ANALYSIS OF UNCERTAINTY IN SIMULATIONS OF SURFACE OIL DRIFT IN THE GULF OF MEXICO

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SINTEF

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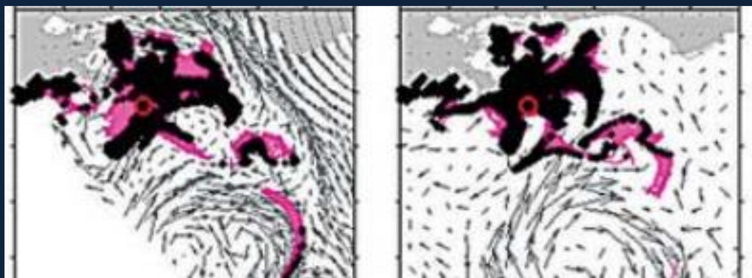
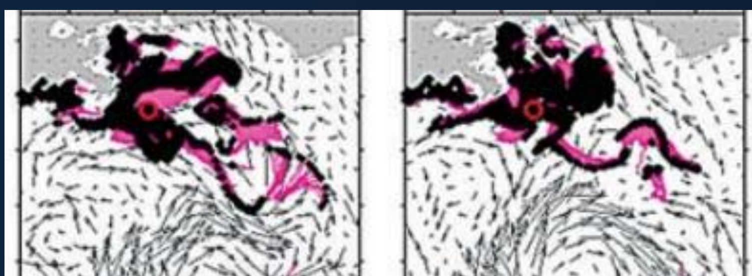
USF Surface Oil Forecasts forced by Different Hydrodynamic Models, May 25, 2010

USF West Florida Shelf Model | Global HYCOM

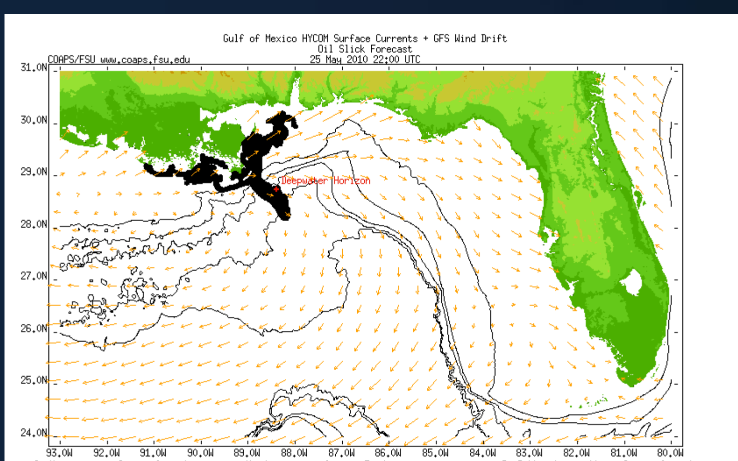


GoM HYCOM | South Atlantic Bight-GOM model

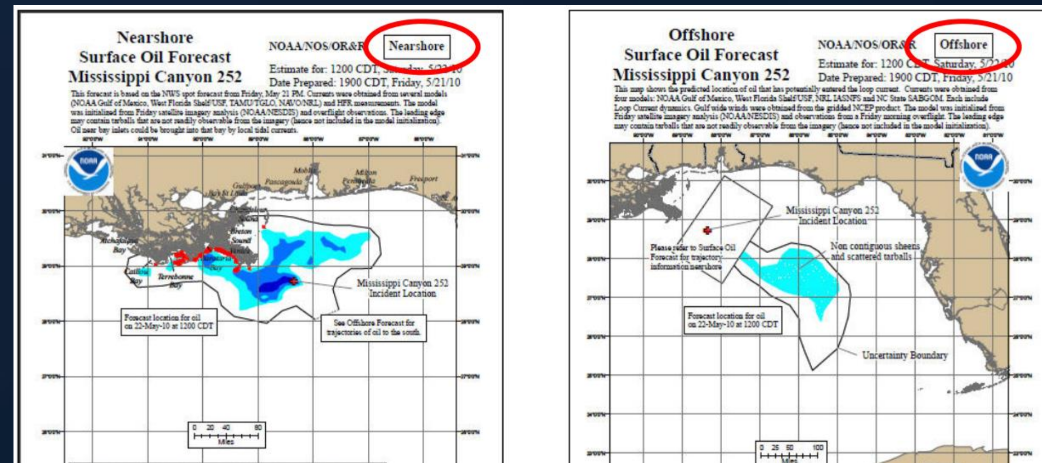


Liu et al., 2011

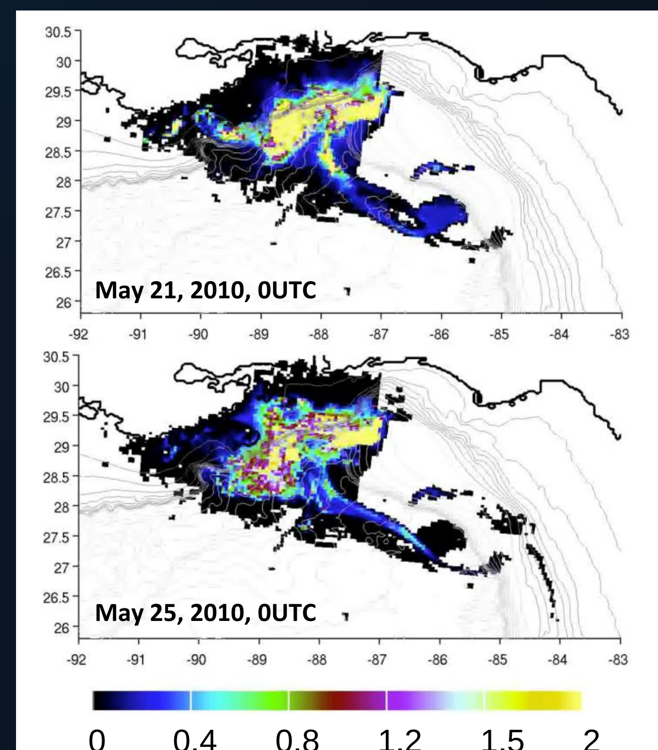
FSU Surface Oil Drift Model Surface Oil Forecast, May 25, 2010



NOAA Operational Modeling Environment (GNOME) Surface Oil Forecast, May 21, 2010



SAR/TCNNA Surface Oil Volume (m^3/km^2)

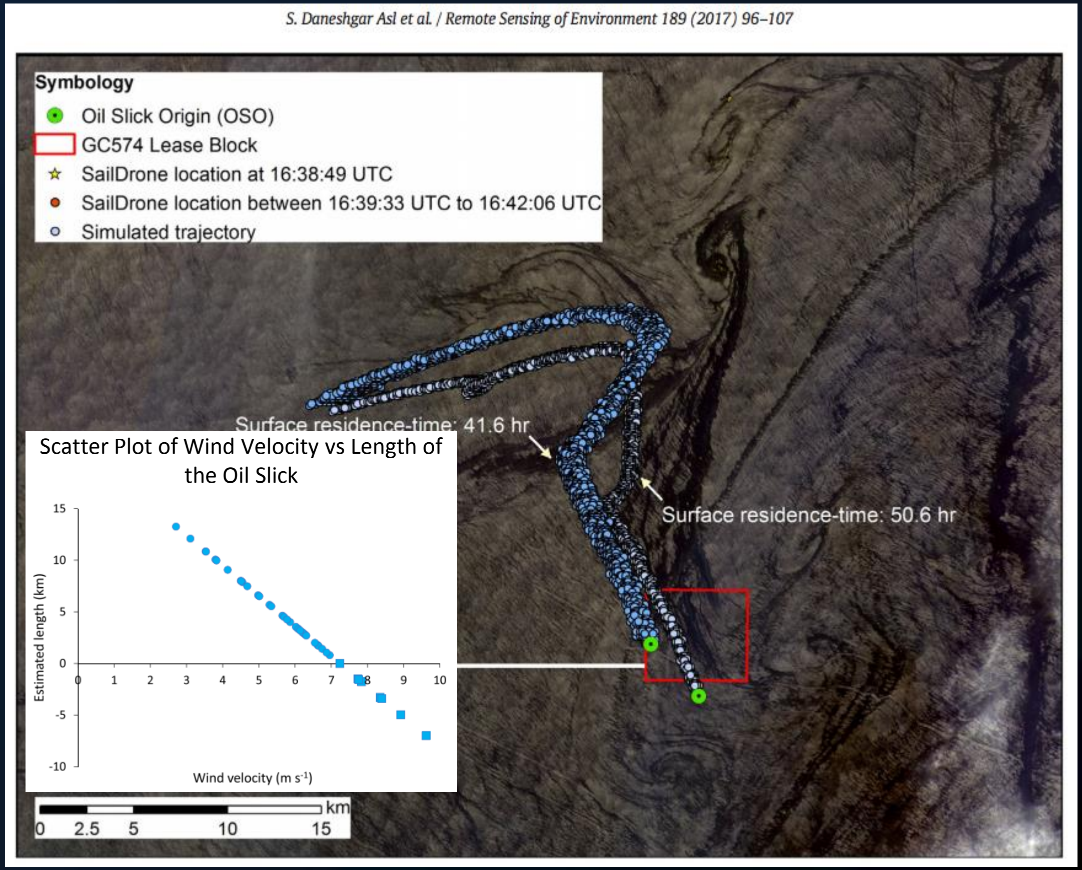


Uncertainties in Predictions of Surface Oil Trajectories

- Inconsistency between simulated and observed oil characteristics
  - Surface/subsurface oil
  - Type of oil
  - Concentration/volume/coverage Time integrated/average vs instantaneous

