Modeling the drift and spread of oil slicks in the Northern Gulf of Mexico using SAR imagery and forcing from a high-resolution hydrodynamic model

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Norwegian Meteorological Institute

GULF OF MEXICO RESEARCH INITIATIVE

UNIVERSITY OF MIAMI

Water Mapping

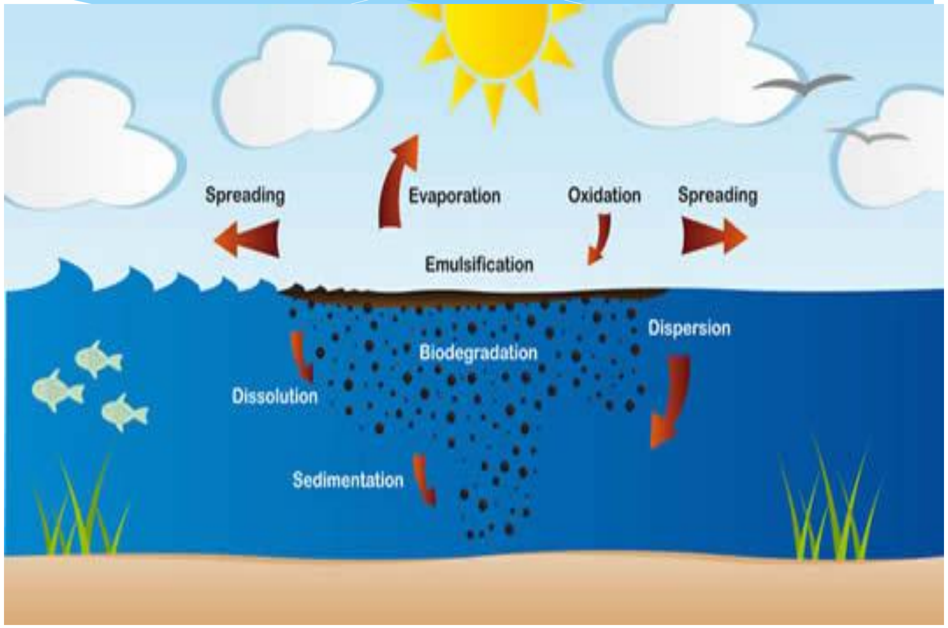
Deepwater Horizon oil spill in 2010: considered the largest accidental marine oil spill in the history of the petroleum industry, with an estimated total discharge of 4.9 million barrels (780,000 m^3) over a period of around 5 months.

BP announced a commitment of up to $500 million over 10 years to fund an independent research program designed to study the impact of the oil spill and its associated response on the environment and public health in the Gulf of Mexico.

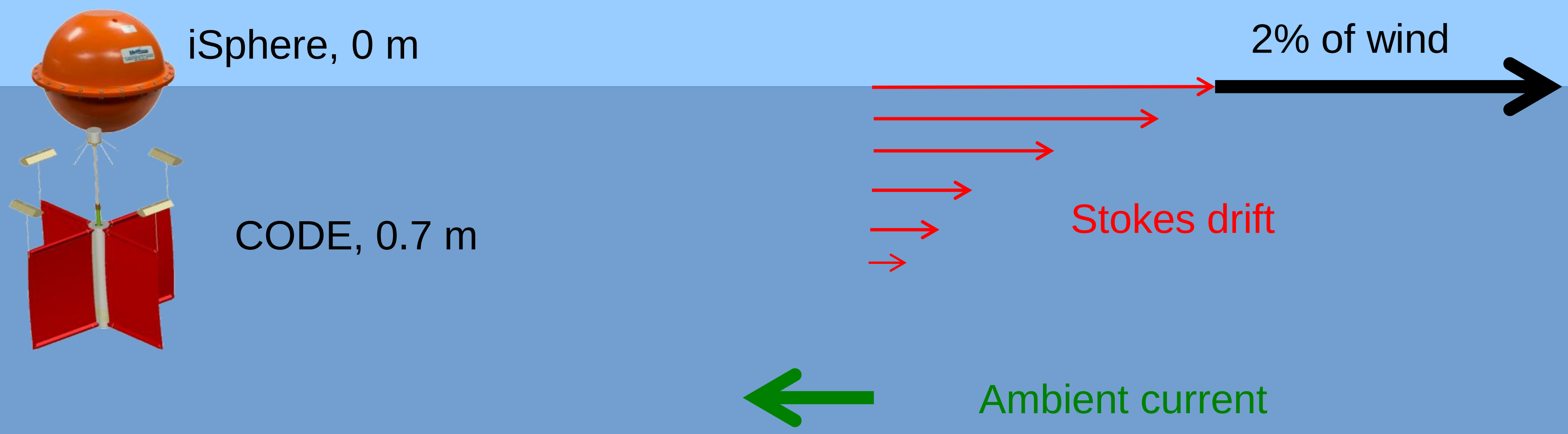
Gulf of Mexico Research Initiative: Investigating the effect of oil spills on the environment and public health

The fate and transport of a surface oil slick over time is controlled by many different components and processes, and modeling requires an inter-disciplinary effort

* Winds, ocean currents, Stokes drift
* Turbulent movement of oil within the upper ocean,
* Oil weathering processes such as evaporation, emulsification and vertical dispersion into the water column.
* Waves enhance vertical mixing of surface oil, with the actual depth of downward mixing and its possible return to the surface dependent on wave height, turbulence, and wind, along with the oil droplet size, mass, and resultant buoyancy.

