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

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The goal of this initial work was 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
• Oil plume model
• Oil droplets
• Simulations
• Results
• Next Steps
Models

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

SABGOM: data-assimilating 3D ocean circulation model

Oil plume model
Socolofsky et al. (2011)

LTRANS: 3D particle-tracking with advection, diffusion, and oil droplet transformations
SABGOM: data-assimilating 3D ocean circulation model

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

LTRANS: 3D particle-tracking with advection, diffusion, and oil transformations
Oil plume model predicts the depth of the primary subsurface intrusion of oil droplets.

SABGOM: data-assimilating 3D ocean circulation model

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

Oil plume model
Socolofsky et al. (2011)
SABGOM: data-assimilating 3D ocean circulation model

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

LTRANS predicts transport and transformation of oil droplets
Circulation: SABGOM

Hyun and He, (2010)

- 5-km spatial resolution, 36 terrain-following vertical layers
- Nested inside global data (SST & SSH) assimilative HYCOM model
- NCEP NAM surface forcing
- Major rivers and tides
- Mellor-Yamada 2.5 turbulence closure
Circulation: SABGOM

Used for surface oil forecast during spill

Hyun and He, (2010)
Circulation: SABGOM

Hyun and He, (2010)

Hindcast simulation conducted

Hindcast Simulation (4/20 – 7/29)

SSH + Surface Current

Apr-20-2010

Eddy Franklin

Hourly 3-d circulation output
For Deepwater Horizon

Oil plume model

Socolofsky et al. (2008)
Socolofsky and Bhaumik (2008)
Socolofsky et al. (2011)
Estimate of trap height compares well with observations of peak fluorescence.

**Oil plume model**

Socolofsky et al. (2008)
Socolofsky and Bhaumik (2008)
Socolofsky 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
Particle movement during 5-min time step is:

- Advection
- Turbulence
- Rise/sink speed

Advection: Runge-Kutta method (RK4)
Vertical turbulence: Random Displacement Model (RDM)
Horizontal turbulence: Random walk
No numerical diffusion in horizontal or vertical

Reflective boundary conditions

Oil droplets: LTRANS

North et al. (2006, 2008)
Schlag et al. (2008)
North et al. (2011)
Oil droplets are assigned an ascent speed derived from equations in Zheng and Yapa (2000) for contaminated fluid particles and solid particles, with separate formulations for three classes of droplets:

- Small spherical shape, diameter < 1 mm
- Intermediate ellipsoidal shape, diameter > 1 mm and < Cd
- Large spherical cap shape, diameter > Cd (Cd: critical diameter)

**Small spherical shape:**

Modified Stokes for small droplets of interest

\[ U_T = \frac{R \mu}{\rho d} \]

- \( U_T \) = terminal velocity
- \( R \) = Reynolds number
- \( \mu \) = dynamic viscosity
- \( \rho \) = density
- \( d \) = diameter
Droplet model matches Zheng and Yapa (2000) test cases

FIG. 2. Terminal Velocity of Carbon Tetrachloride Drops in Tap Water at 20°C
Droplet model matches Zheng and Yapa (2000) test cases

FIG. 2. Terminal Velocity of Carbon Tetrachloride Drops in Tap Water at 20°C
Model simulations: fixed diameter

Vary droplet size for each run: 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, 1 particle every 1-2 min)

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

Oil droplet density = 858 kg m\(^{-3}\). Water density and dynamic viscosity based on interpolated salinity and temperature from SABGOM.
Model predicts the formation of a subsurface plume of droplets with diameters \( \leq 80 \, \mu m \)

Also, horizontal distribution differs between surface and subsurface particles

June 3, 2101  North et al. (2011)
Comparison with 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
LTRANS predicts a southwest-tending plume that was aligned along the Camilli et al. transect.
Particle depths were within the range of those observed by Camilli et al. or slightly above it.
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
Initial oil droplet diameter

- 30 μm
- 100 μm
- 300 μm

Animations: degradation significantly influences transport
Degradation significantly influences horizontal and vertical distributions

After 60 d

North et al. (in prep)
Degradation significantly influences hydrocarbon concentrations.

Model predicts that most subsurface oil was transported east.

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. 3 July 2010

North et al. (in prep)
Potential interaction with bottom sensitive to degradation and droplet size

North et al. (in prep)
Understanding degradation processes is critical for prediction of the fate of subsurface oil droplets

- Droplet diameter significantly influenced transport of oil
- Droplets with diameters $\leq 80 \, \mu m$ (no aging) and $< 100 \, \mu m$ (with aging) formed subsurface plumes
- Degradation rates influence vertical and horizontal oil transport and interaction with bottom
- Model predicts oil droplets were transported to the southwest and to the east of the well and intersected with the bottom

Comparison with observations will continue
Next steps for E. North and Ian Mitchell

- Incorporate multi-phase plume model into LTRANS initial conditions
- Adapt LTRANS to run with input from multiple nested ROMS models
- Adapt LTRANS to run with input from SUNTANS
- Enhance oil droplet degradation, and add dissolution and surface oil weathering parameterizations (Collaborations welcome!)
- Gather and synthesize field data to compare with model simulations
- Run simulations of the GISR experiments and validate with observations
- Run model simulations for Deepwater Horizon oil spill and validate with observations
- Run model simulations with multiple ocean states and response strategies