- Biases/errors in the forcing fields
  - Winds
  - Ocean currents
  - Air-sea interaction
  - Waves

- Uncertainties in model parameters
  - Oil weathering
  - Wind effects
  - Ocean currents
  - Waves



FSU Surface Oil Drift Model

The oil particle trajectories are computed as a superposition of advective processes and turbulent diffusion

$$\frac{d\mathbf{x}}{dt} = \mathbf{u}_a(\mathbf{x},t) + \mathbf{u}_d(\mathbf{x},t)$$

Advective velocity:

$$\mathbf{u}_a = \mathbf{u}_c + C_w \|\mathbf{u}_{10}\| \Theta + C_s \mathbf{u}_s$$

- $\mathbf{u}_c$: Ocean surface current
- C_w: Wind drag coefficient
- $\|\mathbf{u}_{10}\|$: Wind speed
- Θ: Unit vector directed at some angle from the wind
- C_s: Wave Coefficient
- $\mathbf{u}_s$: Stokes Drift

Turbulent diffusive velocity parameterized as a random fluctuation

$$\mathbf{u}_d = \|\mathbf{u}_d\| \xi \cdot \exp(i2\pi\xi)$$

- ξ: Random variable ~N(0,1)

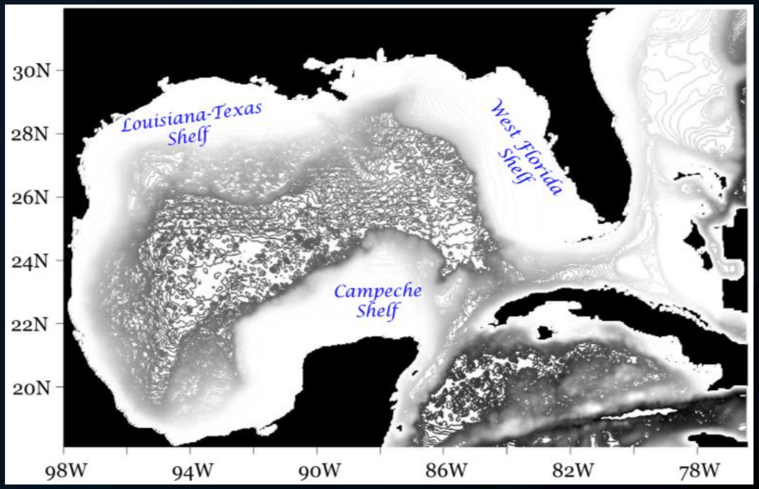
$$\|\mathbf{u}_d\| = \sqrt{\frac{6\nu}{\Delta t}}$$

- Half-life: Oil particles are removed randomly based on a prescribed half-life

- Surface currents: 1/25° Gulf of Mexico HYbrid Coordinate Ocean Model (HYCOM) Analysis/Reanalysis *(hycom.org/dataserver/goml0pt04):*
  - **20.1** (Analysis: 2003/01 – 2010/07, obsolete)
  - **31.0** (Analysis: 2009/04/01 – 2014/07/31)
  - **51.0** (Reanalysis: 1993/01/01 – 2012/12/31)

- Winds: NCEP CFSR

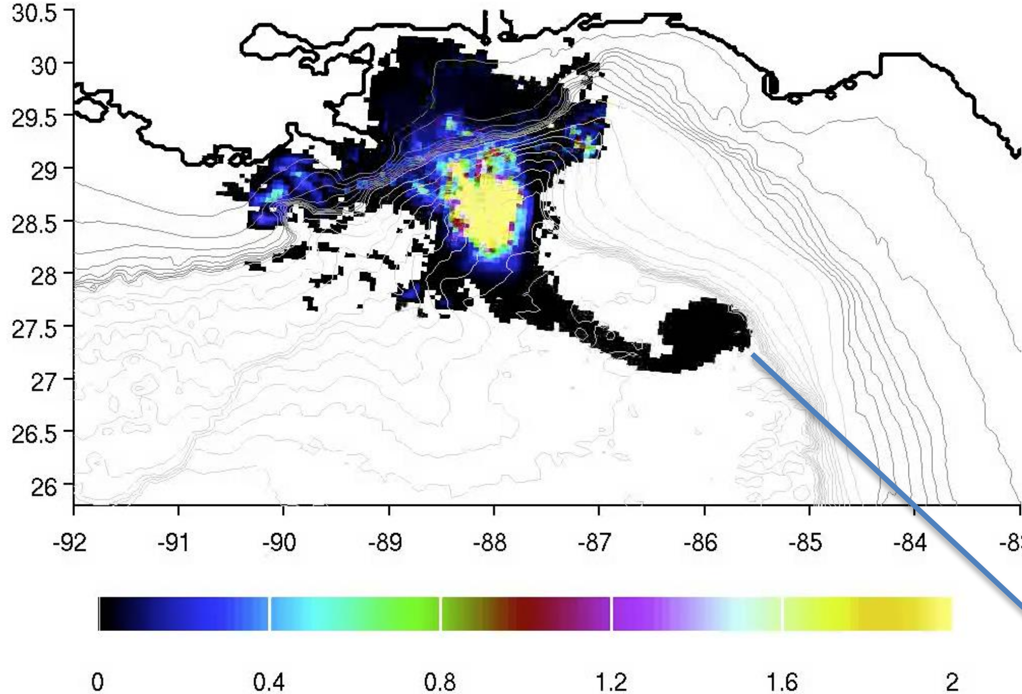
Gulf of Mexico HYCOM Domain



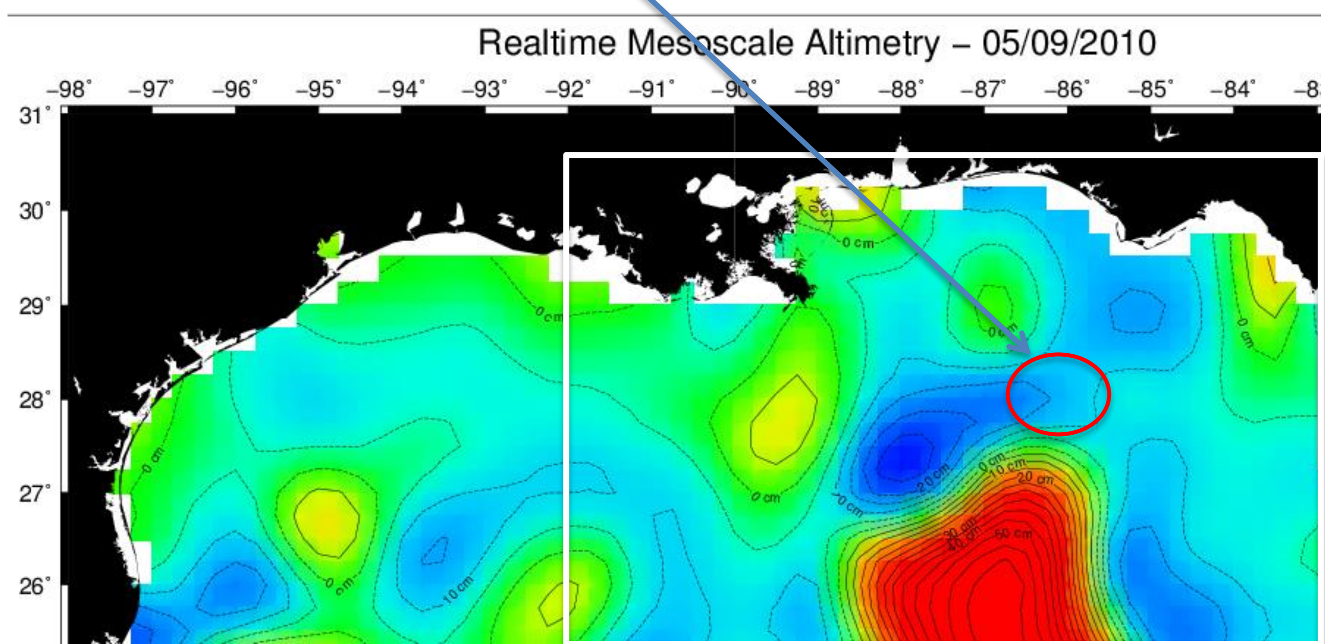
Uncertainties in the Forcing Fields

Ocean Currents

$$\mathbf{u}_a = \mathbf{u}_c + C_w \|\mathbf{u}_{10}\| \Theta + C_s \mathbf{u}_s$$

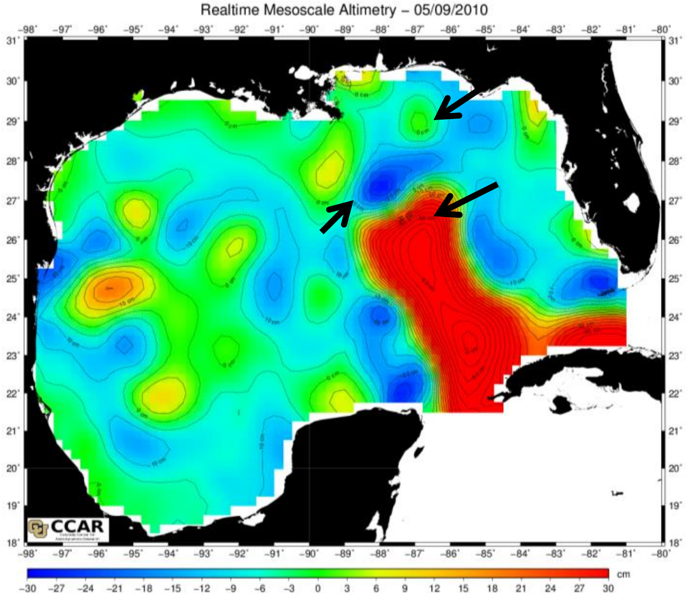


- **The "Tiger tail" developed during May 8 – May 9, 2010**
- **Oil filament formed in the southeastern direction advecting oil towards the Loop Current**
- **Then oil propagated along the Loop Current front. The tip of the tail formed in a "saddle point" between two cyclones.**