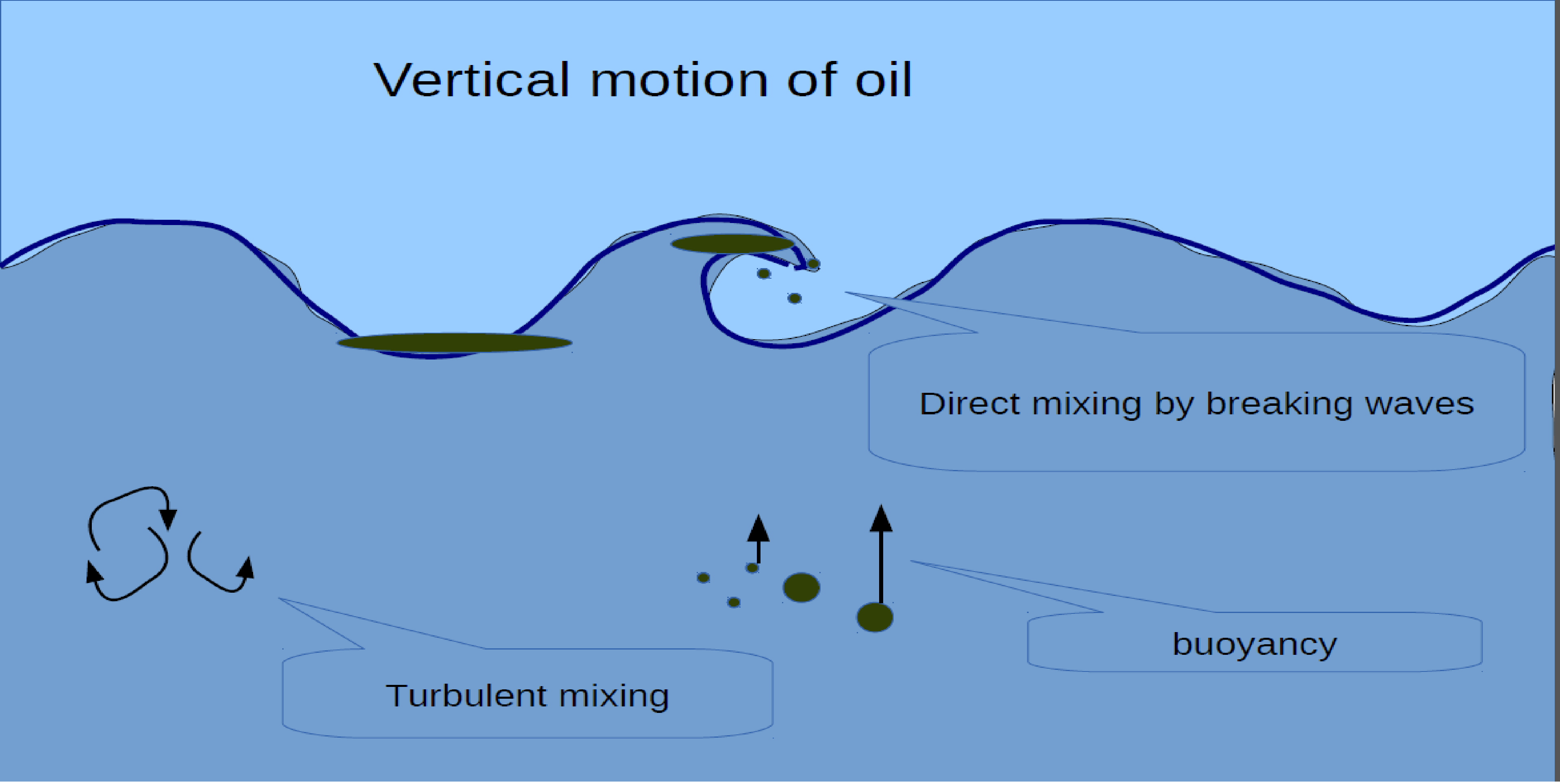


Horizontal motion of oil



The following horizontal forcing is considered:

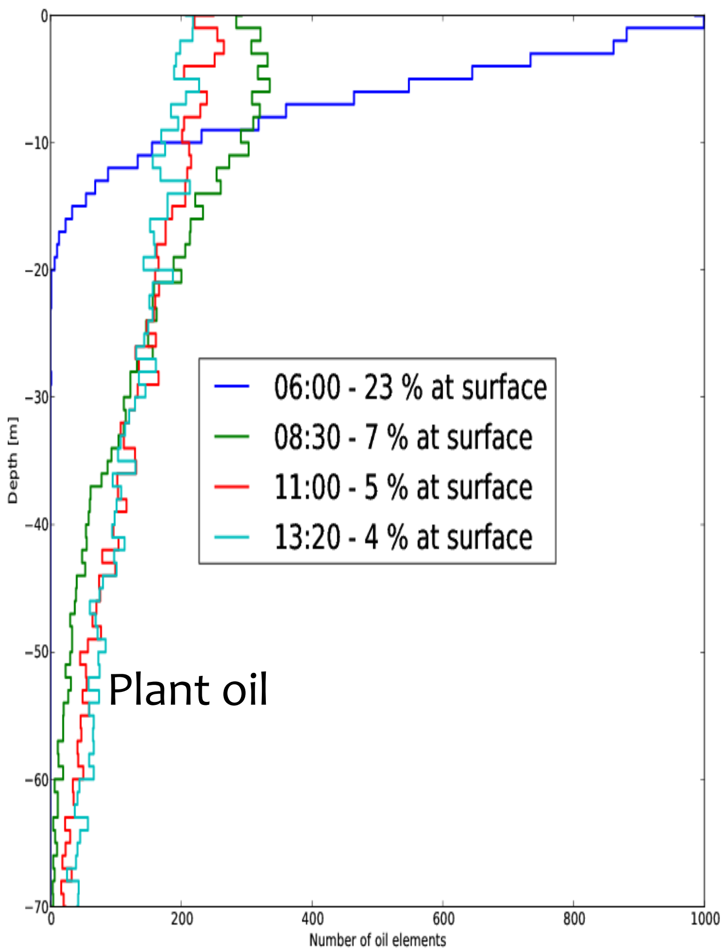
- **Movement with ocean currents**, from ~1.8 km resolution HYCOM model
- **Stokes drift**, with surface values from a 10km WAM wave model (ECMWF), and depth variation calculated according to Breivik et al. (2014, 2016).
- **Direct wind drift** of oil (slick) at the ocean surface: 2% of the wind vector from the ECMWF model in combination with Stokes drift (~1.5% of wind), the combined surface drift of 3.5% of wind corresponds to empirical observations

