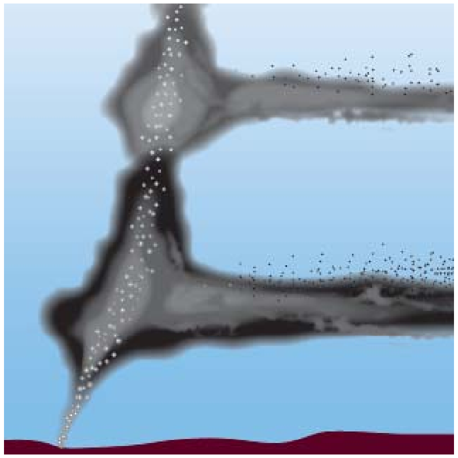
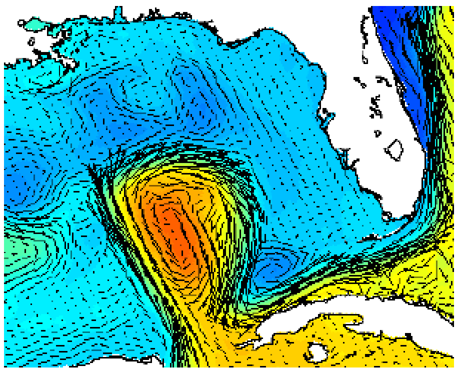
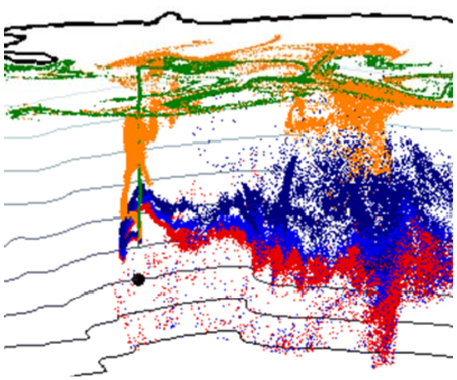






Simulating the dispersal of aging oil from the Deepwater Horizon spill with a Lagrangian approach

Elizabeth W. North[1], E. Eric Adams[2], Zachary Schlag[1], Christopher R. Sherwood[3], Rouying He[4], Kyung Hyun[4], Scott Socolofsky[5], Richard Signell[3], Scott D. Peckham[6]

[1]University of Maryland Center for Environmental Science

[2]Massachusetts Institute of Technology

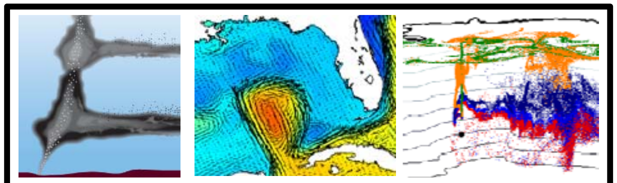
[3]US Geological Survey

[4]North Carolina State University.

[5]Texas A&M University

[6]University of Colorado

RAPID

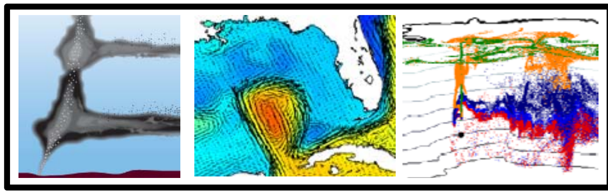


Objectives and Outline

The goal of this study is to **simulate the subsurface dispersal of oil in the Gulf of Mexico** with the objective of predicting the potential spread of different size classes of oil as they age over time.

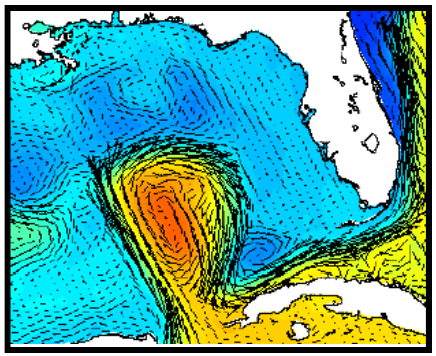
Outline

- Models
- Circulation: SABGOM
- Oil plume: SMIP
- Oil droplets: LTRANS
- Results of sensitivity analysis
- Conclusions

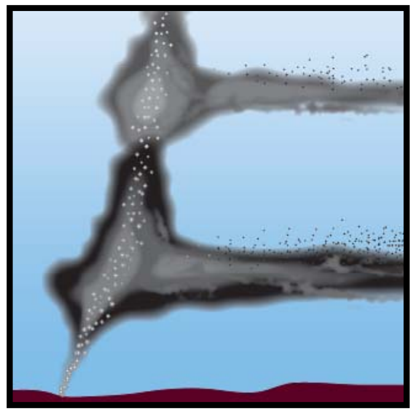


Models

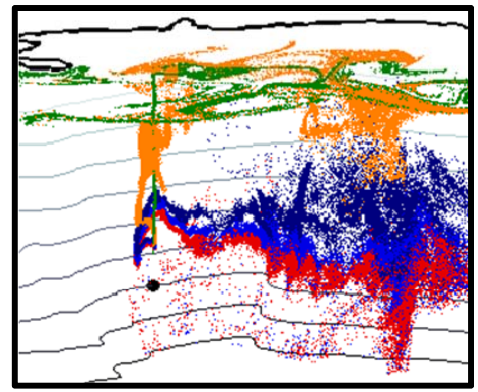
We integrated three models to simulate the subsurface transport of oil droplets



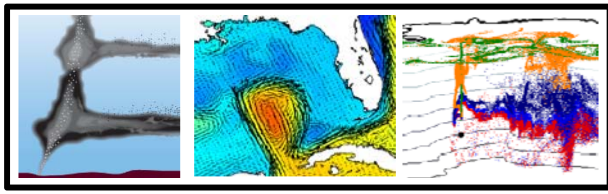
SABGOM: data-assimilating 3D ocean circulation model



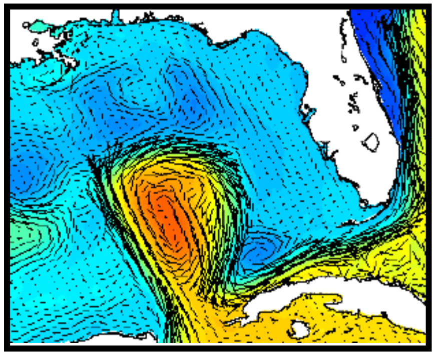
SMIP: multiphase oil plume model



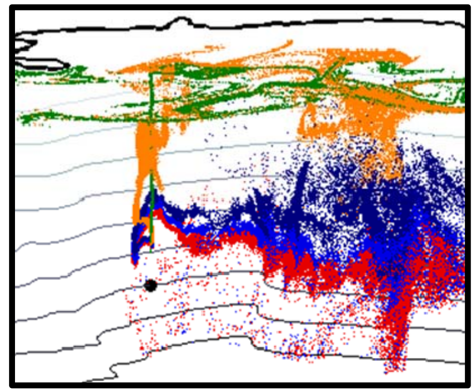
LTRANS: 3D particle-tracking with advection, diffusion, and oil droplet transformations



Models

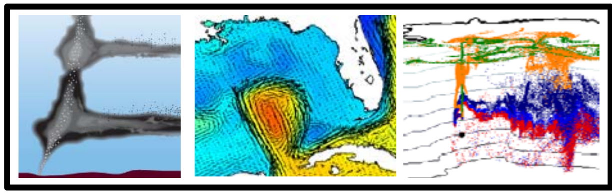


SABGOM: data-assimilating
3D ocean circulation model



LTRANS: 3D particle-tracking
with advection, diffusion, and
oil transformations

SABGOM predicts SSH, 3D currents, diffusivity, temperature, and salinity for LTRANS



Circulation: SABGOM

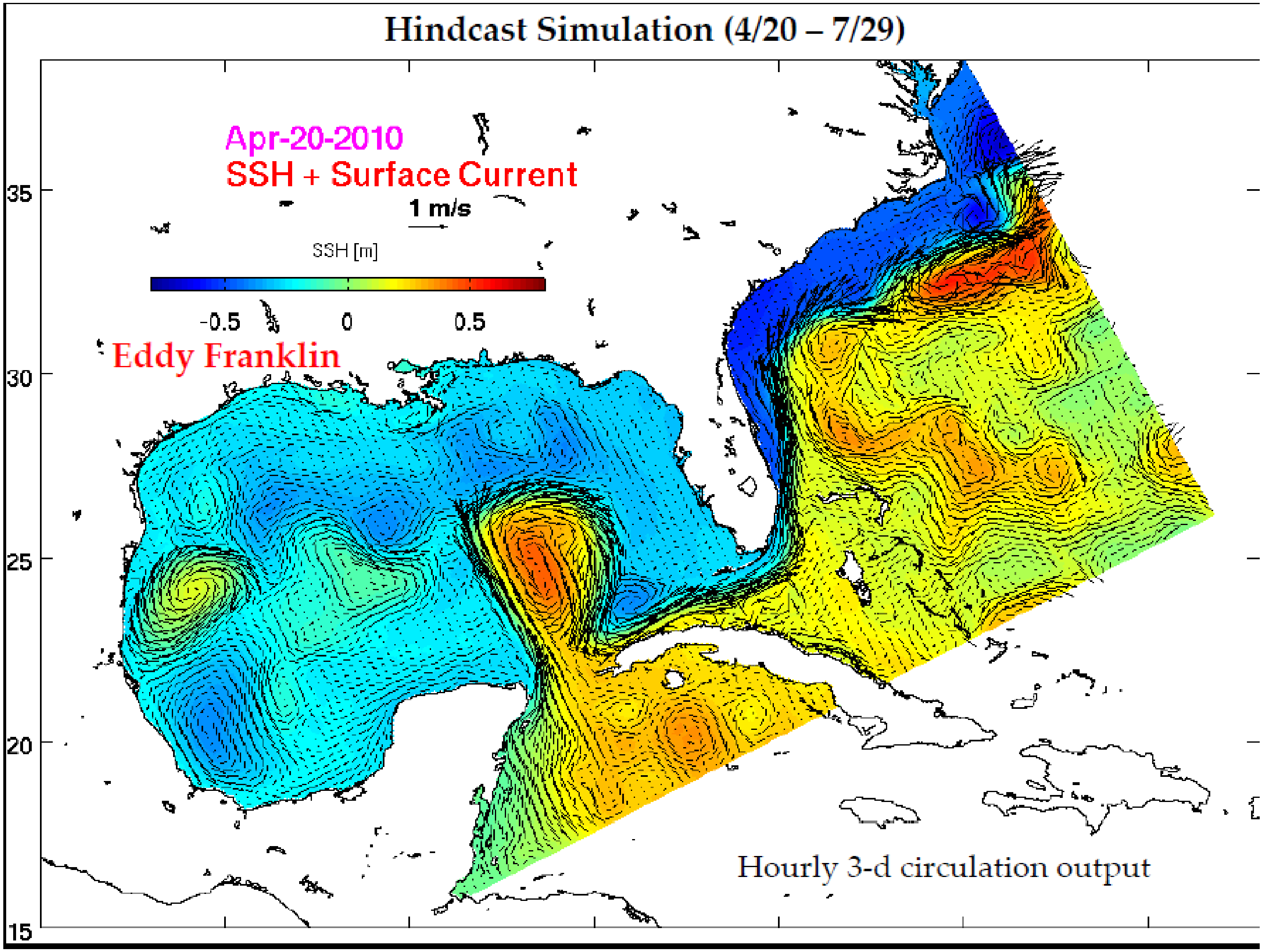
Hyun and He, (2010)

