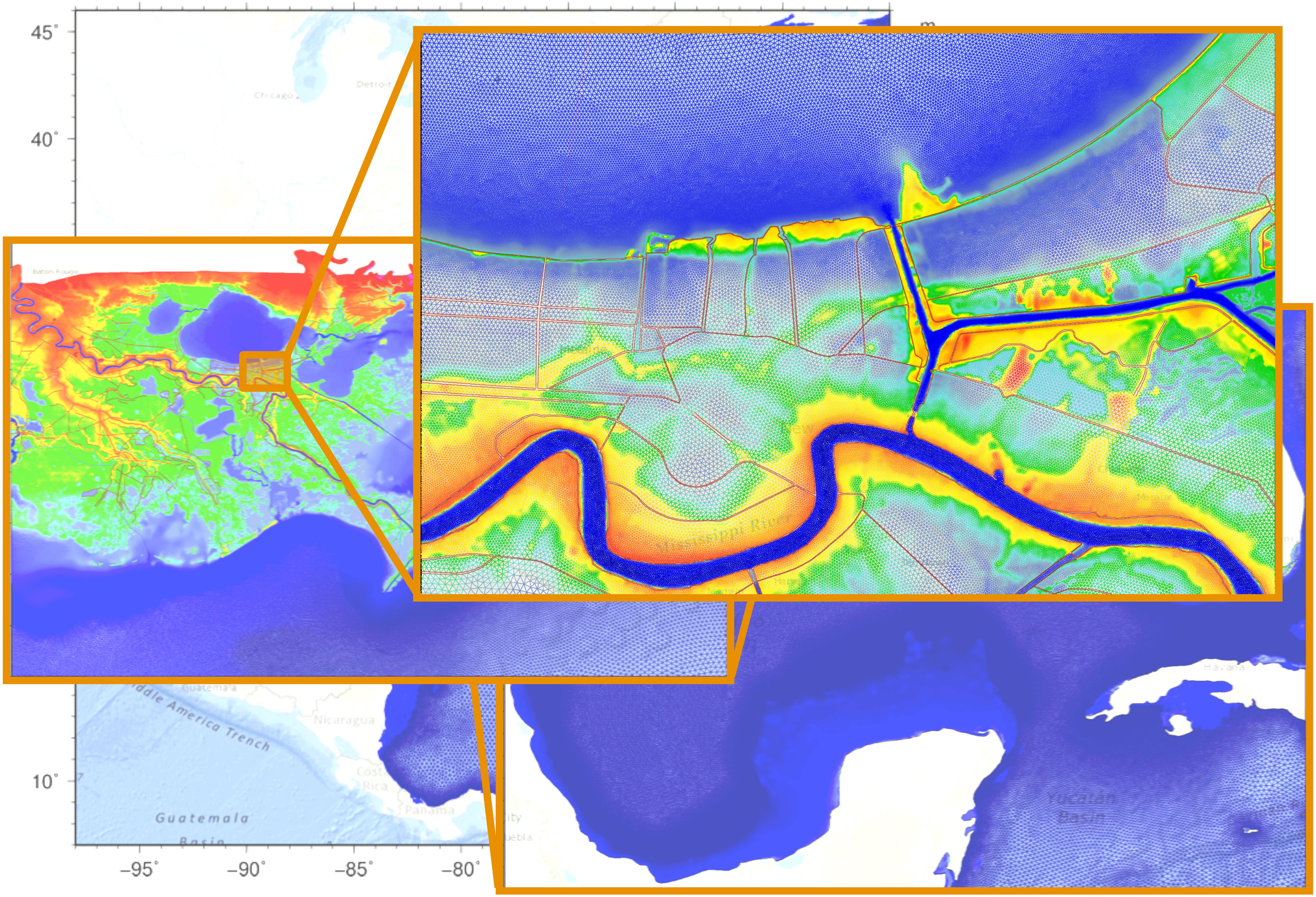
Coastal Models of Oil Transport in the Gulf of Mexico during Normal and Extreme Conditions

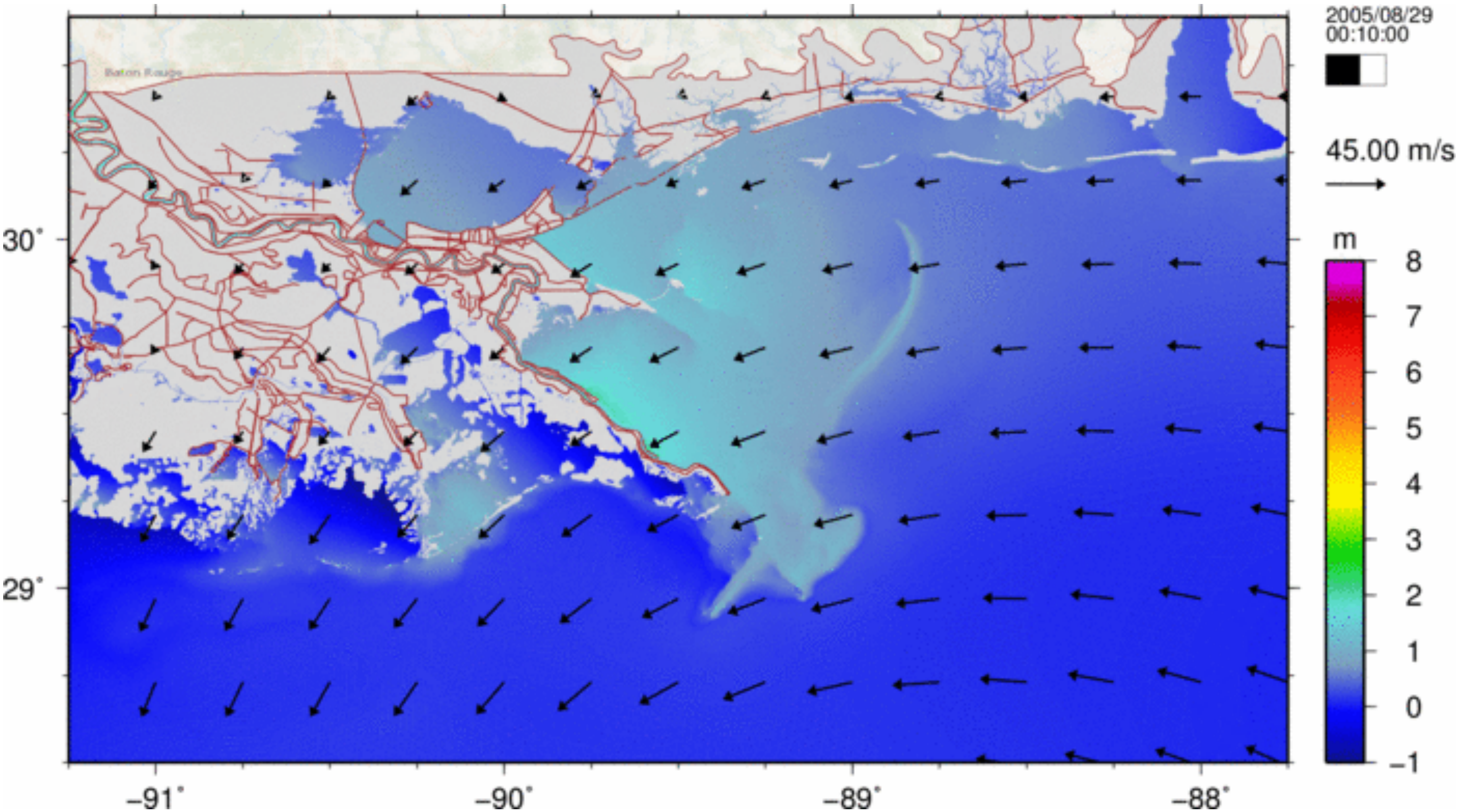
Joel ‘Casey’ Dietrich, CN Dawson, H Arabshahi, A Muhammad
Institute for Computational Engineering and Sciences
University of Texas at Austin