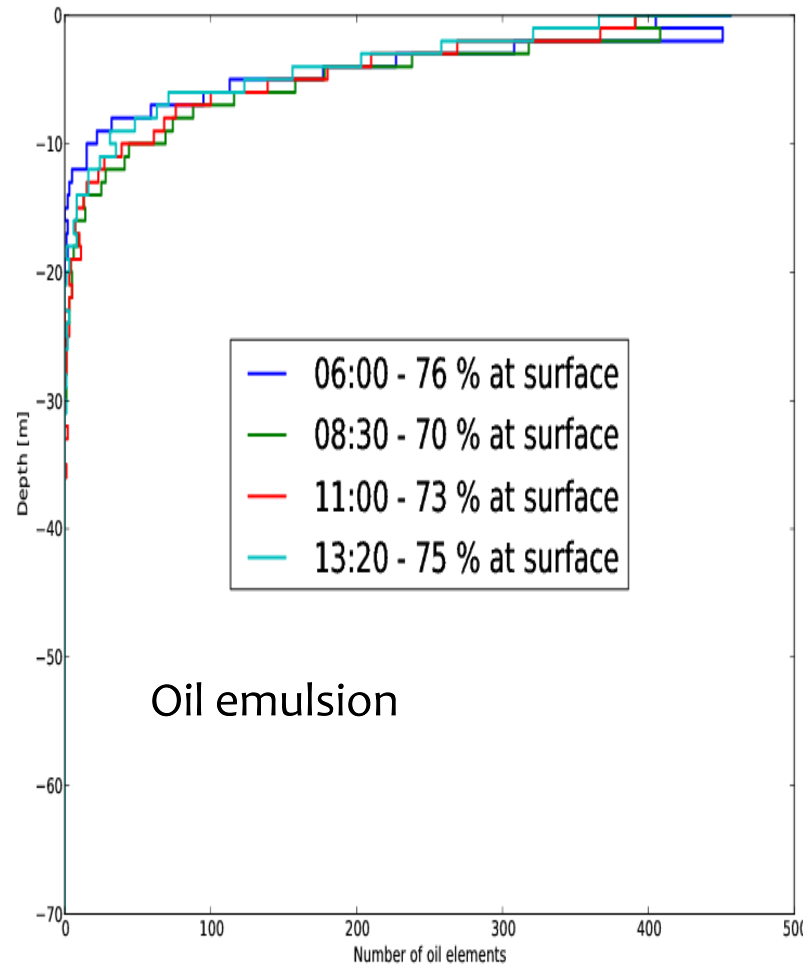


The following vertical movement is considered:
Oil at ocean surface is **entrained by waves** at a rate depending on wave dissipation and oil properties, according to Tkalich et al. (2002).
Buoyant rising is calculated from oil droplet radii and density, as well as sea water viscosity and vertical density gradient.
Vertical turbulent motion is calculated numerically with a binned random walk scheme (Thygesen and Adlandsvik, 2007) in which the eddy diffusivity, obtained from ocean model or parameterized from wind, controls the probability for each particle being mixed upwards or downwards.

Vertical distribution of different oil types:

There is a distinct difference between the transport of e.g. a biogenic oil and a mineral oil emulsion, in particular in the vertical direction, with faster and deeper entrainment of significantly smaller droplets of the biogenic oil. The difference in depth profiles for the two types of oils is substantial, with most of the biogenic oil residing below depths of 10 m, compared to the majority of the emulsion remaining above 10 m depth.





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OilLibMETNorway.csv

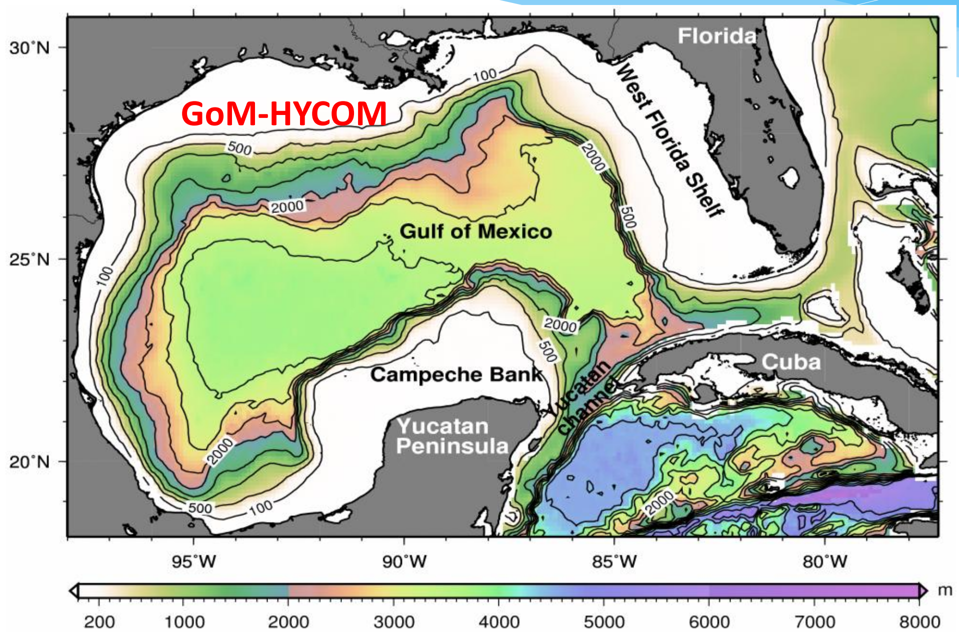
Fil Rediger Visning Sett inn Format Data Verktøy Tillegg Hjelp Alle endringer er lagret i Disk