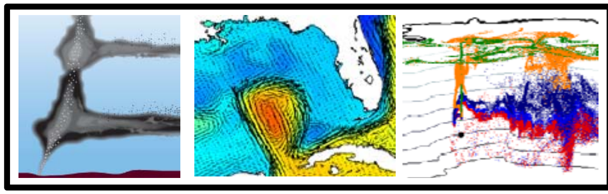
SABGOM ROMS

Used during Response

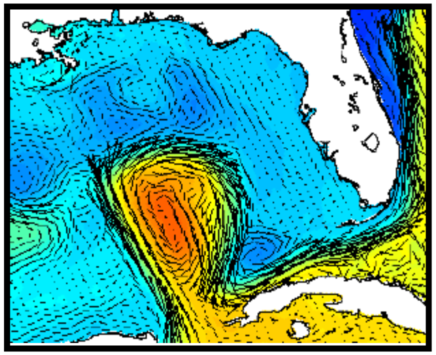
Hindcast simulation conducted

Compares well with observations

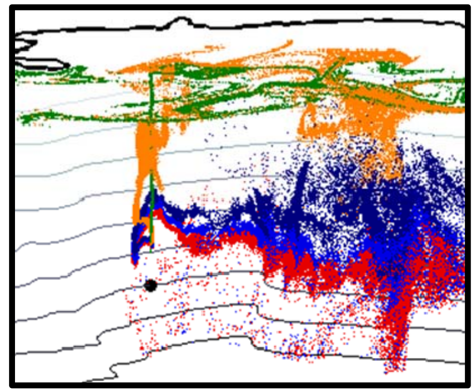




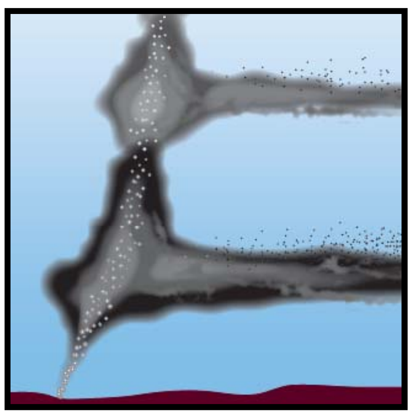
Models



SABGOM: data-assimilating
3D ocean circulation model

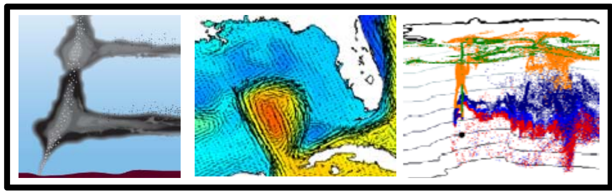


LTRANS: 3D particle-tracking
with advection, diffusion, and
oil transformations



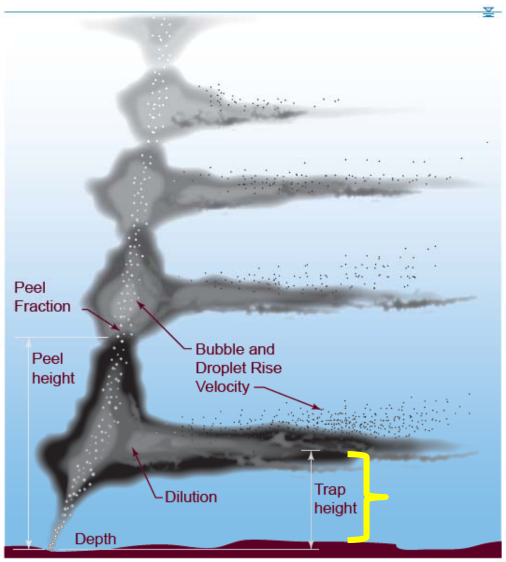
SMIP: multiphase
oil plume model

SMIP predicts depth of
primary subsurface
intrusion of oil droplets

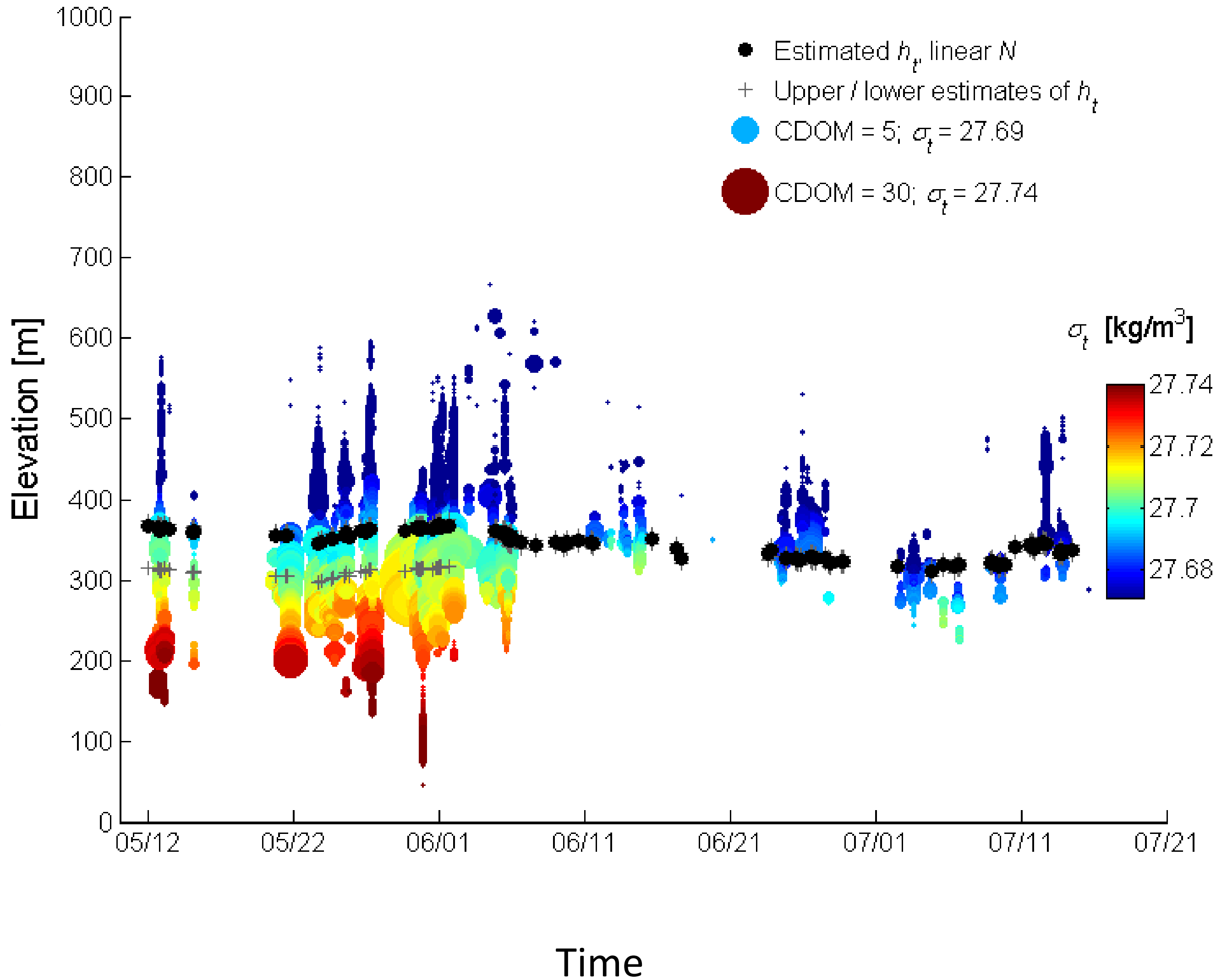


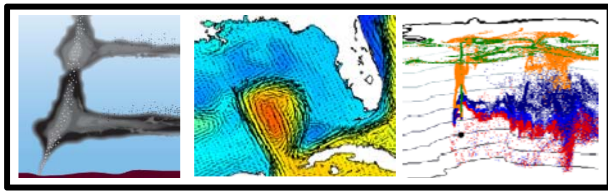
Oil plume: SMIP

Socolofsky et al. (2008)
Socolofsky and Bhaumik (2008)
Socolofsky et al. (2011)

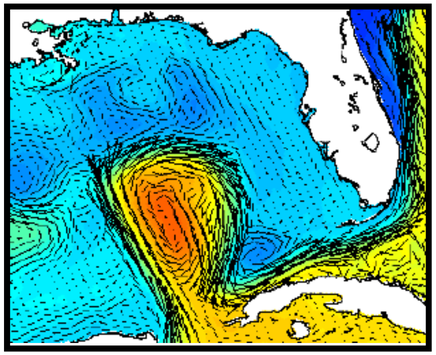


Estimate of **trap height** of 1st intrusion compares well with observations of peak fluorescence

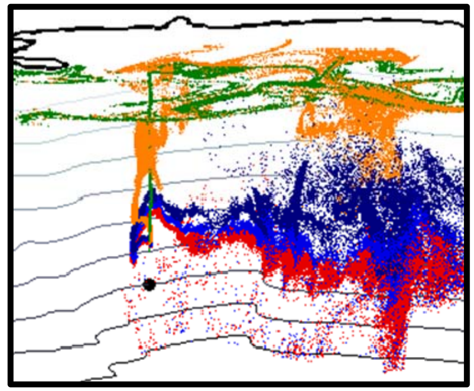




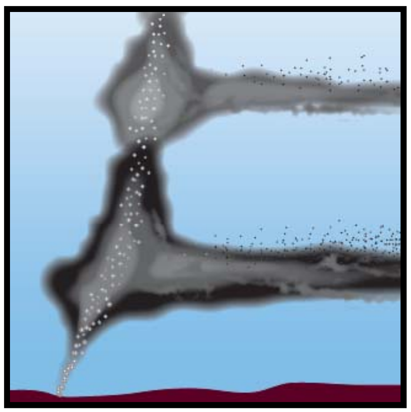
Models



SABGOM: data-assimilating 3D ocean circulation model

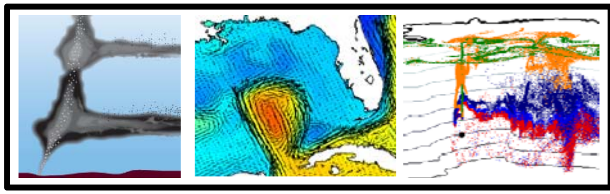


LTRANS: 3D particle-tracking with advection, diffusion, and oil transformations



SIMP: multiphase oil plume model

LTRANS predicts transport and transformation of oil droplets

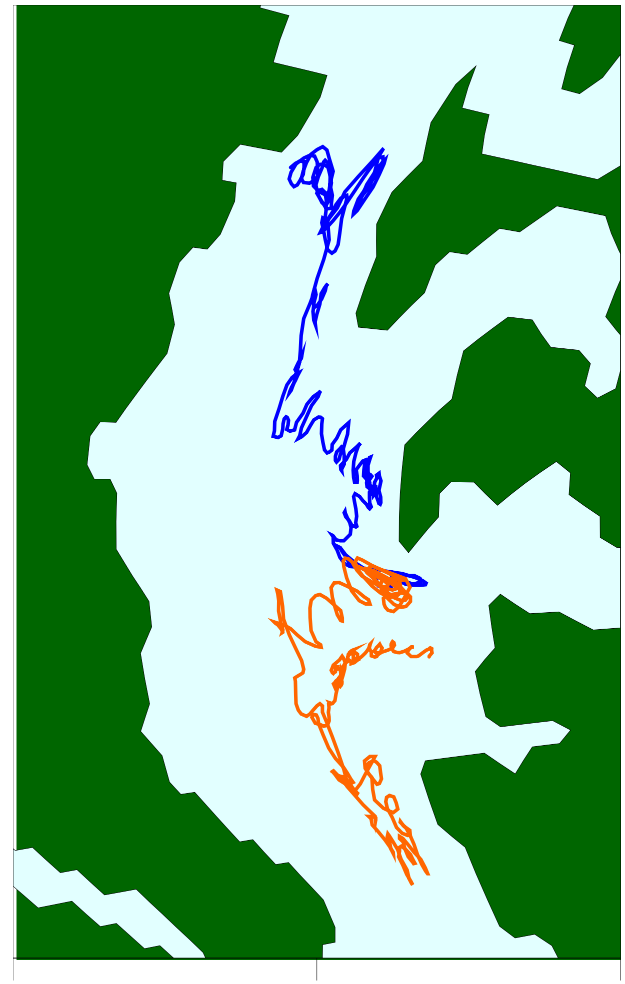


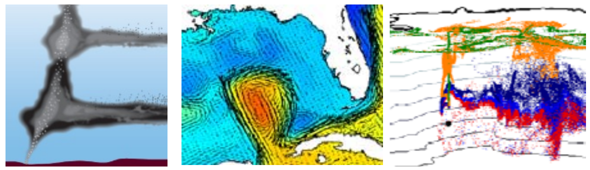
Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (2011)

Lagrangian TRANSport model (LTRANS v.2)

- 3D particle tracking model that calculates trajectories of particle motion
- Includes interpolation scheme designed to maintain fidelity with ROMS hydrodynamic model predictions
- Runs offline (with stored hydrodynamic output) to maximize flexibility and computational power and ensure a robust number of particles





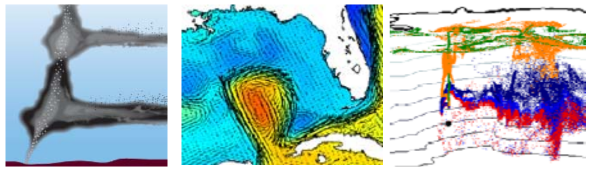
Oil droplets: LTRANS

Oil droplets are assigned an ascent speed derived from equations in Zheng and Yapa (2000) for small spherical shape, diameter < 1 mm

Modified Stokes for small droplets of interest

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

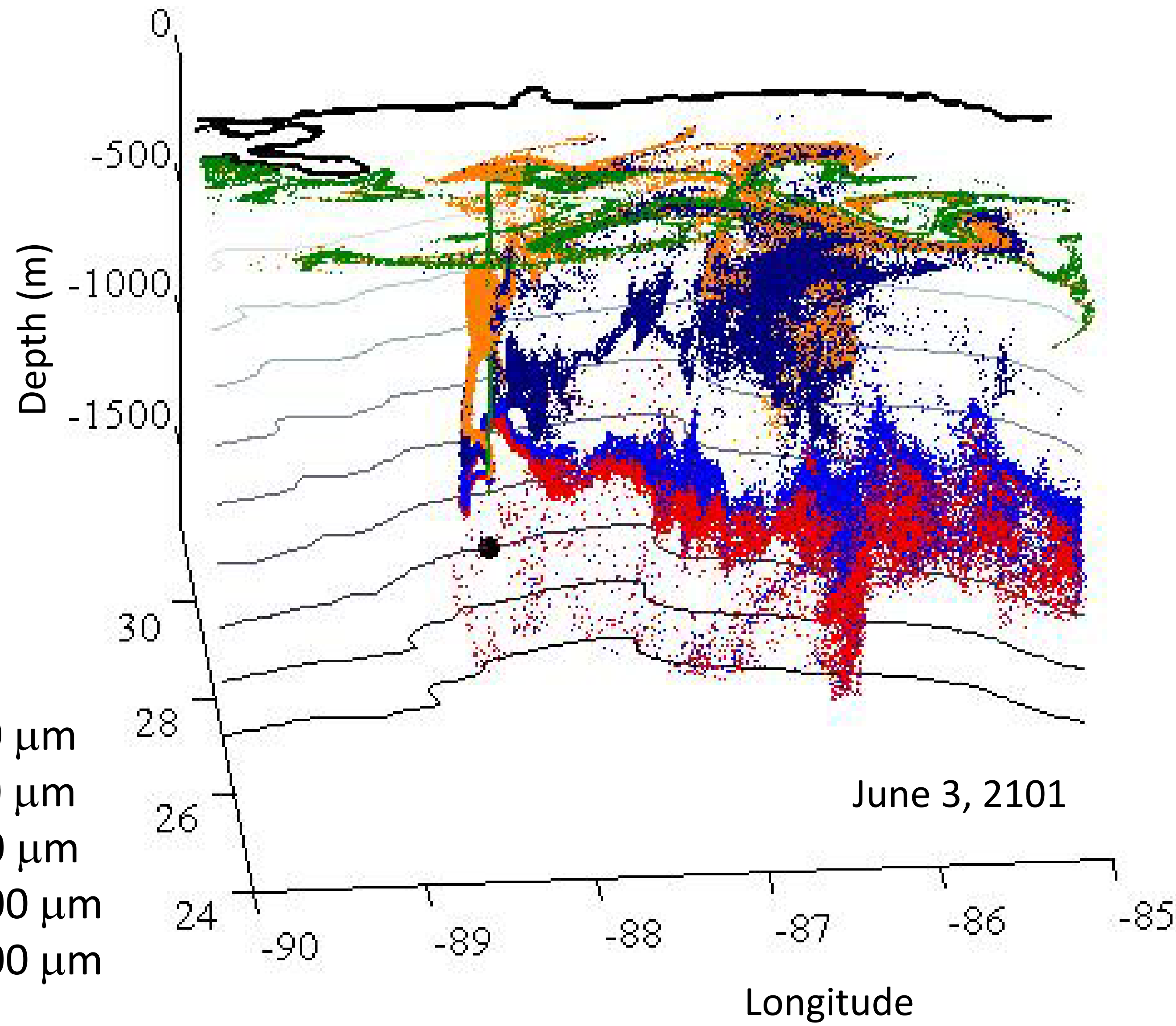
U_T = terminal velocity
R = Reynolds number
μ = dynamic viscosity
d = diameter