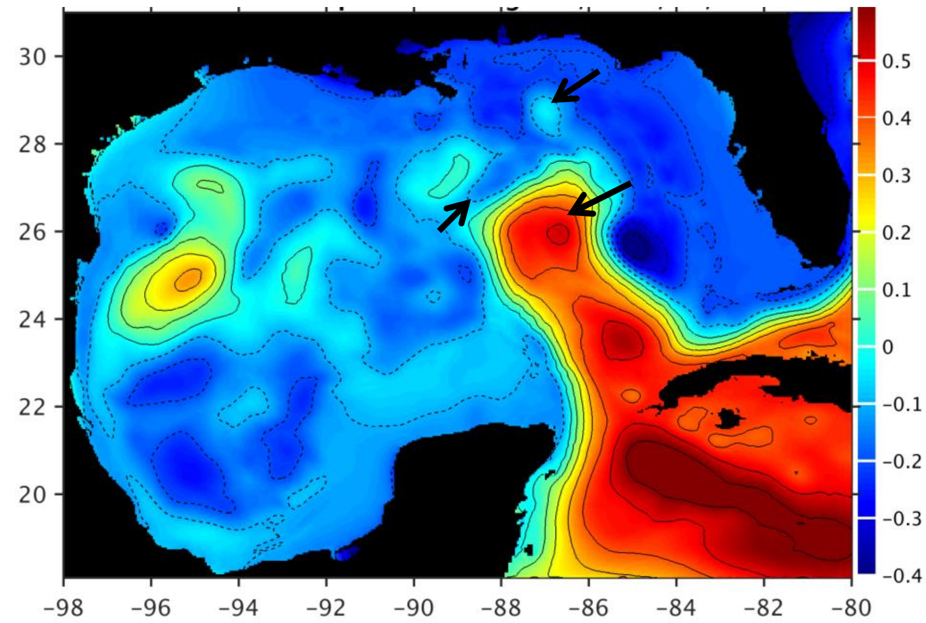


SSH fields (m) 9 May, 2010

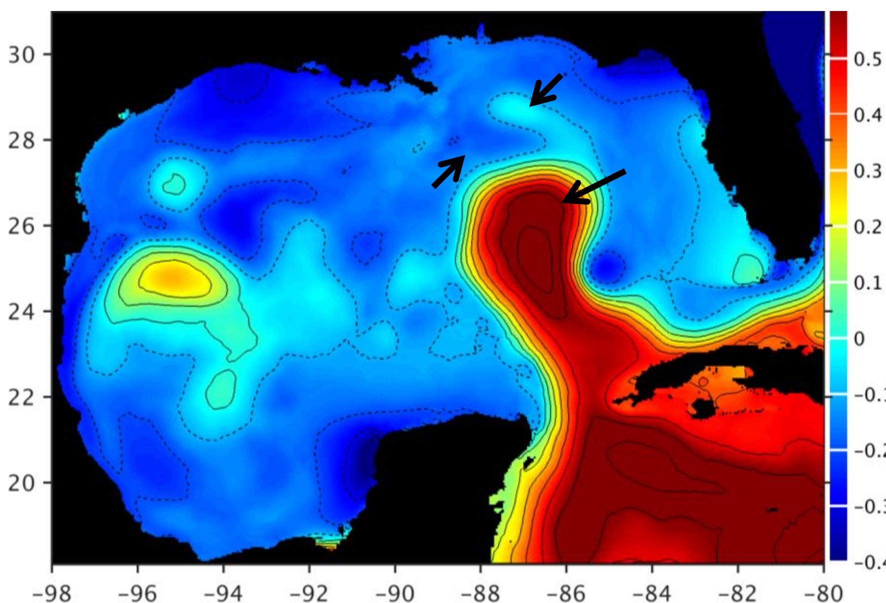
Colorado Center for Astrodynamics Research (CCAR) Gridded Altimeter-based Product



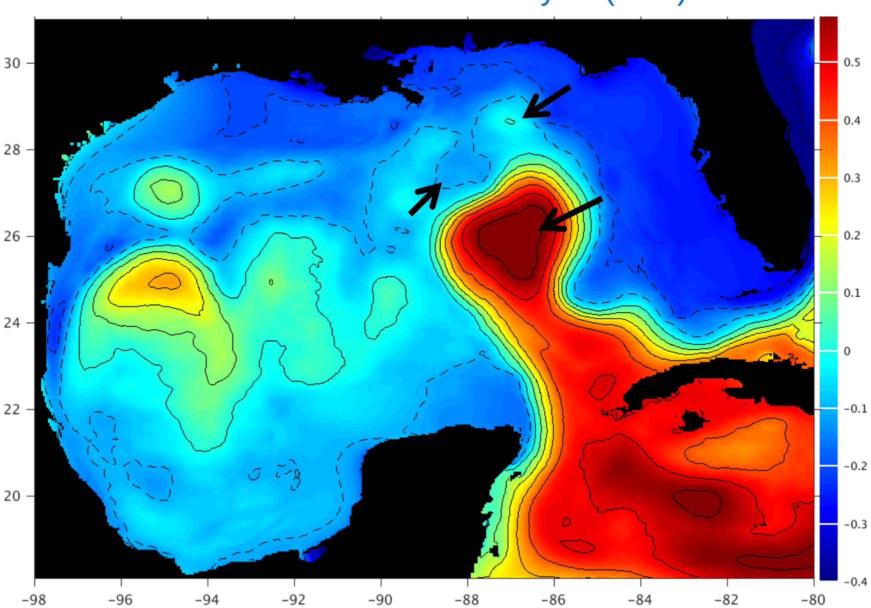
0.08º GoM HYCOM Reanalysis (50.1)



0.08º GoM HYCOM Analysis (20.1)

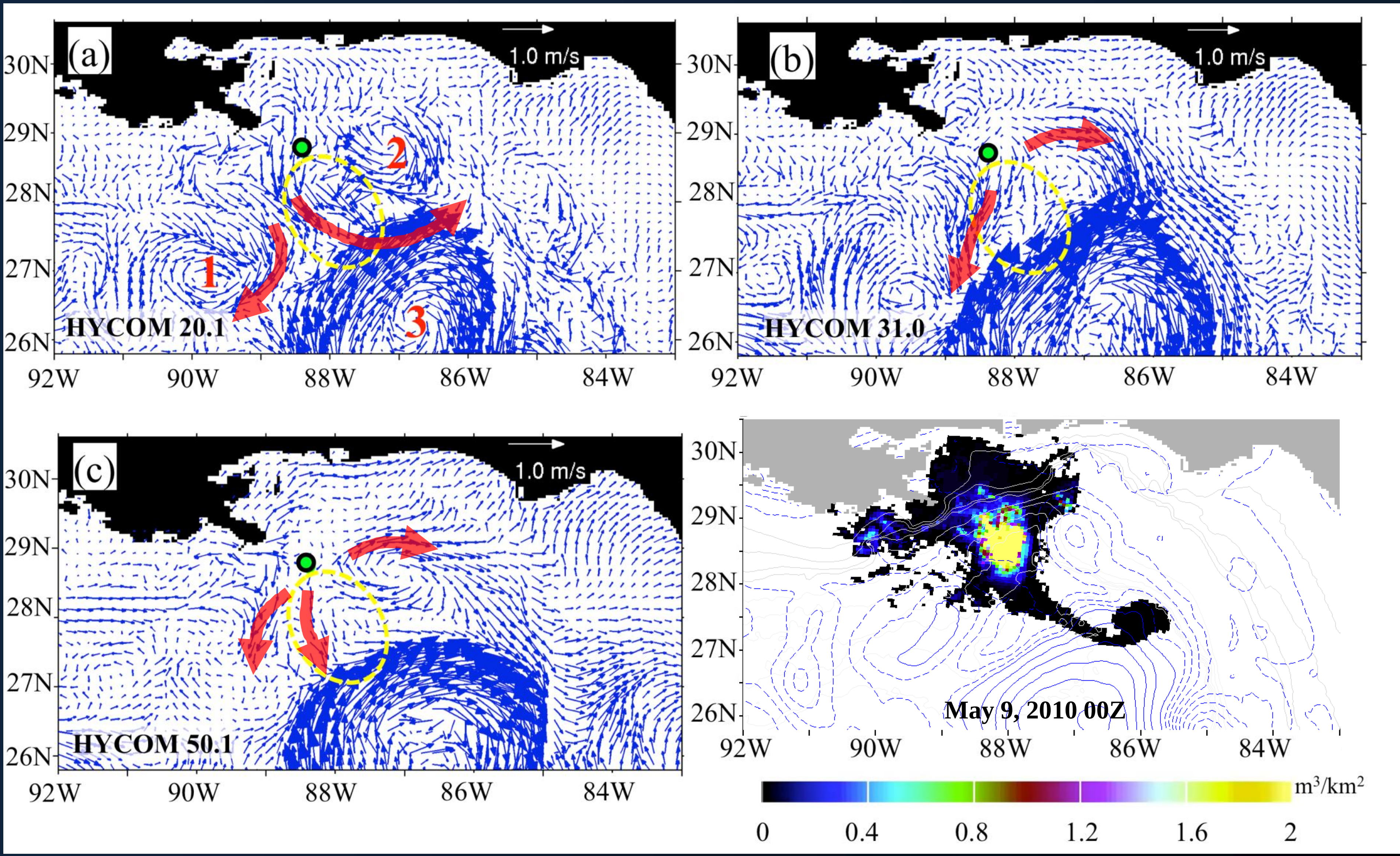


0.08º GoM HYCOM Analysis (31.0)