knutfd@met.no Kommentarer Del

NOAA database of ~1000 different oil types

	A	C	D						M	X	Y
1	2	adios									
2	Oil Name	Location	Field Name	Reference	API	Pour Point Min (I	Pour Point Max (	Product Type	Asphaltene Cont	Wax Content	Density#1 (kg/m	Density#1 Re
3	ALVE	NORWAY	ALVE	Sørheim K. R. et al., 2010, Kartleg		2.7315e2	2.7315e2	Crude	3e-4	5.0e-2	7.961e2	2.8865e2
4	ALVHEIM BLEN	NORWAY	ALVHEIM	Leirvik F., Myrhaug J. L., 2009, W		2.7015e2	2.7015e2	Crude	6e-4	5.3e-2	8.40e2	2.8865e2
5	ALVHEIM BOA	NORWAY	ALVHEIM	Leirvik F., Myrhaug J. L., 2009, W		2.3715e2	2.3715e2	Crude	3e-4	2.8e-2	8.481e2	2.8865e2
6	ALVHEIM KAME	NORWAY	ALVHEIM	Leirvik F., Myrhaug J. L., 2009, W		<2.3415e2	<2.3415e2	Crude	1e-4	3.2e-2	8.50e2	2.8865e2
7	ALVHEIM KNEL	NORWAY	ALVHEIM	Leirvik F., Myrhaug J. L., 2009, W		2.7315e2	2.7315e2	Crude	1.1e-3	4.9e-2	8.315e2	2.8865e2
8	AVALDSNES	NORWAY	JOHAN SVERDI	Sørheim K. R., 2012, Avaldsnes c		2.7615e2	2.7615e2	Crude	1.8e-2	2.9e-2	8.91e2	2.8865e2
9	BALDER	NORWAY	BALDER	Moldestad M. Ø., Schrader T., 2002, Ringhorne, Forseti og Balder - E				Crude			9.14e2	2.8865e2
10	BALDER BLEND	NORWAY	BALDER	Sørheim K. R., Leirvik F., 2010, K		2.7615e2	2.7615e2	Crude	8e-3	3.5e-2	8.64e2	2.8865e2
11	BRAGE	NORWAY	BRAGE	Farooq U., 2013, Brage crude oil -		2.6715e2	2.6715e2	Crude	1e-3	4.7e-2	8.26e2	2.8865e2
12	BREAM	NORWAY	BREAM	Strøm T., Leirvik F., 2011, Weathe		2.9115e2	2.9115e2	Crude	1.8e-2	4.3e-2	8.57e2	2.8865e2
13	CAURUS	NORWAY	CAURUS	Strøm T., Leirvik F., 2011, Caurus		2.5215e2	2.5215e2	Crude	5e-4	2.6e-2	7.95e2	2.8865e2
14	DRAUGEN	NORWAY	DRAUGEN	Leirvik F., 2008, Draugen - Egensl		2.4915e2	2.4915e2	Crude	1.3e-3	2.4e-2	8.23e2	2.8865e2
15	EKOFISK	NORWAY	EKOFISK	Moldestad M. Ø. et al., 2002, Eko		2.6115e2	2.6115e2	Crude	6e-4	4.74e-2	8.548e2	2.8865e2
16	EKOFISK BLEN	NORWAY	EKOFISK	Moldestad M. Ø. et al., 2002, Eko		2.7315e2	2.7315e2	Crude	7e-4	4.93e-2	8.507e2	2.8865e2
17	EKOFISK BLEN	NORWAY	EKOFISK	Hellstrøm K. C., Brandvik P. J., 20		2.4015e2	2.4015e2	Crude	3e-4	2.90e-2	8.41e2	2.8865e2
18	EKOFISK J	NORWAY	EKOFISK	Hellstrøm K. C., Brandvik P. J., 20		2.6115e2	2.6115e2	Crude	2e-4	3.69e-2	8.46e2	2.8865e2
19	ELDFISK	NORWAY	ELDFISK	Moldestad M. Ø. et al., 2002, Eko		2.6715e2	2.6715e2	Crude	7e-4	4.59e-2	8.125e2	2.8865e2
20	ELDFISK B	NORWAY	ELDFISK	Hellstrøm K. C., Brandvik P. J., 20		2.7315e2	2.7315e2	Crude	2e-4	4.30e-2	8.54e2	2.8865e2
21	ELDFISK BLENI	NORWAY	ELDFISK	Hellstrøm K. C., Brandvik P. J., 20		2.6115e2	2.6115e2	Crude	1e-4	2.79e-2	8.46e2	2.8865e2
22	ELDFISK KOMP	NORWAY	ELDFISK	Hellstrøm K. C., Brandvik P. J., 20		2.7315e2	2.7315e2	Crude	8e-4	3.55e-2	8.42e2	2.8865e2
23	ELLI	NORWAY	JOTUN	M. Resby J. L. et al., 1999, Jotun		2.7615e2	2.7615e2	Crude	2e-3	1.13e-1	8.39e2	2.8865e2
24	ELLI SOUTH	NORWAY	JOTUN	M. Resby J. L. et al., 1999, Jotun		2.8515e2	2.8515e2	Crude	9e-4	8.28e-2	8.38e2	2.8865e2
25	EMBLA	NORWAY	EMBLA	Moldestad M. Ø. et al., 2002, Eko		2.4915e2	2.4915e2	Crude	2e-4	7.88e-2	8.163e2	2.8865e2
26	FORSETI	NORWAY	BALDER	Moldestad M. Ø., Schrader T., 20		2.7015e2	2.7015e2	Crude	7e-3	2.4e-2	9.16e2	2.8865e2
27	FOSSEKALL	NORWAY	SKULD	Guyomarch J., 2013, Weathering		2.9115e2	2.9115e2	Crude	8e-3	9.1e-2	8.54e2	2.9315e2
28	FRAM	NORWAY	FRAM	Andreassen I., Sørheim K. R., 20		2.7615e2	2.7615e2	Crude	1.1e-3	5.3e-2	8.50e2	2.8865e2
29	FRØY	NORWAY	FRØY	Brandvik P. J. et al., 1996, Weath		2.8515e2	2.8515e2	Crude	2.0e-3	5.1e-2	8.36e2	2.8865e2
30	GARANTIANA	NORWAY	GARANTIANA	Farooq U., Johnsen M., 2013, Gar		3.0315e2	3.0315e2	Crude	8.0e-3	1.07e-1	8.73e2	2.8865e2