Oil droplets: LTRANS

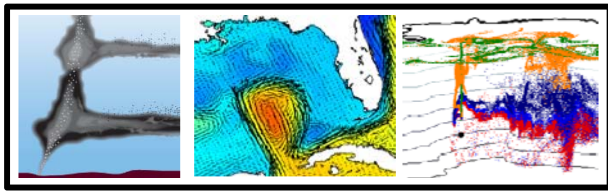
North et al. (2011)

Predicts formation of a subsurface plume of droplets with diameters ≤ 80 μm



Oil droplet diameter (fixed)

- 10 μm
- 30 μm
- 80 μm
- 100 μm
- 300 μm

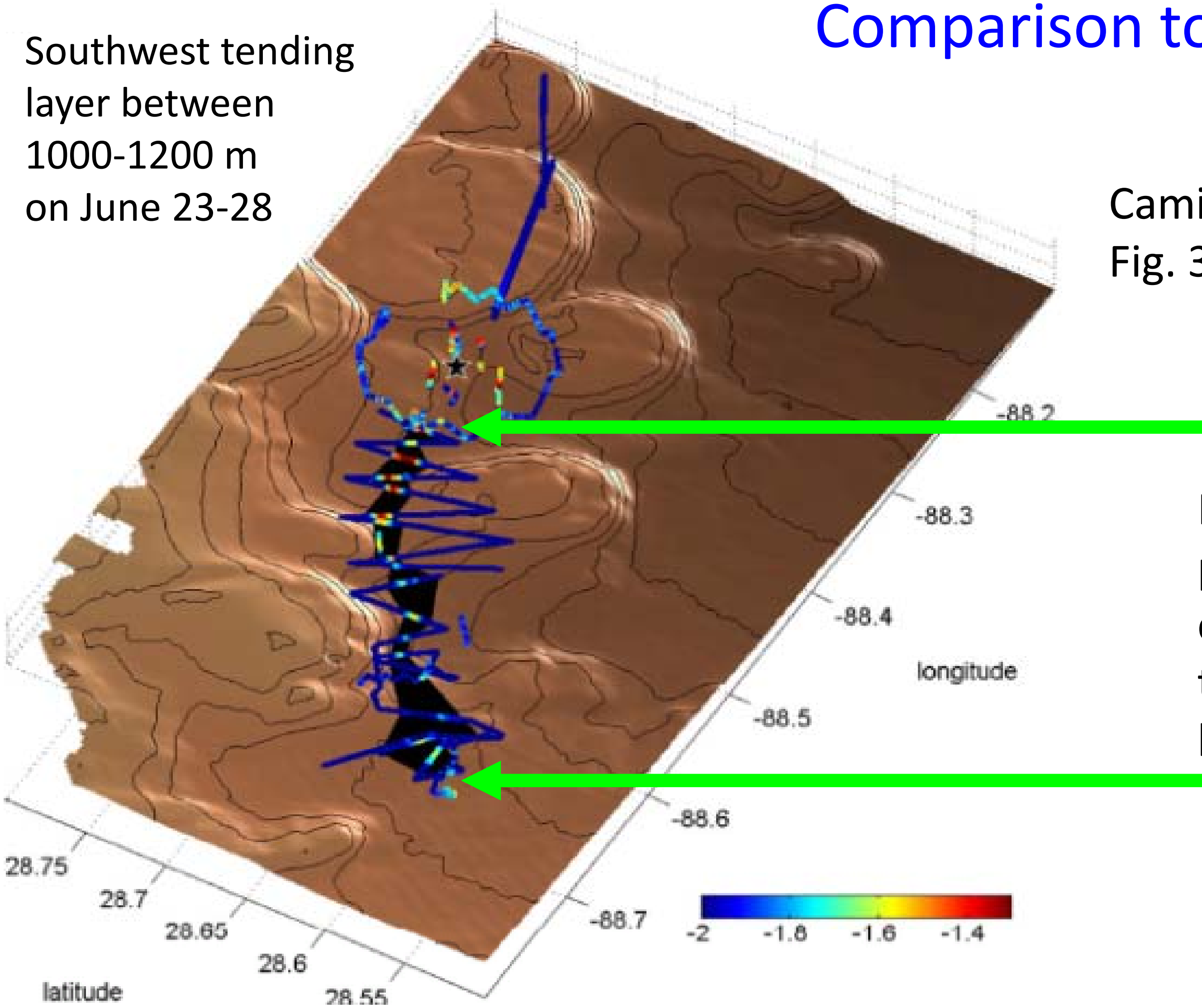


Oil droplets: LTRANS

North et al. (2011)

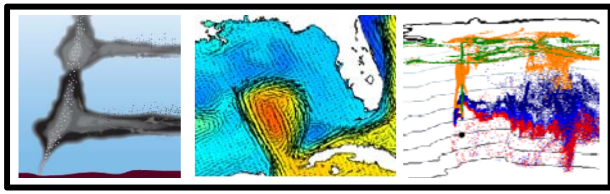
Comparison to observations

Southwest tending layer between 1000-1200 m on June 23-28



Camilli et al. 2010
Fig. 3A

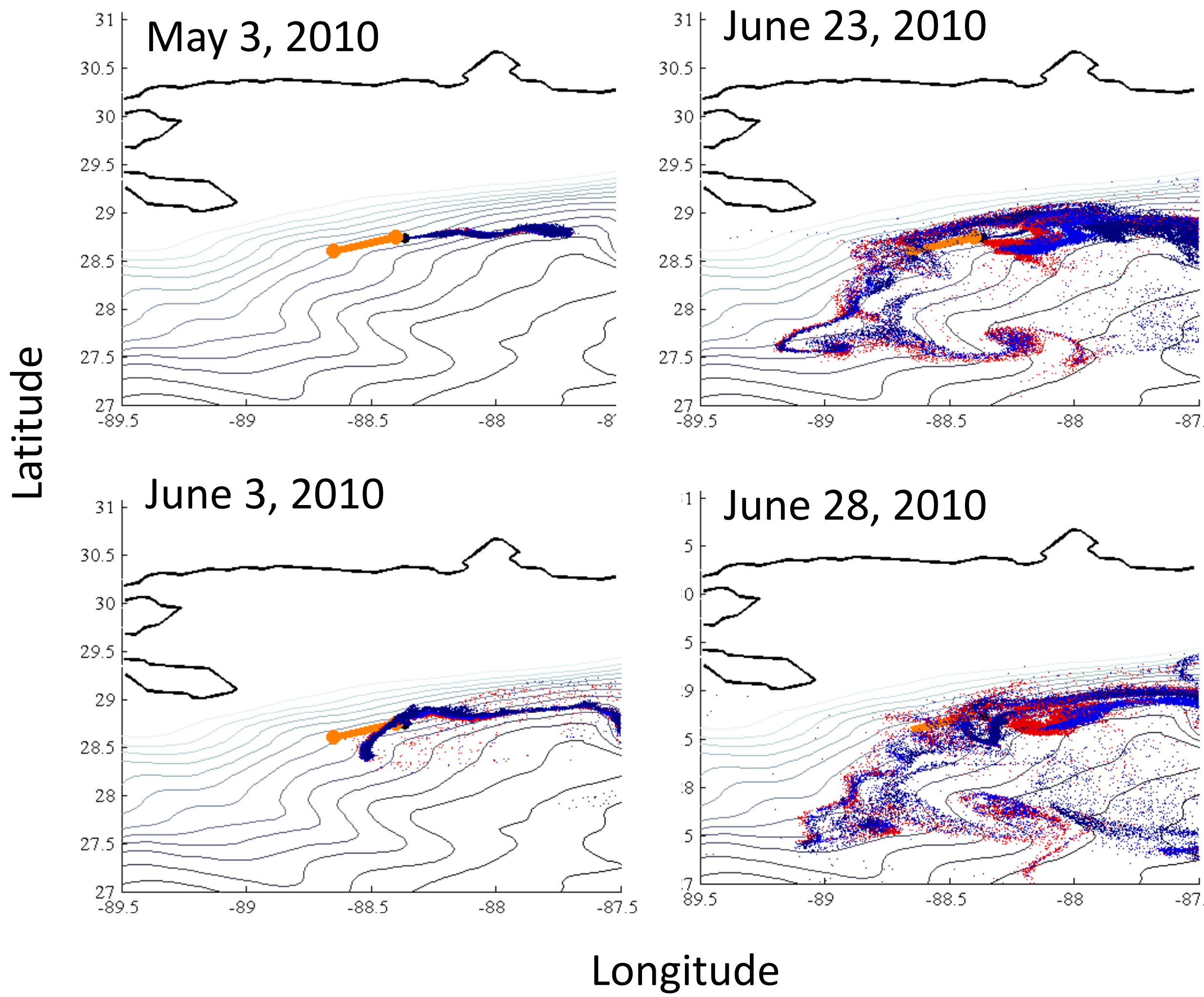
Model predictions compared to these two locations

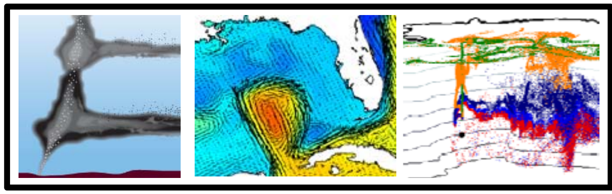


Oil droplets: LTRANS

North et al. (2011)

LTRANS predicts a southwest-tending plume that was aligned along the Camilli et al. transect

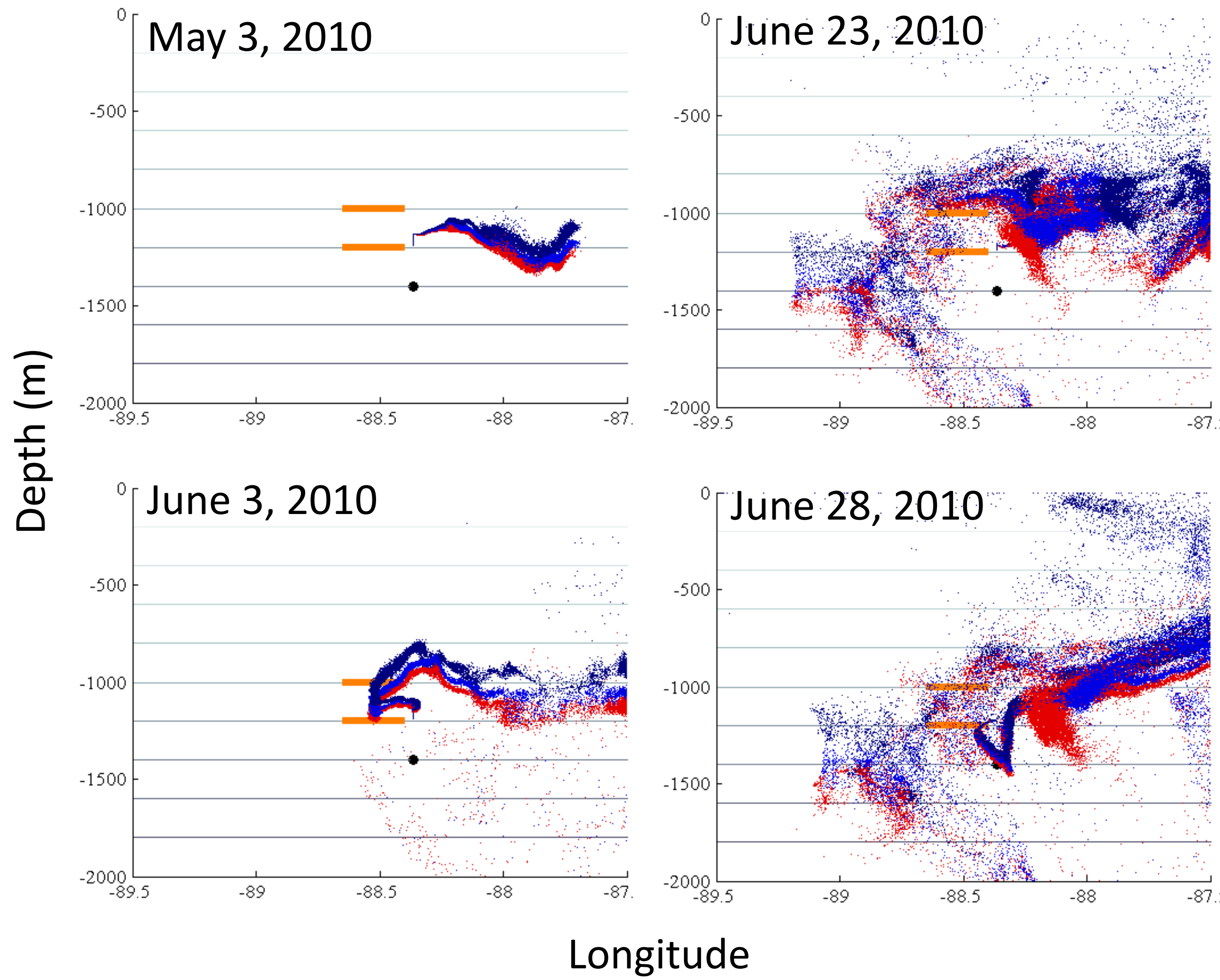


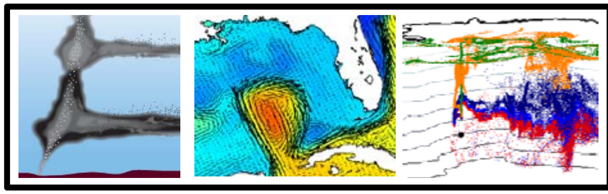


Oil droplets: LTRANS

North et al. (2011)