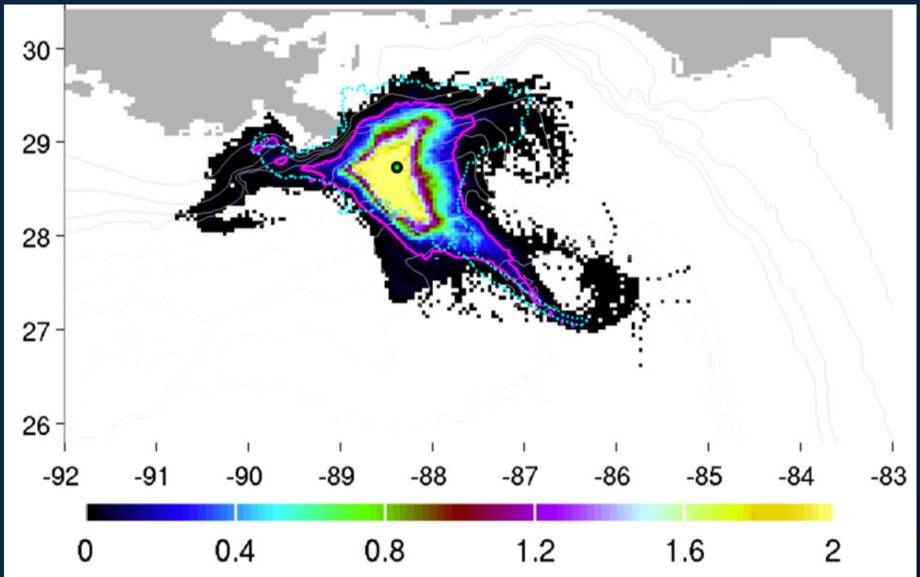


The Near-Surface Circulation from HYCOM Analysis/Reanalysis

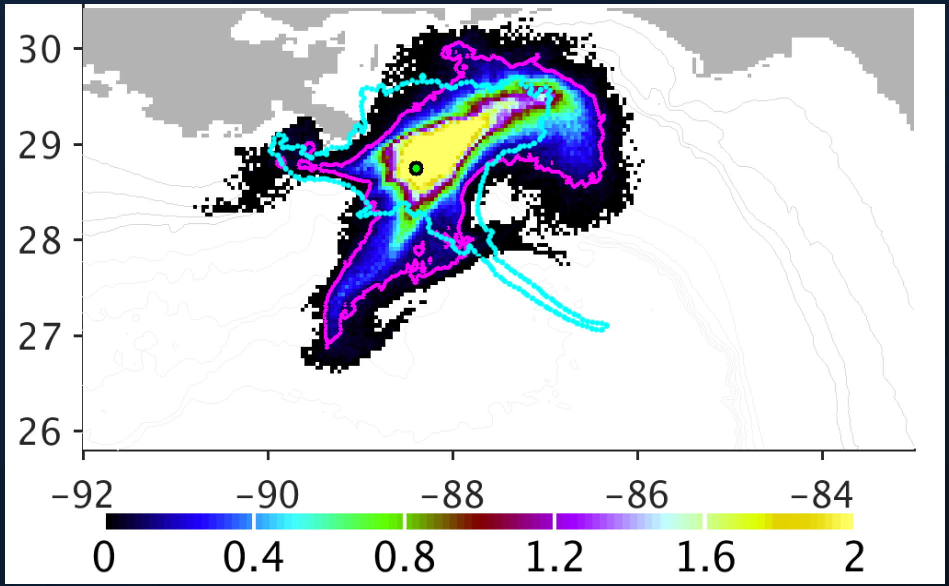
8 May, 2010



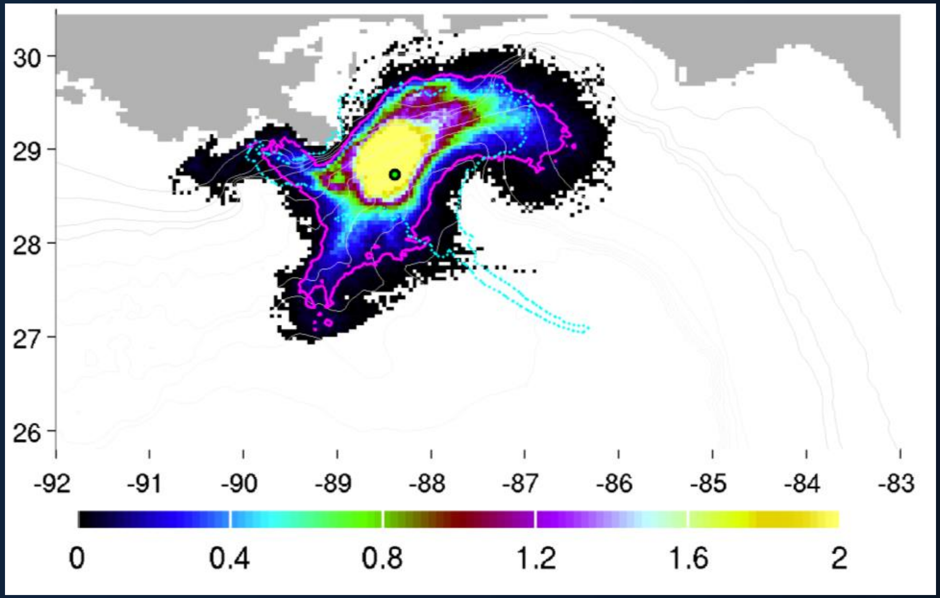
HYCOM 20.1



HYCOM 31.0



HYCOM 50.1



Oil Forecasts from the Oil Drift Simulations Forced by Different HYCOM Analyses

Model Parameters

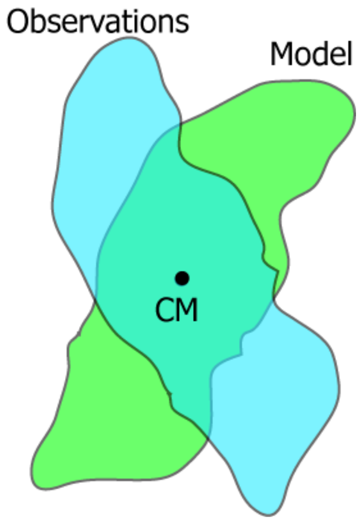
- Half-life: 7 days
- Wind forcing: CFSR
- Wind deflection angle: Speed-dependent
- No Wave Effect

Uncertainties in the Model Parameters

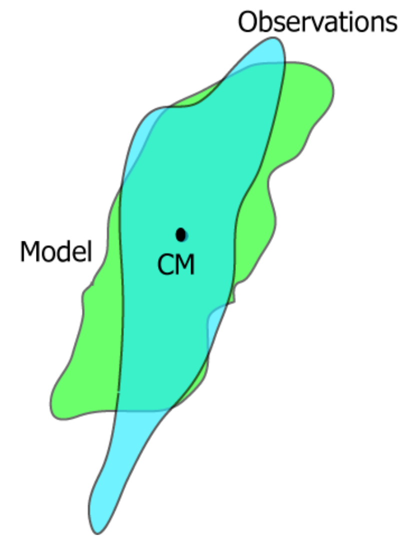
Half-Life and Wind Coefficients

$$\mathbf{u}_a = \mathbf{u}_c + C_w \left\| \mathbf{u}_{10} \right\| \Theta + C_s \mathbf{u}_s$$

Requirements for an Objective Validation Metric



Similar dispersion, shape, and center location
Different shape orientation (rotation)



Similar dispersion and center location
Different shape

- **Attributes that are considered significant to the shape of the oil slicks:**

  - Scale
  - Translation
  - Rotation

- **A skill metric should also be resistant to noise**

Validation Metrics: Topological Approach

Hausdorff Distance (HD)

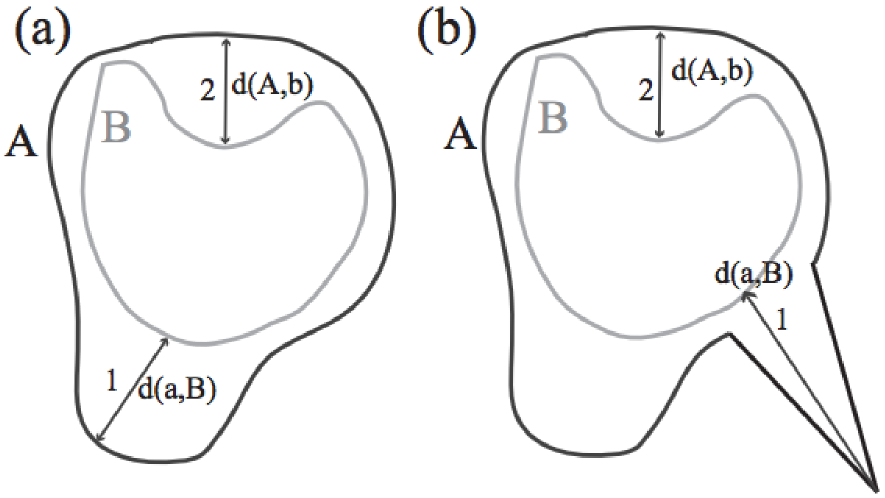
Definition. Let (M, d) be a metric space and $A, B \subset M$. We define the ***Hausdorff distance***, d_H, by

$$d_H(A,B) = \max\left\{\sup_{a\in A} d(a,B), \sup_{b\in B} d(A,b)\right\},$$

where $d(a,B) = \inf_{b\in B} d(a,b)$ and similarly for $d(A,b)$.