Model setup

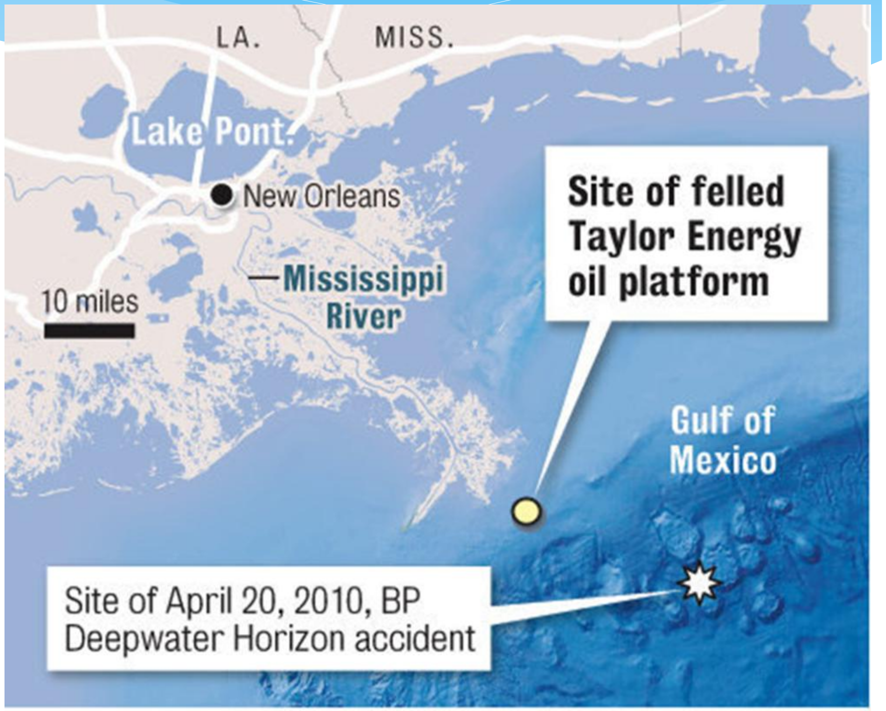


- High resolution hydrodynamic model: Gulf of Mexico Hybrid Coordinate Ocean Model (1/50 deg. ~ 1.8 km)
- Coastal to offshore interactions well represented *(Le Hénaff and Kourafalou, OceDyn., 2016)*
- Detailed river plume dynamics; *(Schiller & Kourafalou, OceMod. 2010)*
- Daily river inputs / all major rivers
- Atmospheric Forcing: ECMWF Cycle T1279 ~16km (2010)
- Waves: 0.25 degrees resolution ~10km; Parameters: U_{stokes}, V_{stokes}, Hs, Tm

Our study focuses on two sites.

We use SAR images to initialize oil spill simulations from a known active leakage site, the Taylor Energy platform near the Mississippi Delta (leaking oil since 2004).

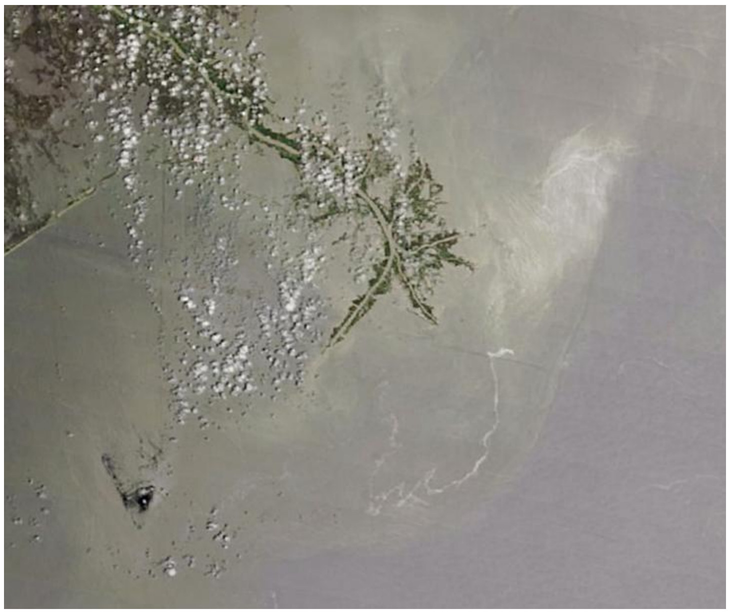
Various horizontal and vertical mixing processes are studied in order to evaluate the relative importance of each individual process, and the drift and spread of a simulated oil slick is compared to the evolution of the real oil slick as picked up in satellite imagery

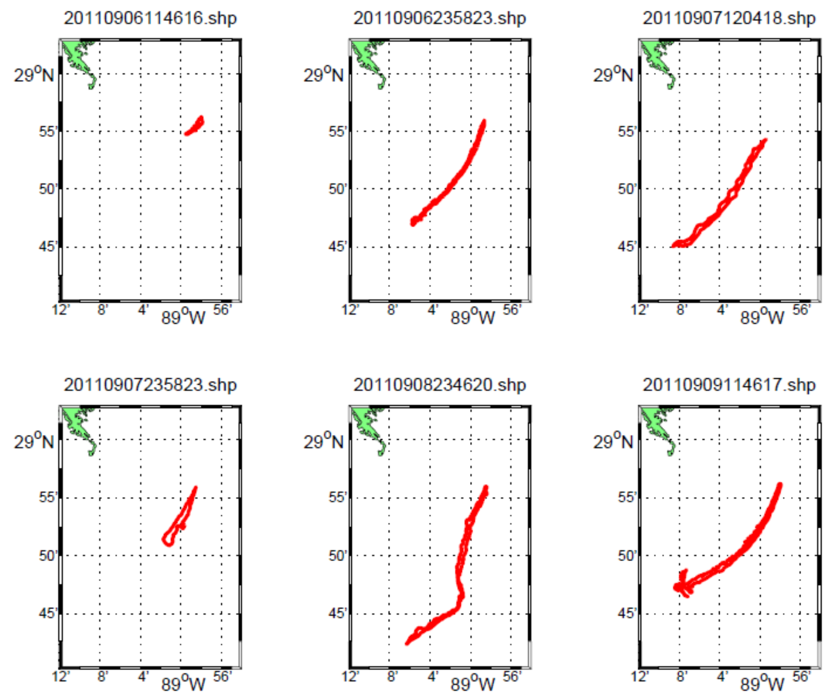


NOLA.com | The Times-Picayune

Taylor site: Due to the oceanographic regime, oil emulsions tend to occur in a band that stretches about 80 km to the southwest and the northeast.