Particle depths were within the range of those observed by Camilli et al. or slightly above it



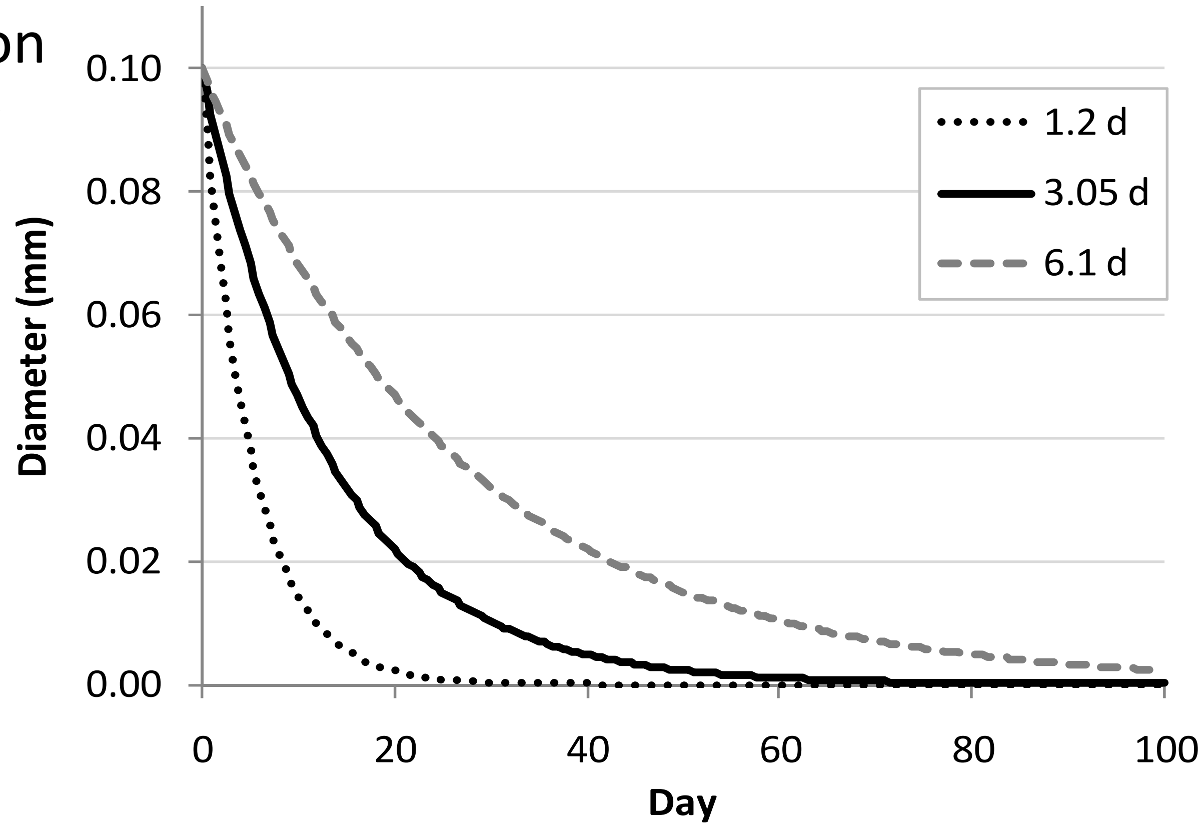


Sensitivity study

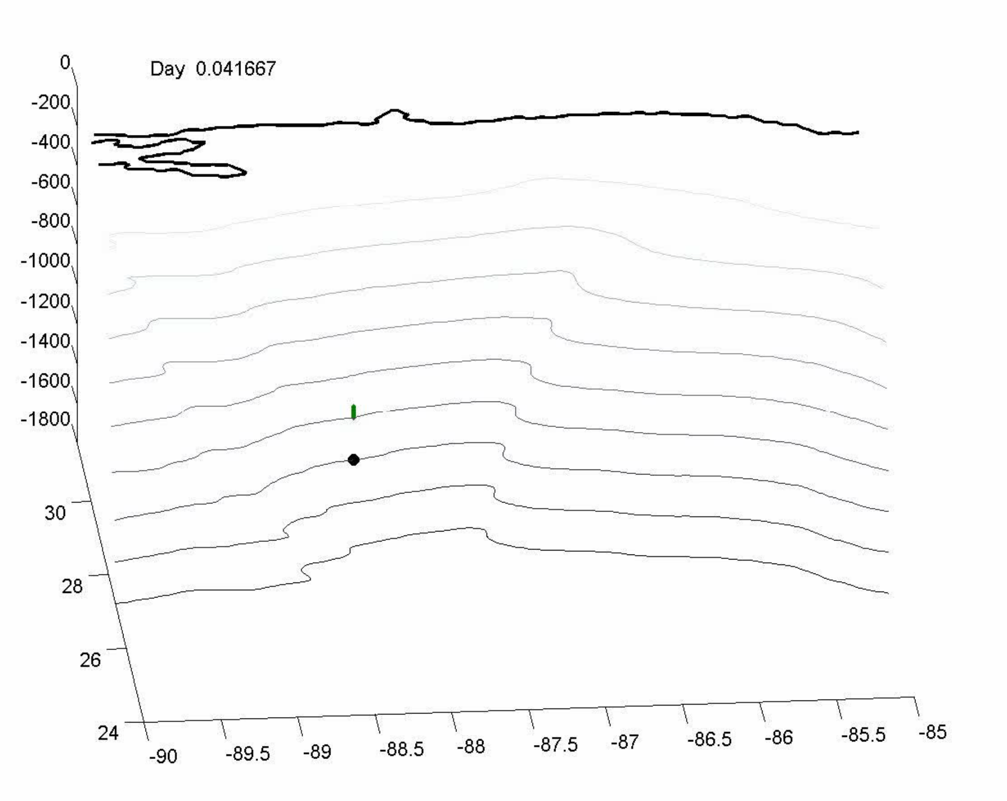
What happens when include droplet shrinkage due to degradation?

First order decay rate

- Assume density and composition are constant
- Change in mass controlled by change in diameter (D)
- Based on degradation half life observed by Hazen et al. (2010):
  - slow = 6.1 d
  - average = 3.05 d
  - fast = 1.2 d
- Dissolution when droplet diameter < 0.2 μm

