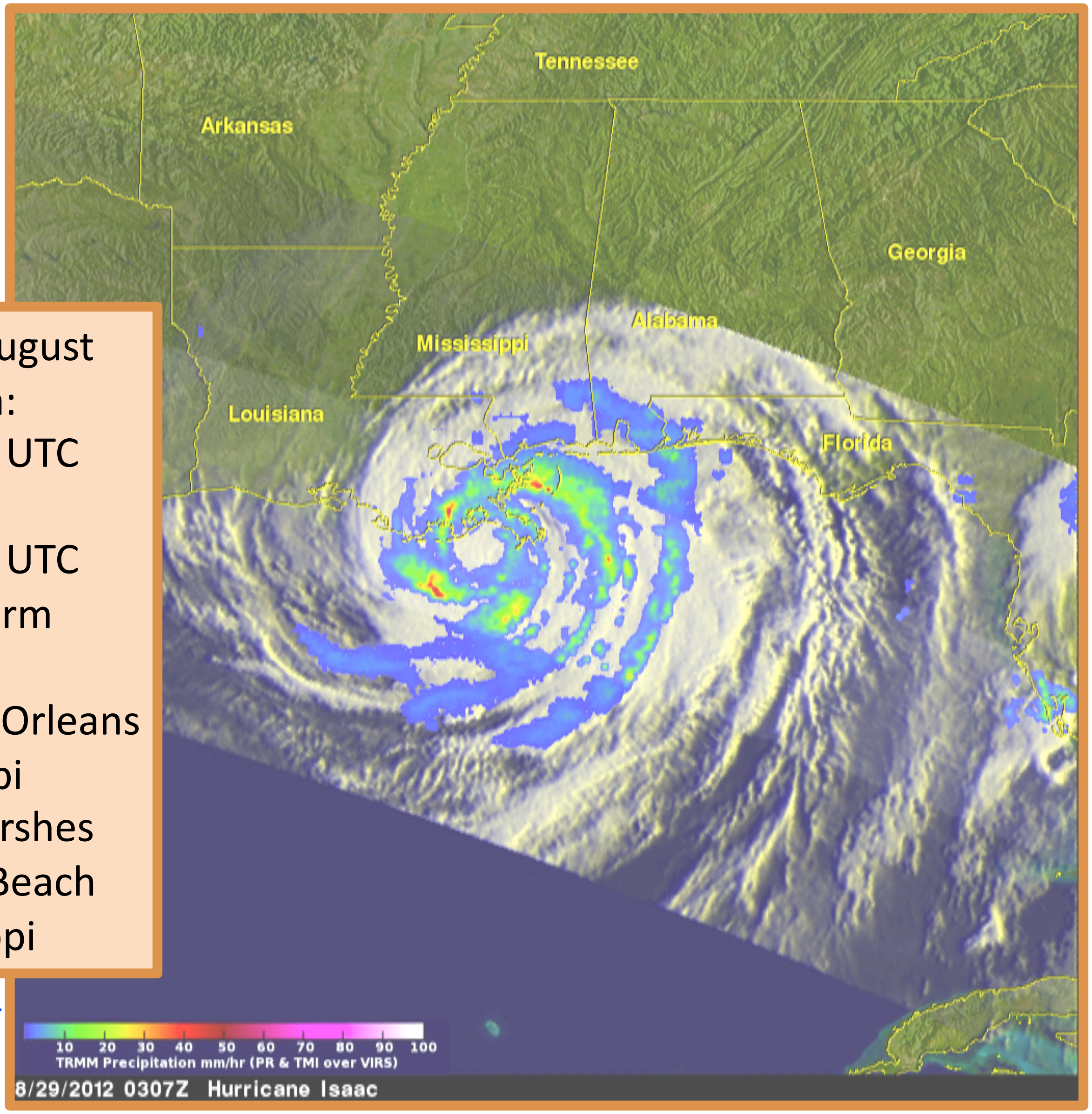
Description Courtesy Wikipedia

- Passed over Hispaniola and Cuba as a tropical storm
- Continued as tropical storm through Gulf of Mexico
  - Low central pressure
  - Late development of core
- Finally developed into Category 1 as it approached Louisiana

Isaac (2012) : Slow Crawl across Southern Louisiana

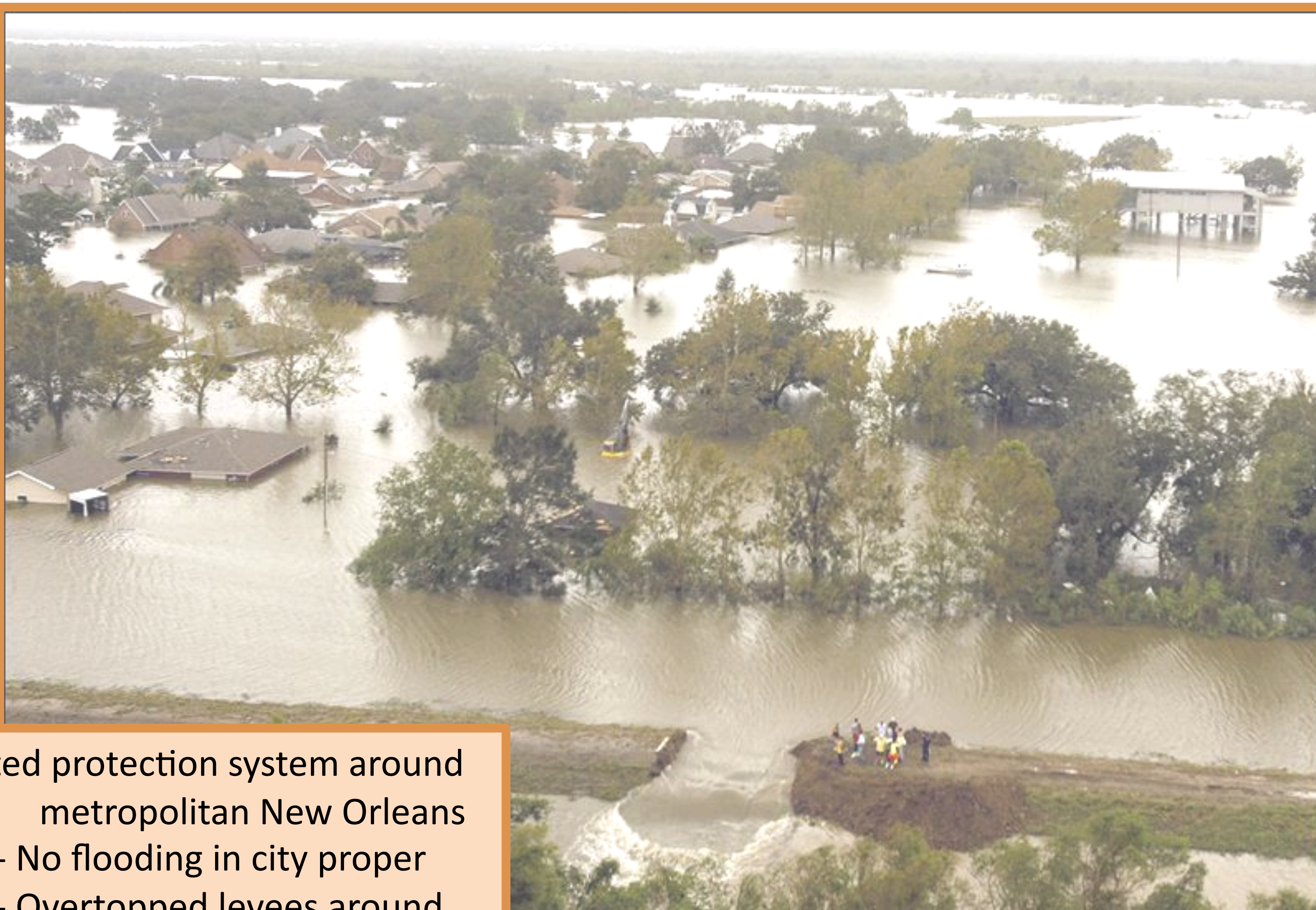
- Two landfalls over 28-29 August
  - Mississippi River delta:
    - 1845 CDT / 2345 UTC
  - Port Fourchon:
    - 0200 CDT / 0700 UTC
- Extremely slow moving storm
  - Heavy rainfall
    - 20in within New Orleans
    - 10in in Mississippi
  - Surge pushed into marshes
    - 3.4m near Shell Beach
    - 2.5m in Mississippi

[Description Courtesy Wikipedia](#)



[Image Courtesy NASA](#)

Isaac (2012) : Flooding outside New Orleans

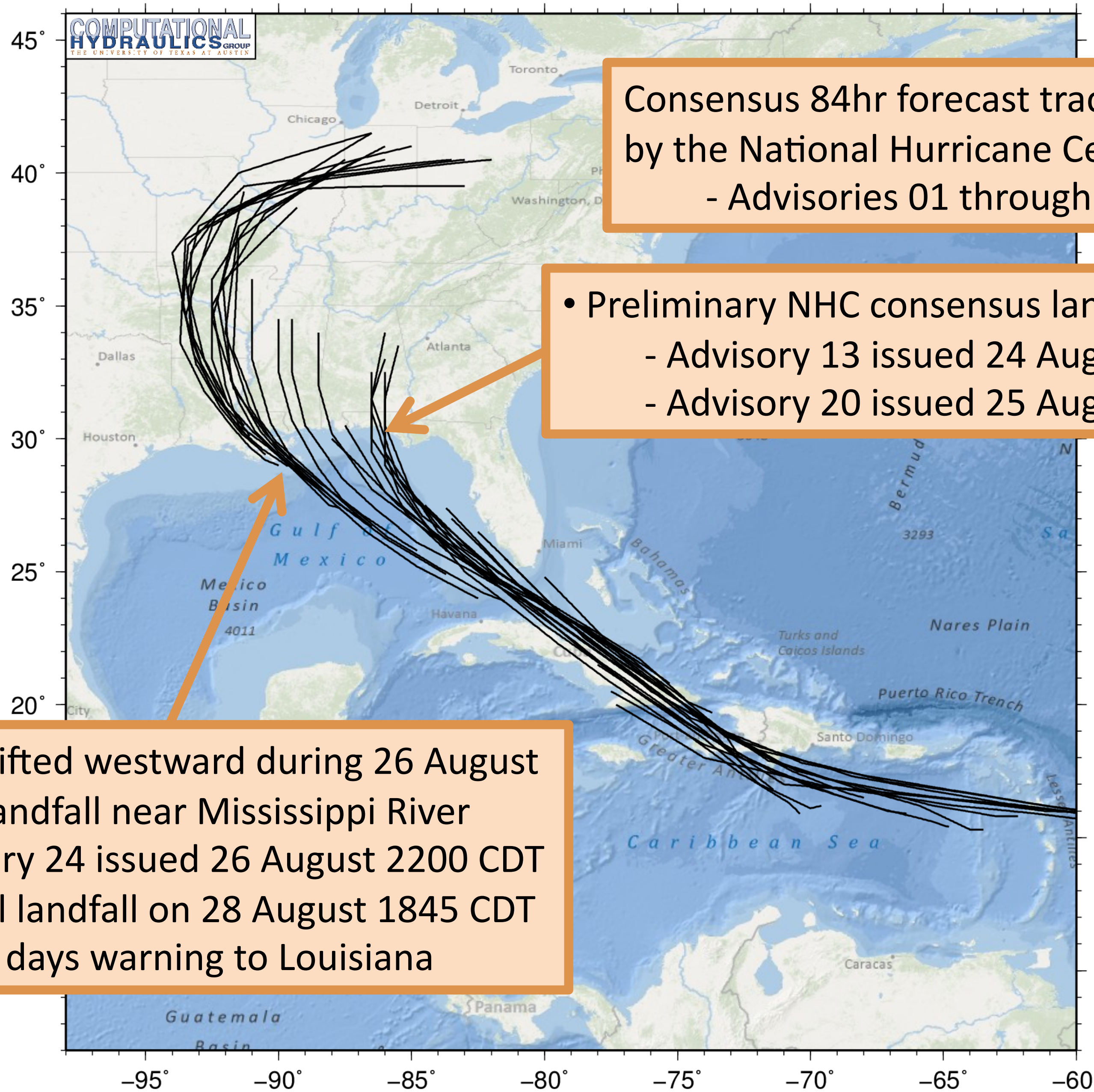


- Tested protection system around metropolitan New Orleans
  - No flooding in city proper
  - Overtopped levees around surrounding communities

Description Courtesy Wikipedia

Image Courtesy Times-Picayune

Isaac (2012) : Track Uncertainty

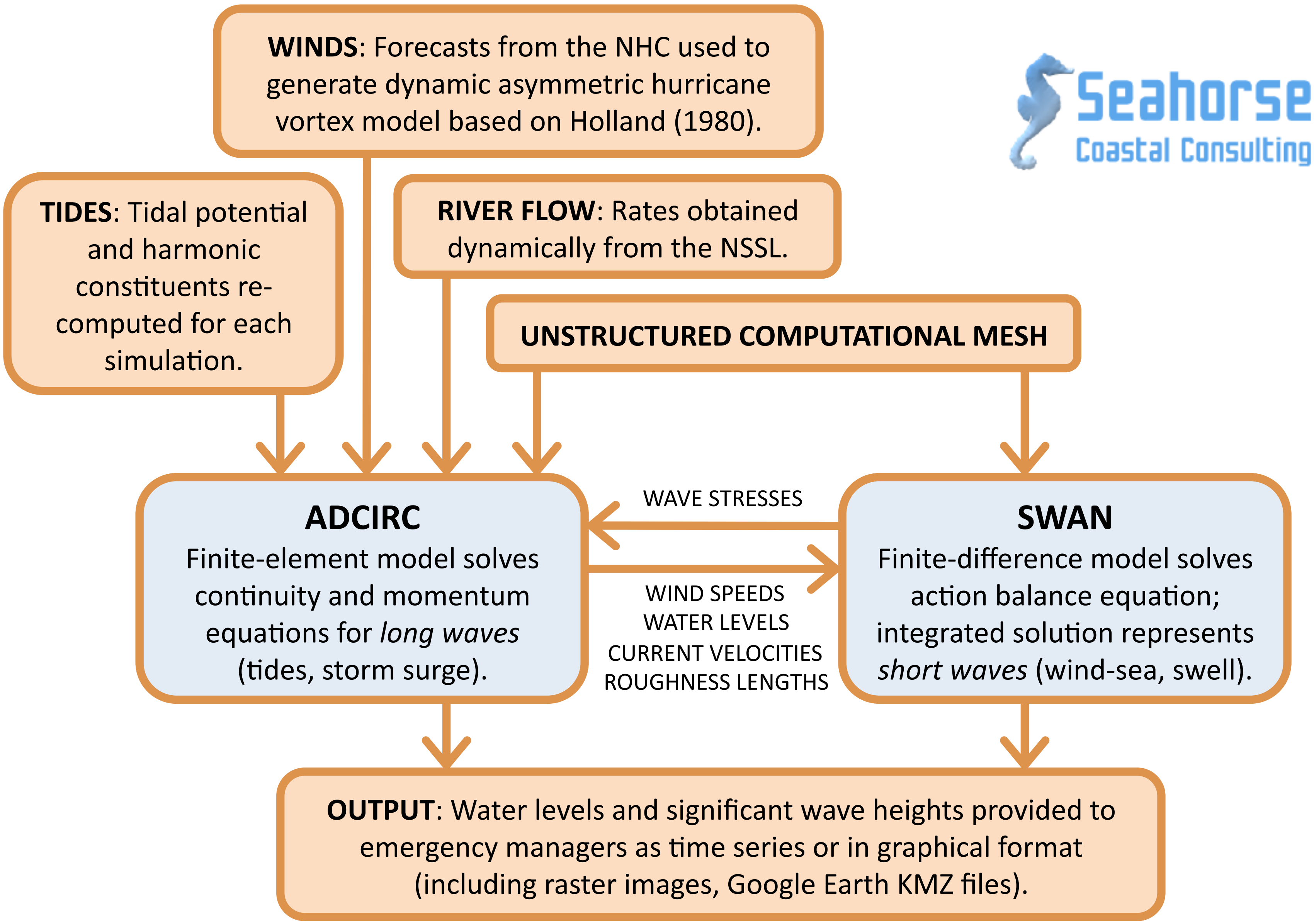


Consensus 84hr forecast tracks issued by the National Hurricane Center (NHC)
- Advisories 01 through 38

- Preliminary NHC consensus landfall in Florida
  - Advisory 13 issued 24 August 0400 CDT
  - Advisory 20 issued 25 August 2200 CDT

- Forecast shifted westward during 26 August
- Projected landfall near Mississippi River
  - Advisory 24 issued 26 August 2200 CDT
  - Official landfall on 28 August 1845 CDT
- Less than 2 days warning to Louisiana

ASGS : ADCIRC Surge Guidance System



ASGS : Hurricane Season 2012

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 in Portsmouth VA

Louisiana State University

- Provide forecasts for Louisiana and northern Gulf states via Google Maps application (cera.cct.lsu.edu)
- Primary providers of guidance during Isaac (2012)