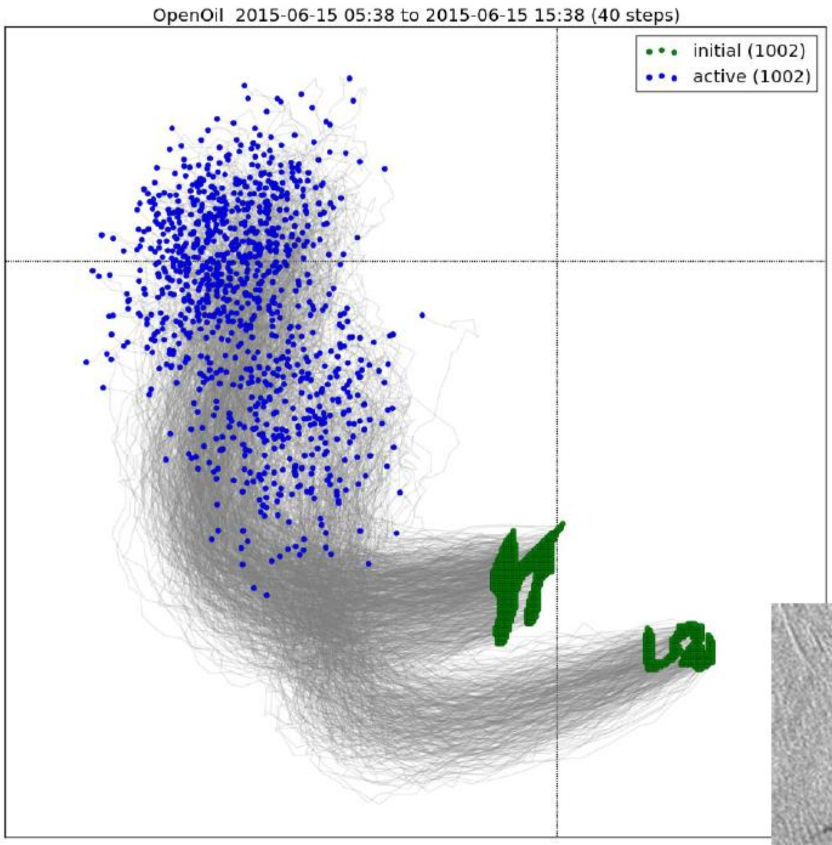
The persistent formation of oil emulsions coupled with the quasi-deterministic location provided a test-bed location to assess the detection of emulsified oil using SAR data.

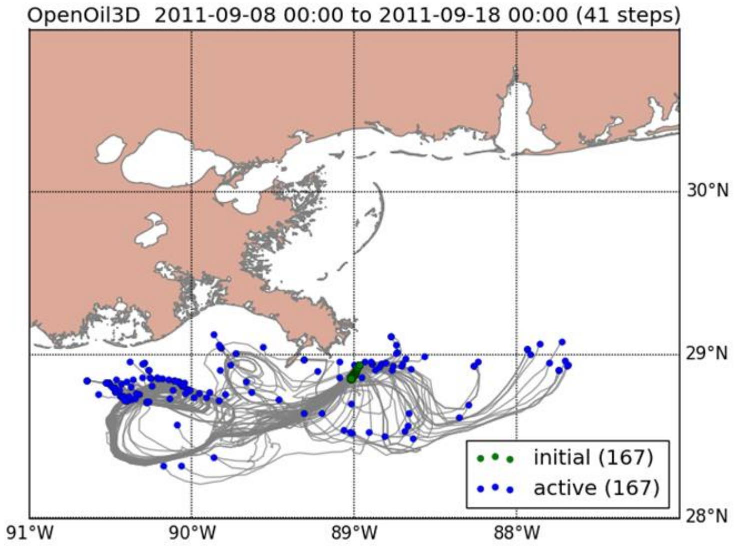




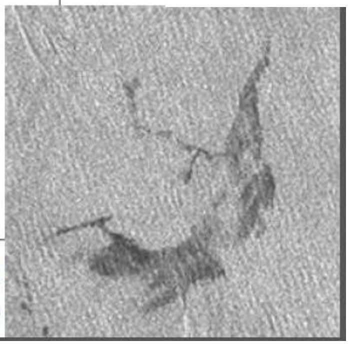
SAR images of oil slicks are described in a geospatial vector data format, and interpreted by the oil spill model to seed oil within the observed shape of the oil slick, and then initiate trajectory simulations.