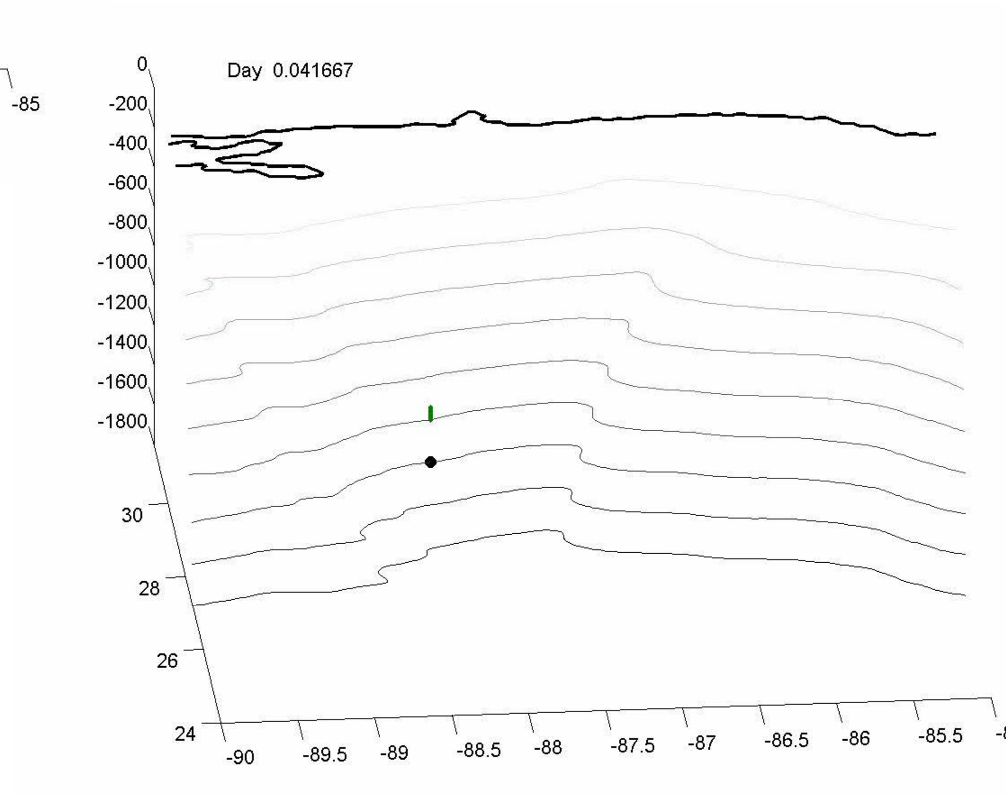


Degradation significantly influences transport



Average Rate

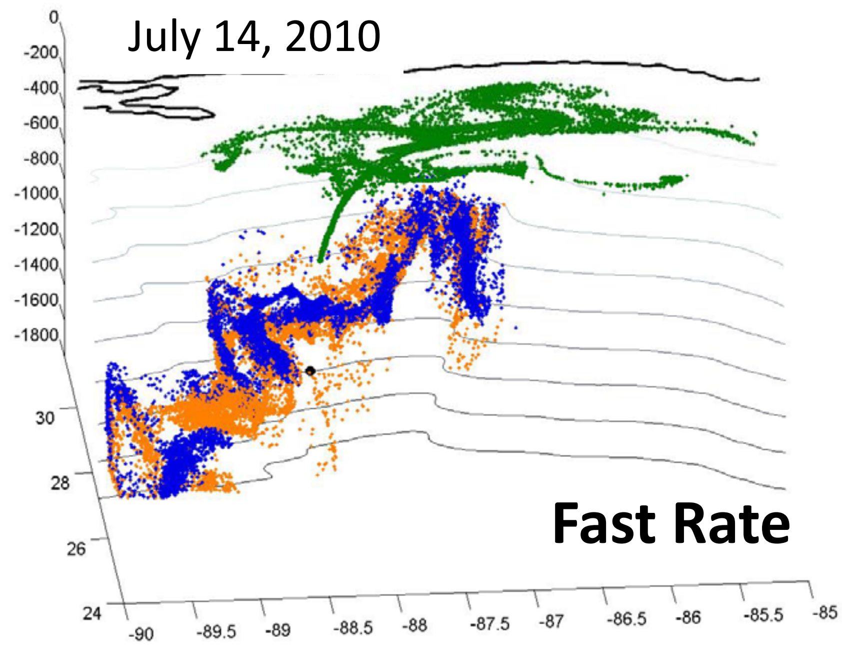
Fast Rate

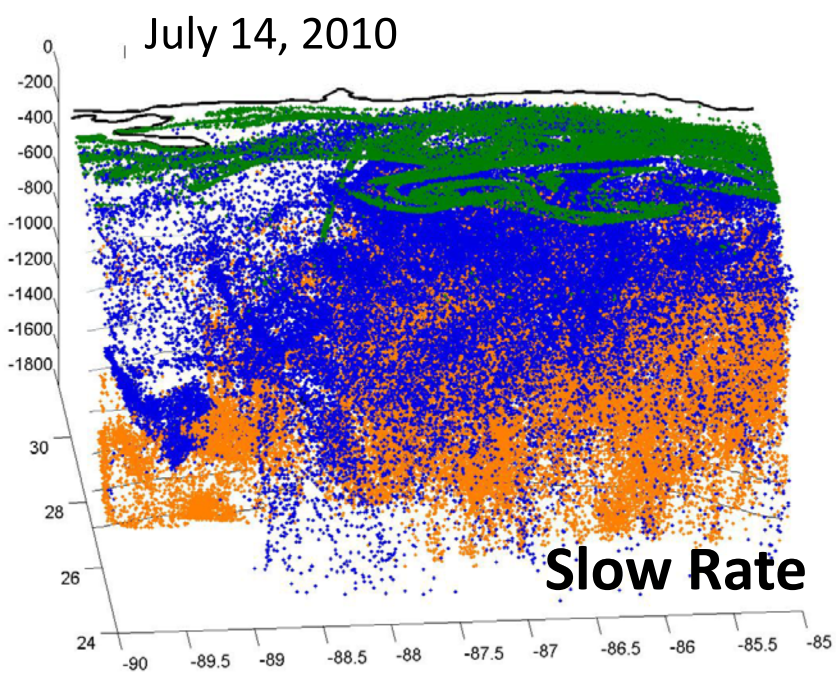


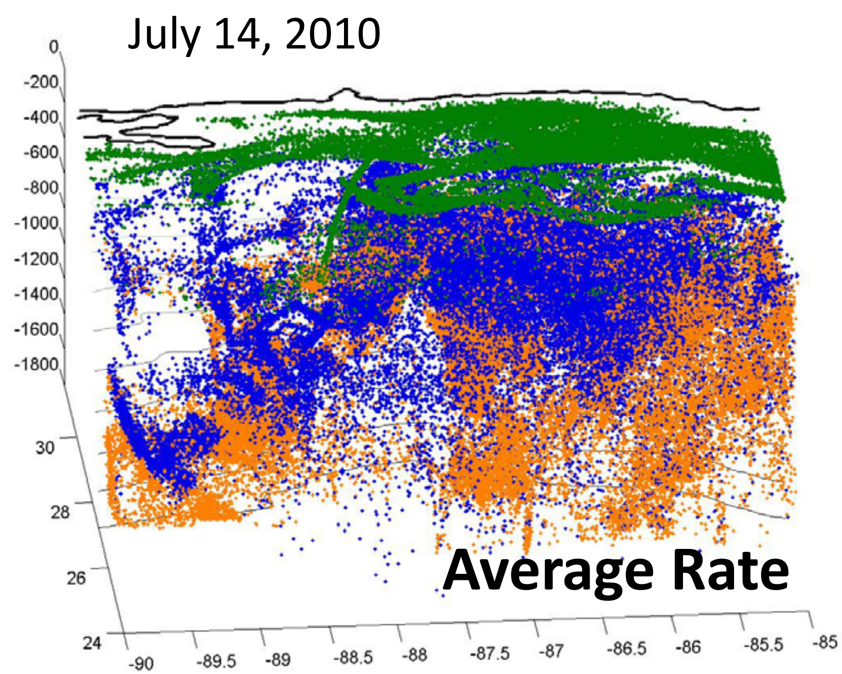
Initial oil droplet diameter

- 30 μm
- 100 μm
- 300 μm

Degradation significantly influences vertical distributions

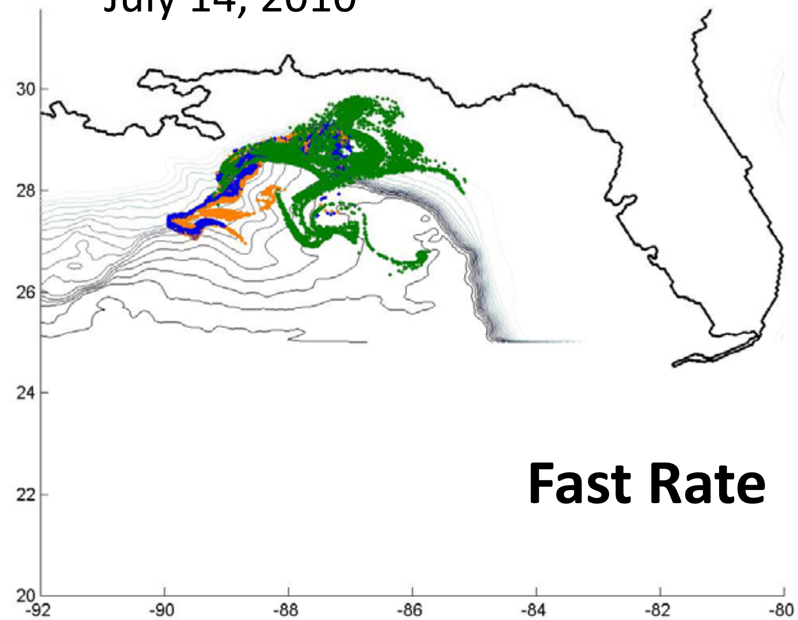




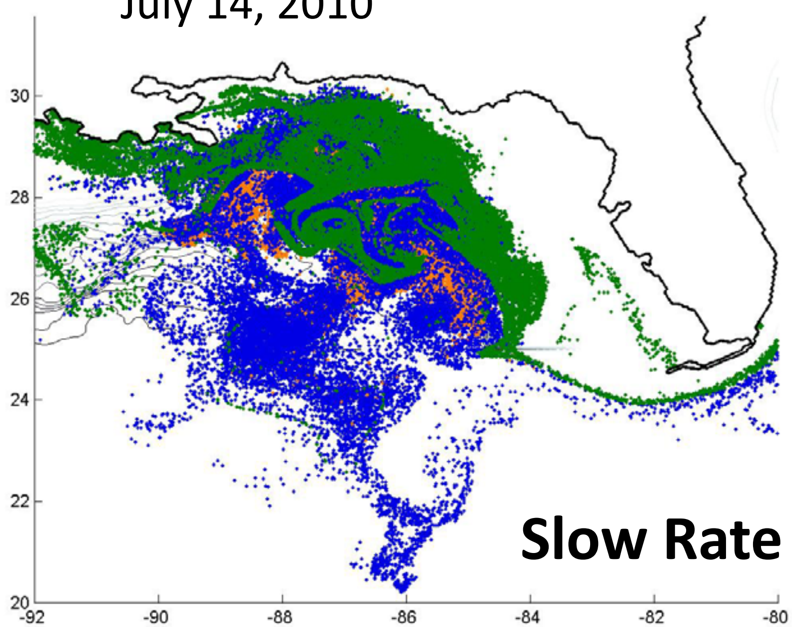


Degradation significantly influences horizontal distributions

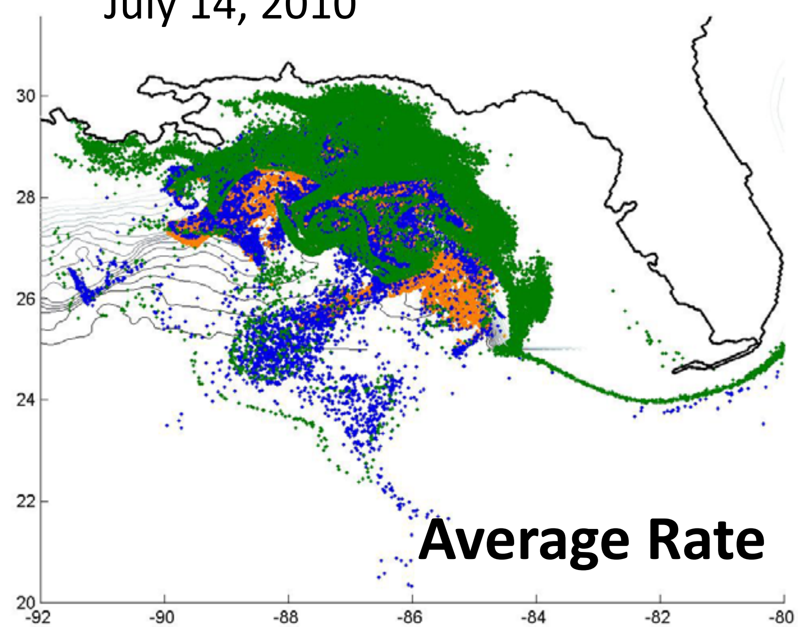
July 14, 2010



July 14, 2010

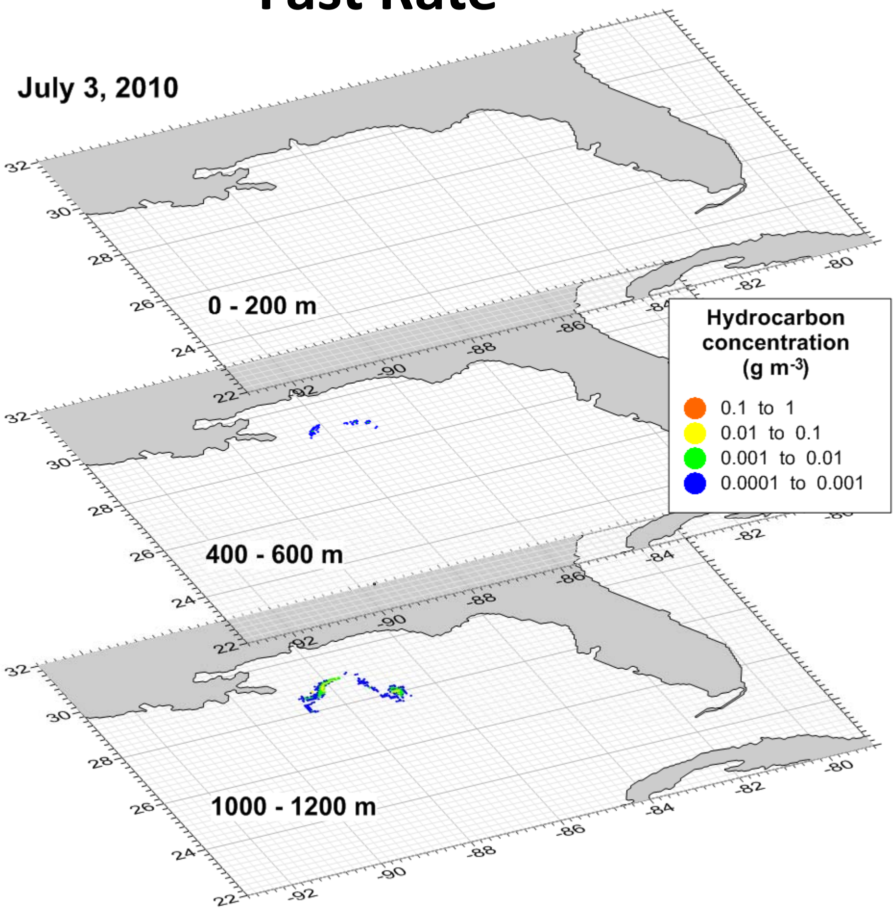


July 14, 2010

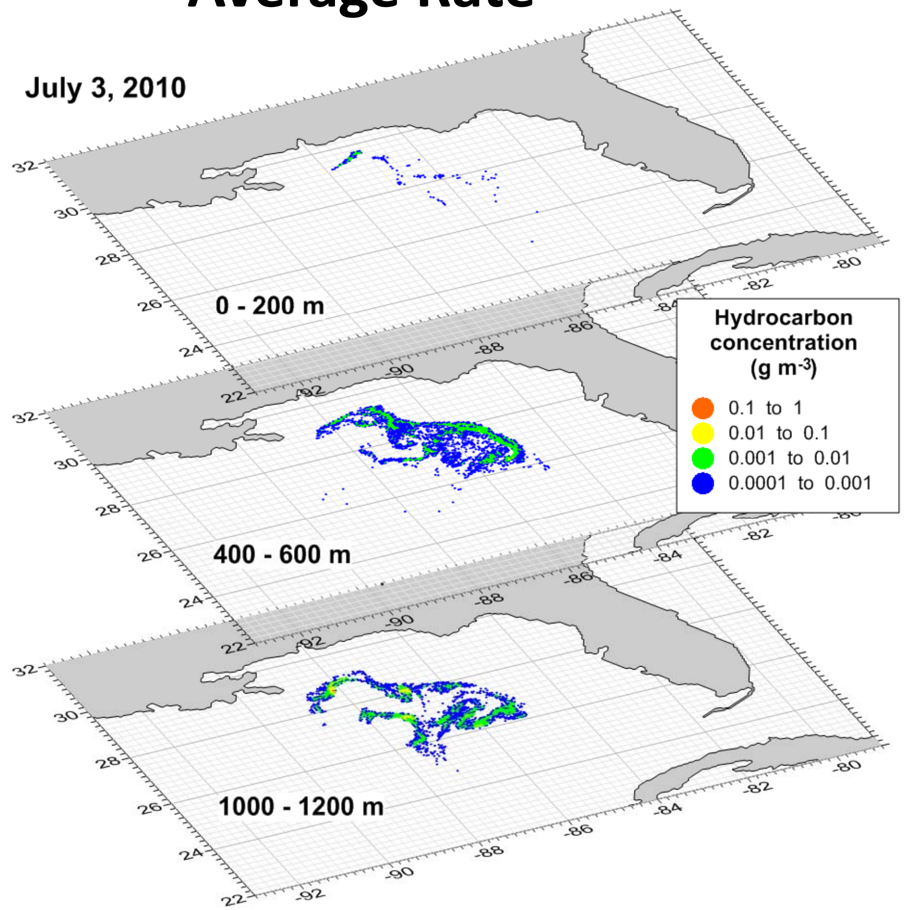


Degradation significantly influences hydrocarbon concentrations

Fast Rate



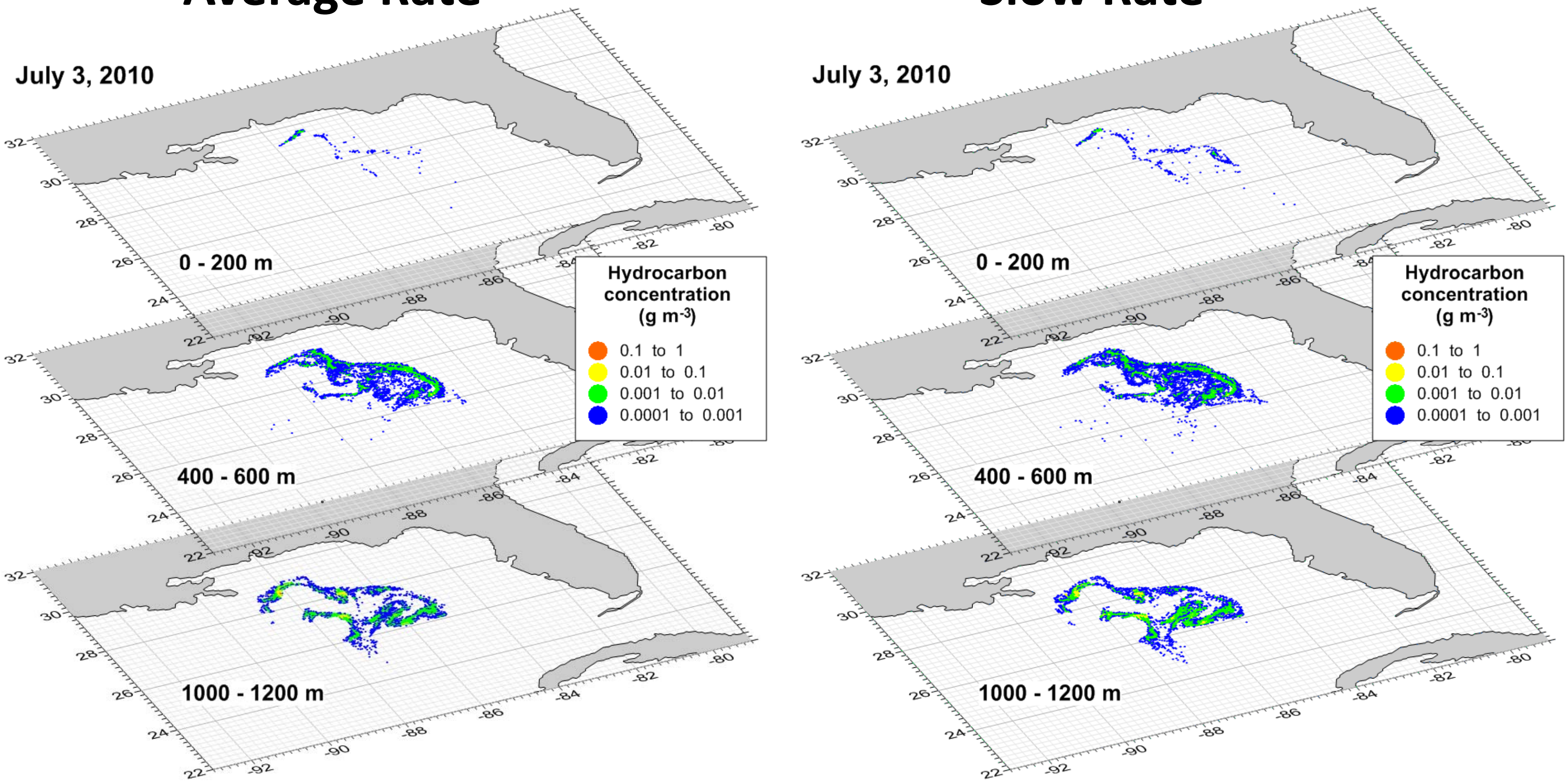
Average Rate



Concentrations resulting from the distributions of 10, 30, and 50 μm diameter particles, assuming that 30% of the oil released from the DH spill went into these size classes.

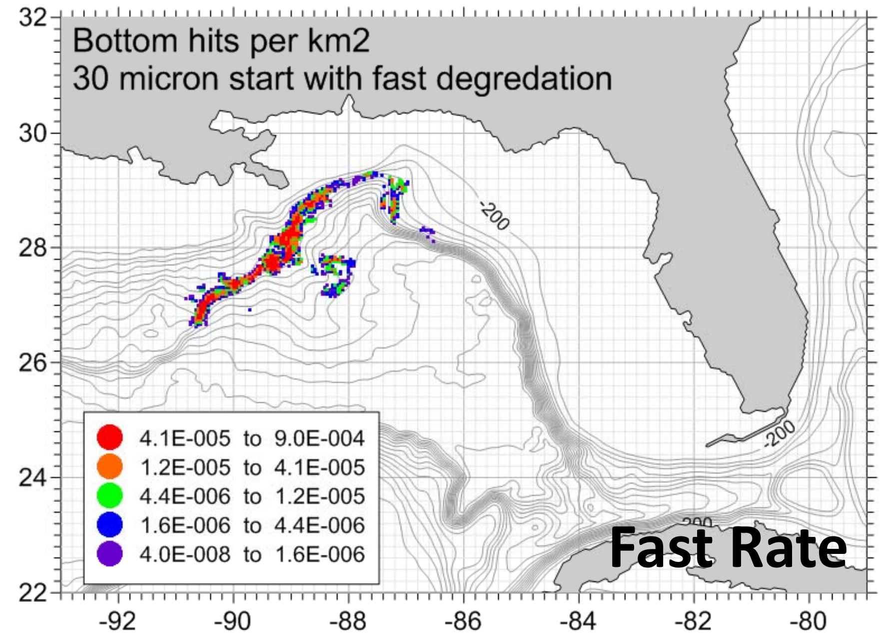
Degradation significantly influences hydrocarbon concentrations

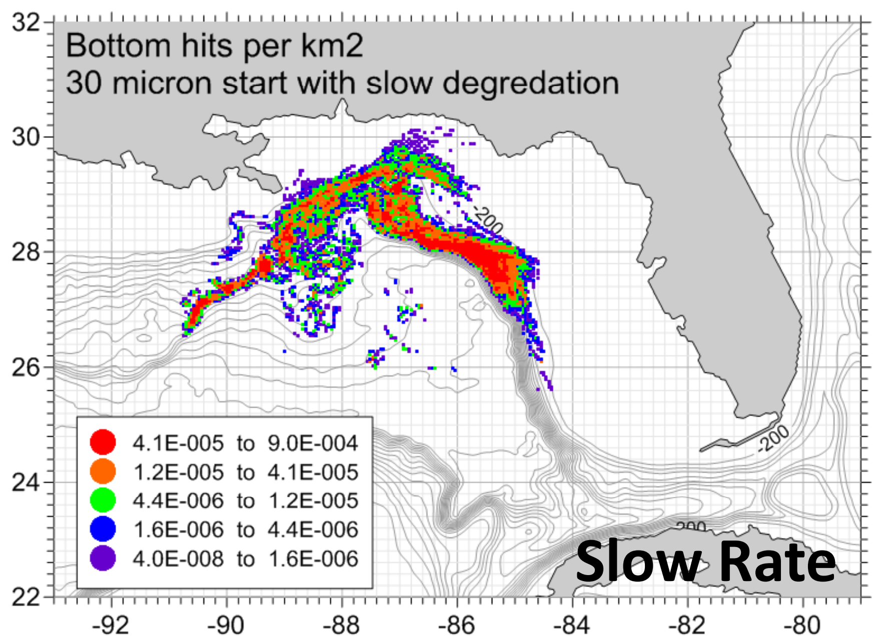
Average Rate **Slow Rate**