Advances in Computational Mechanics 2013
***with special track*: Finite Elements in Flow Problems 2013**
Omni Hotel, San Diego CA
Wednesday, 27 February 2013

Inundation of Gulf Coastline : Unstructured Mesh



Inundation of Gulf Coastline : Katrina (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.

Surface Oil Transport : Deepwater Horizon Oil Spill (2010)

Deepwater Horizon was a 9-year-old, mobile offshore drilling unit

Located 66km from the Louisiana coastline, in 1500m of water

Platform was engulfed on 20 April by an explosion of methane gas; structure burned for more than 24hr before sinking on 22 April

Explosion killed 11 workers and injured 17

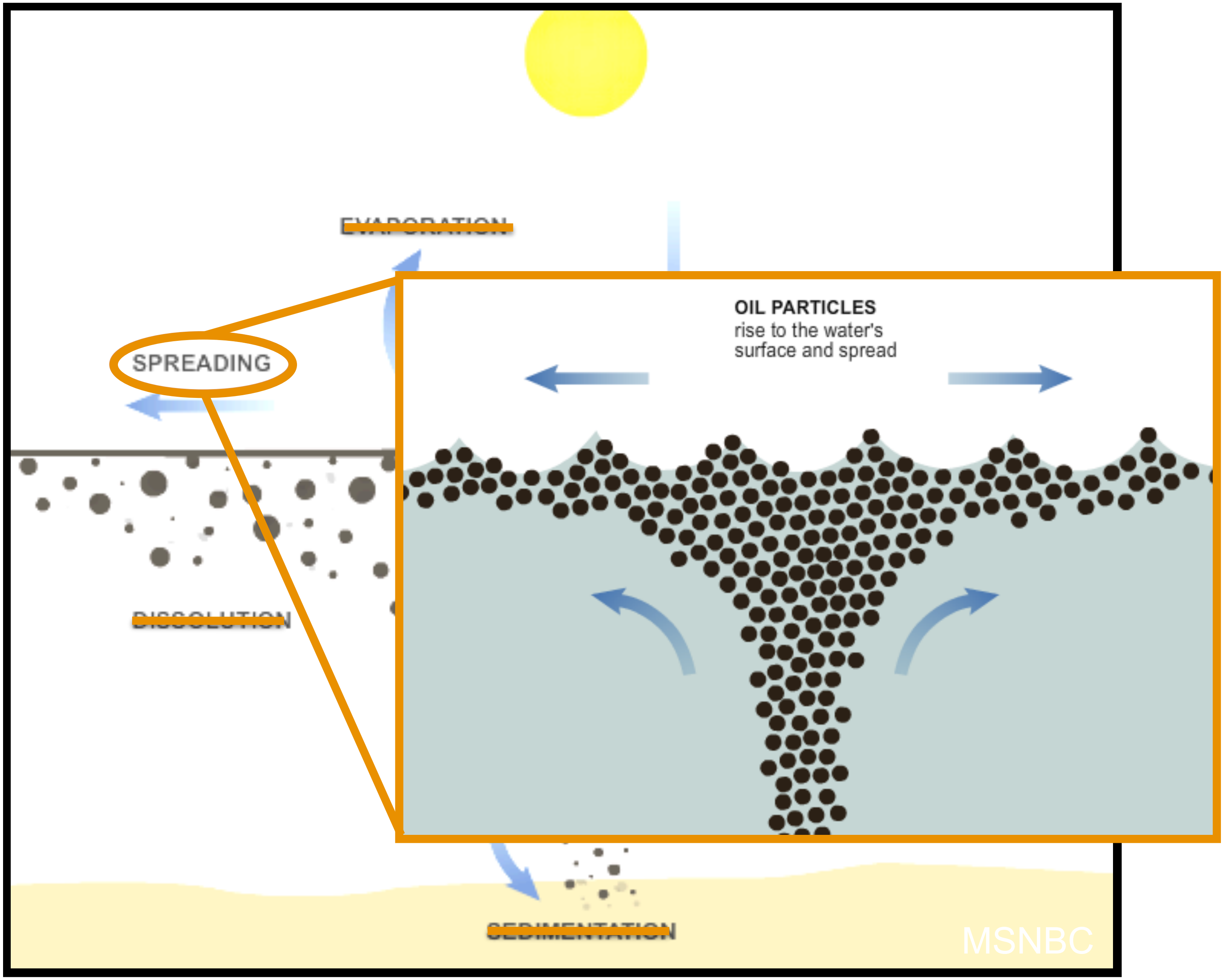
Oil spill flow rates:

- Estimated to have begun at a rate of 9900 $m^3\ d^{-1}$
- Diminished over time to a final rate of 8400 $m^3\ d^{-1}$ on 15 July 2010