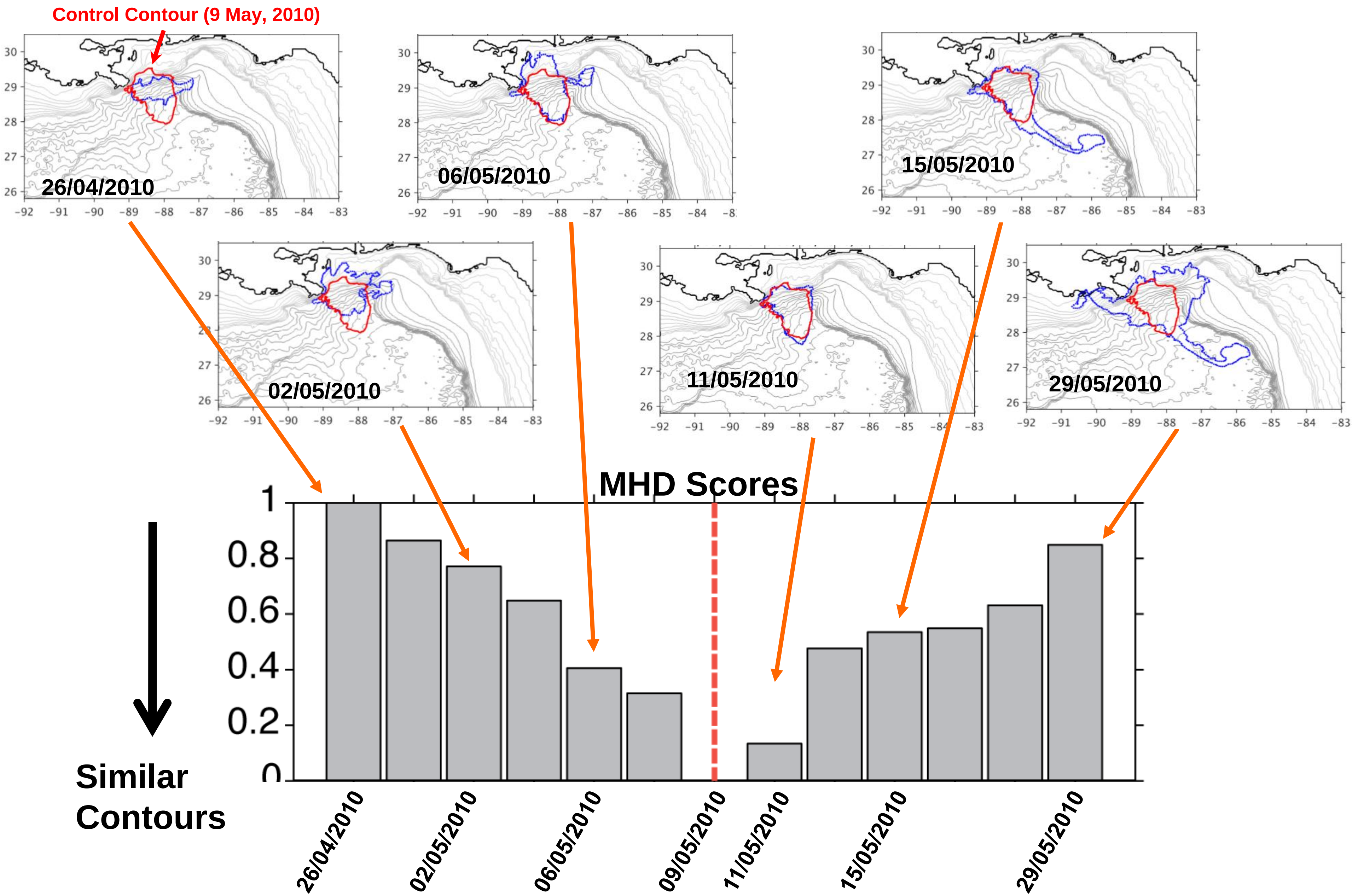
Modified Hausdorff Distance (MHD)

$$d_{MH}(A,B) = \max\left\{\frac{1}{|A|}\sum_{a\in A} d(a,B), \frac{1}{|B|}\sum_{b\in B} d(A,b)\right\}$$