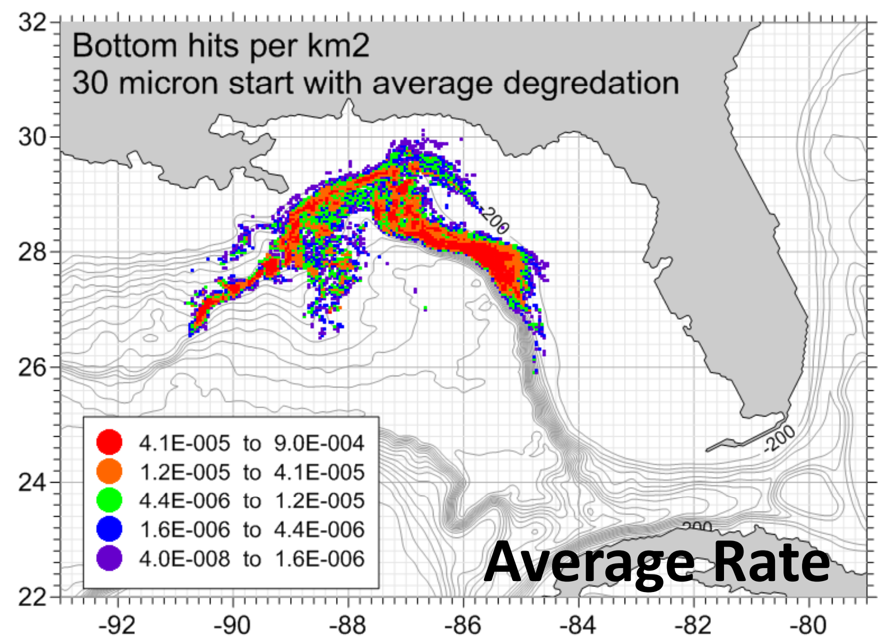


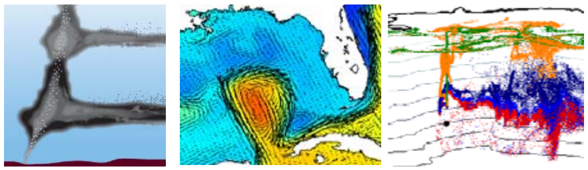
Concentrations resulting from the distributions of 10, 30, and 50 μm diameter particles, assuming that 30% of the oil released from the DH spill went into these size classes.

Degradation significantly influences potential interaction with the bottom









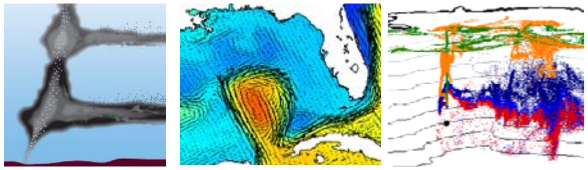
Conclusions

RAPID

Understanding degradation processes is critical for prediction of the fate of subsurface oil droplets

- Droplet diameter influenced horizontal transport of oil
- Droplets with diameters ≤ 80 μm (no aging) and < 100 μm (with aging) formed subsurface plumes
- Degradation rates influence vertical and horizontal oil transport and interaction with bottom

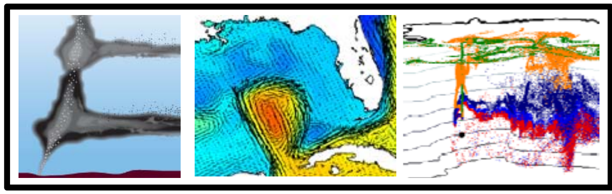
Additional comparisons with observations is the next priority



Information Needs

What was the size distribution and mass of oil droplets at the well head (initial conditions) and in the plume at different locations/times (validation)?

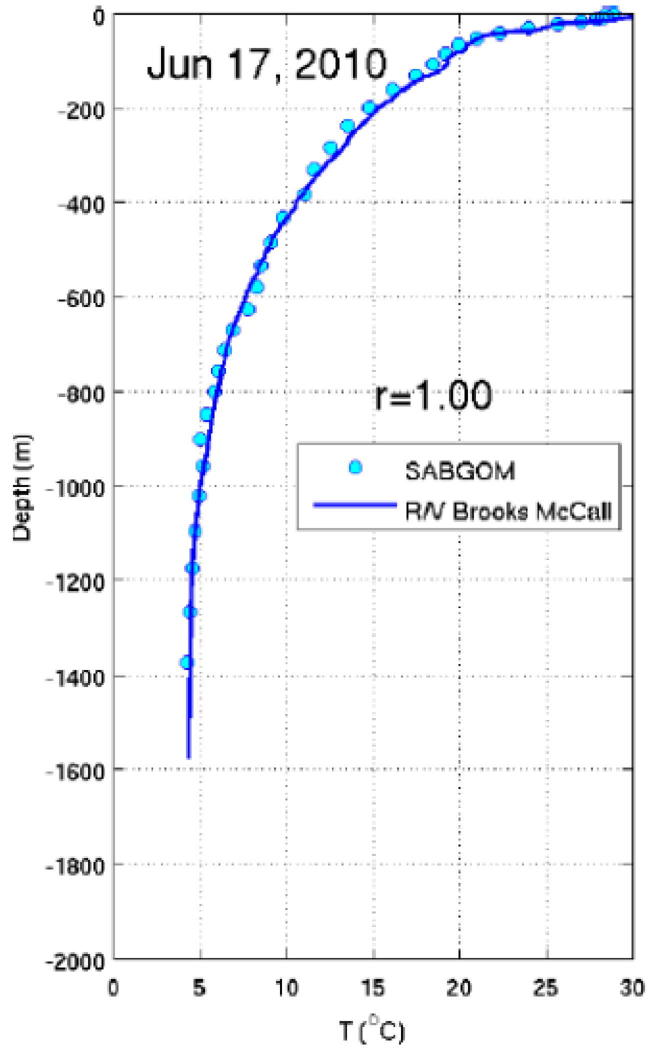
How do these droplets degrade over time? How does temperature influence these rates?