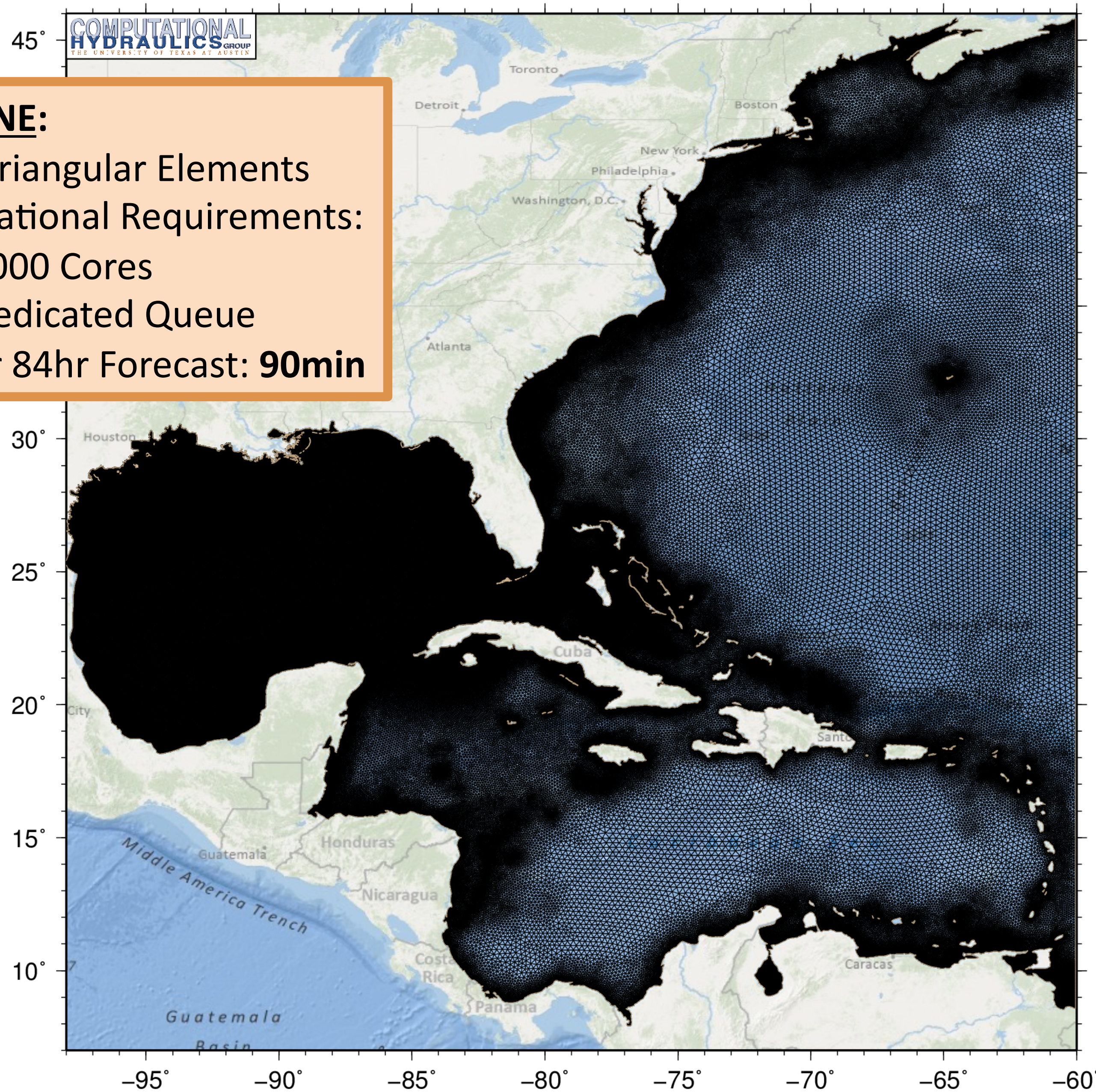
University of Texas at Austin

- 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

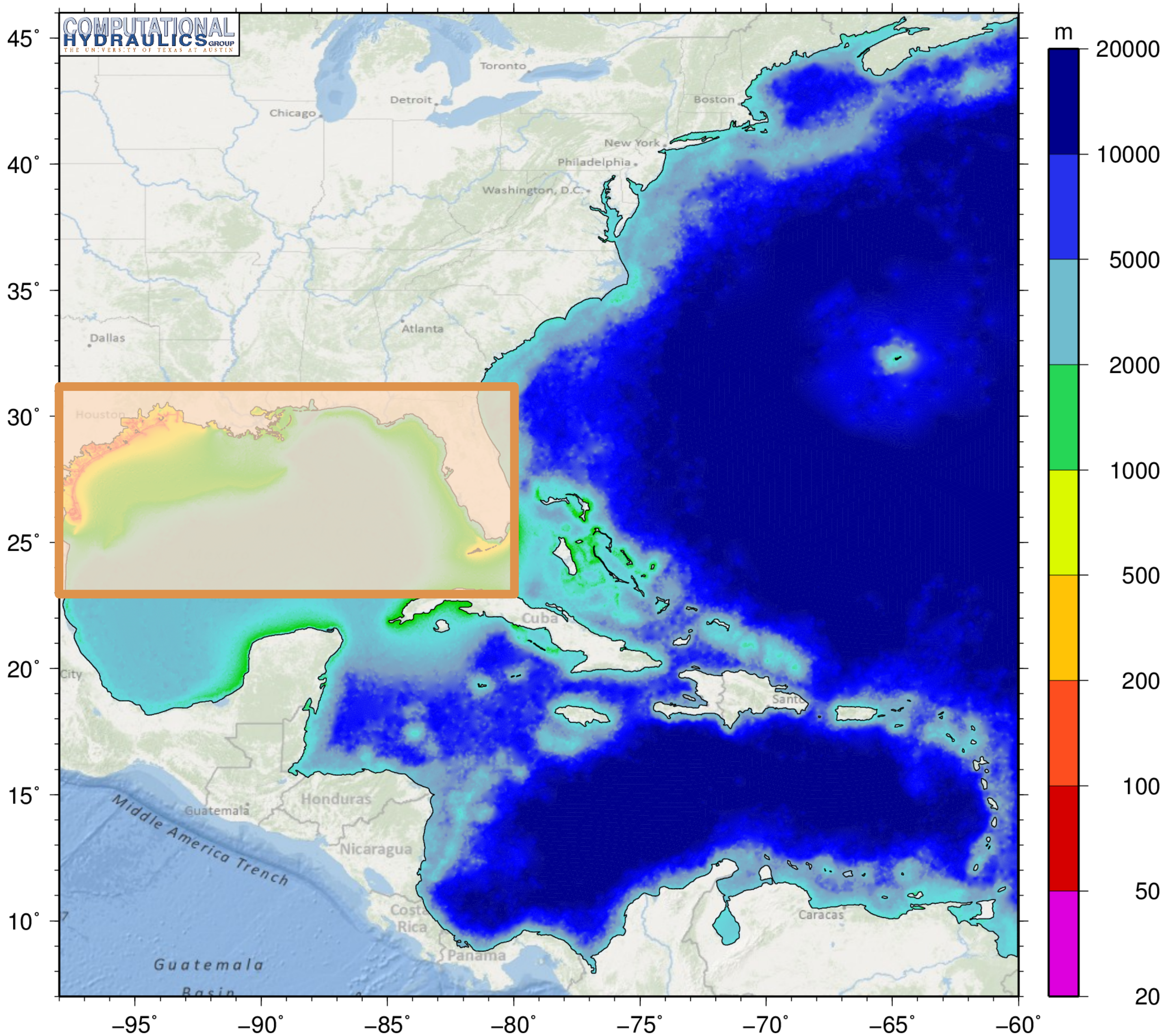
TX2008r35h : Unstructured Mesh

VERY FINE:
6.67M Triangular Elements
Computational Requirements:
- 4000 Cores
- Dedicated Queue

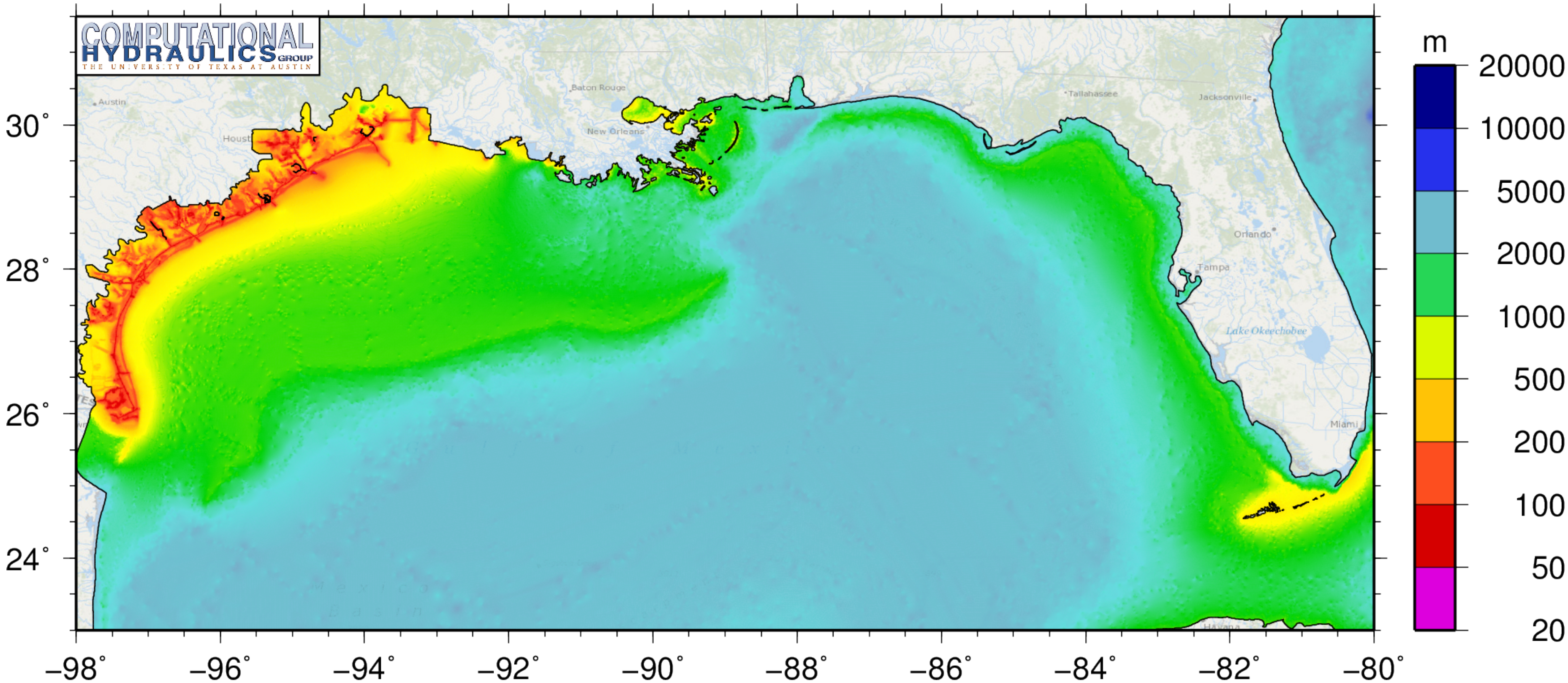
Time for 84hr Forecast: **90min**



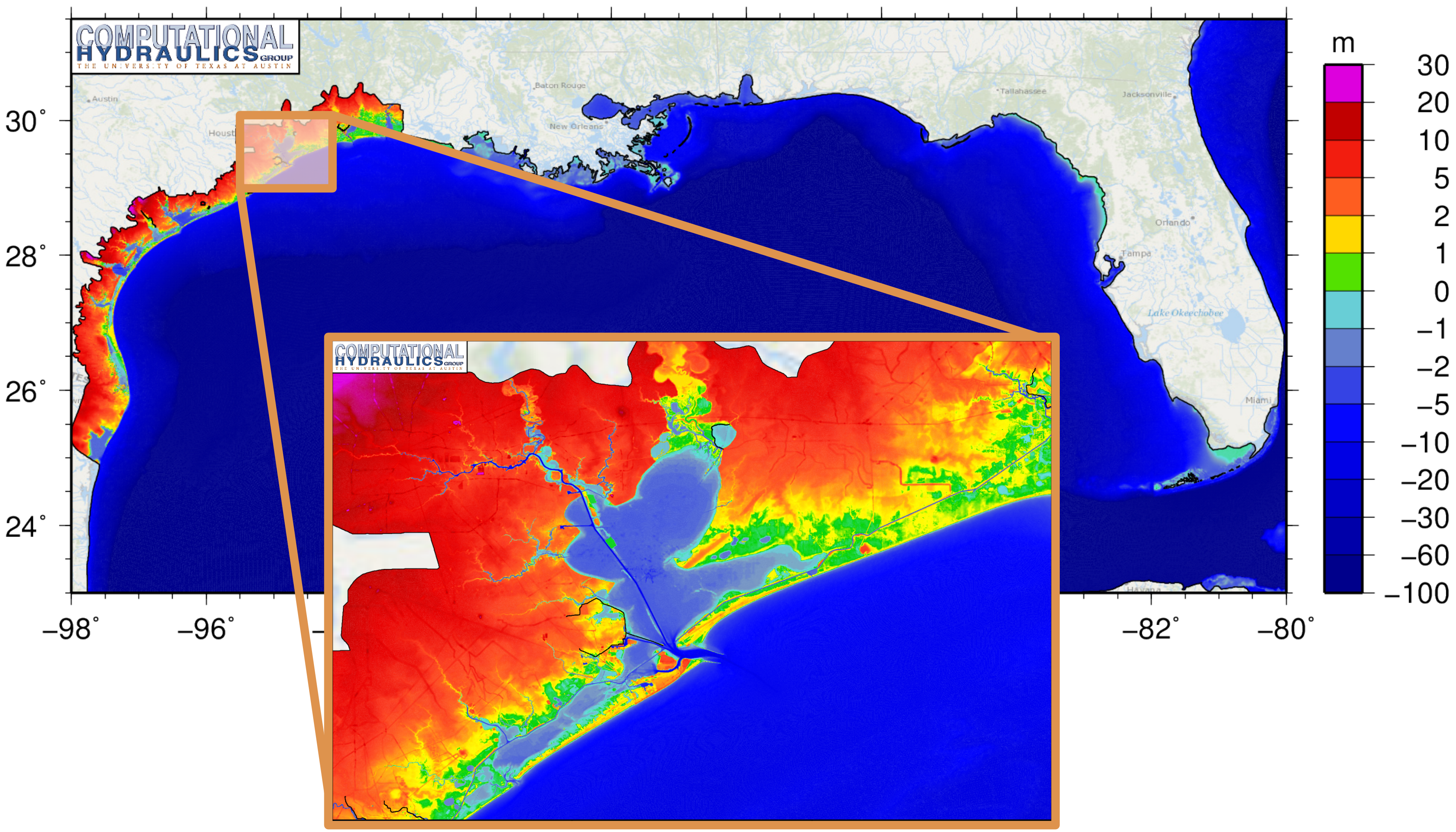
TX2008r35h : Unstructured Mesh Sizes



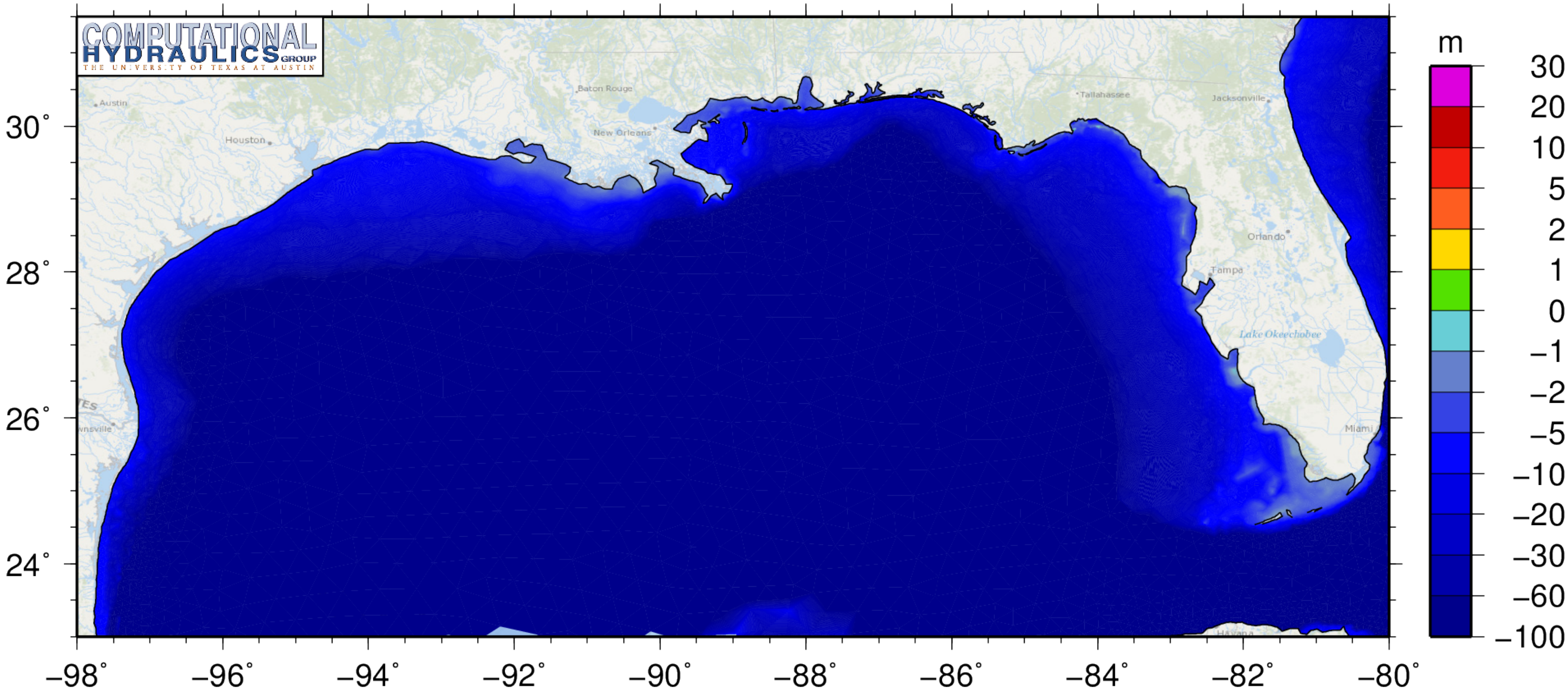
TX2008r35h : Unstructured Mesh Sizes



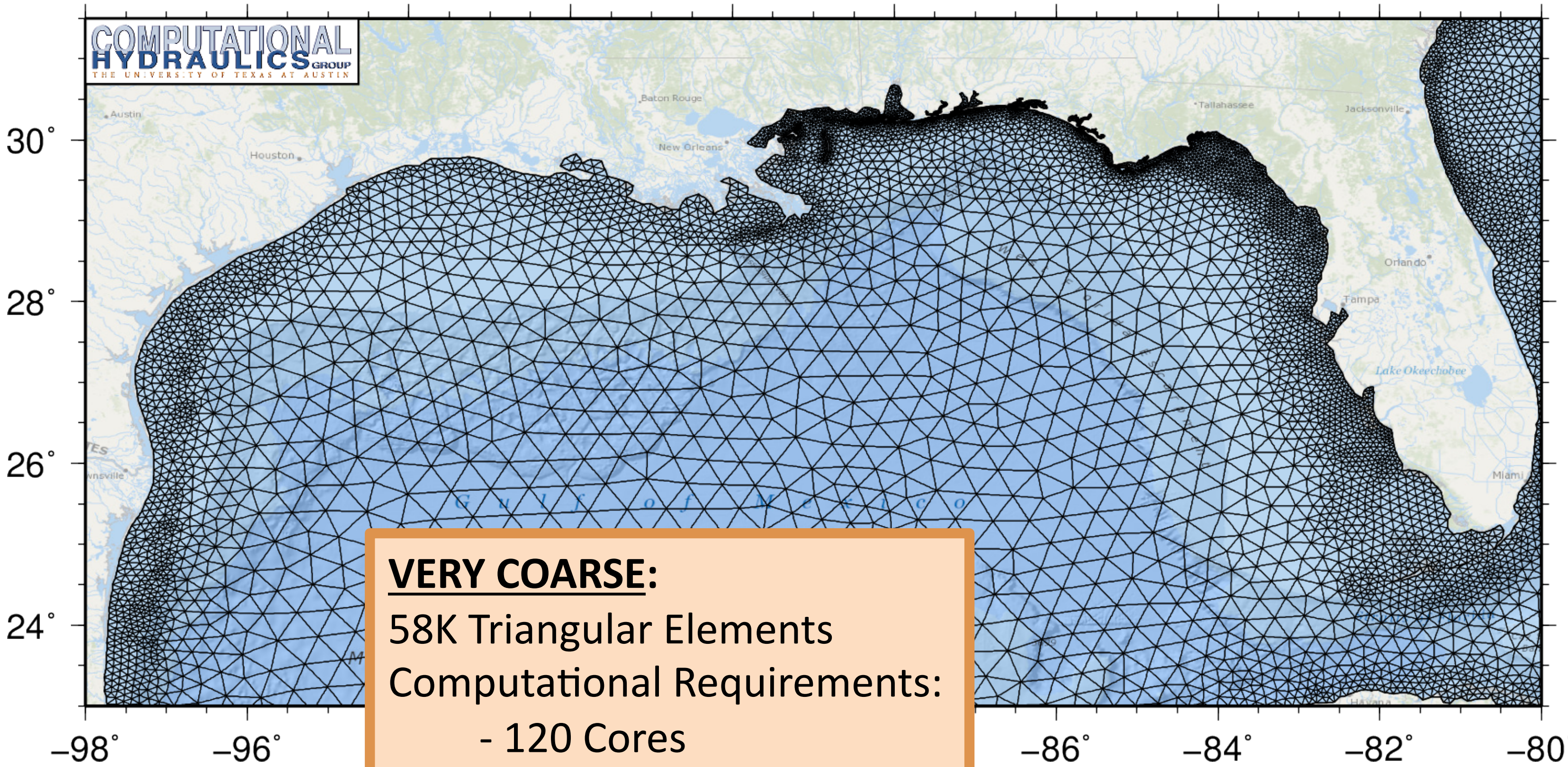
TX2008r35h : Bathymetry / Topography



EC95d : Bathymetry



EC95d : Unstructured Mesh



<u>VERY COARSE</u>:

58K Triangular Elements

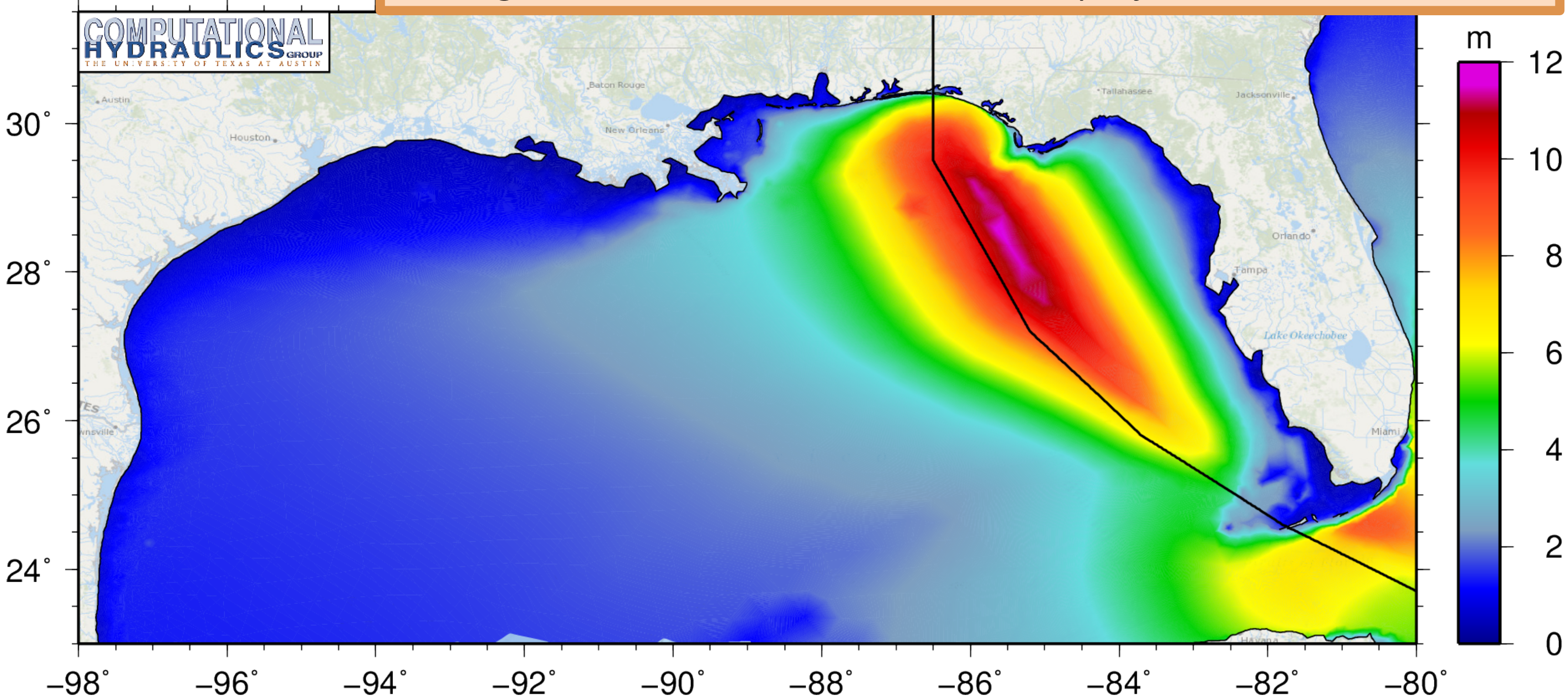
Computational Requirements:

- 120 Cores
- Development Queue

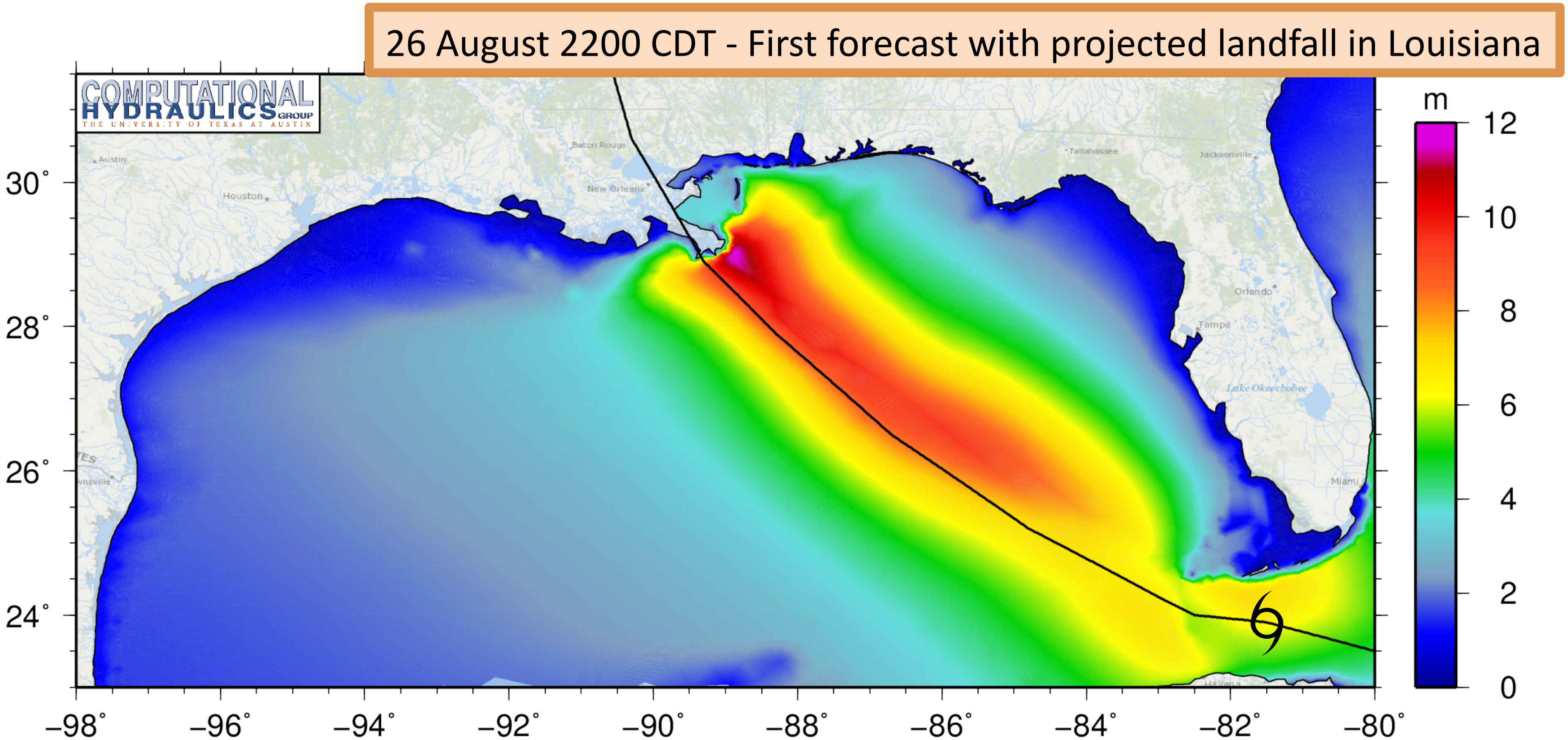
Time for 84hr Forecast: **30min**

Advisory 20 : Maximum Significant Wave Heights

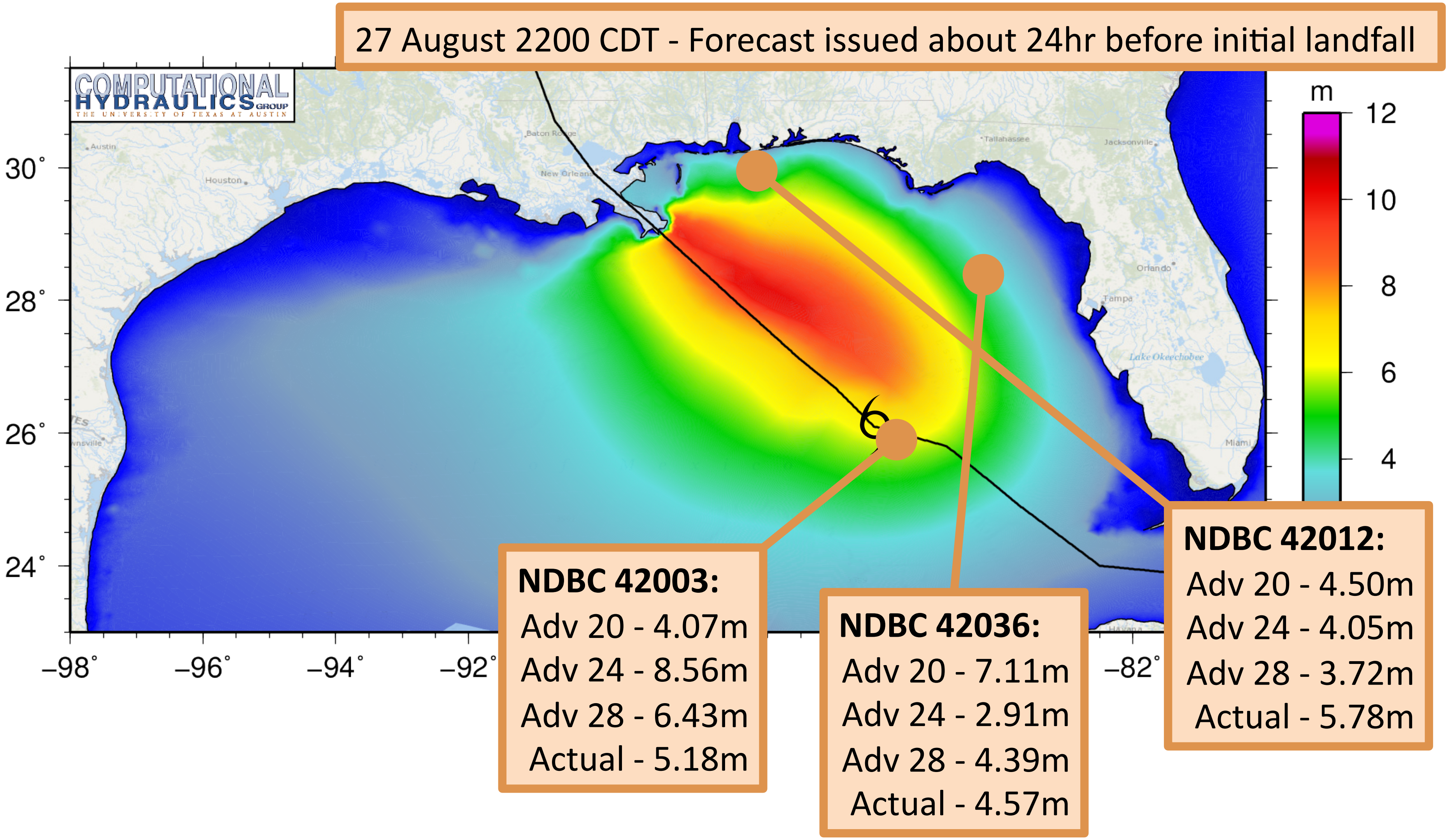
25 August 2200 CDT - Last forecast with projected landfall in Florida



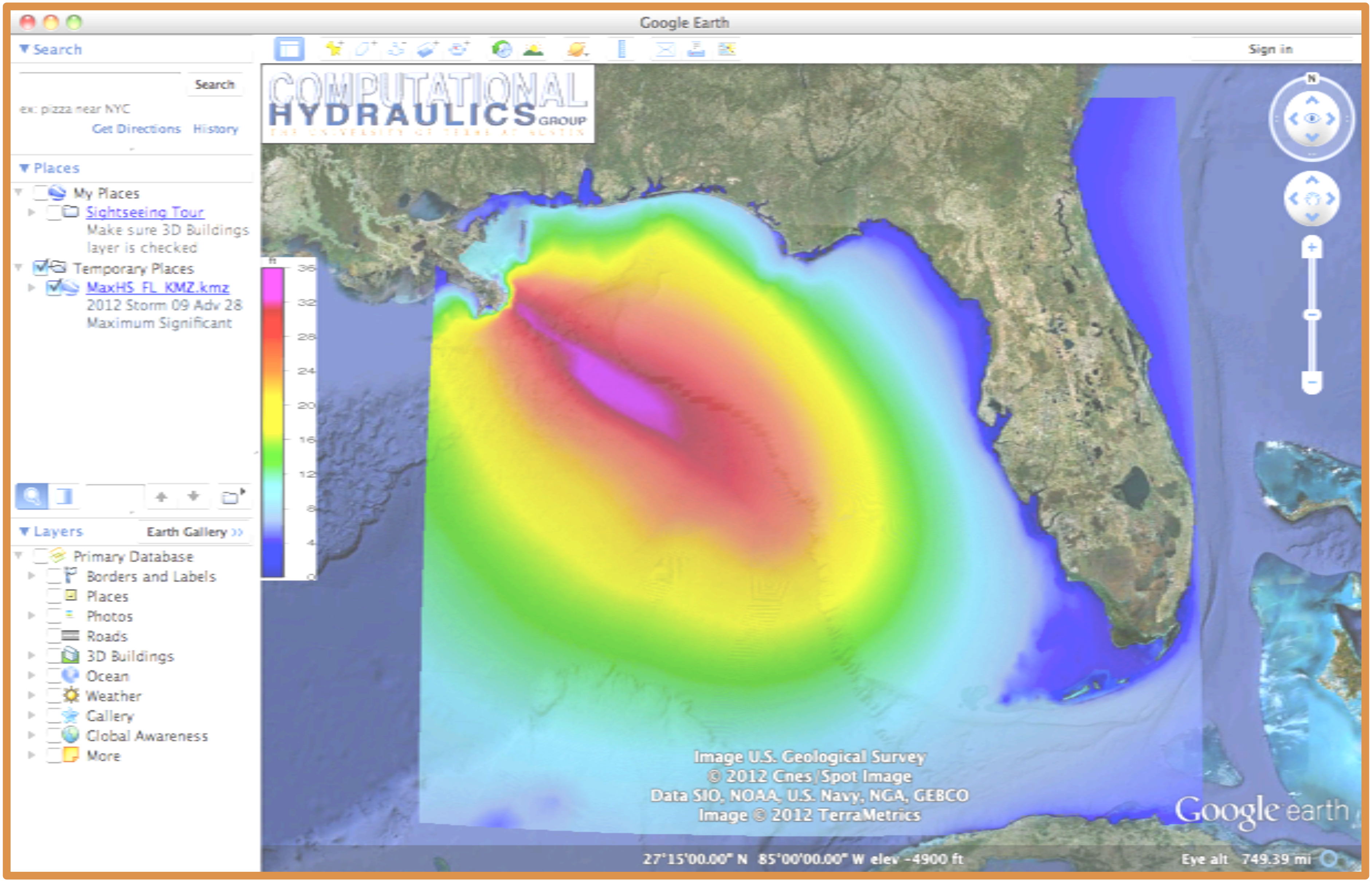
Advisory 24 : Maximum Significant Wave Heights



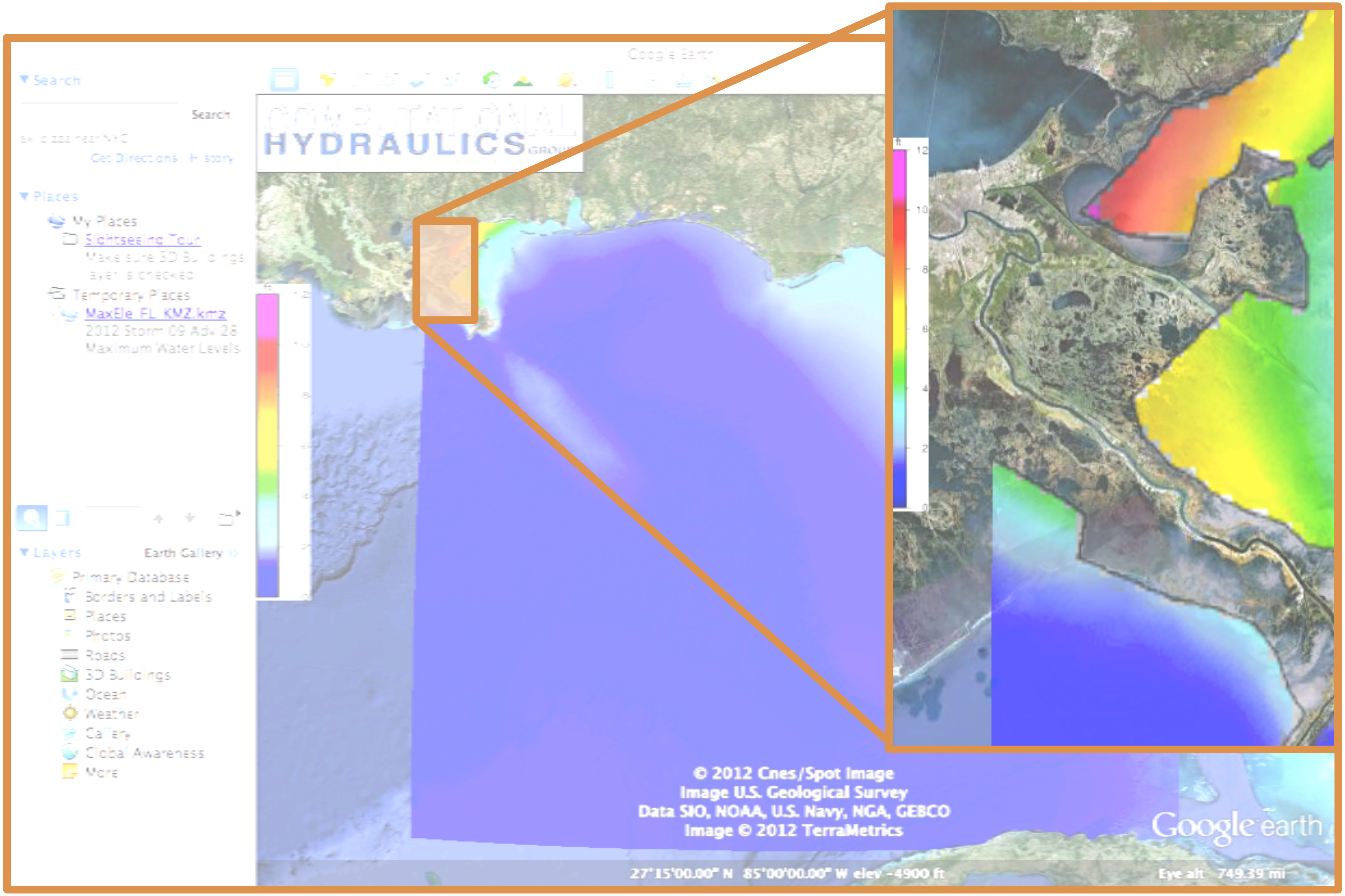
Advisory 28 : Maximum Significant Wave Heights