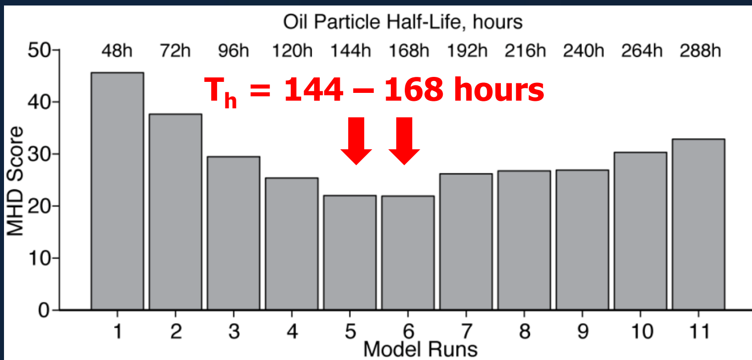
Dukhovskoy et al., JGR, 2015

Oil Volume Contours Compared to the Contour on 9 May, 2010



Estimation of Half-Life (T_h) from SAR Observations and Oil Drift Model

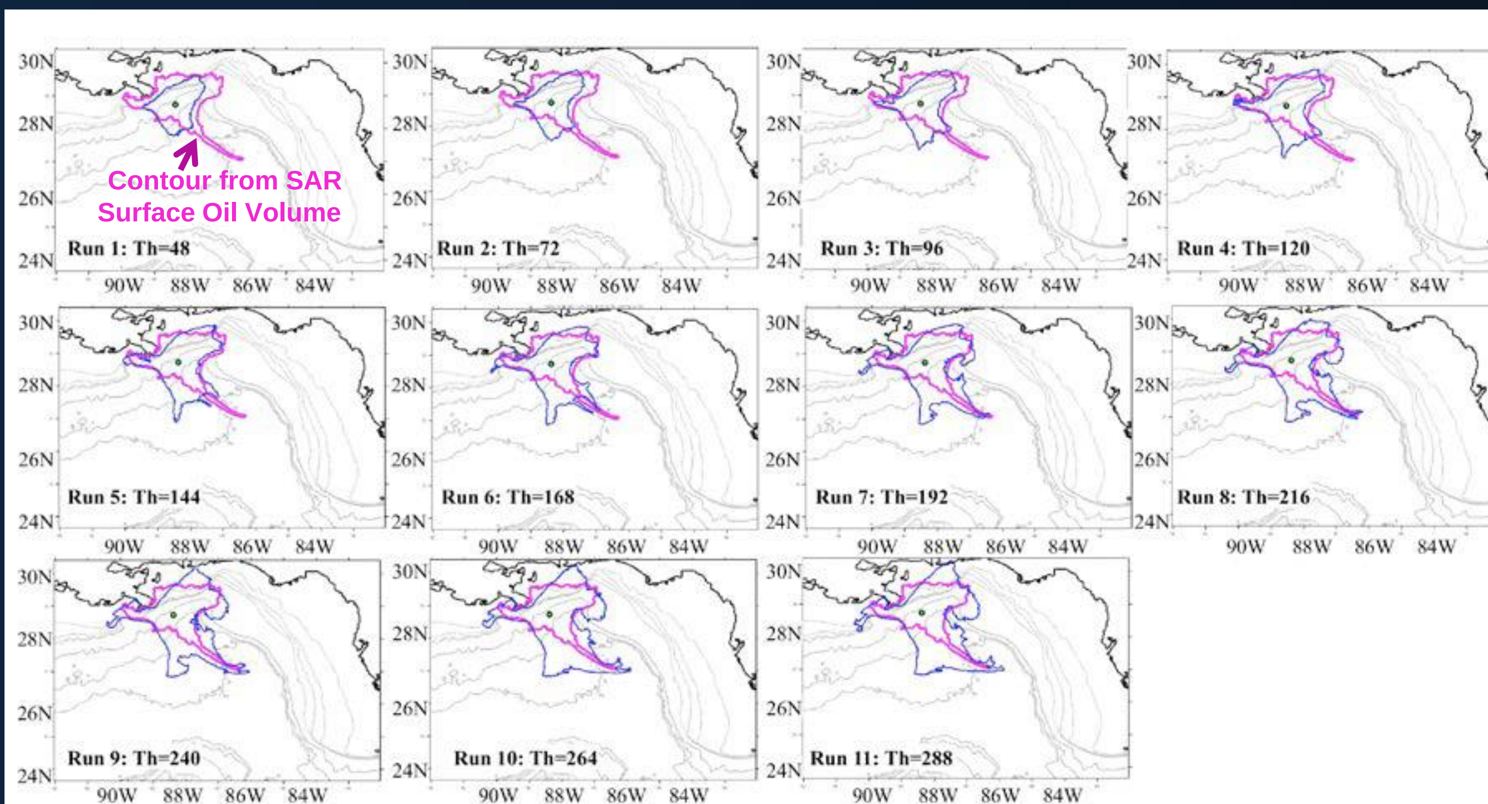
MHD Scores



Oil Forecasts from the Oil Drift Simulations with Varying Half-Life

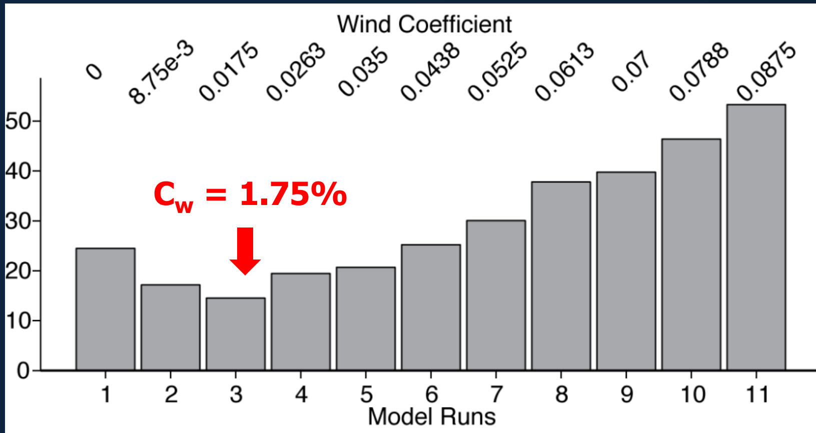
Model Parameters

- Half-life: Varying
- Wind forcing: CFSR
- Wind deflection angle: Speed-dependent
- Wind coefficient: 2%



Estimation of Wind Coefficient from SAR Observations and Oil Drift Model

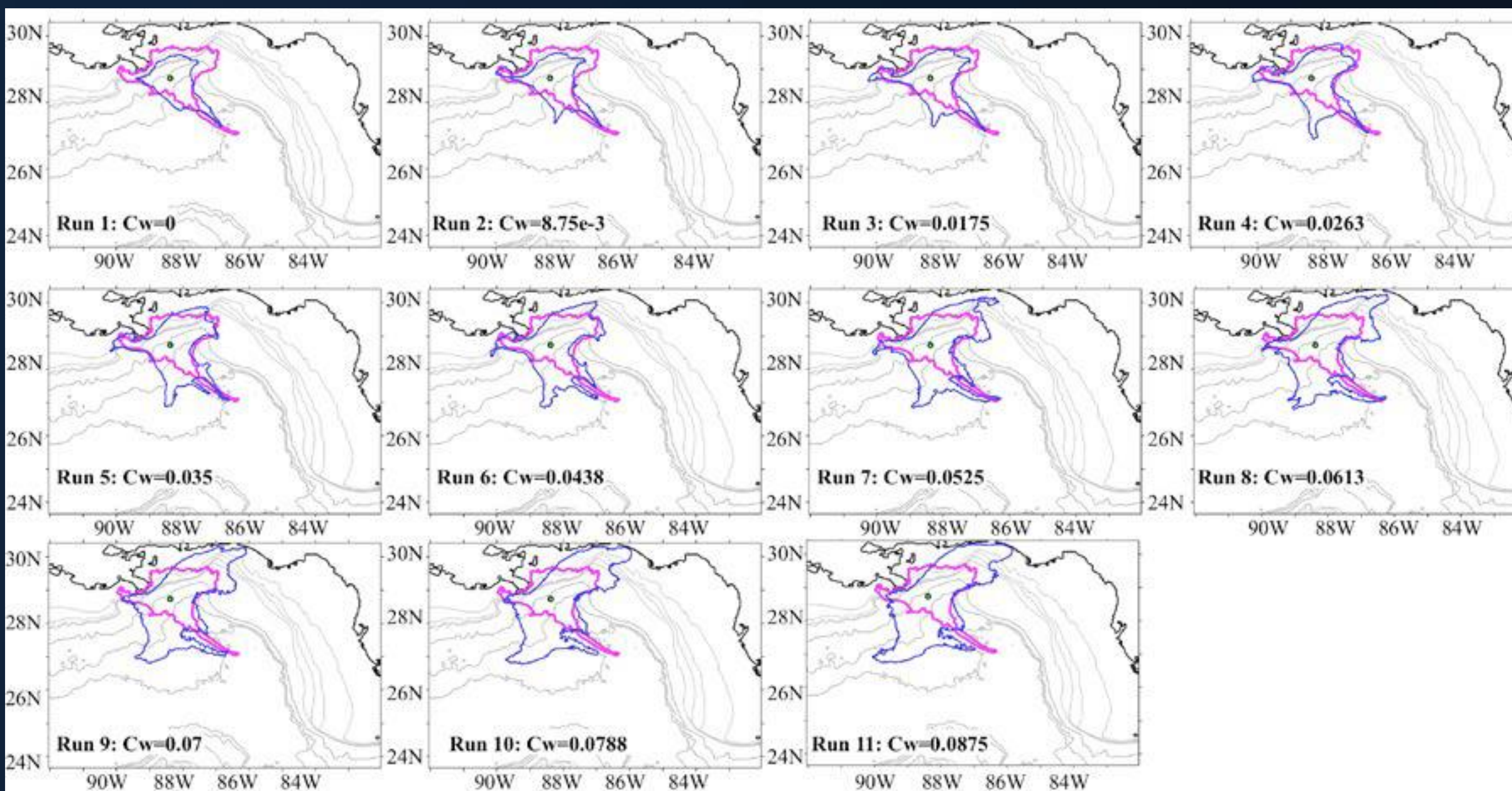
MHD Scores



Oil Forecasts from the Oil Drift Simulations with Varying Wind Coefficient

Model Parameters

- Half-life: 144 hours
- Wind forcing: CFSR
- Wind deflection angle: Speed-dependent
- Wind coefficient: Varying



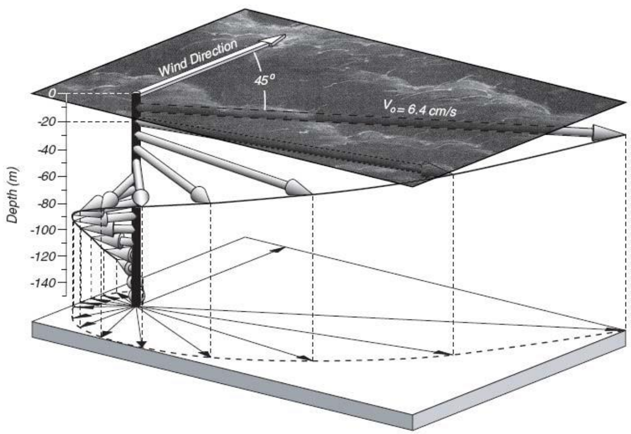
Uncertainties in the Forcing Fields

Surface Ocean Currents
vs
Layer-Averaged Currents

$$\mathbf{u}_a = \mathbf{u}_c + C_w \|\mathbf{u}_{10}\| \Theta + C_s \mathbf{u}_s$$

Impact of Representation of the Ocean Surface Currents on Simulated Oil Drift Trajectories

Ekman current generated by a 10 m/s wind

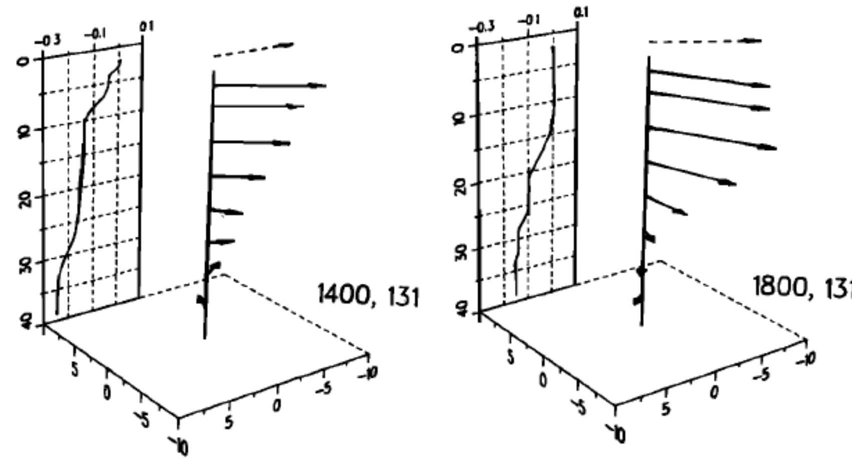


$$\left[u^2(z) + v^2(z)\right]^{1/2} = V_0 \exp(az) \qquad a = \sqrt{\frac{f}{2A_z}}$$

Introduction to Physical Oceanography, http://oceanworld.tamu.edu/resources/ocng_textbook/chapter09/chapter09_02.htm

Velocity profiles from ship observations in the Pacific off California (April, 1980)

Strong vertical shear of the wind-driven velocity appears when temperature stratification develops in the upper ocean during the day

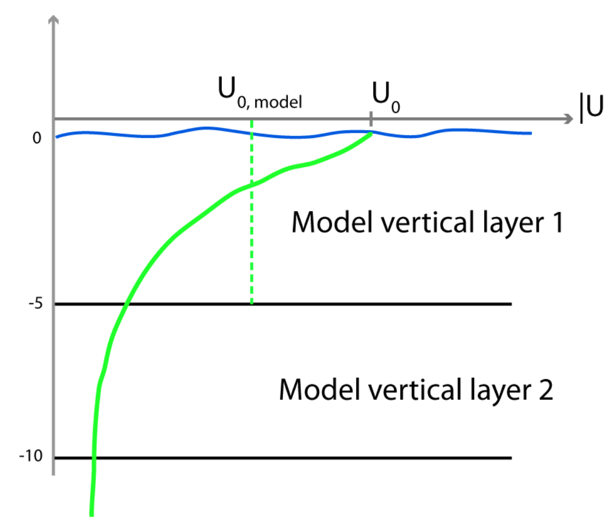


Research Questions:

(1) *How sensitive is simulated surface oil drift trajectories to the representation of the ocean surface currents?*

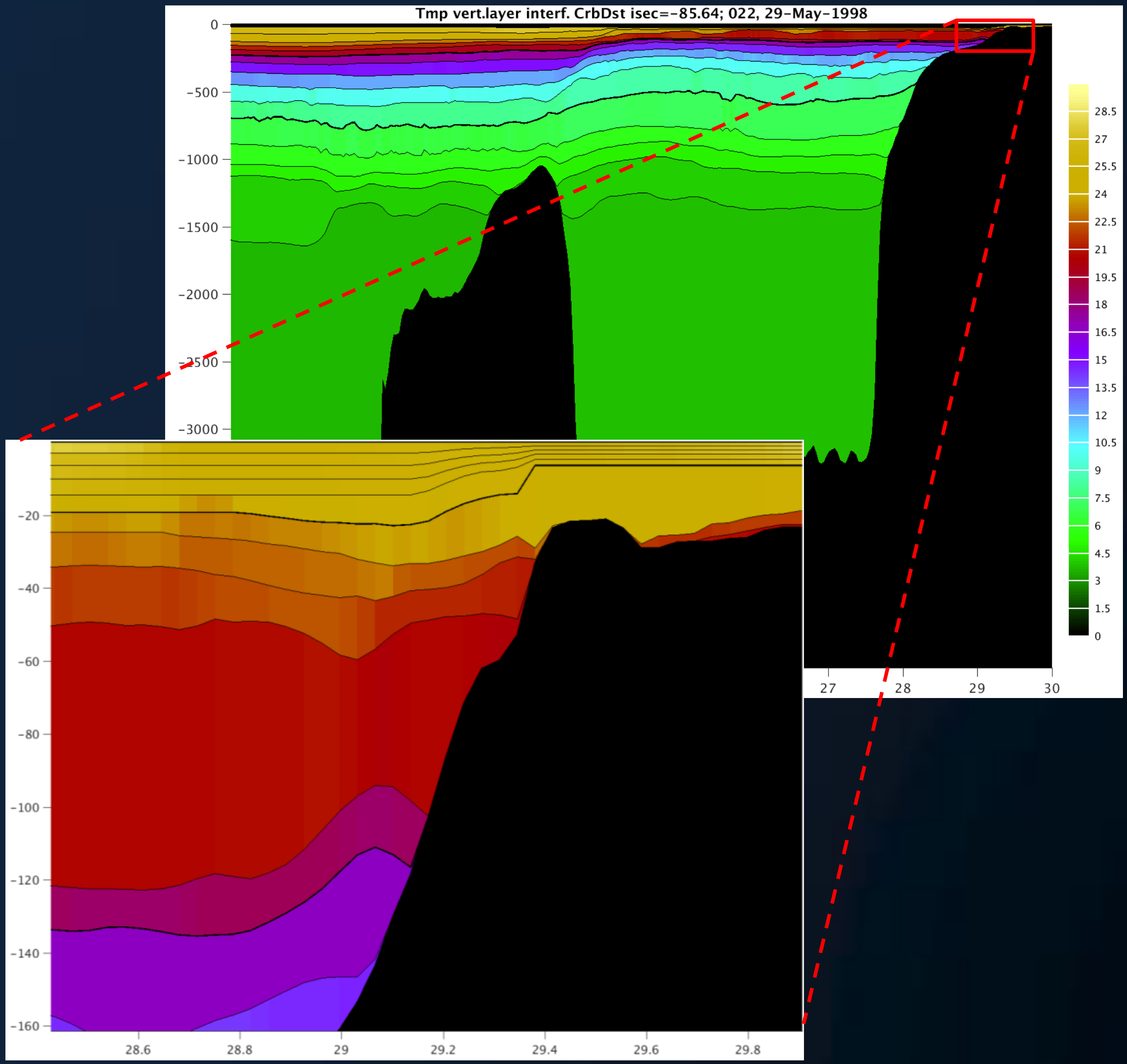
(2) *How different is the depth-averaged velocity relative to the surface current?*

(3) *How do parameters approximating the surface current in a typical surface oil drift model change for different layer-averaged velocities?*



Vertical Coordinate Layers in HYCOM

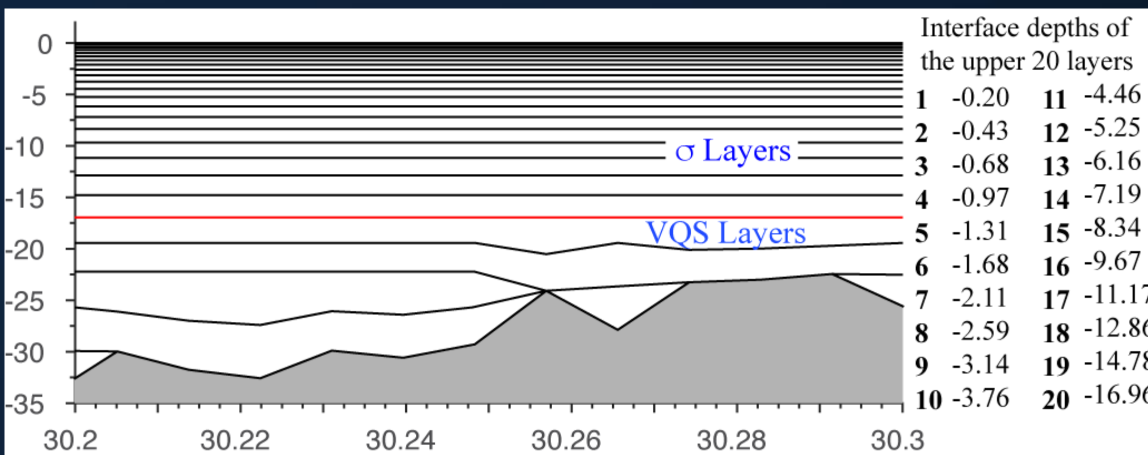
HYCOM Native Vertical Grid



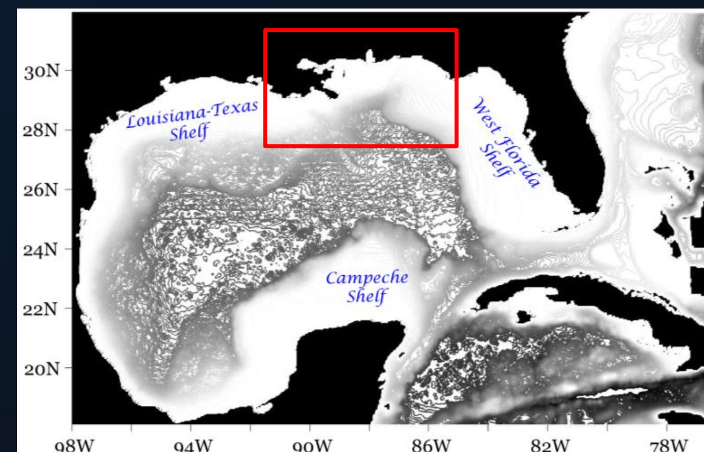
NCOM Configuration for the Sensitivity Experiments

- The Navy Coastal Ocean Model (NCOM) is configured for the northern Gulf of Mexico with super-fine vertical discretization of the near-surface ocean layer
- The model is used to perform sensitivity experiments with the oil drift model