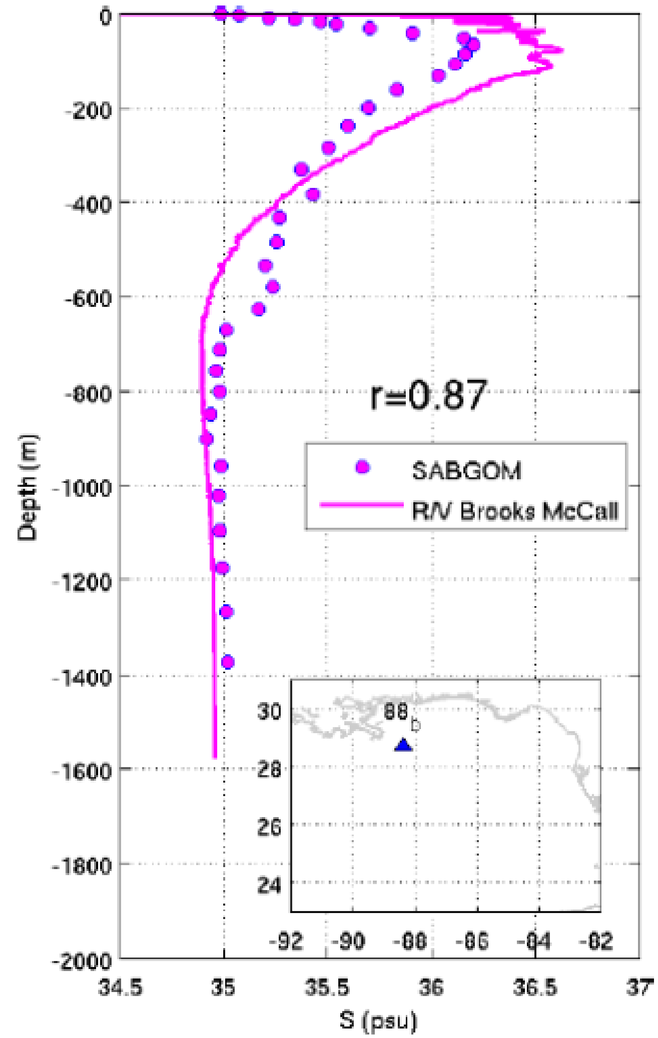
Circulation: SABGOM

Hyun and He, (2010)

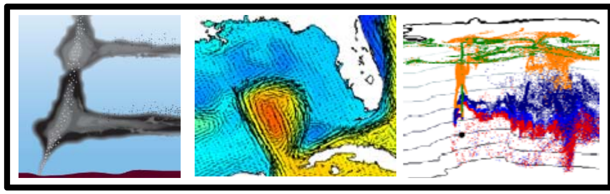
SABGOM hindcast shows good agreement with observations



Temperature (°C)



Salinity

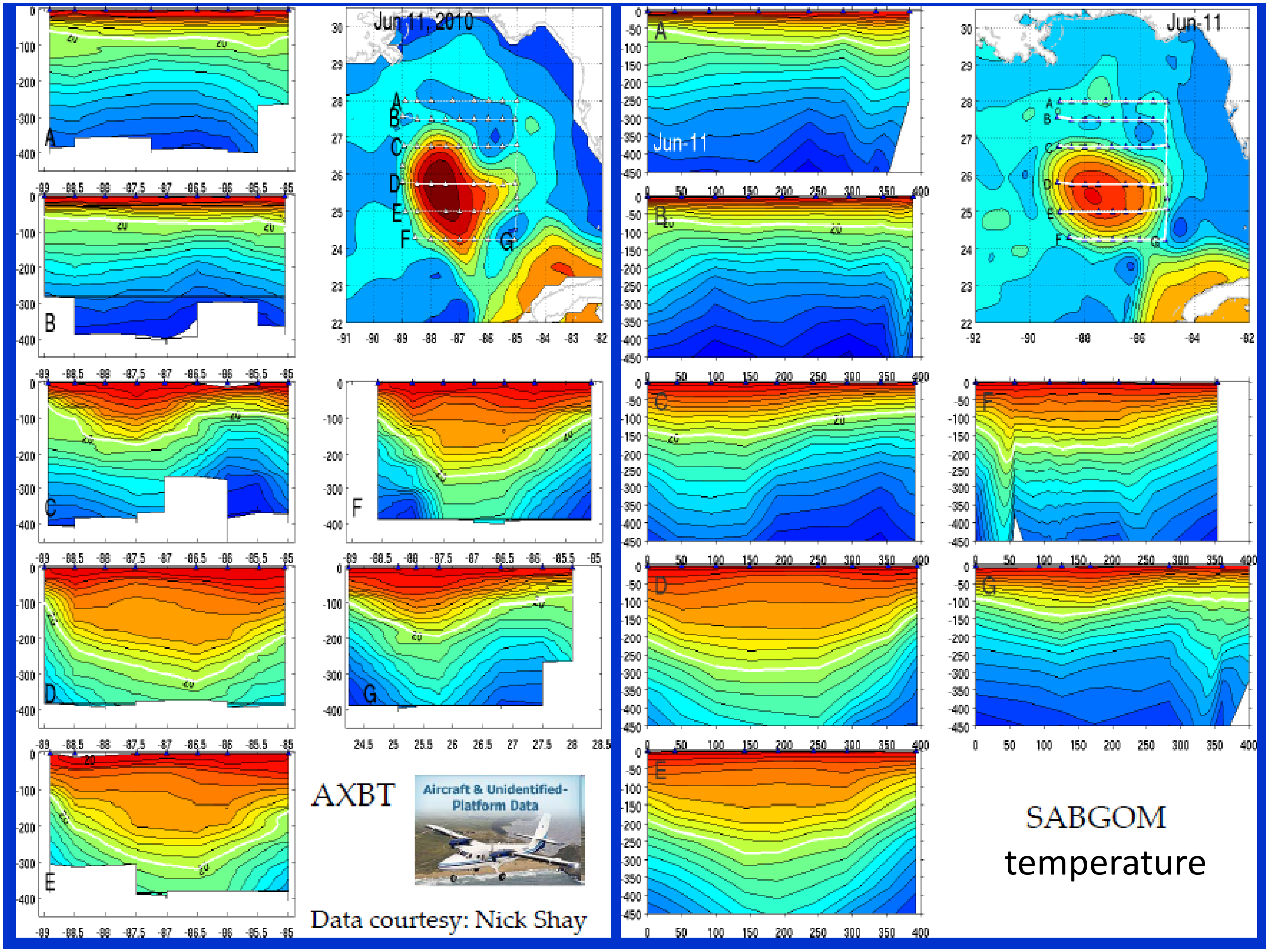


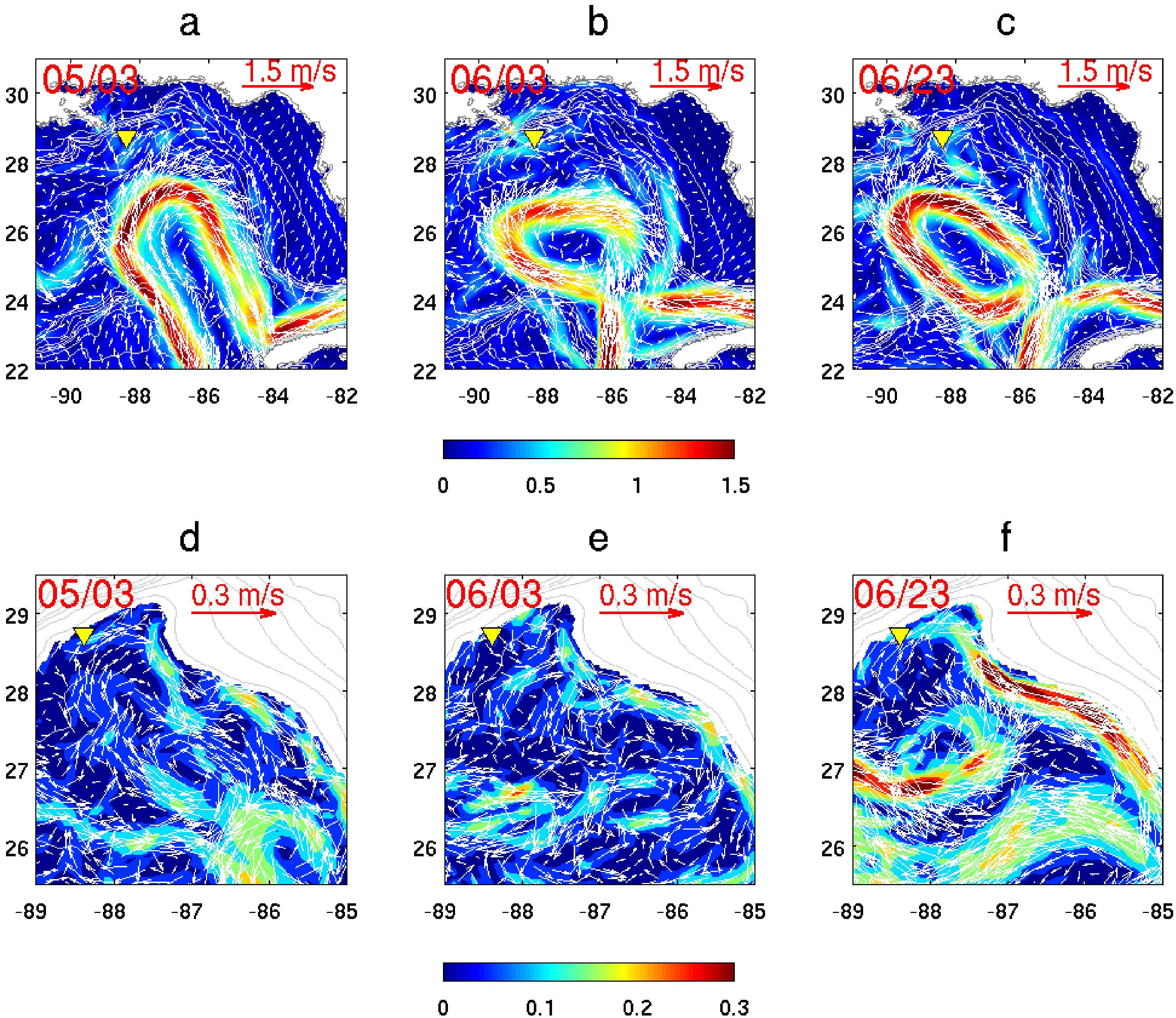
Circulation: SABGOM

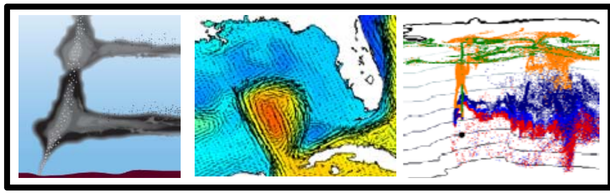
Hyun and He, (2010)

SABGOM reproduces Eddy Franklin

Overall, SABGOM reproduces Gulf of Mexico circulation reasonably well

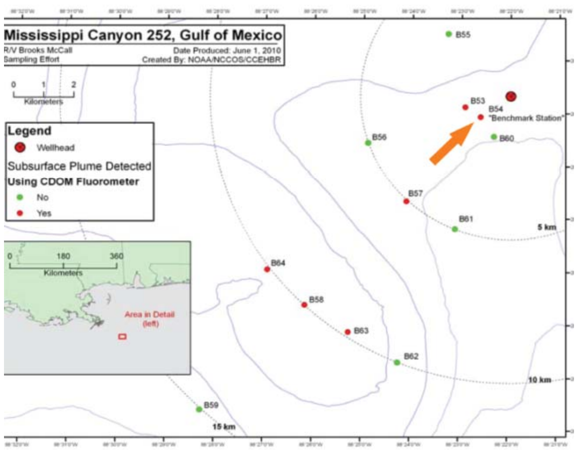


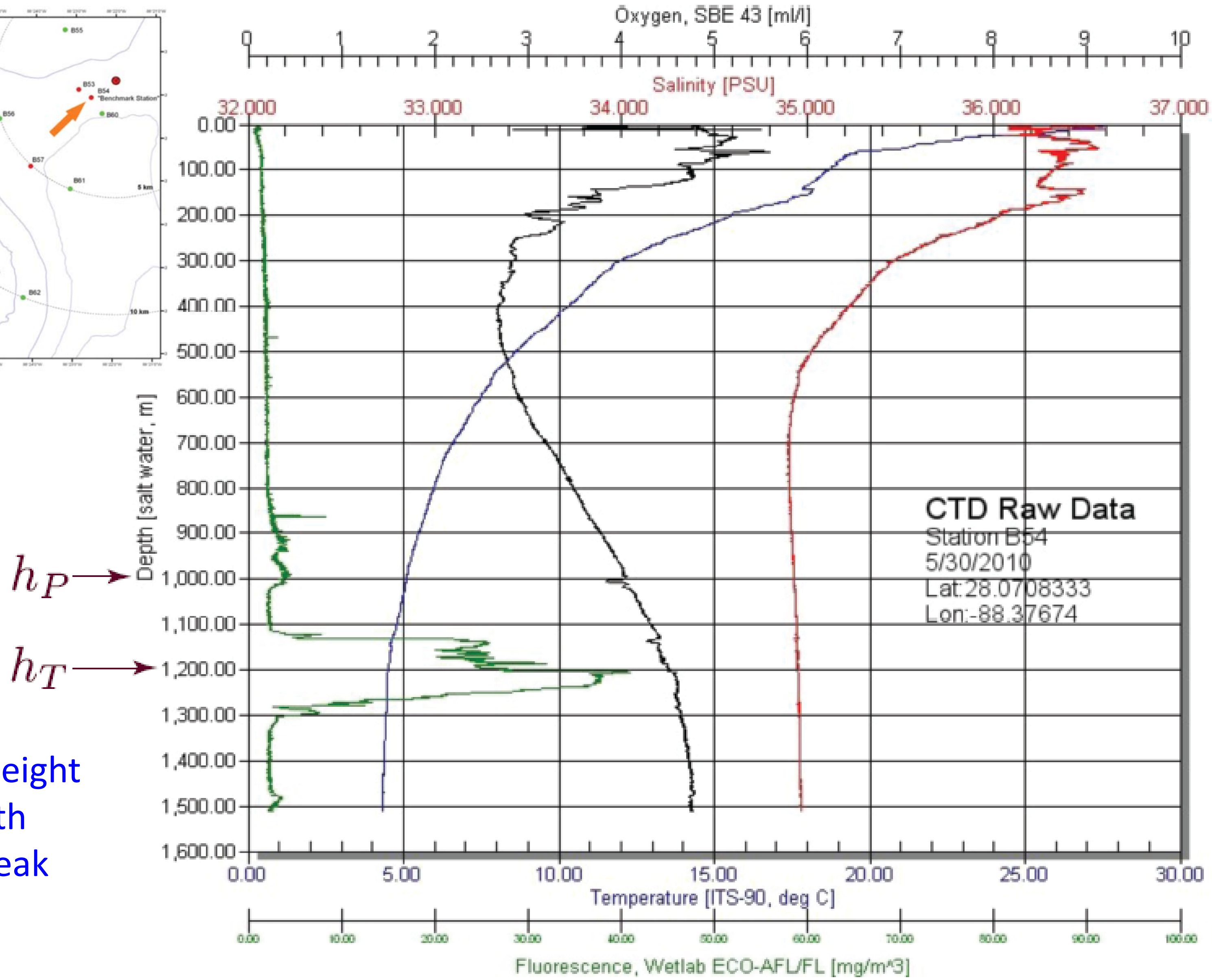

a
b
c
05/03
06/03
06/23
1.5 m/s
30
28
26
24
22
-90
-88
-86
-84
-82
0
0.5
1
1.5
d
e
f
0.3 m/s
29
28
27
26
-89
-88
-87
-86
-85
0
0.1
0.2
0.3