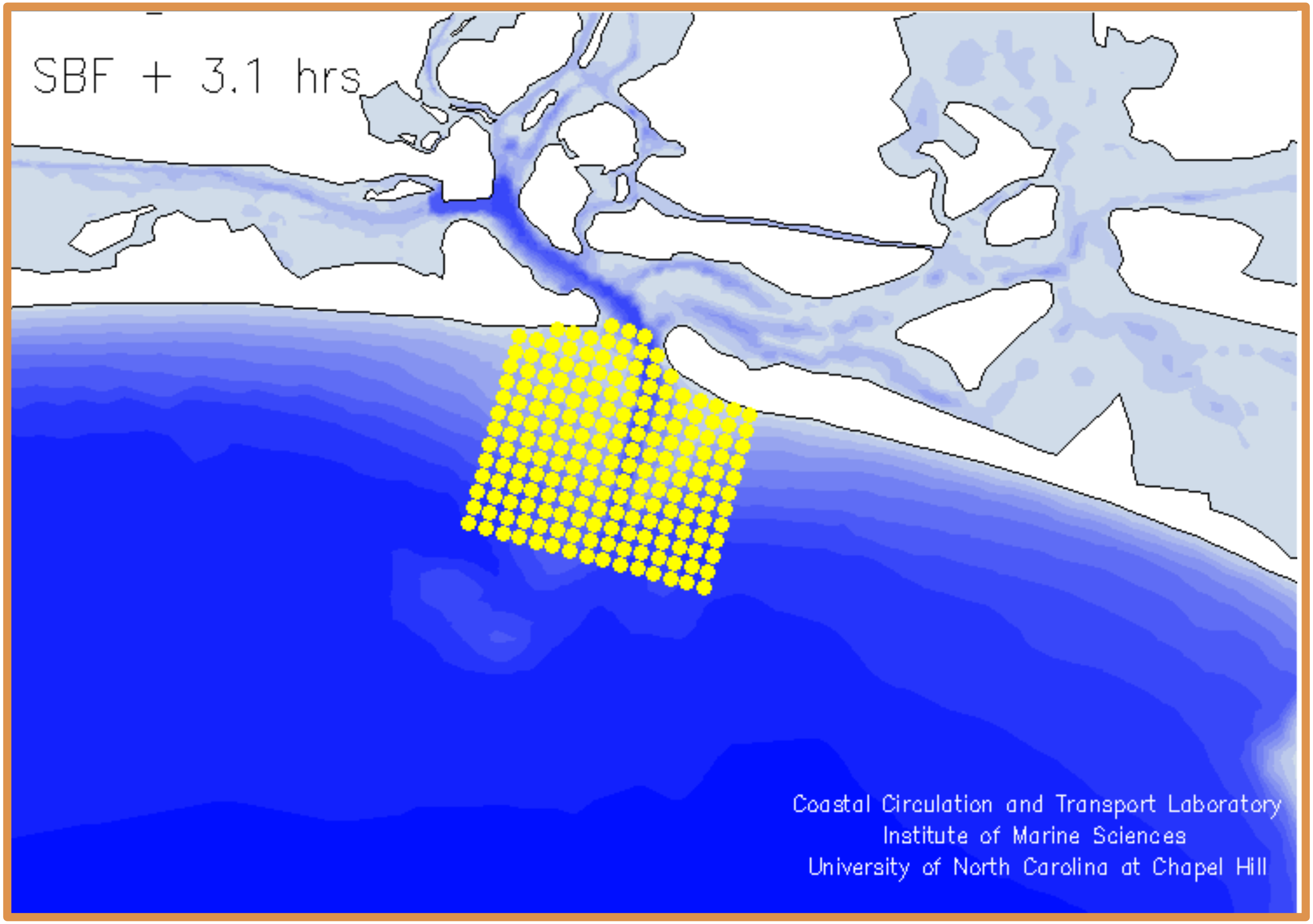
Emergency responders relied on satellite and aerial imagery

- Where will the oil move?
- What if a hurricane approaches?

Surface Oil Transport : Challenges



Surface Oil Transport : Lagrangian Particles



Surface 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):

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

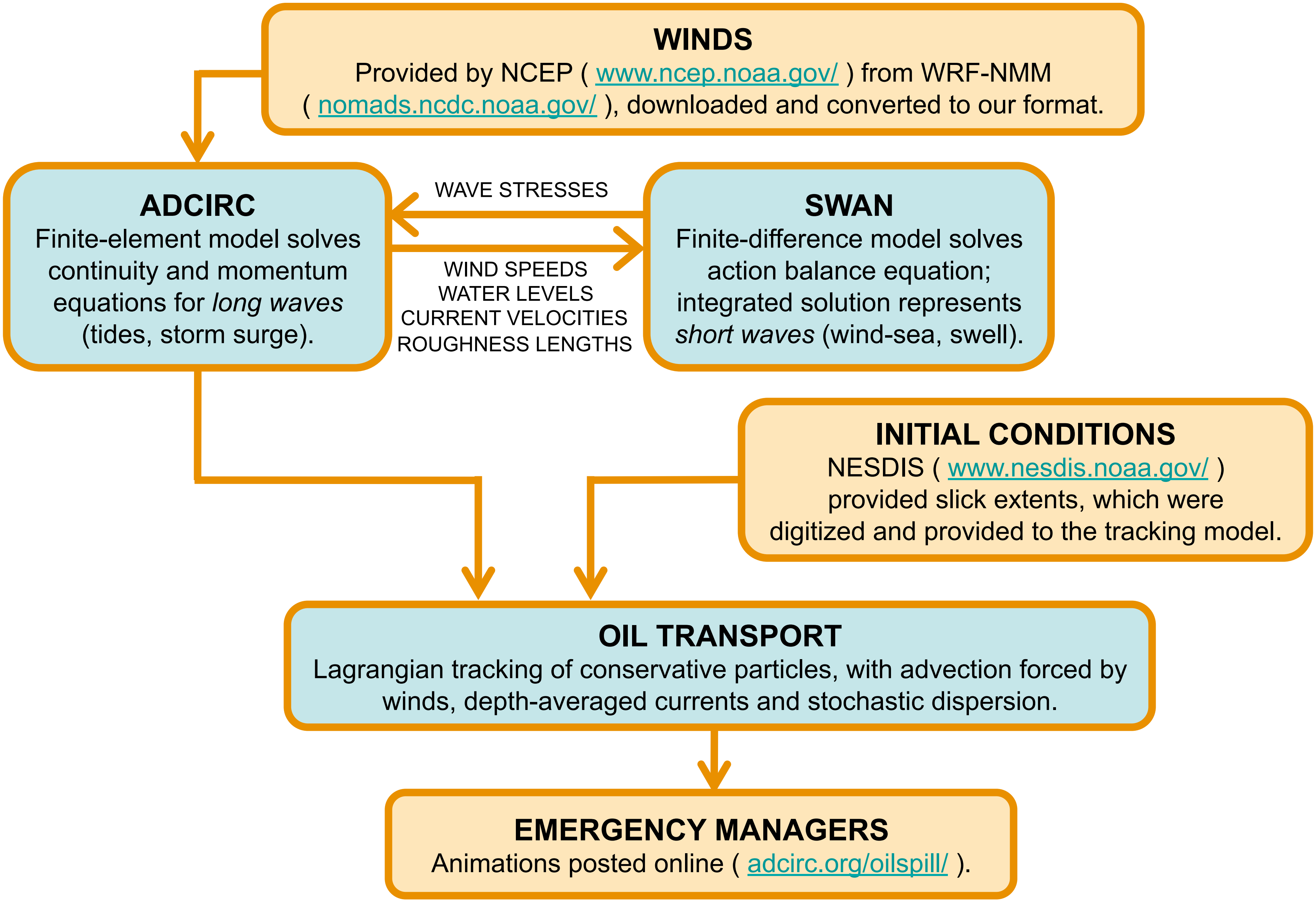
- with: $0 < R < 1$ is a random number,
  $\vec{E}_v = 10$ m²/s are turbulent coefficients, and
  $\vec{c} = 12$ are scaling coefficients;
- and where the velocities are a linear combination of currents and winds:

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

- with: $F_c = 1$ and $F_w = 0 - 0.03$.

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.

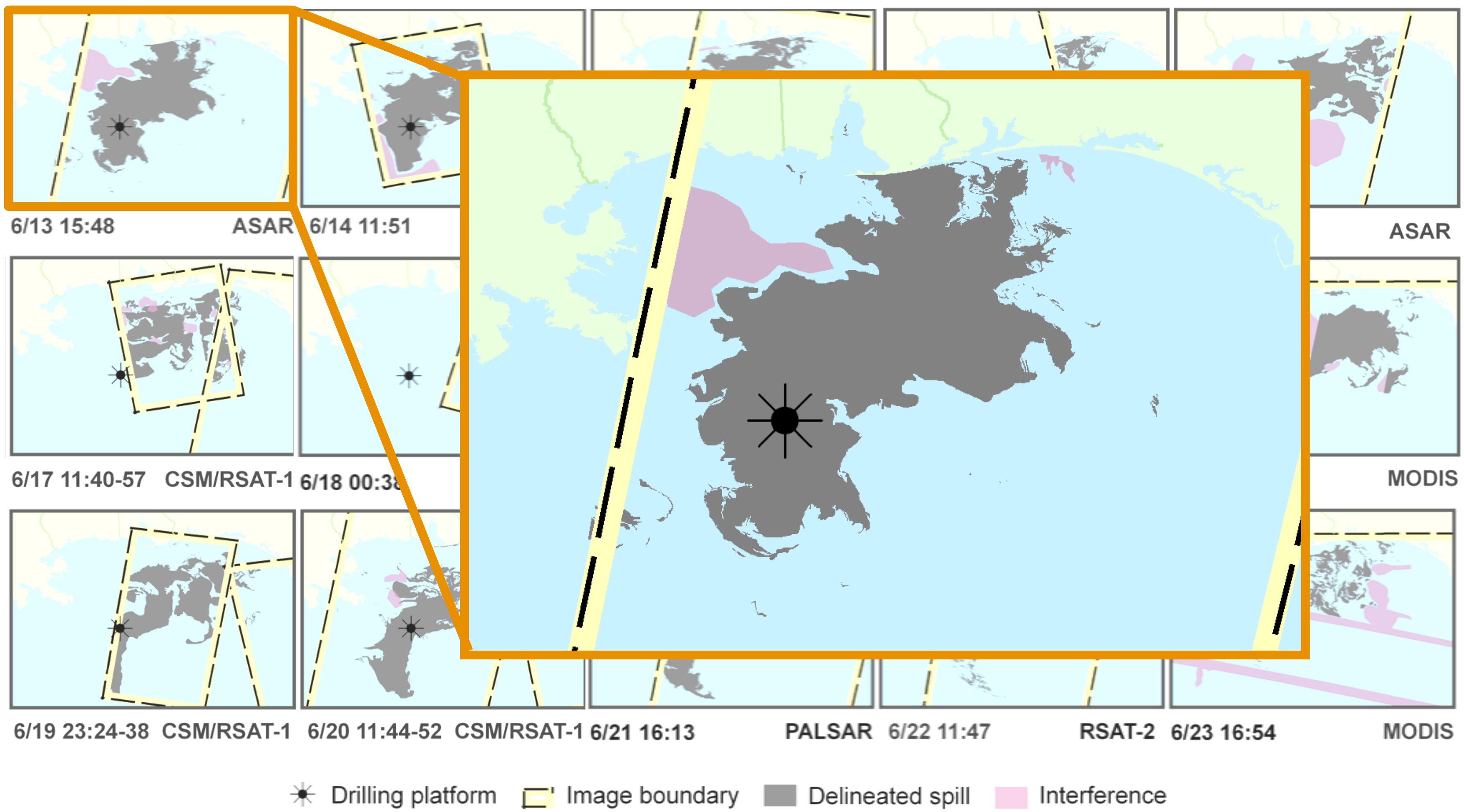
Surface Oil Transport : ADCIRC Surge Guidance System