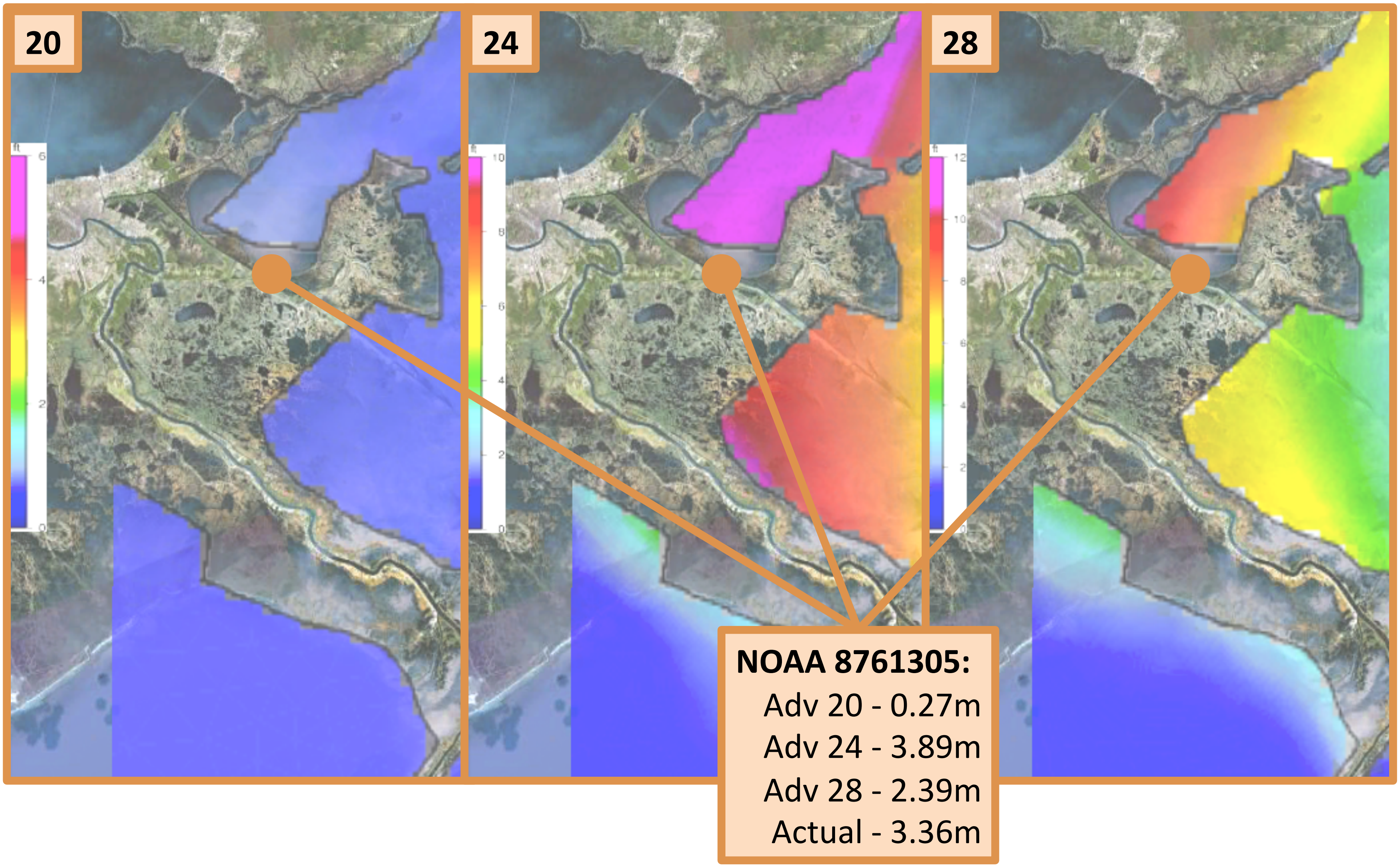
Advisory 28 : Maximum Significant Wave Heights



Advisory 28 : Maximum Water Levels



Advisories 20/24/28 - Maximum Water Levels



Forecast Modeling for Hurricane Isaac

Summary:

Operational forecast system provided guidance for waves and storm surge

Automation worked without problems through 38 forecast cycles

Guidance shared with Texas State Operations Center and NWS offices from Texas to Florida

Moving Forward:

Improvements to computational meshes

Utilize ASGS capability to perturb storm characteristics (track, size, etc.)

Expand Web-based guidance

Image Courtesy Times-Picayune

1. Forecast Modeling for Hurricane Isaac
2. Oil Spill Modeling in the Nearshore

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.

Nearshore Oil Transport : Lagrangian Particles

Particle positions are tracked through the unstructured mesh:

$$\vec{x}_p(t+\Delta t) = \vec{x}_p(t) + \vec{u}\left(\vec{x}_p, t\right)\Delta t + \vec{D}$$

- where the dispersion uses a stochastic perturbation (Proctor *et al.*, 1994):

$$\vec{D} = (2R-1)\sqrt{\vec{c}\vec{E}_v \Delta t}$$

- with: $0 < R < 1$ is a random number,

  $\vec{E}_v = 10$ m²/s are turbulent coefficients, and

  $\vec{c} = 12$ are scaling coefficients;

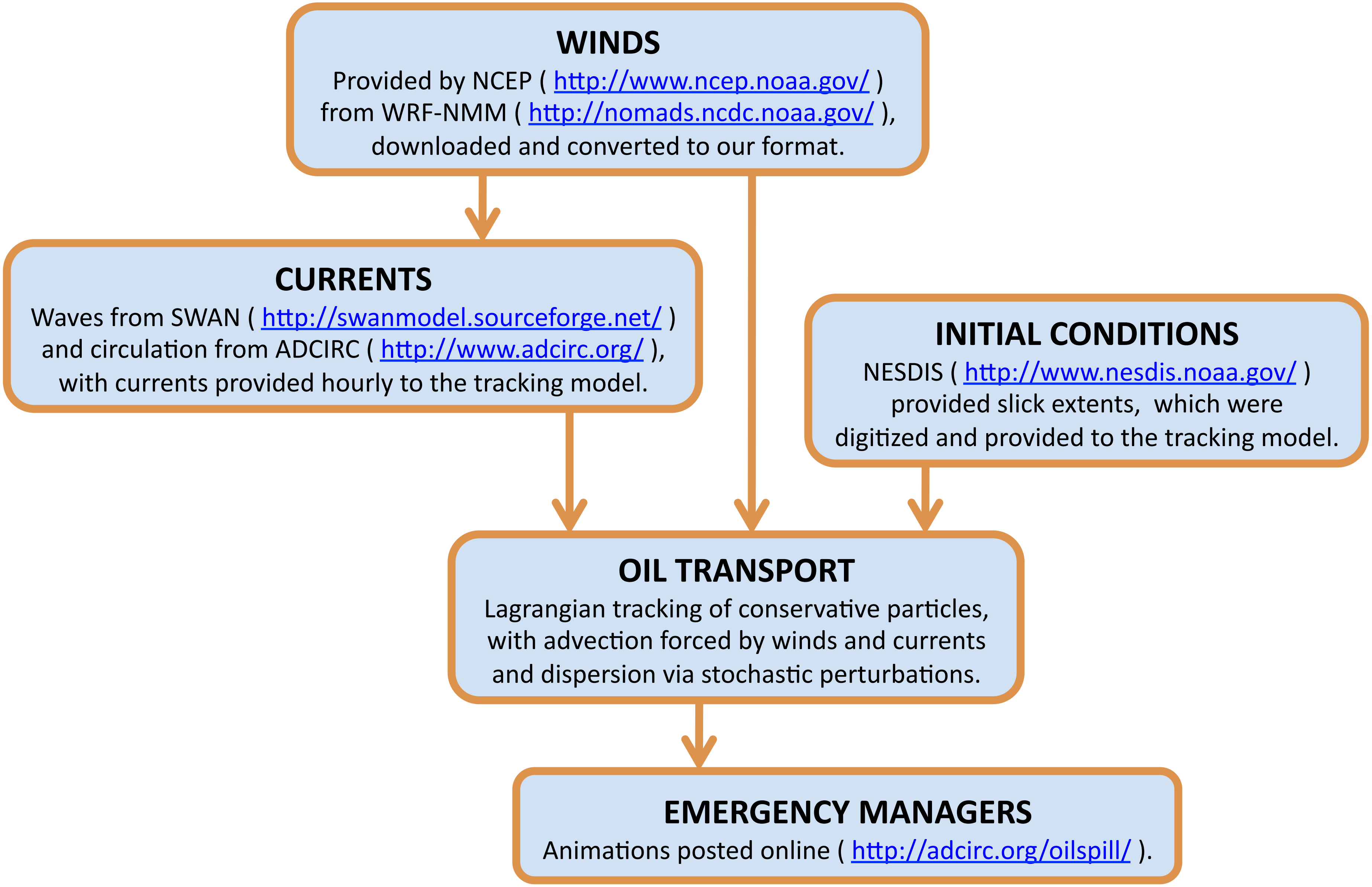
- and where the velocities are a linear combination of currents and winds:

$$\vec{u}\left(\vec{x}_p, t\right) = F_c \vec{u}_c\left(\vec{x}_p, t\right) + F_w \vec{u}_w\left(\vec{x}_p, t\right)$$

- with: $F_c = 1$ and $F_w = 0$.

Using hybrid OpenMP/MPI, 11M particles can be tracked on a 10M-element mesh in about **5.5 min/day** using 256 cores on TACC Ranger.

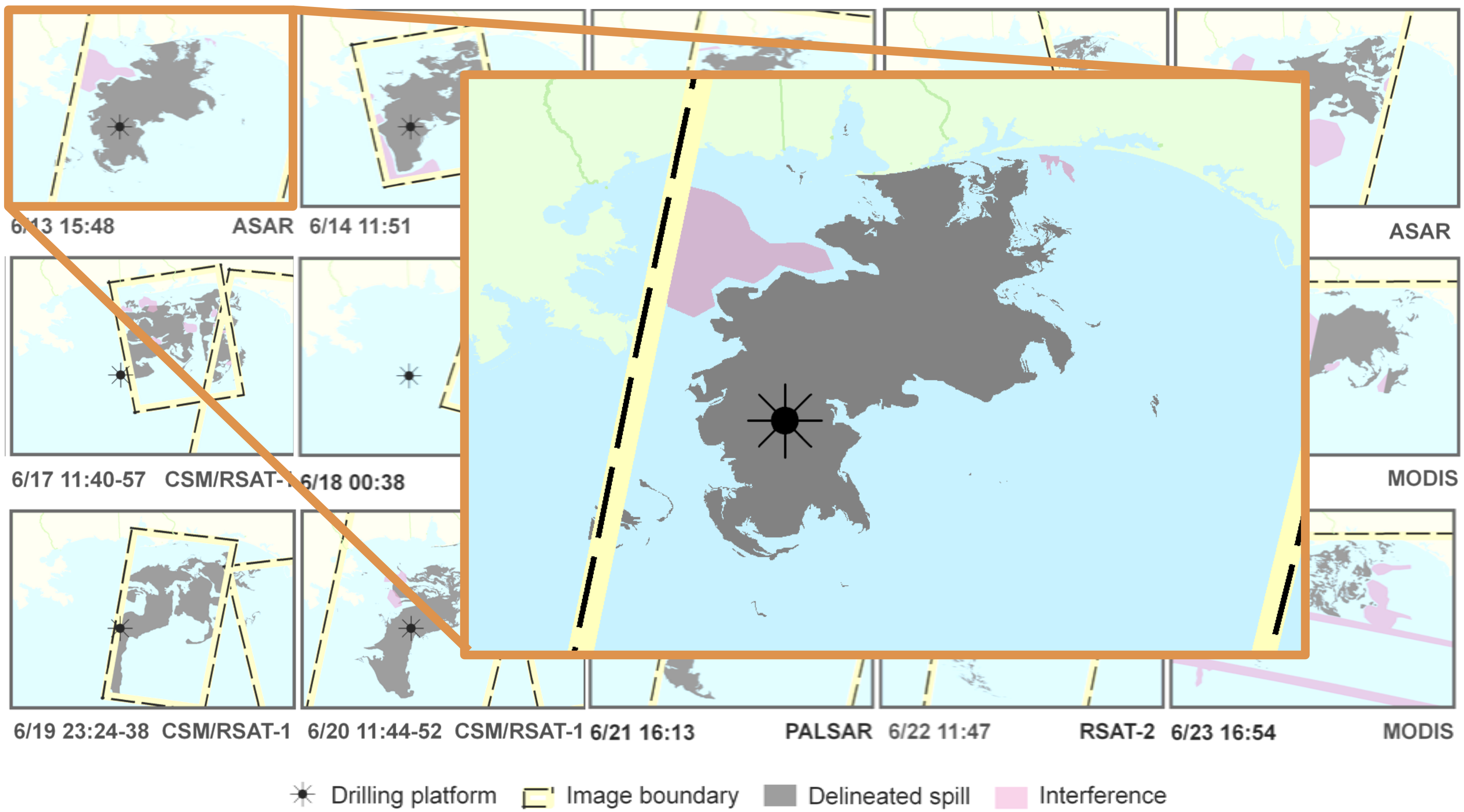
Nearshore Oil Transport : Flow Chart



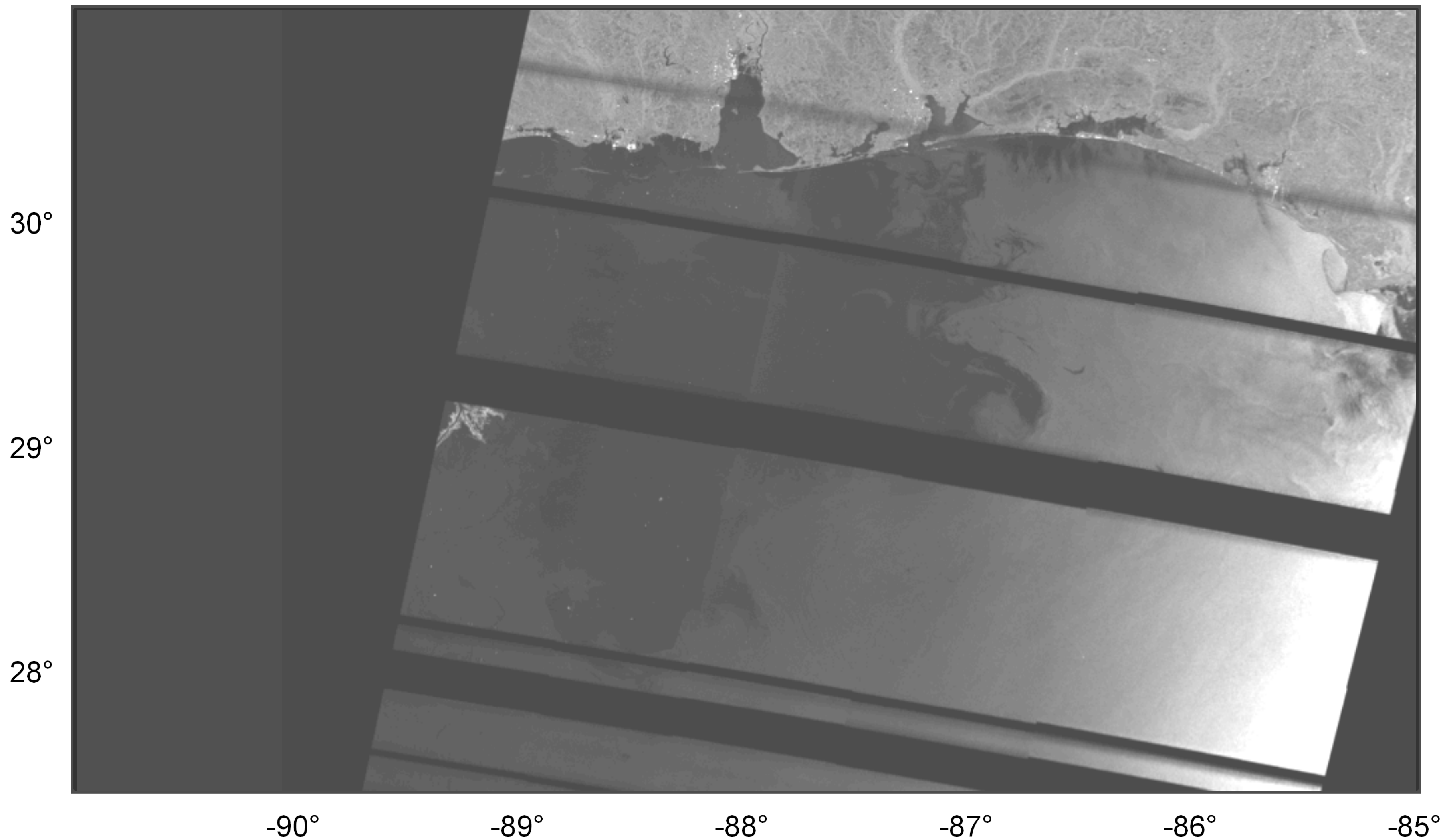
13-23 June 2010 : Satellite Imagery

Examples of available imagery during 13-23 June 2010:

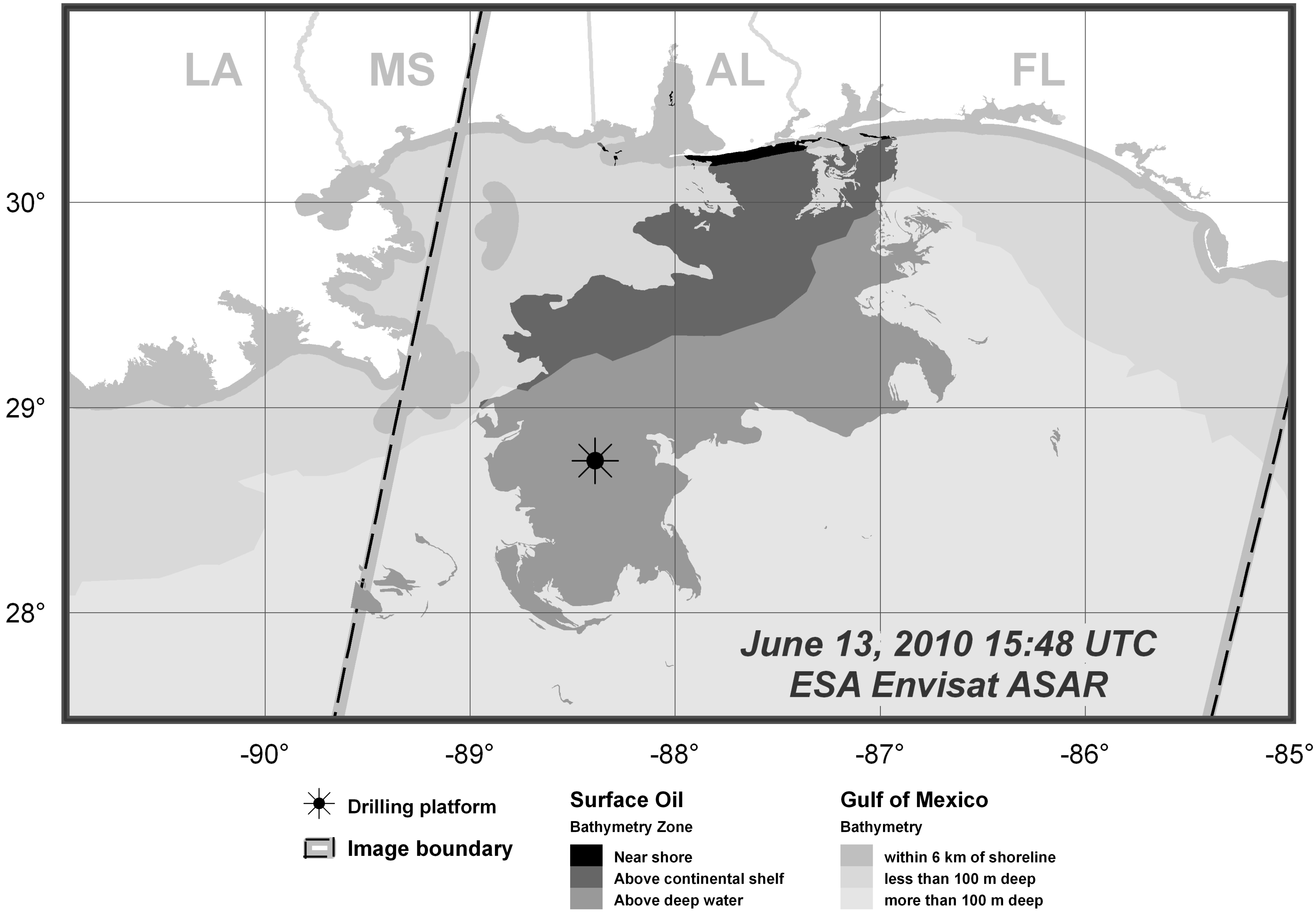
- NESDIS consolidated observations from a suite of satellite sensors

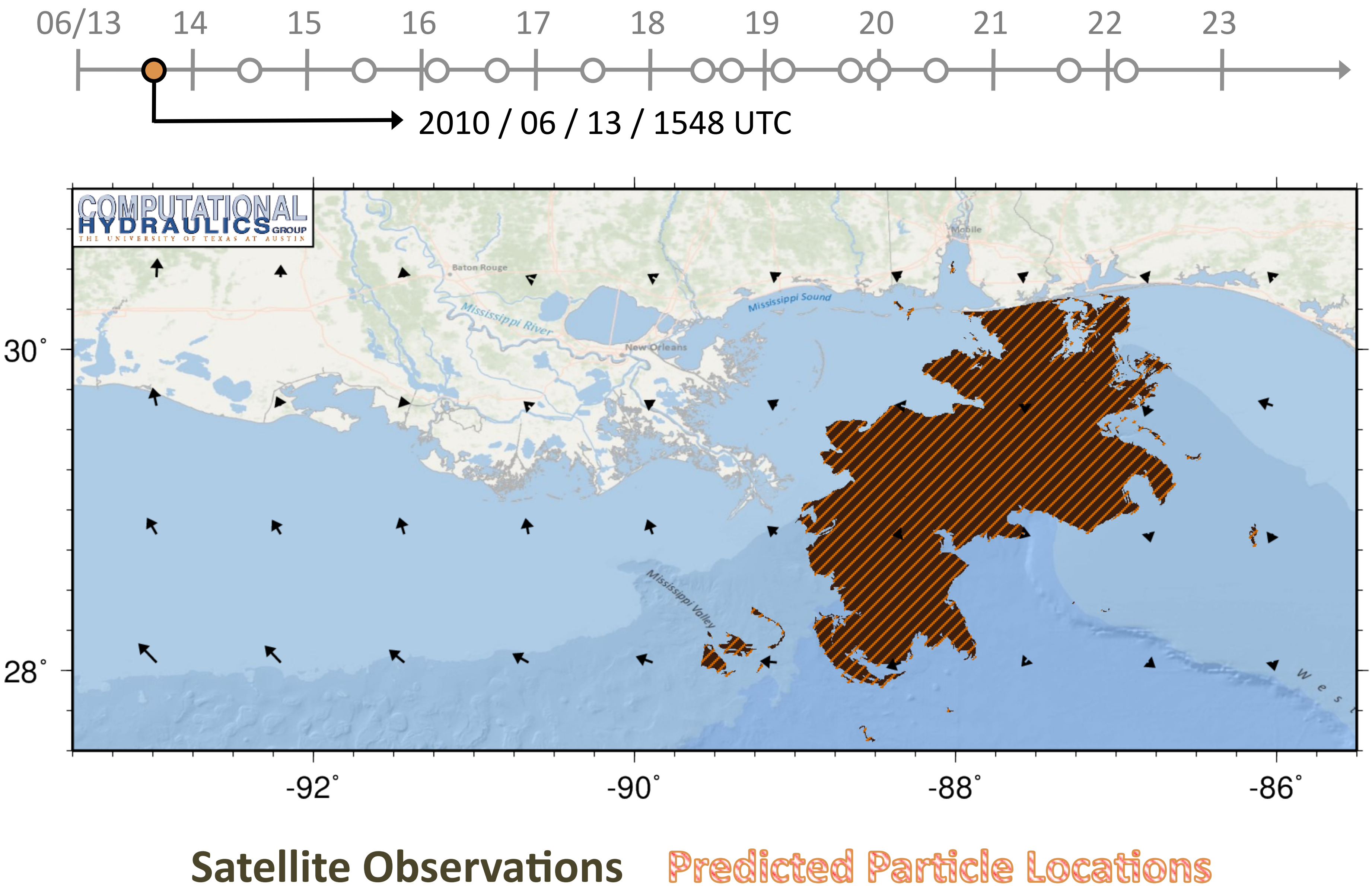


13-23 June 2010 : Satellite Imagery



13-23 June 2010 : Satellite Imagery





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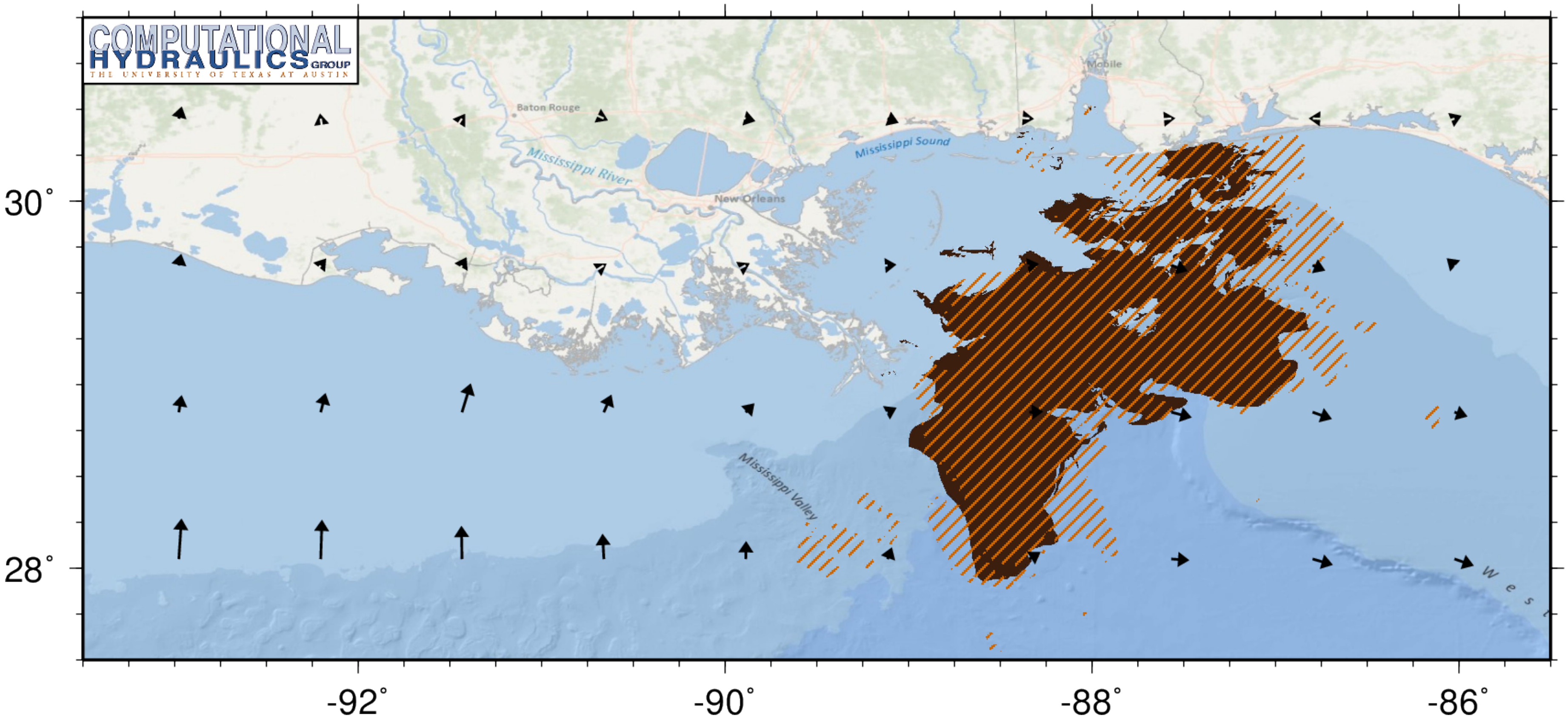
2010 / 06 / 13 / 1548 UTC
COMPUTATIONAL HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
Baton Rouge
Mississippi River
New Orleans
Mississippi Sound
Mobile
Mississippi Valley
30˚
28˚
-92˚
-90˚
-88˚
-86˚
Satellite Observations
Predicted Particle Locations

06/13 14 15 16 17 18 19 20 21 22 23

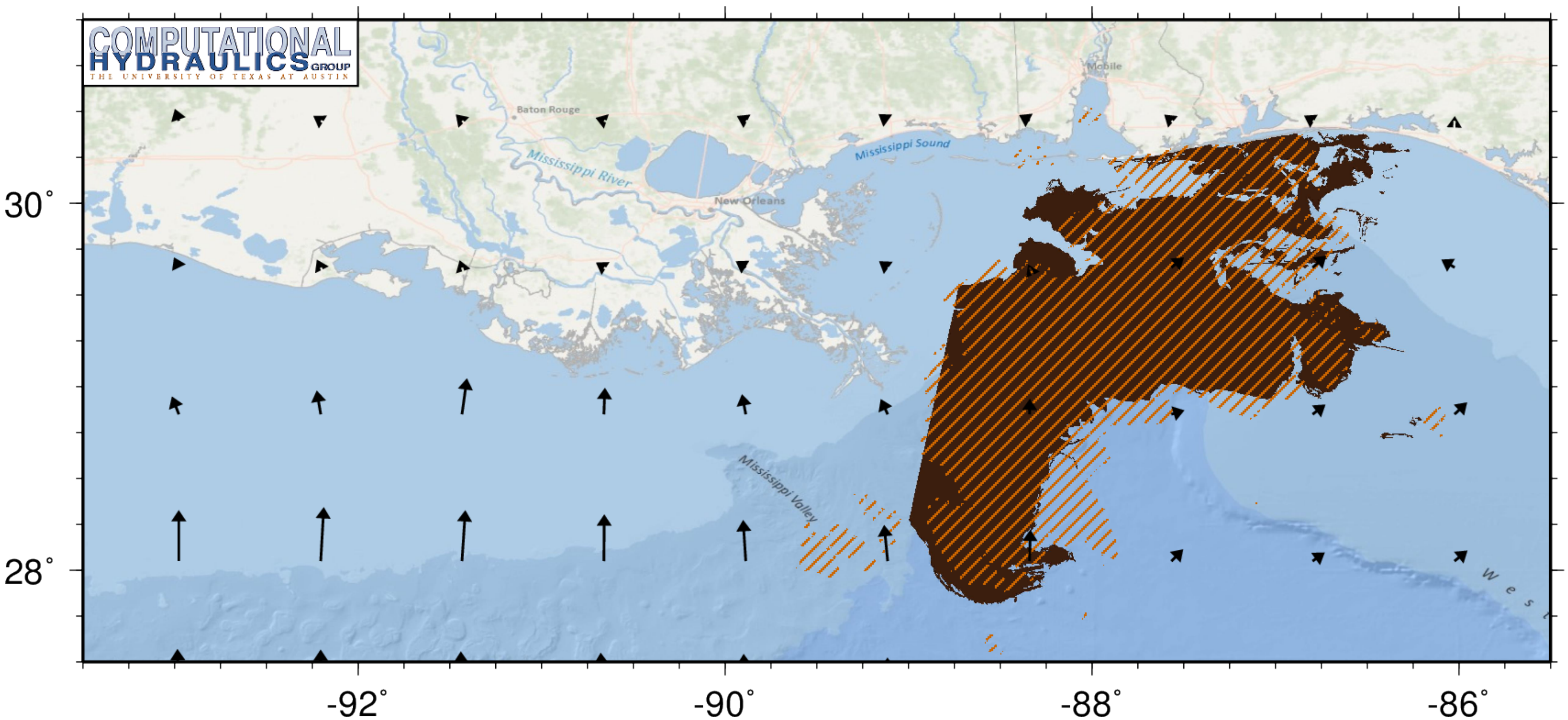
2010 / 06 / 14 / 1151 UTC (+ 20 hr / + 0.8 d)



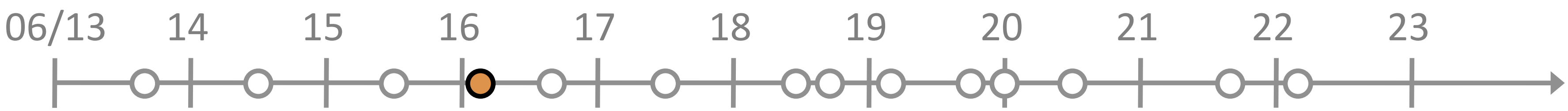
Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

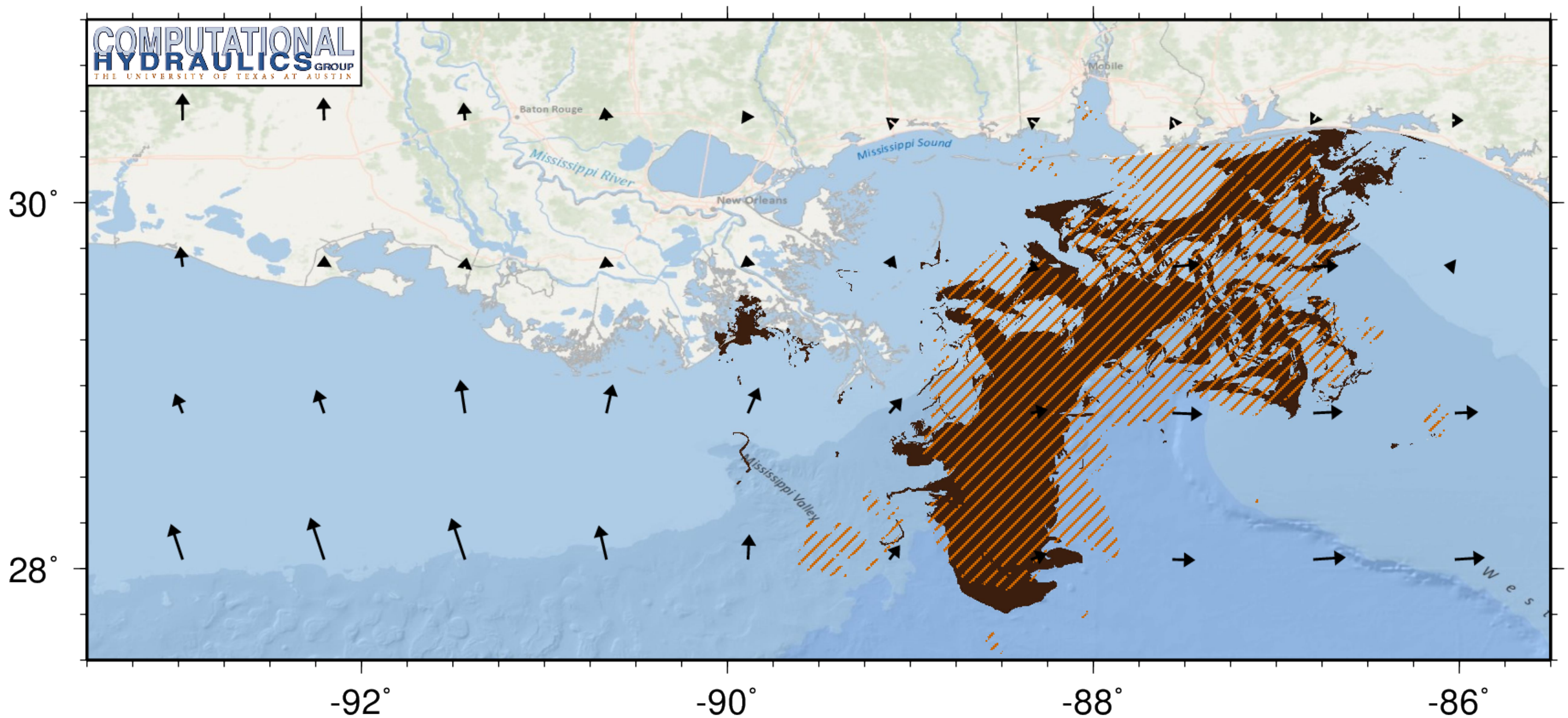
2010 / 06 / 15 / 1151 UTC (+ 44 hr / + 1.8 d)