Initialization from satellite image

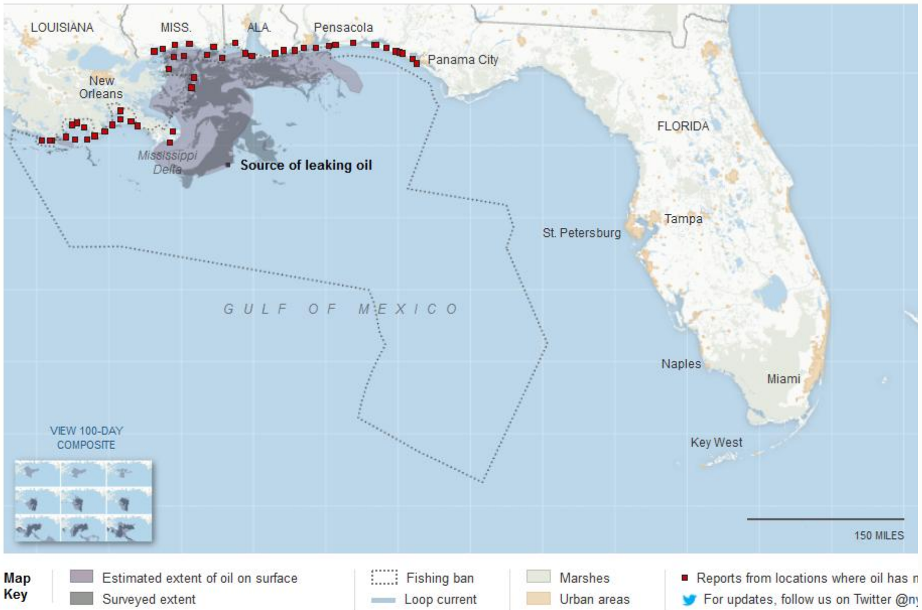


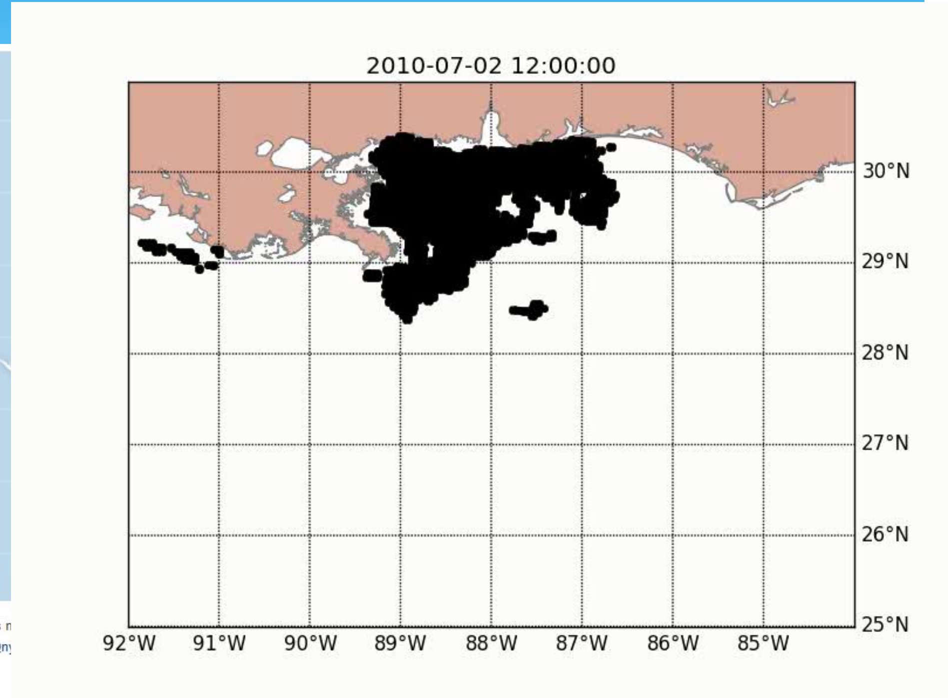


Example of oil slick
seen in SAR image



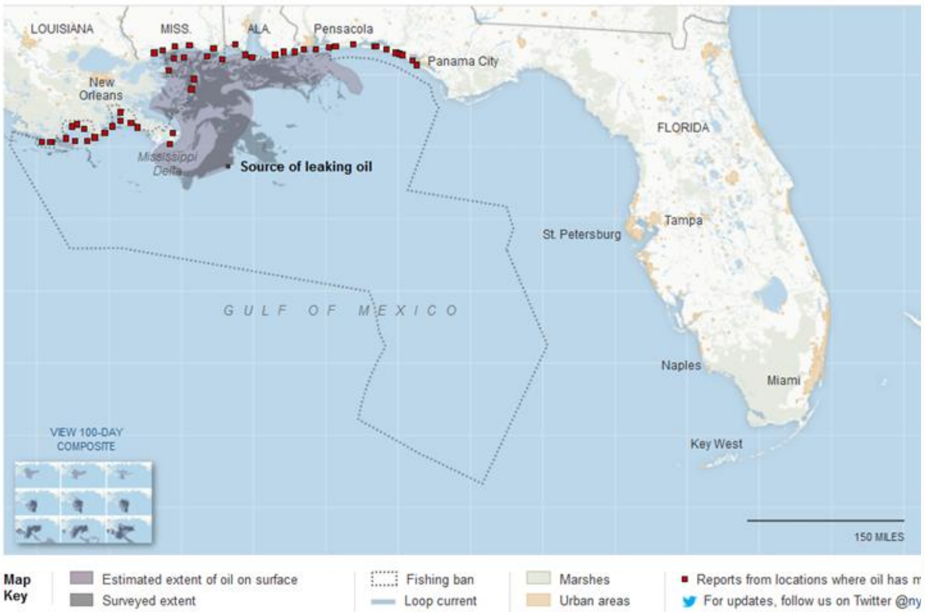
Oil slick trajectory simulation without wave forcing (no Stokes drift, no whitecapping)

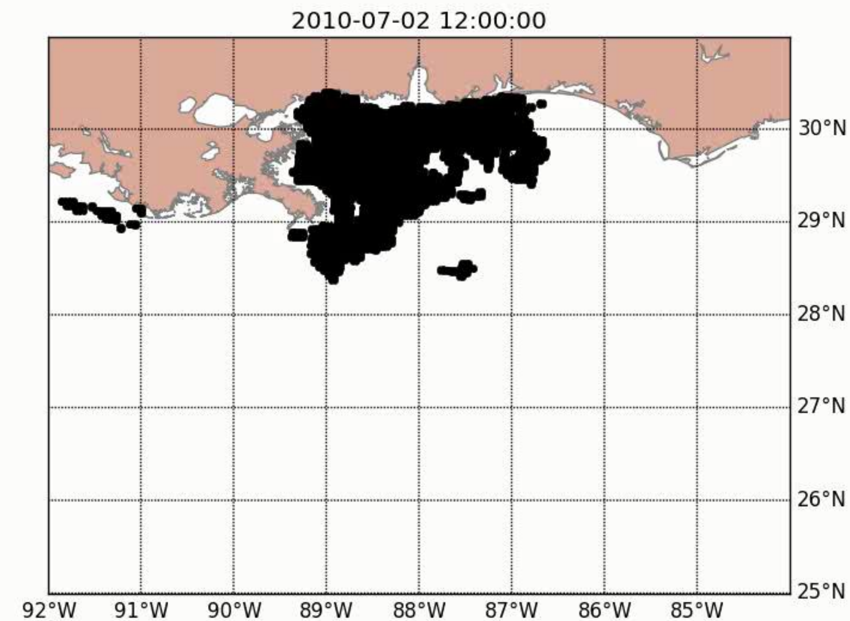




About the Oil Slick and Landfall Locations
The **"estimated extent"** of the oil slick is an estimate by the National Oceanic and Atmospheric Administration of where oil is mostly likely to go based on wind and ocean current forecasts, as well as analysis of aerial photography and satellite imagery.
The **"surveyed extent"** shows areas where oil was visible on the water surface during aerial and satellite surveys of the Gulf. The surveyed extents are not available every day and may be incomplete on occasion because poor weather conditions prevented observation in some areas.