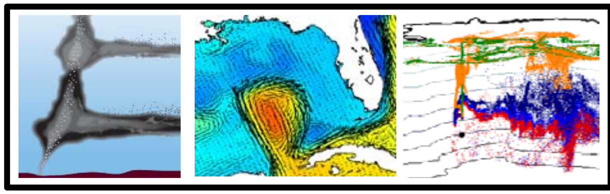
Oil plume: SMIP

Socolofsky et al. (2008)
Socolofsky and Bhaumik (2008)
Socolofsky et al. (2011)





Estimate of trap height compares well with observations of peak fluorescence



Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (*submitted*)

Droplet model matches Zheng and Yapa (2000) test cases

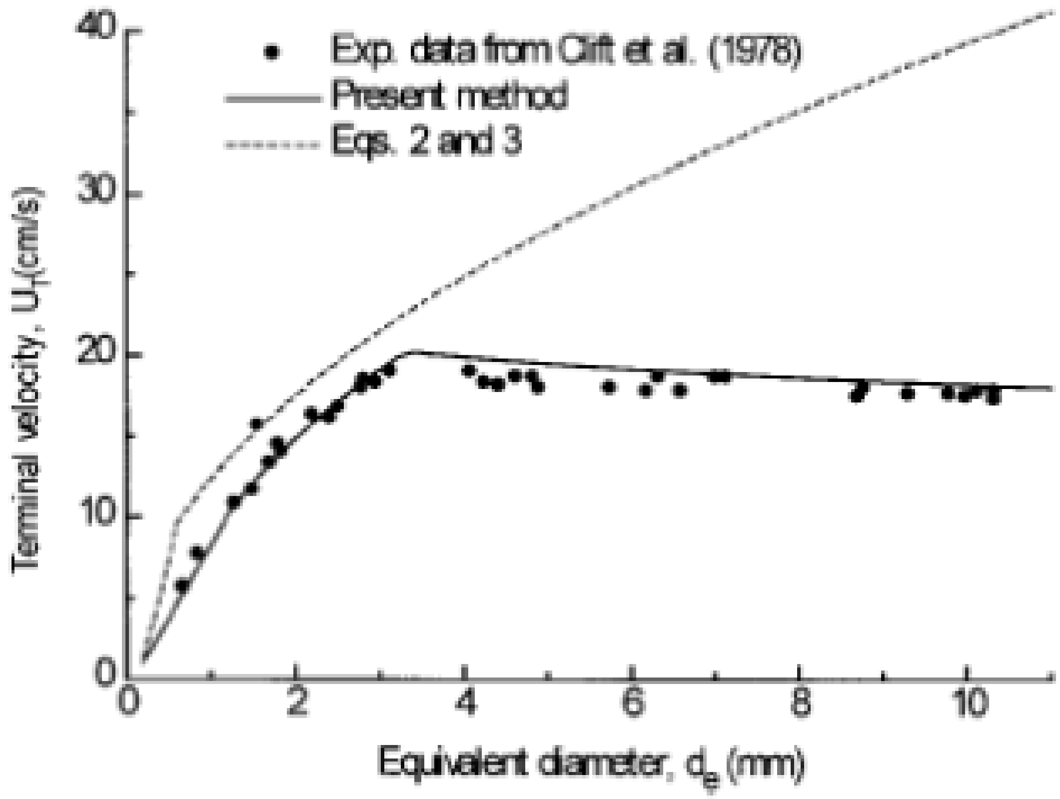
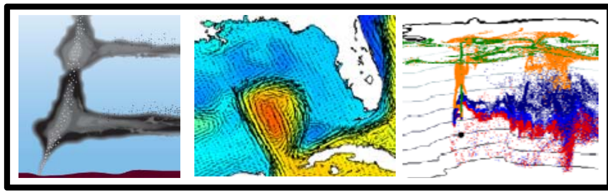


FIG. 2. Terminal Velocity of Carbon Tetrachloride Drops in Tap Water at 20°C



Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (*submitted*)

Droplet model matches Zheng and Yapa (2000) test cases

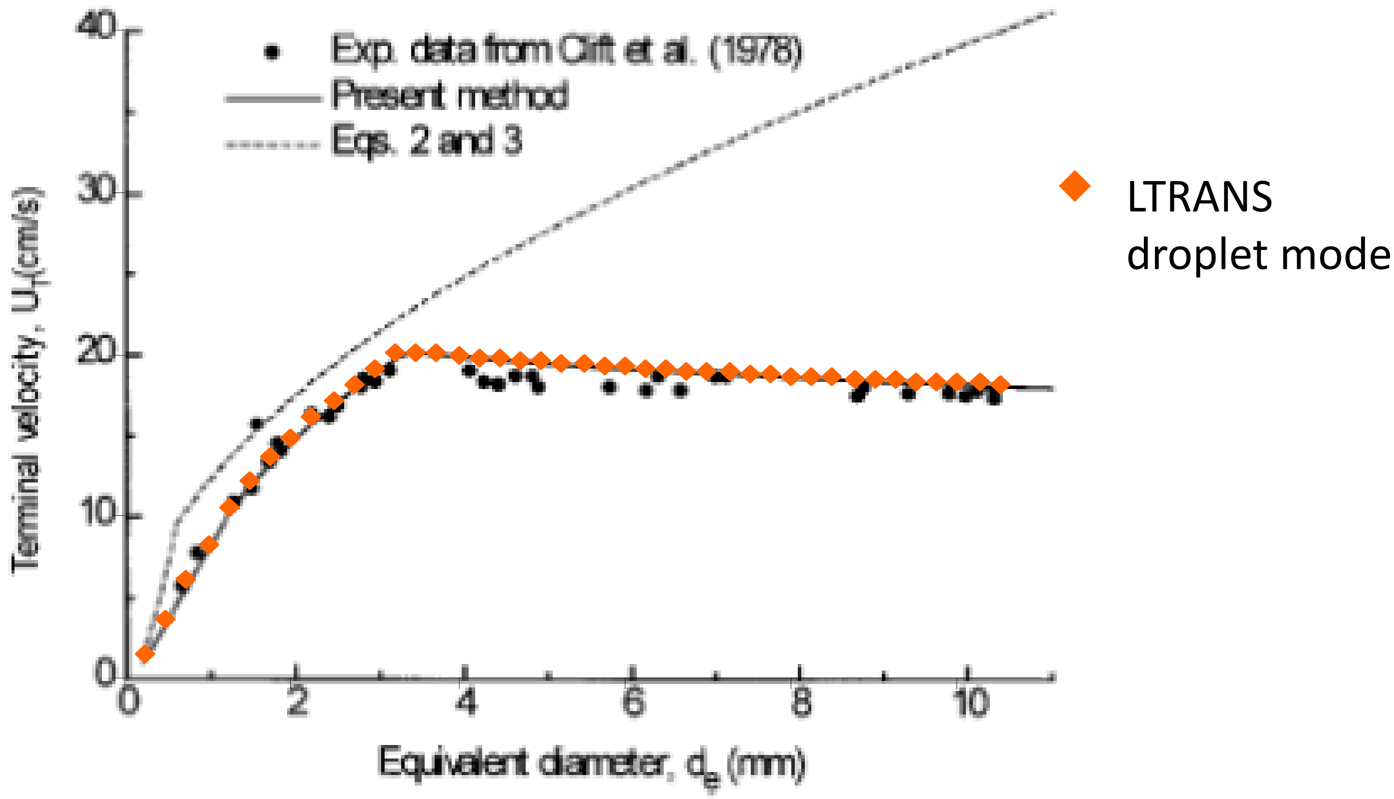
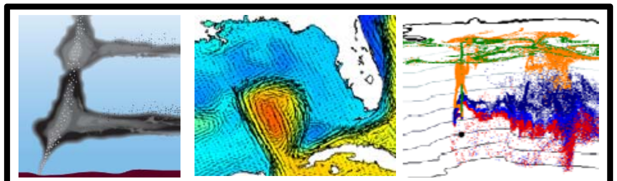


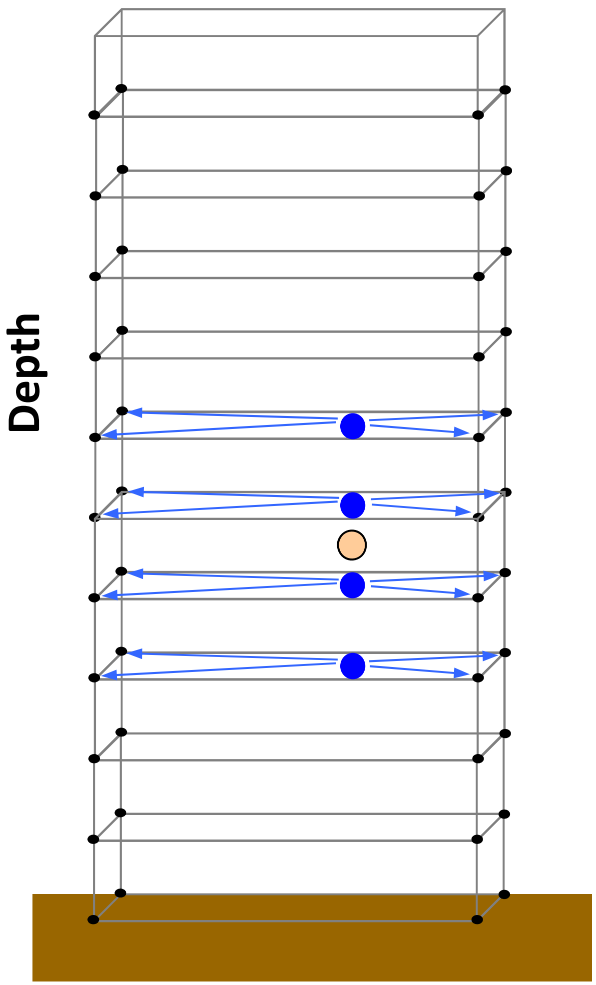
FIG. 2. Terminal Velocity of Carbon Tetrachloride Drops in Tap Water at 20°C



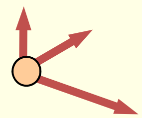
Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (*submitted*)

Water column interpolation scheme

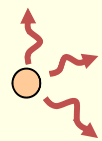


Particle movement during 5-min time step is:



Advection

+

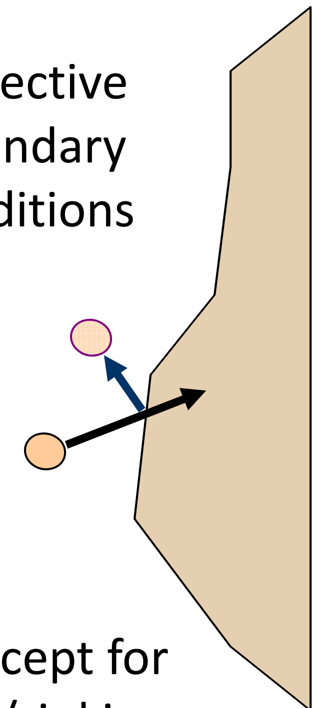


Turbulence

+

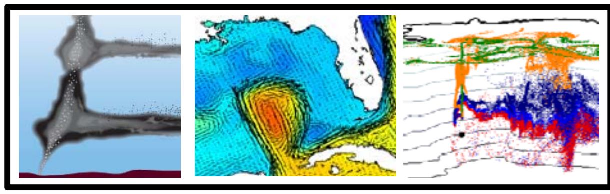
Rise/sink speed

Reflective boundary conditions



. . . except for rising/sinking

Advection: Runge-Kutta method (RK4)
Vertical turbulence: Random Displacement Model (RDM)
Horizontal turbulence: Random walk



Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (*submitted*)

Scenario 1: 10, 30, 50, 100, 300 micron particles released from a point, no aging

Where: 28.738N, 88.366W at time-varying trap height

Duration: April 22 – July 27, 2010

Release: 1 particle per 50 barrels of oil based on net oil flow rate from April 22 to July 15 (81,609 particles/run)

Boundaries: Particles stop moving if hit open ocean boundary, and reflect off land and bottom