Satellite Observations **Predicted Particle Locations**



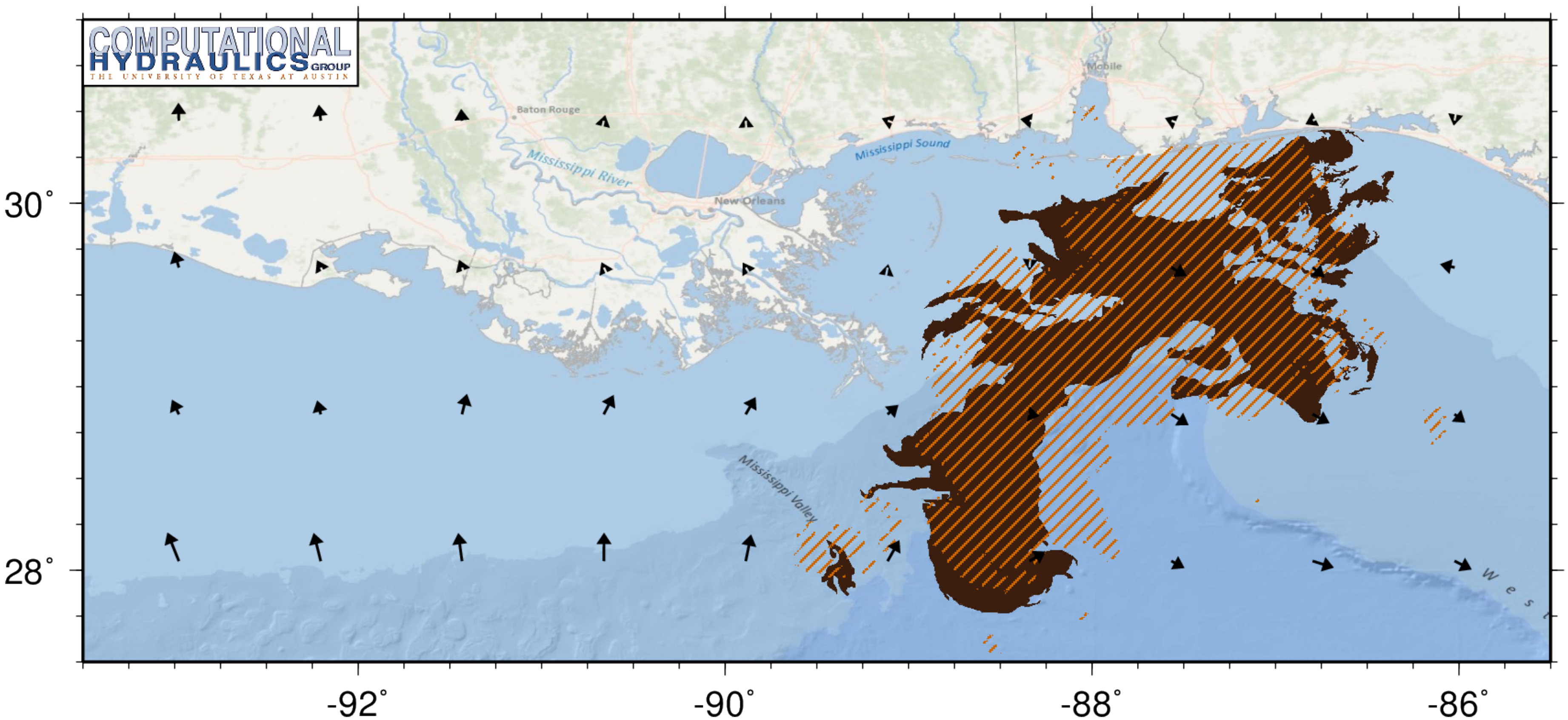
2010 / 06 / 16 / 0140 UTC (+ 58 hr / + 2.4 d)



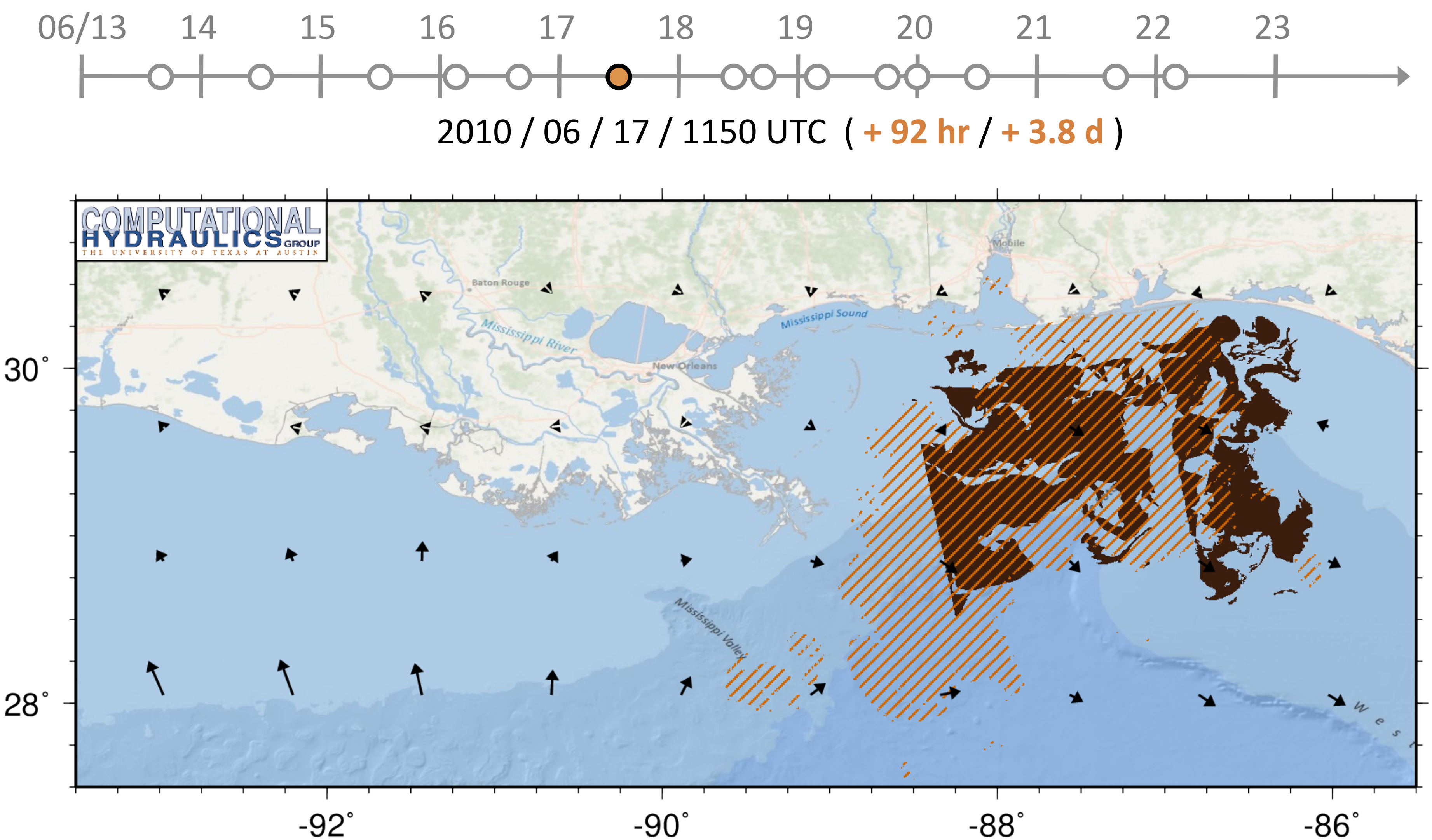
Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

2010 / 06 / 16 / 1555 UTC (+ 72 hr / + 3.0 d)

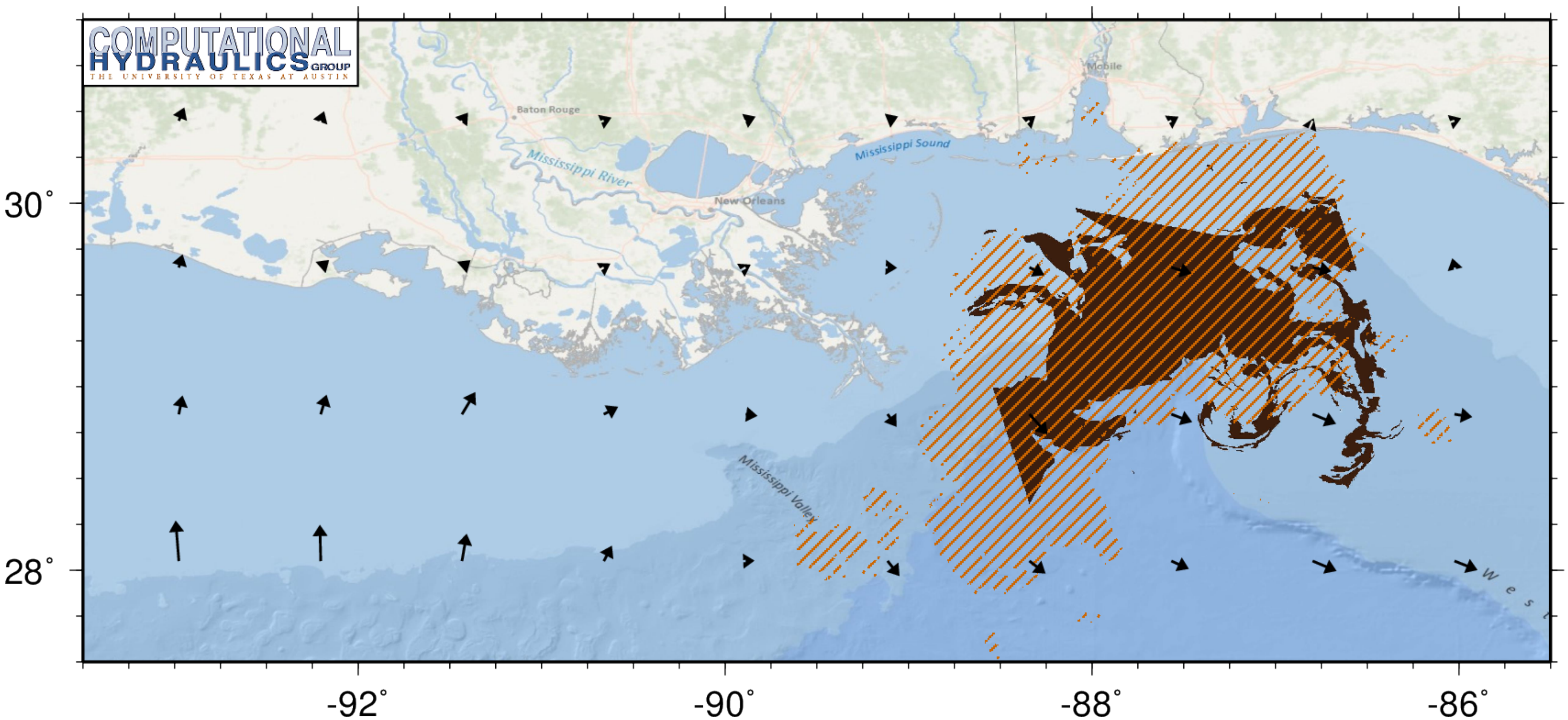


Satellite Observations **Predicted Particle Locations**



Satellite Observations **Predicted Particle Locations**

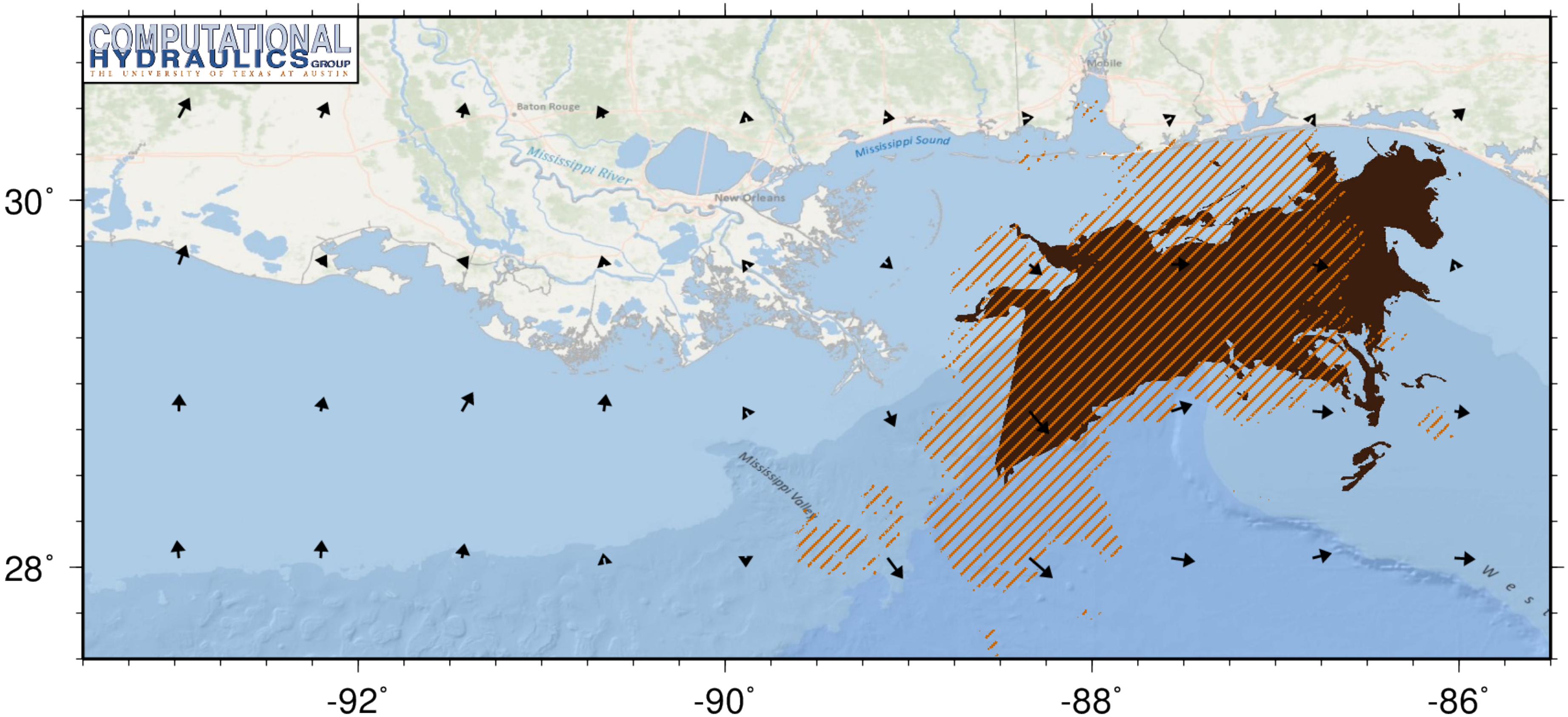
2010 / 06 / 18 / 1109 UTC (+ 115 hr / + 4.8 d)



Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

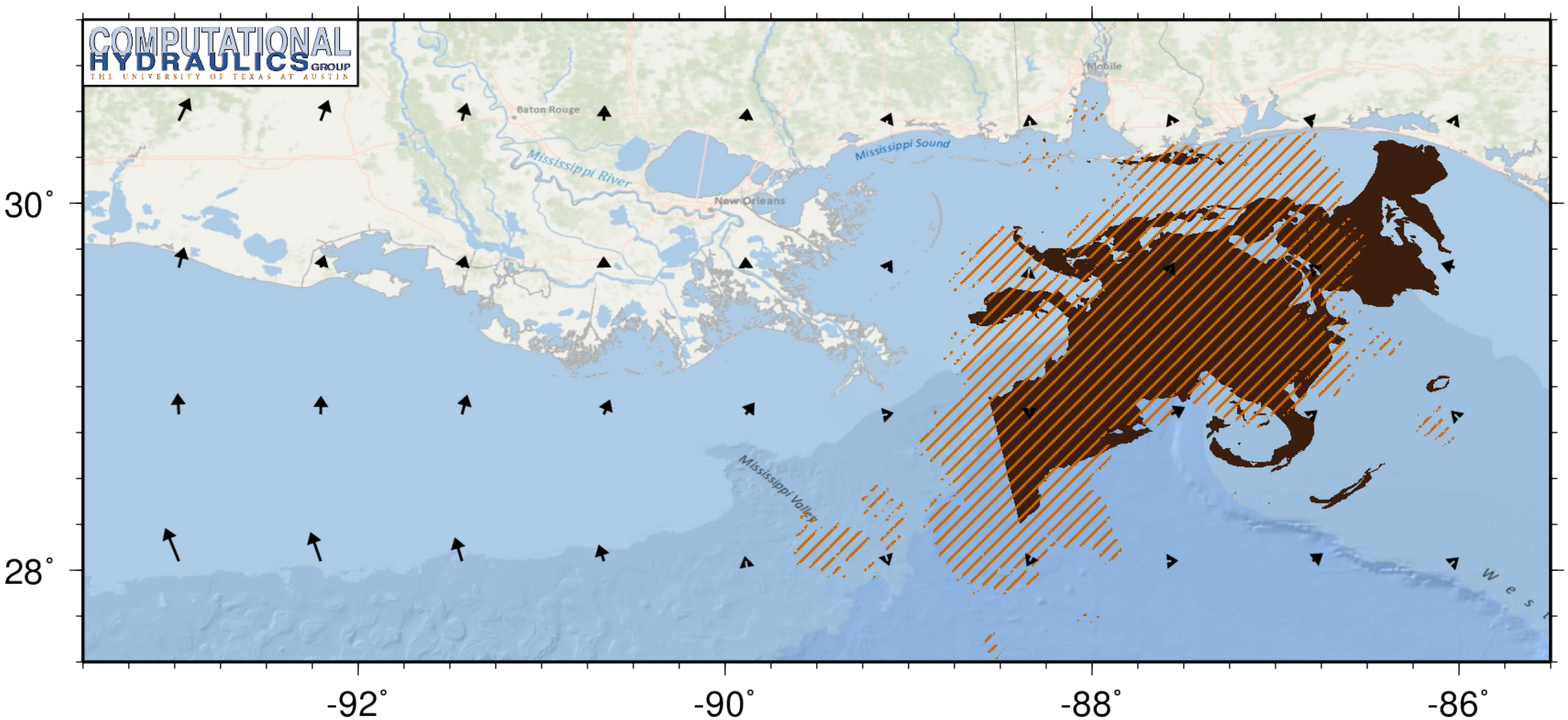
2010 / 06 / 18 / 1637 UTC (+ 121 hr / + 5.0 d)



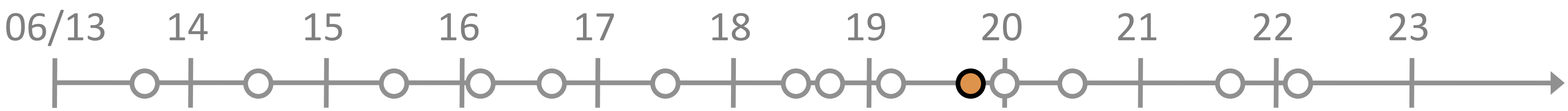
Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