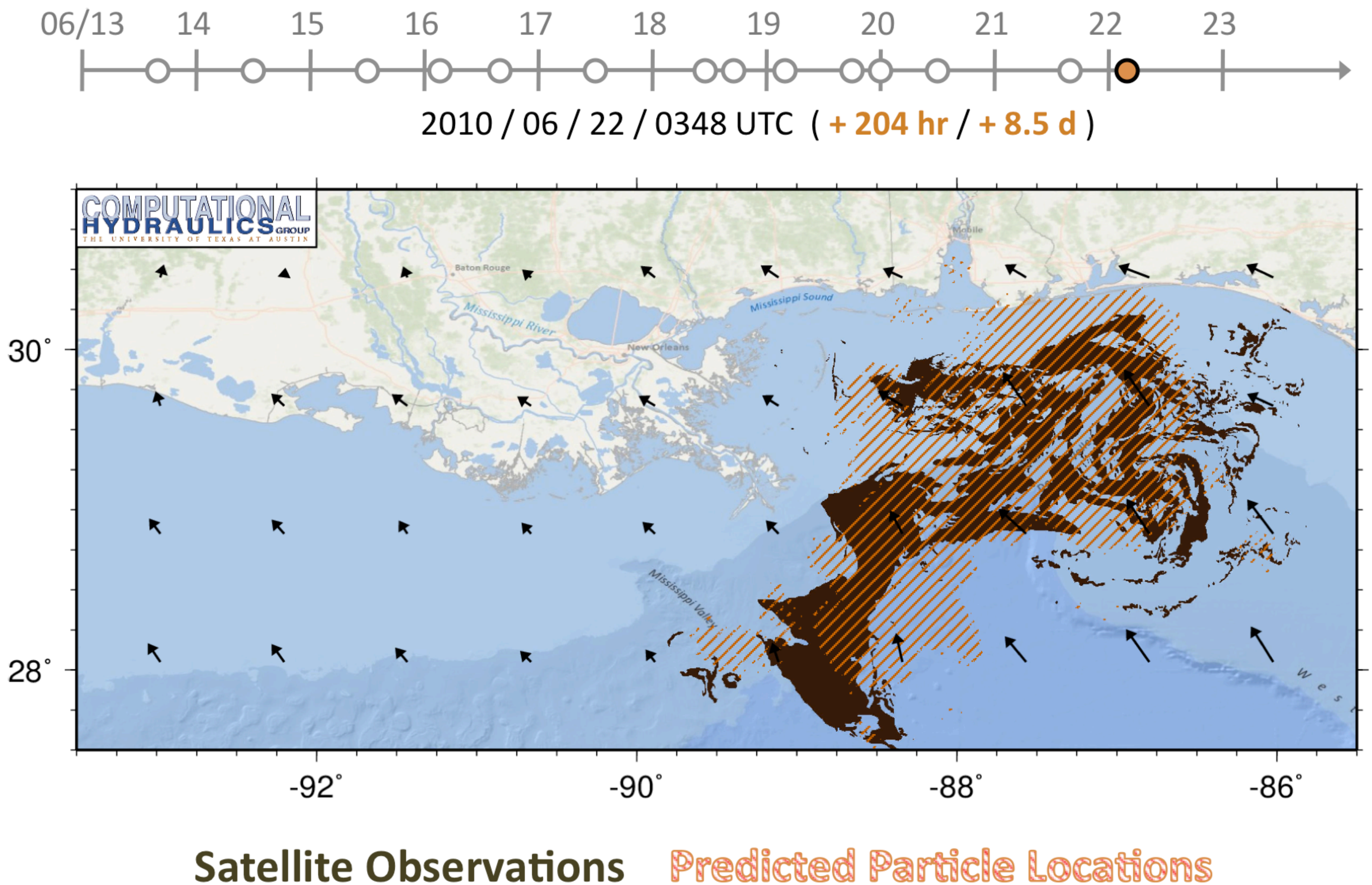
Surface Oil Transport : 13-23 June 2010

Examples of available imagery:

- NESDIS consolidated observations from a suite of satellite sensors

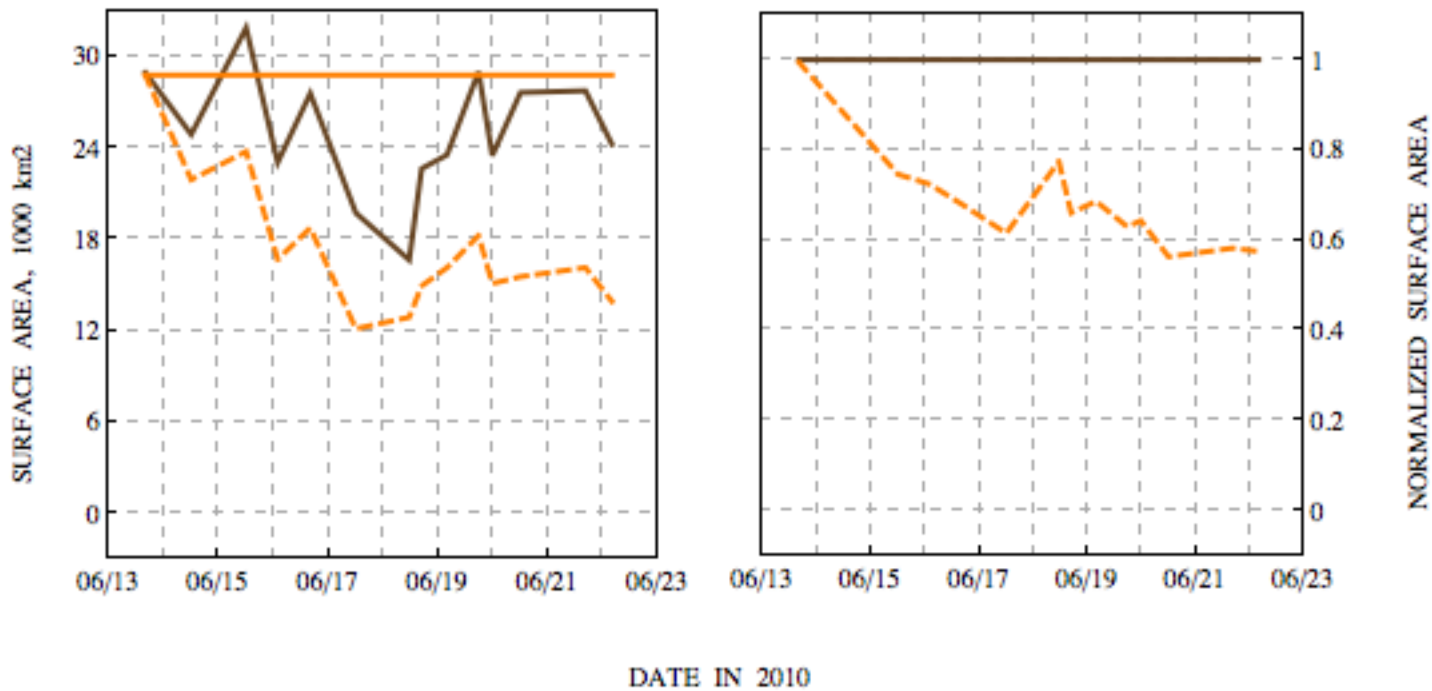


Surface Oil Transport : 13-23 June 2010



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.