Vertical NCOM Layers in a Shallow Water



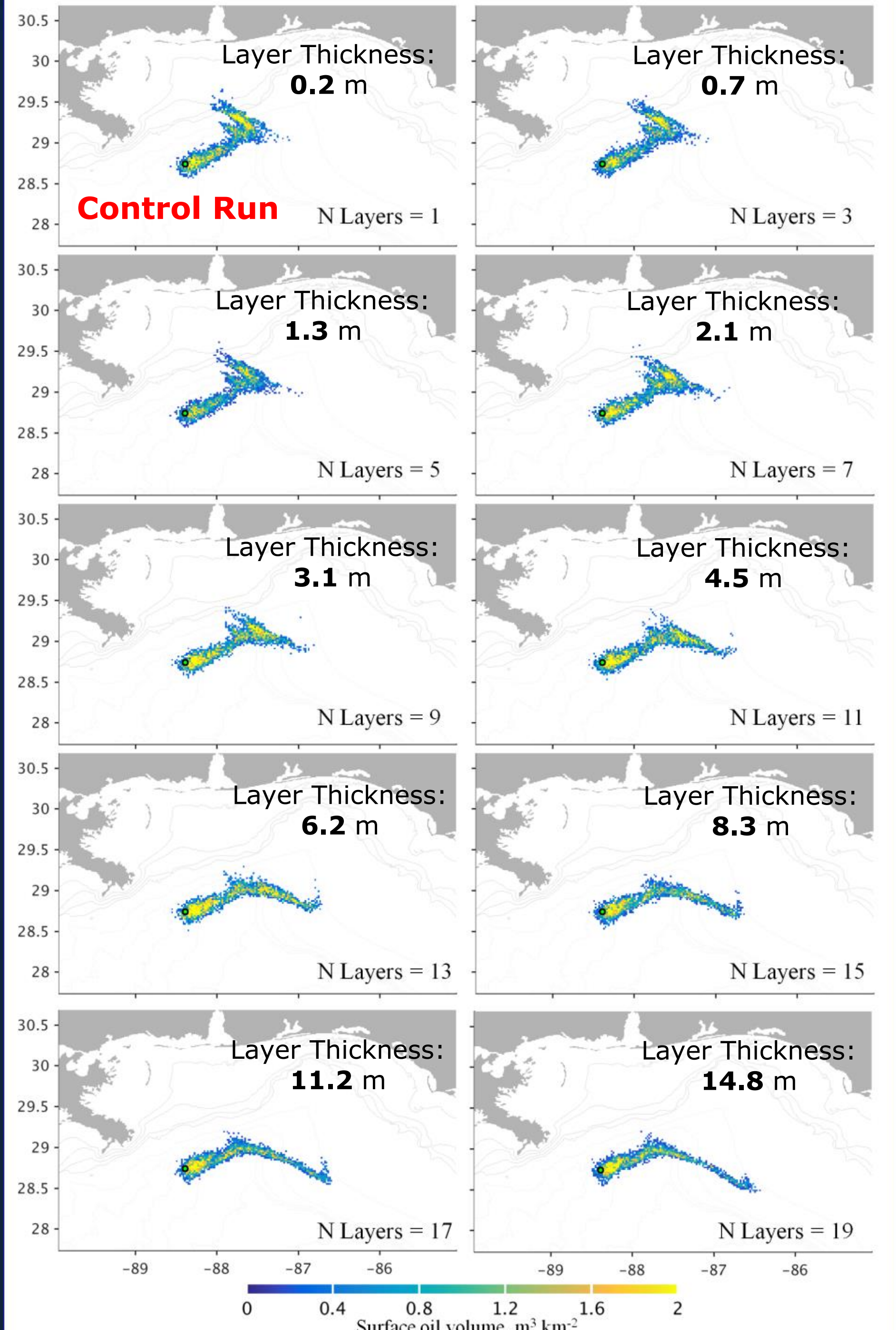
NCOM Domain



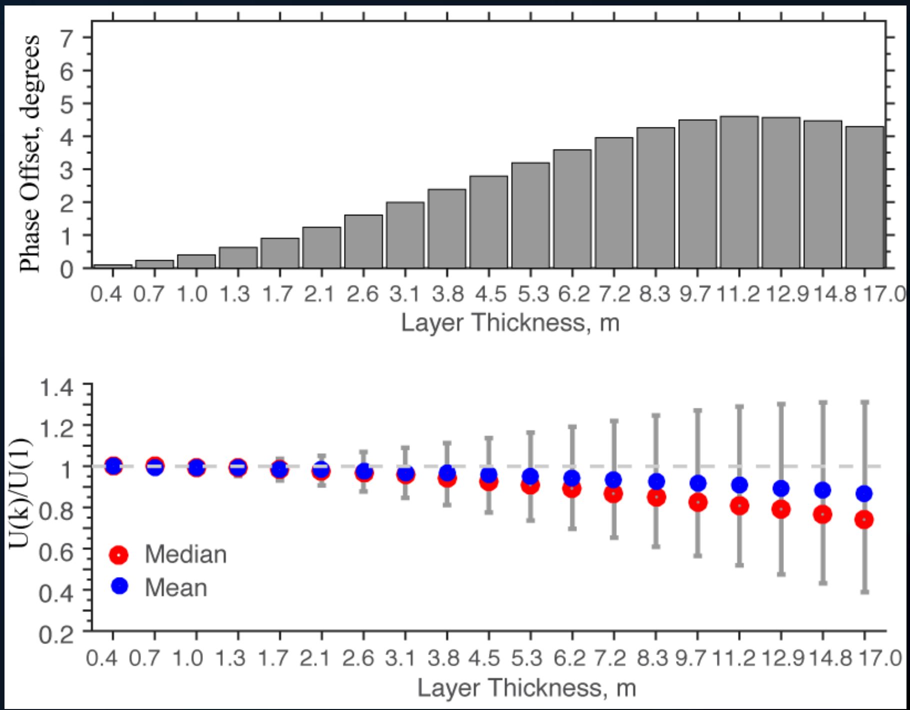
Thicknesses of the depth-averaged layers in the sensitivity experiments

Experiment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
N layers	1	3	5	7	9	11	13	15	17	19
Thickness (m)	0.2	0.7	1.3	2.1	3.1	4.5	6.2	8.3	11.2	14.8

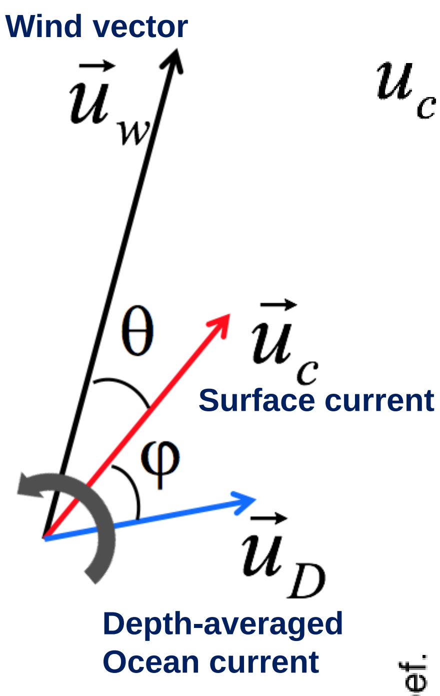
Surface oil volume derived from the sensitivity oil drift model experiments on May 5, 2010



Differences between the surface current vector and depth-averaged ocean current derived from the NCOM simulation



Estimation of Surface Current from the Depth-Averaged Currents and Wind

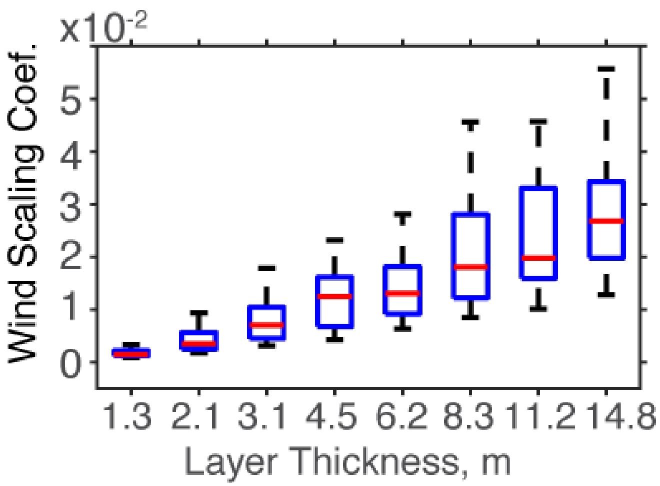


$$u_c + iv_c = C_D e^{i\varphi}(u_D + iv_D) + C_w e^{i\theta}(u_w + iv_w)$$

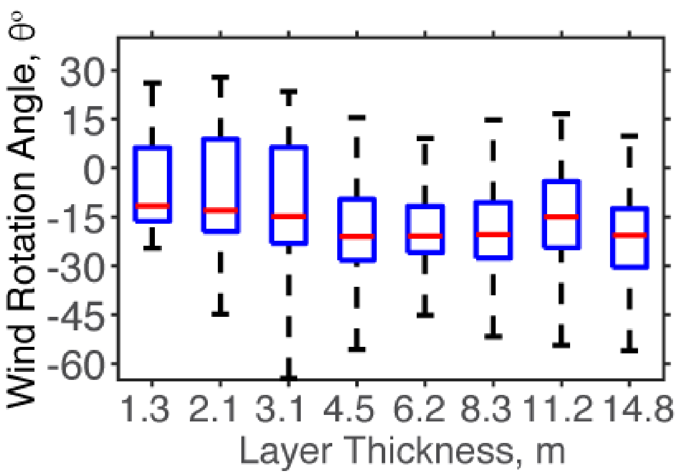
C_D = 1 and φ = 0: Case when the near-surface (layer-averaged) ocean currents from a hydrodynamic model is considered to represent the true surface current

Parameter Estimates from the Sensitivity Experiments

Wind Scaling Coefficient (C_w)



Wind Rotation Angle (θ)



Summary

- **Two groups of uncertainty sources in surface oil drift models have been discussed**
  - ✶ Uncertainties in the forcing fields (ocean currents): Nothing can be done to overcome the problem.
  - ✶ Uncertainties in the model parameters: Parameters can be adjusted to provide the most accurate fit to the observations.

- **Accurate representation of the ocean dynamics in hydrodynamic models advecting the oil particles is crucial for forecasting of the oil trajectories**
  - ✶ Offshore, location of mesoscale features largely determines surface oil spreading.
  - ✶ Onshore, winds, waves, and river runoff play a bigger role.

- **Depth-averaged near-surface currents from hydrodynamic models: The numerical experiments demonstrate sensitivity of the surface oil trajectories to the representation of the ocean surface currents.**
  - ✶ The solutions for surface layers thicker than 1 m notably diverge from the control run simulation (20-cm surface layer).

- **The estimates of the wind coefficient and wind deflection angle in the formula approximating surface oil drift show**
  - ✶ The wind effect is small for the surface layers < 1m (<0.2%) and increases up to 2.8% as the layer thickness.
  - ✶ The wind rotation angle is clockwise. The median is 15°–25°. The estimate has a large uncertainty range.