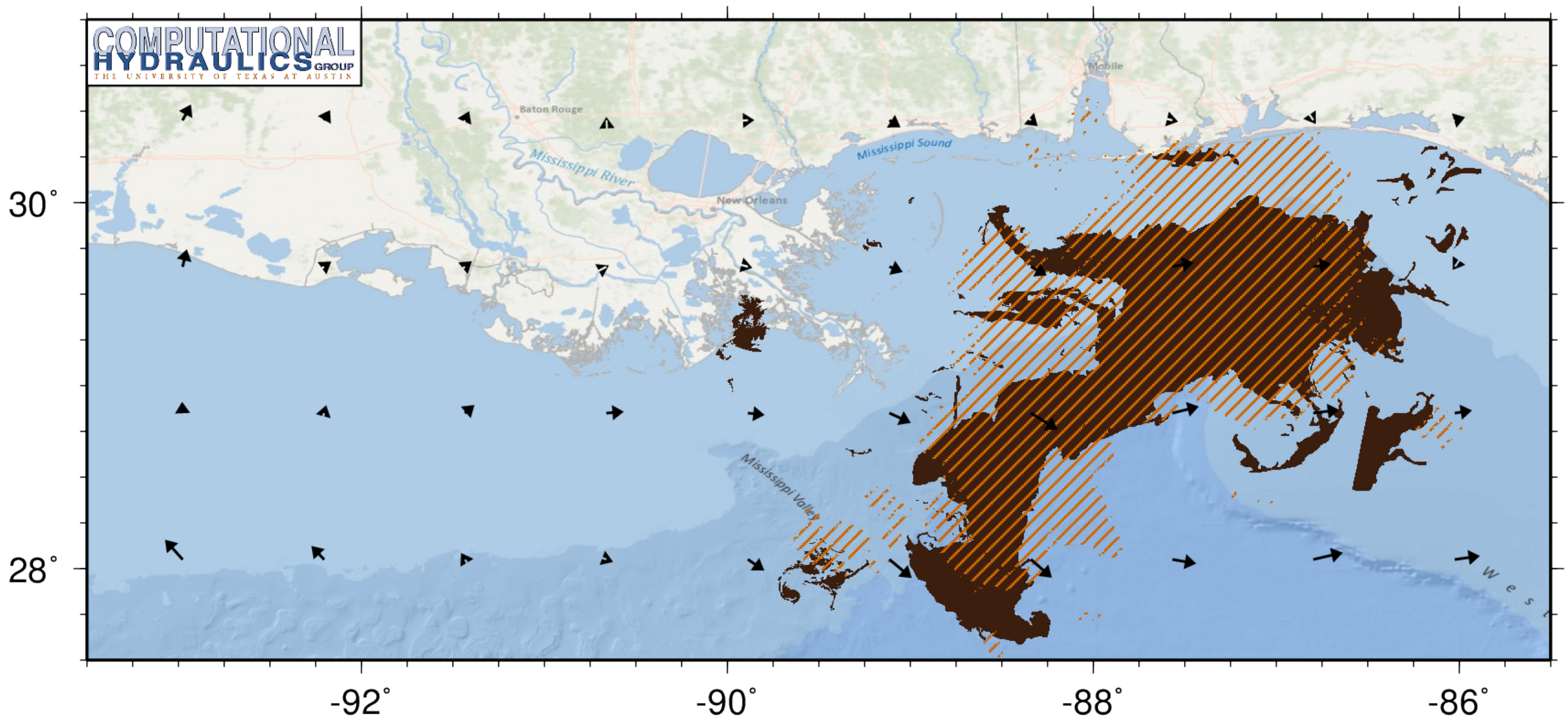
2010 / 06 / 19 / 0341 UTC (+ 132 hr / + 5.5 d)



Satellite Observations Predicted Particle Locations



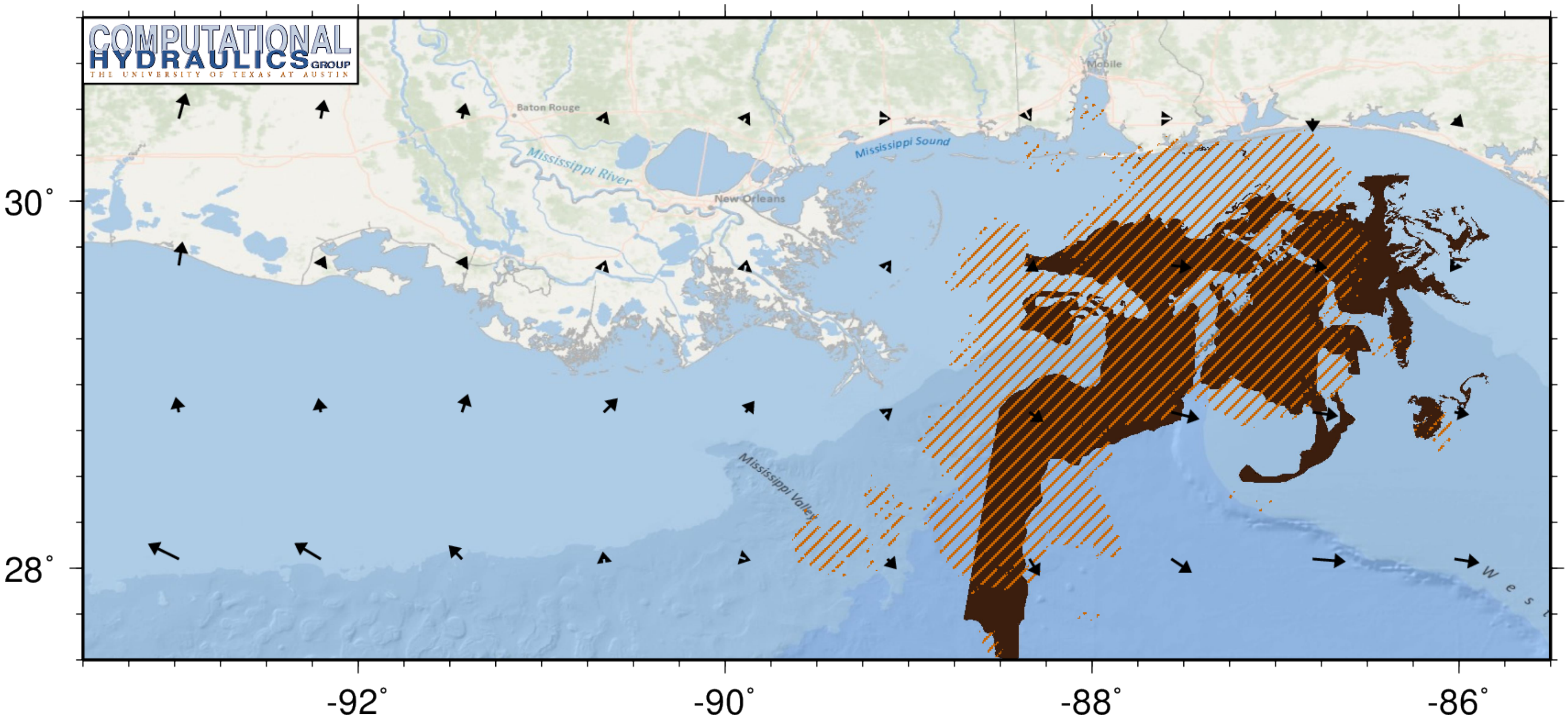
2010 / 06 / 19 / 1730 UTC (+ 148 hr / + 6.2 d)



Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

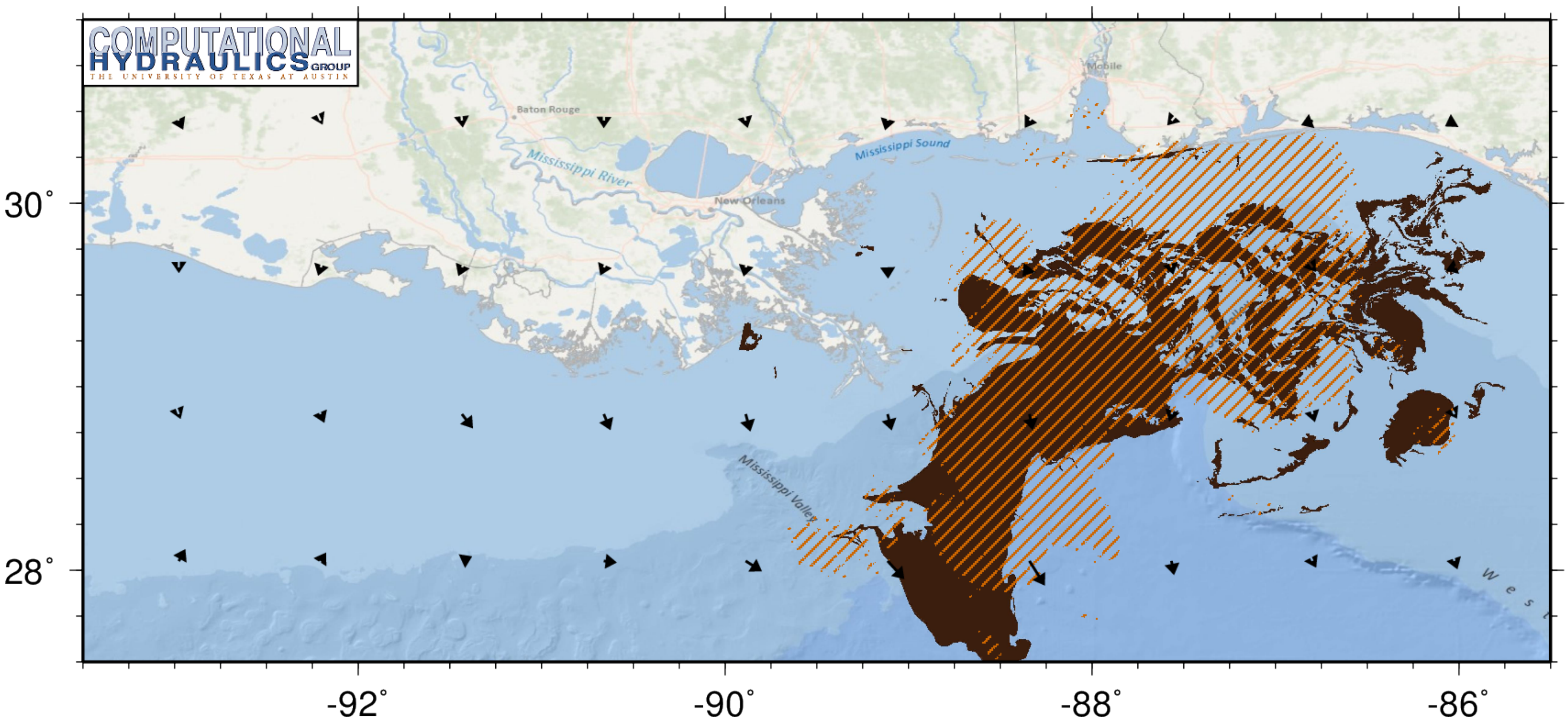
2010 / 06 / 19 / 2330 UTC (+ 152 hr / + 6.3 d)



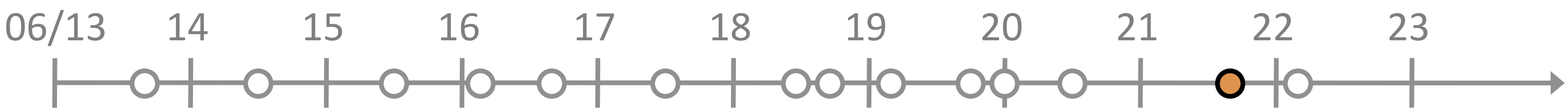
Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

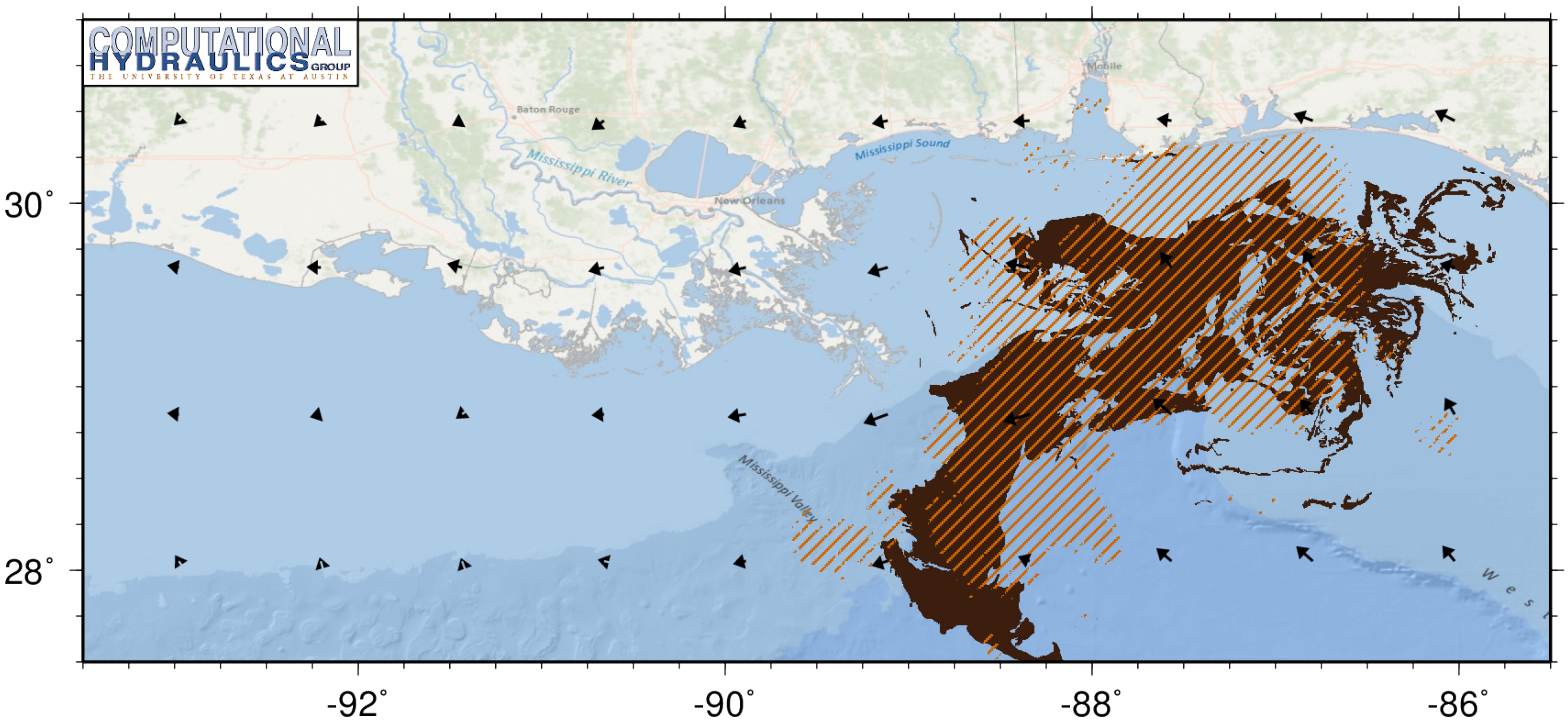
2010 / 06 / 20 / 1150 UTC (+ 164 hr / + 6.8 d)



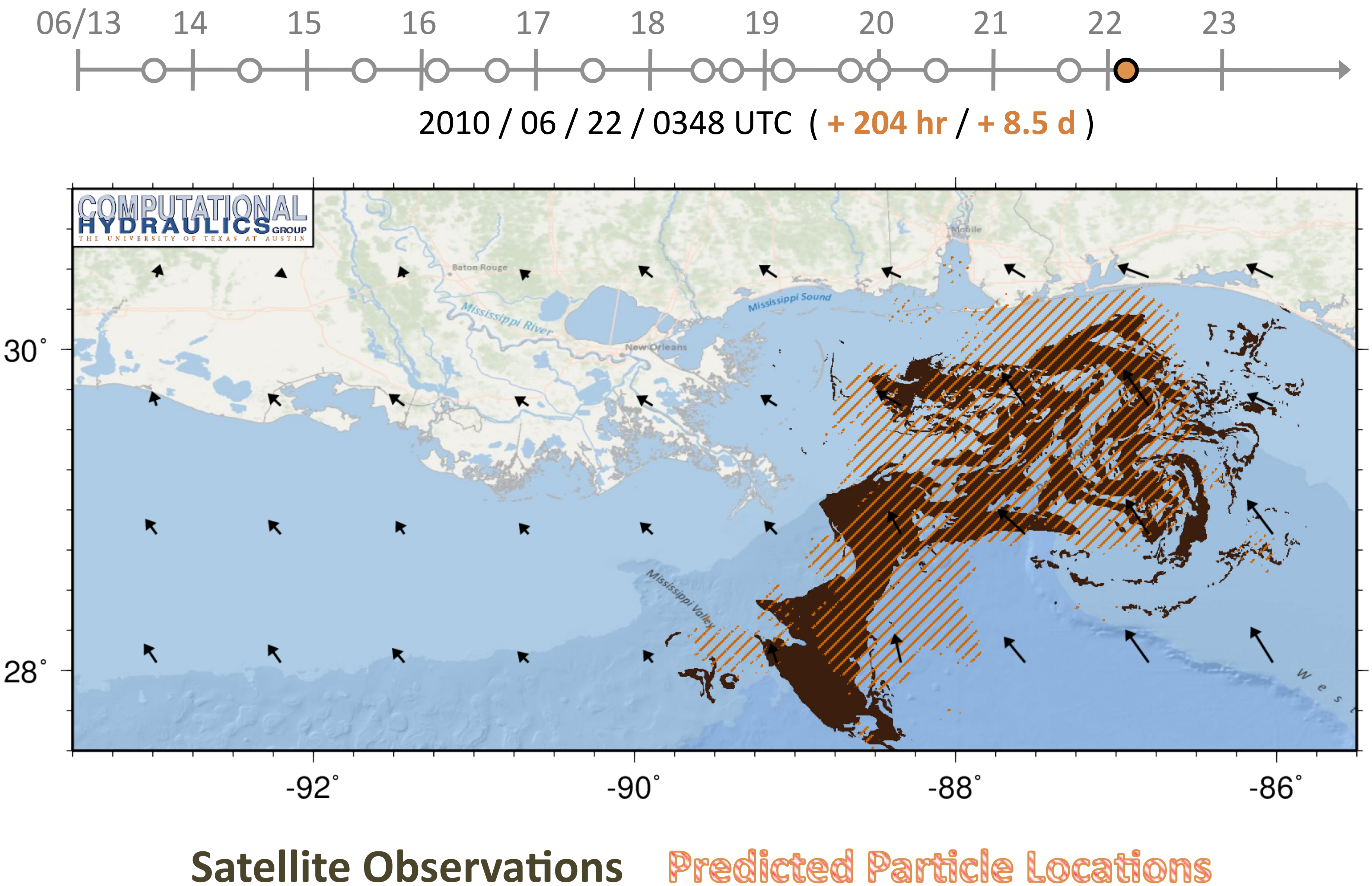
Satellite Observations Predicted Particle Locations



2010 / 06 / 21 / 1613 UTC (+ 192 hr / + 8.0 d)