Surface Oil Transport : 13-23 June 2010



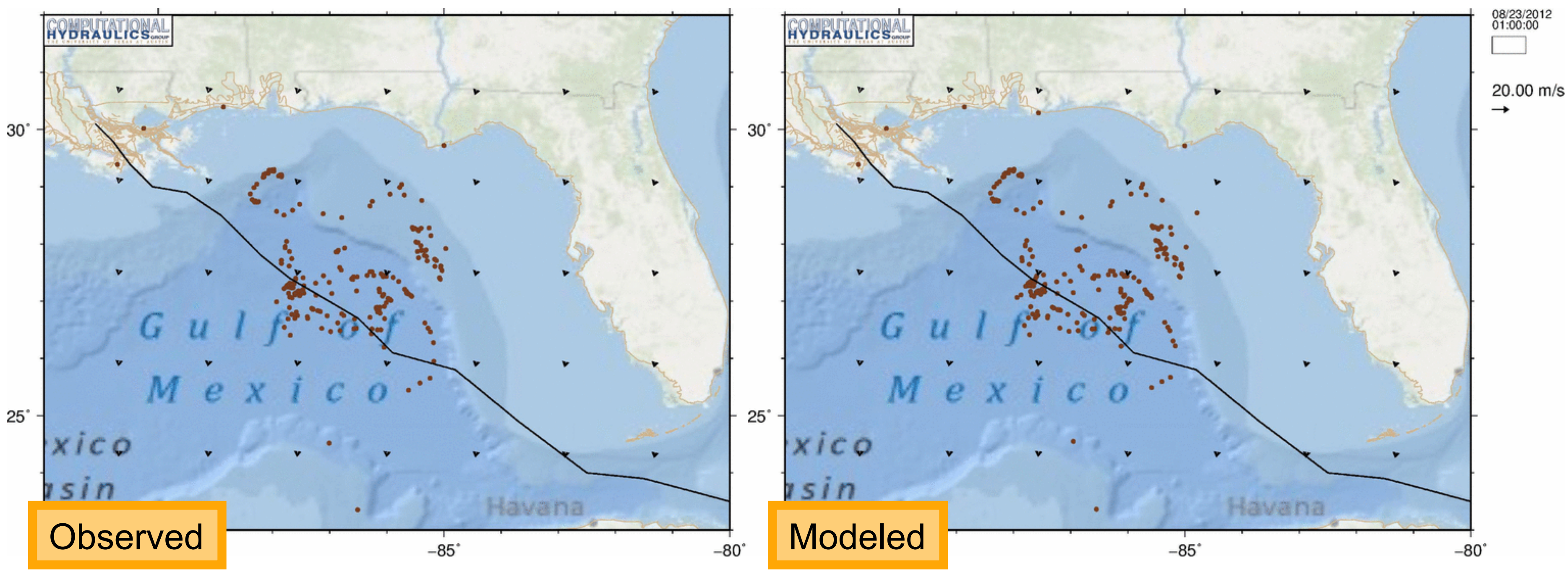
Overlap of our predictions to observations:

- **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

- Qualitative and quantitative match to observations

GLAD Experiment : Isaac (2012)



Hindcast simulation during Isaac (2012)

- Asymmetric vortex wind field (Holland 1980; Mattocks and Forbes 2008) generated by ADCIRC from NOAA best track parameters
- Particles initialized at 2012 / 08 / 23 / 0000 UTC

Depth-averaged currents are insufficient from ADCIRC

- Surface transport augmented by 3% of wind velocities

Must move forward with 3D velocities and transport

3D Oil Transport : Submerged Ridge

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

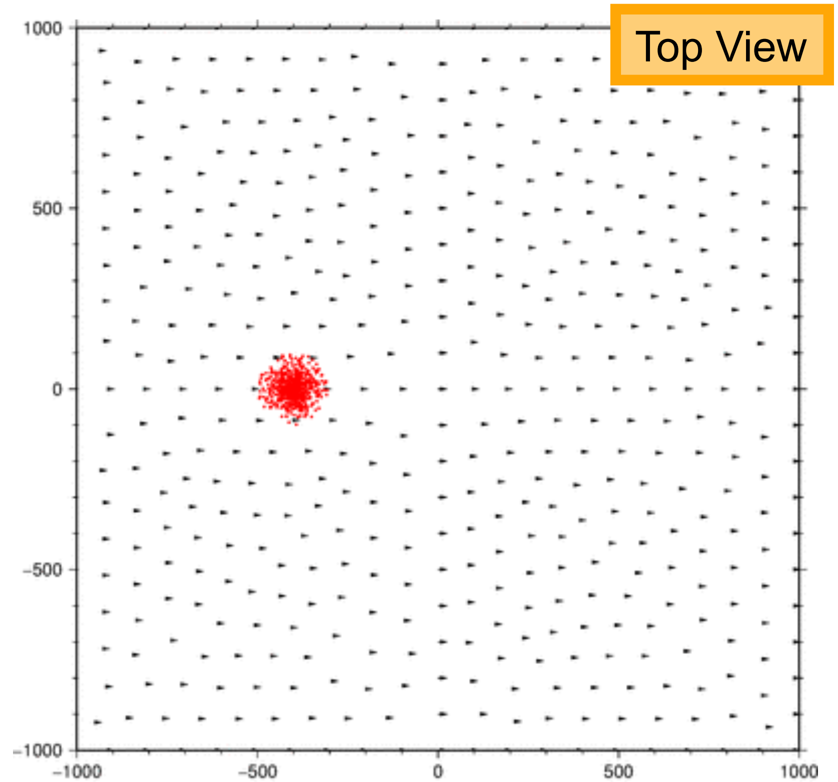
Submerged Ridge Test Case:

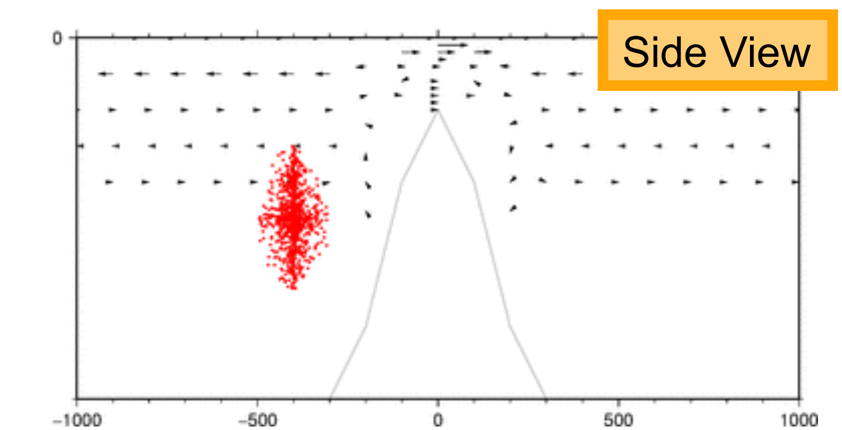
Simple test case to show particle movement

- 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)





3D Oil Transport : Submerged Ridge : Buoyancy

Floating Oil Droplets:

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

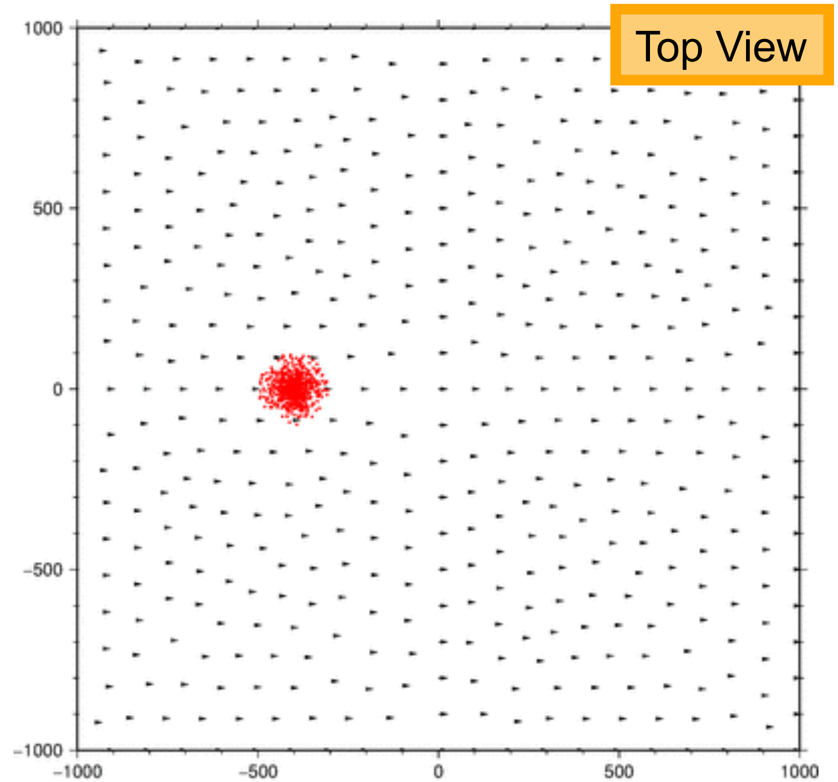
- Spherical droplets (small)
- Ellipsoidal droplets (intermediate)
- Spherical-cap droplets (large)

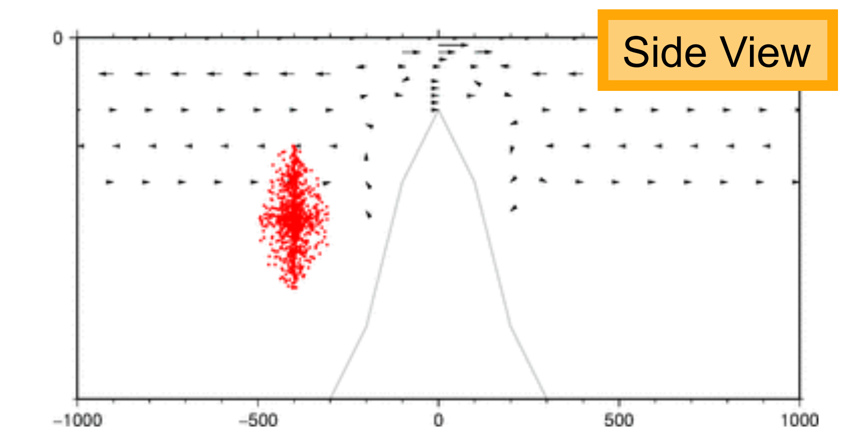
Oil droplets will always fall in spherical class:

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

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





3D Oil Transport : Submerged Ridge : Source Term

Oil Leaks from Seafloor:

At every tracking step, insert particle(s) at a user-defined location

- Number of particles increases over time

Submerged Ridge Test Case:

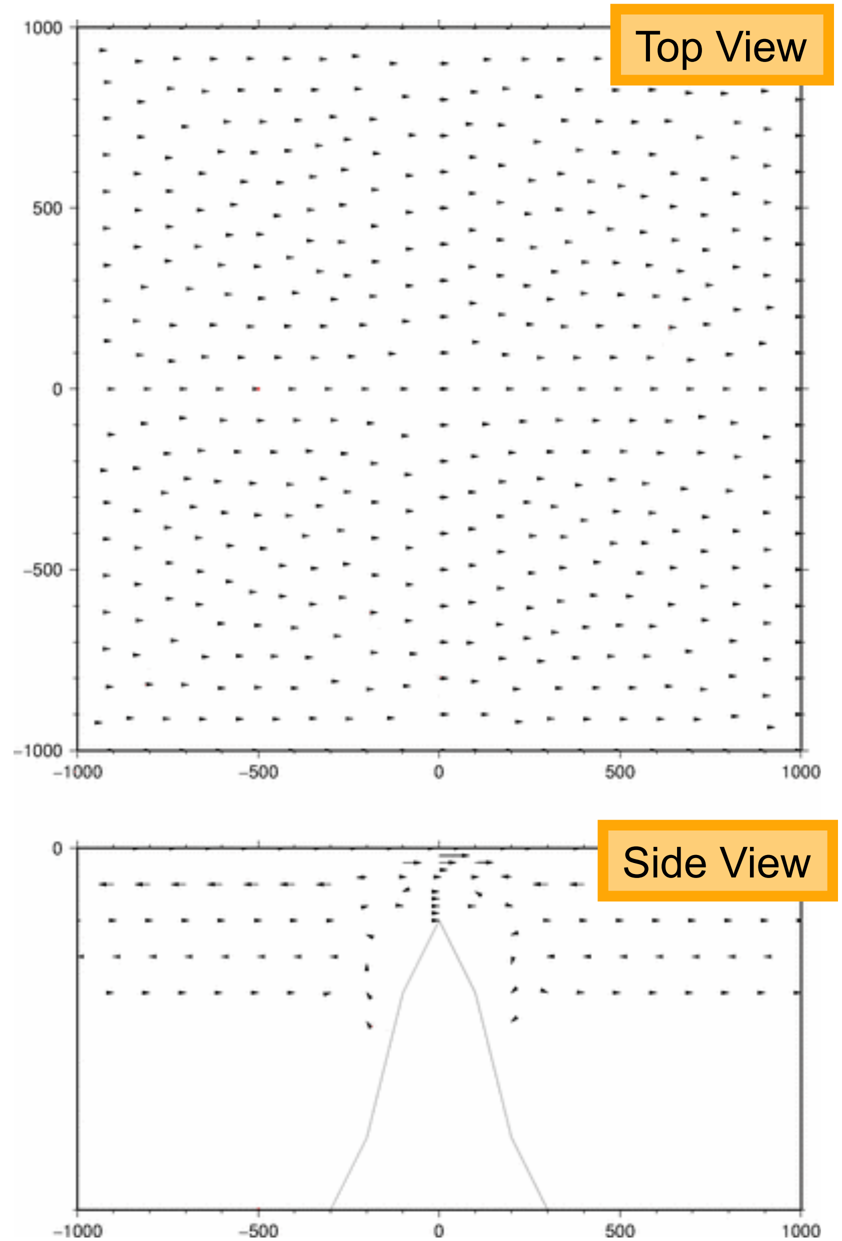
Instead of initializing the particles in a cloud, they are introduced at a source located at (0, -500, -100)m

Assumptions:

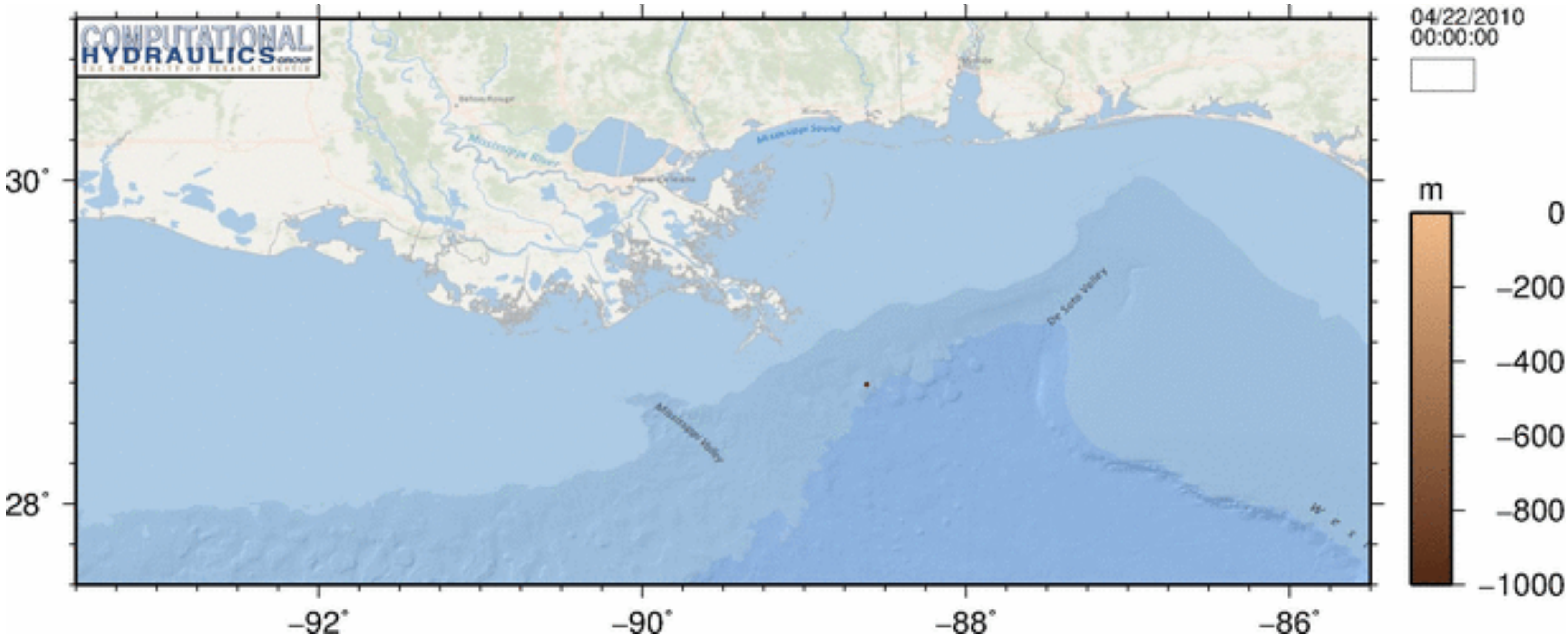
Water - Density of 998.2071 kg/m^3 (at 20°C)

Oil - Density of 858 kg/m^3

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



3D Oil Transport : Initial Results



Hindcast simulation for initial 40 days of DWH

Particles released at wellhead and transported by buoyancy and 3D velocities

- Diameters assigned randomly in the range of **50μm** to **300μm**
- Need parameterizations for dispersion and sinks (evaporation, biodegradation)

Velocities from HYCOM - need 3D baroclinic flow from ADCIRC

Discussion and Future Work

Our initial response had many potential sources of error:

- Winds - Meteorological forcing does not have sufficient resolution in time (6hr) or space (30km) 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 …

What is the benefit of additional resolution in the nearshore?

- Can we start oil particles at the wellhead and move them onto the beaches?
- How much oil would have been pushed into the marshes by a hurricane?