Satellite Observations **Predicted Particle Locations**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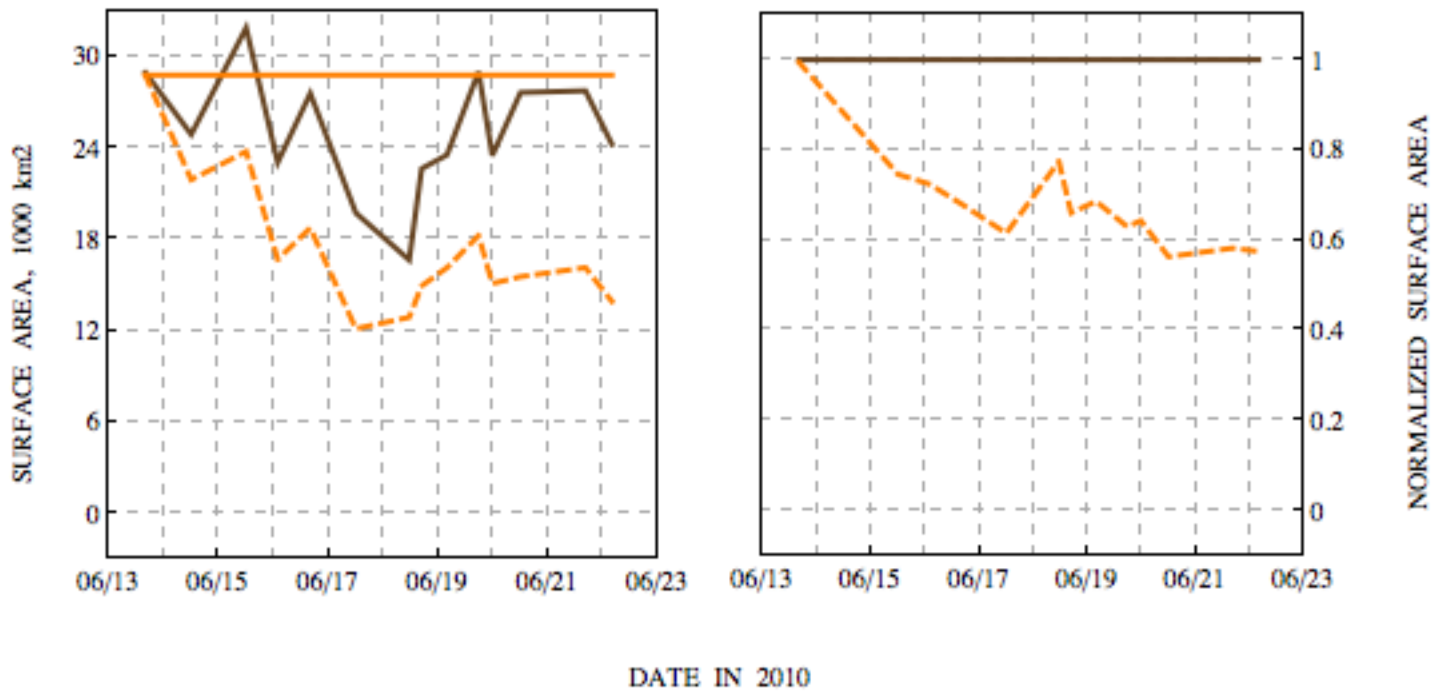
2010 / 06 / 22 / 0348 UTC (+ 204 hr / + 8.5 d)
COMPUTATIONAL
HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
Baton Rouge
Mobile
Mississippi River
New Orleans
Mississippi Sound
Mississippi Valley
30˚
28˚
-92˚
-90˚
-88˚
-86˚
Satellite Observations
Predicted Particle Locations

13-23 June 2010 : Validation



Overlap of our predictions to observations:

- **Solid brown** - Total areas of observed oil in satellite imagery
- **Solid orange** - Total areas of predicted locations of Lagrangian particles
- **Dashed orange** - Overlap between predictions and observations

After one week of simulation, overlap is about 60 percent

- Good qualitative and quantitative match to observations

Submerged Ridge : 3D Transport

Transition to 3D Flow and Transport:

ADCIRC computes 3D flow by adding layers of vertical elements below the mesh

- u,v from horizontal momentum, then w from vertical momentum

Tracking code must account for particle depth

- Interpolate 3D velocities within the vertical element containing particle

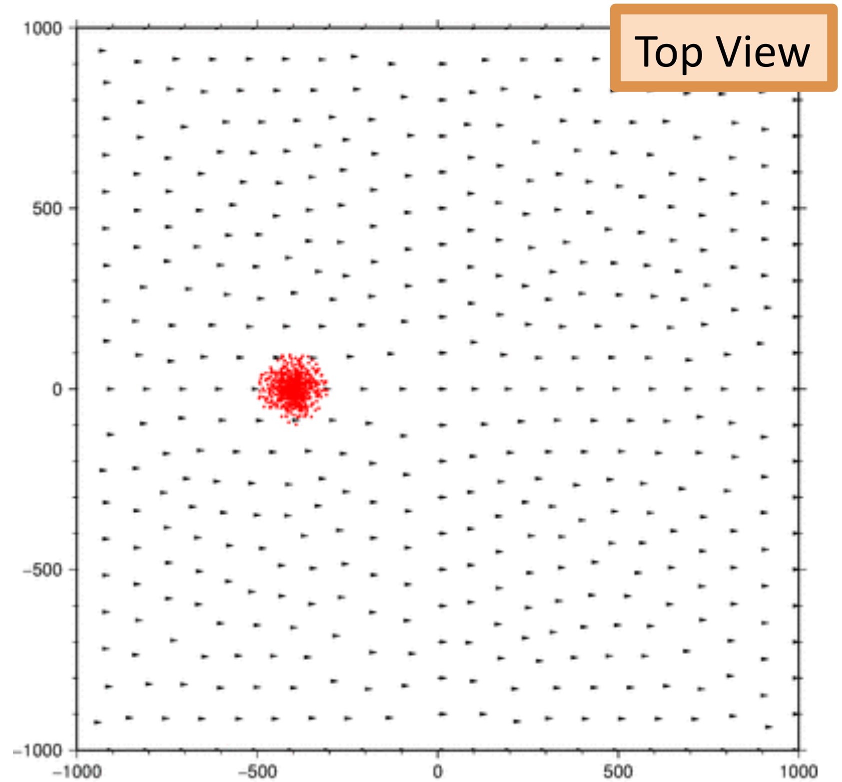
Submerged Ridge Test Case:

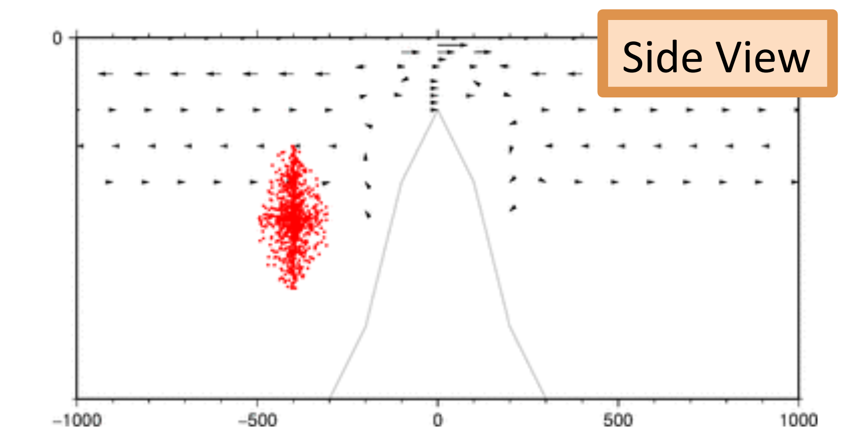
Simple test case to show particle movement

- Domain is 2km x 2km x 100m
- Submerged central ridge with 20m depth

Wind oscillates with magnitude of 10m/s

Initial 'cloud' of 1000 particles (shown in red)





Submerged Ridge : Buoyancy

Floating Oil Droplets:

Zheng and Yapa (2000) divide droplets into shapes/classes based on size:

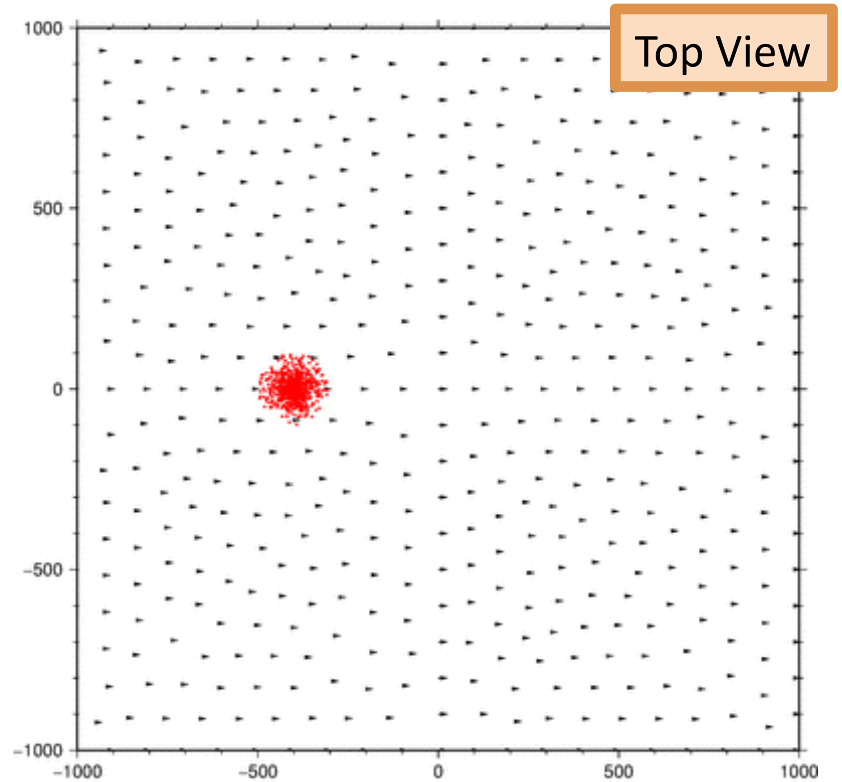
- Spherical droplets (small)
- Ellipsoidal droplets (intermediate)
- Spherical-cap droplets (large)

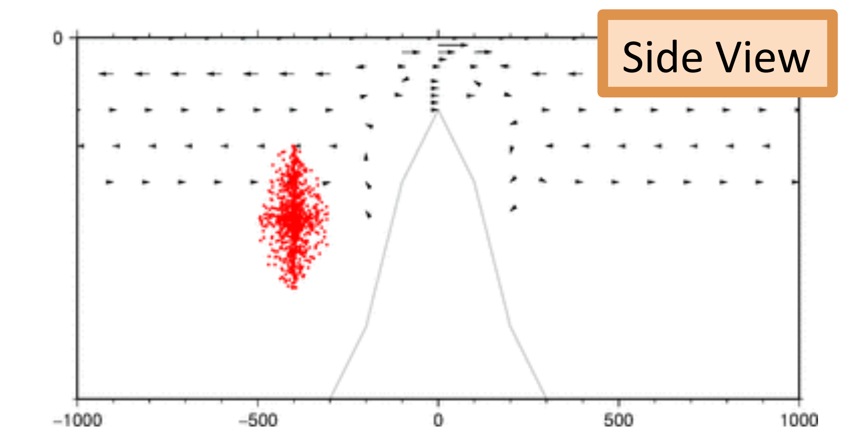
Oil droplets will always fall in spherical class:

$$U_T = \frac{R\mu}{\rho d}$$

Droplet size is most important factor:

Particle Diameter (µm)	Buoyant Velocity (m/hr)
10	0.027
50	0.685
100	2.723
300	20.549





Submerged Ridge : Source Term

Oil Leaks from Seafloor:

At every tracking step, insert a particle

at a user-defined location

- Number of particles increases over time

Submerged Ridge Test Case:

Instead of initializing the particles in a cloud,

they are introduced at a source

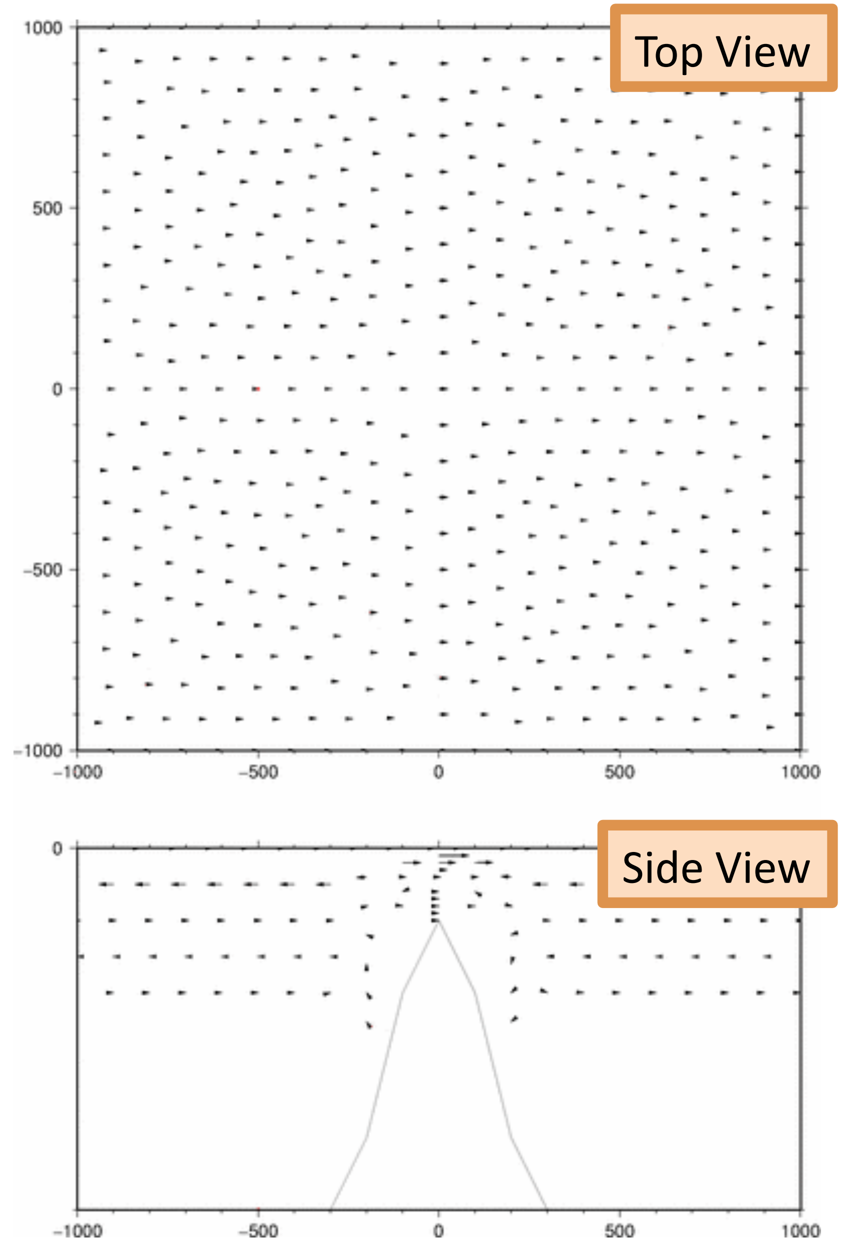
located at (0, -500, -100)m

Assumptions:

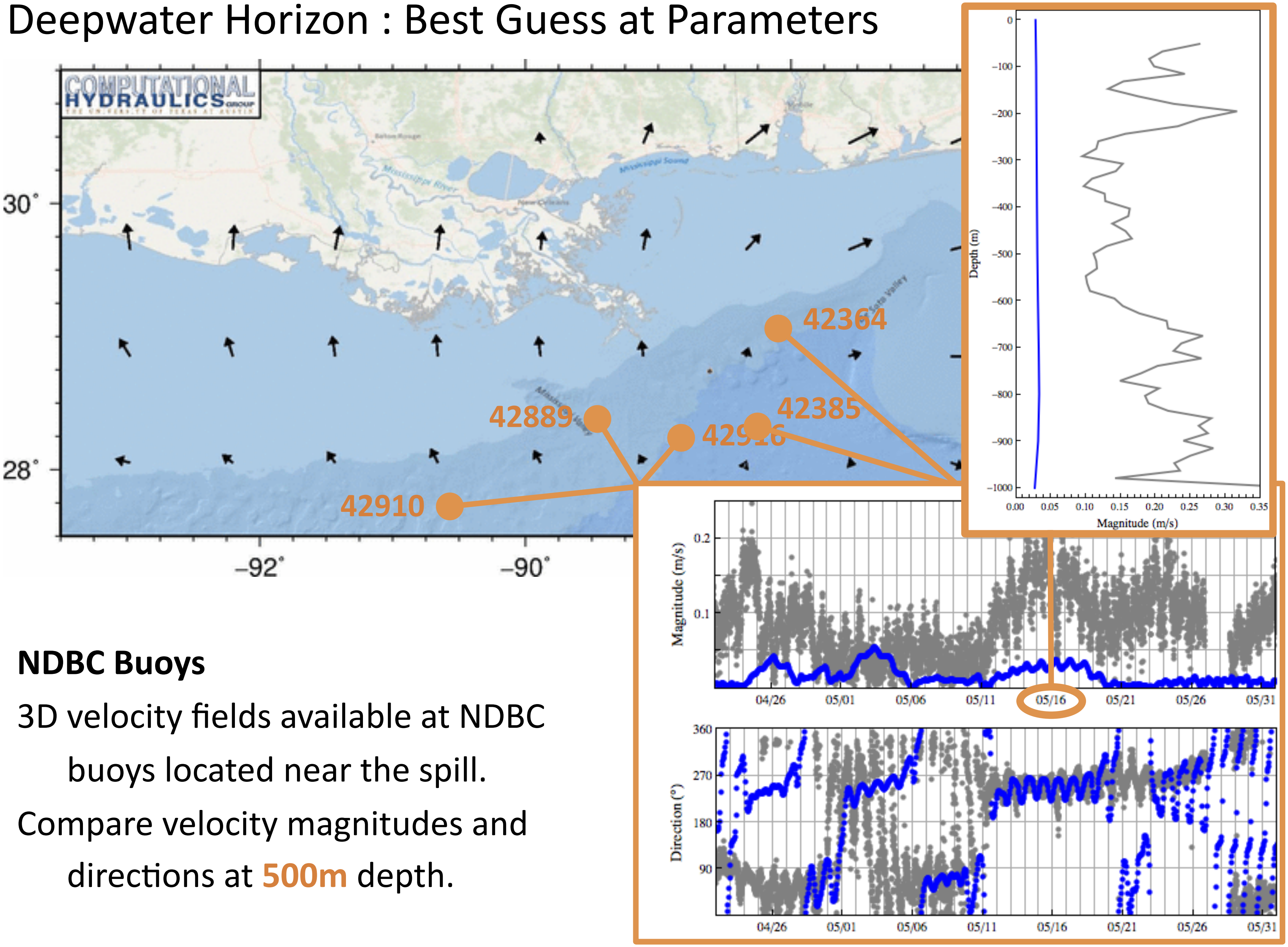
Water - Density of 998.2071 kg/m^3 (at 20°C)

Oil - Density of 858 kg/m^3

- **Droplet size of 50 µm**
- Interfacial tension of 0.023 N/m



Deepwater Horizon : Best Guess at Parameters



NDBC Buoys

3D velocity fields available at NDBC buoys located near the spill.

Compare velocity magnitudes and directions at **500m** depth.

Sources of Error

There are several potential sources of error:

- Winds - Meteorological forcing does not have sufficient resolution in time (6hr) or space (12km) to capture small-scale features
- Currents - ~~Depth-averaged velocities are insufficient in deep water~~
  - **Lacking flow features created by density gradients**
- Waves - Not accounting for increased mixing at the sea surface
- Oil Physics - ~~Lacking a source term at the wellhead~~
  - Lacking sink terms due to evaporation, biodegradation, etc.
- And probably many others …