Oil slick trajectory simulation with wave forcing (with Stokes drift and whitecapping)





NY Times

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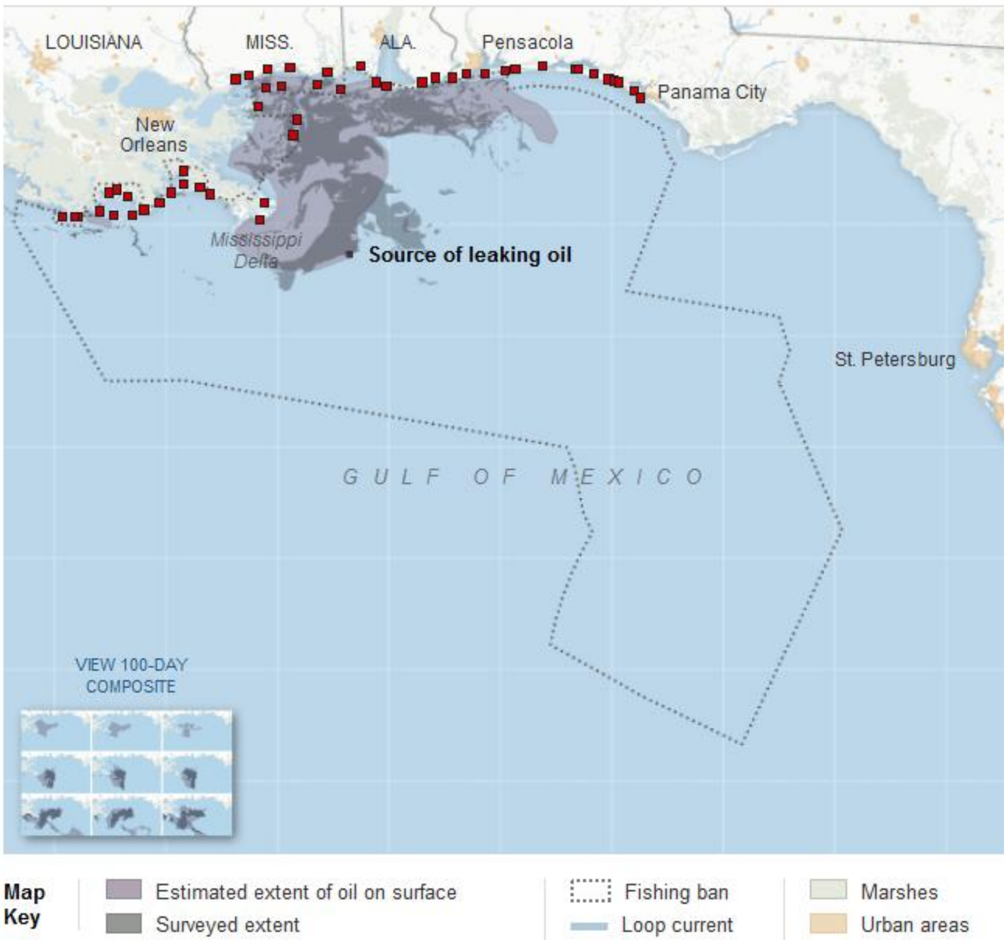
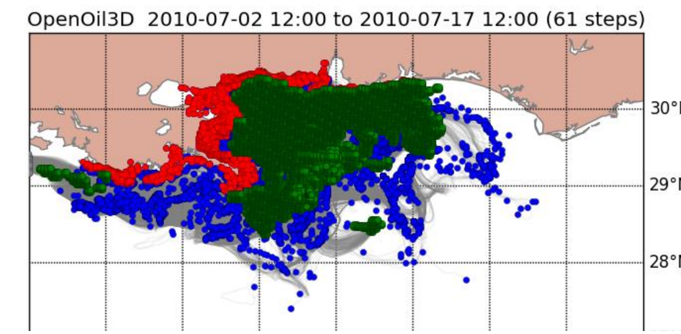
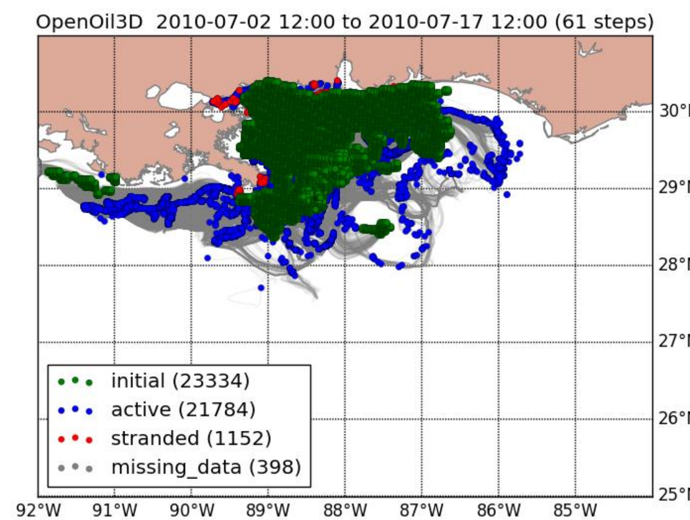
In red: the locations where oil made landfall, based on reports from federal, state and local officials



Oil slick simulation with wave forcing

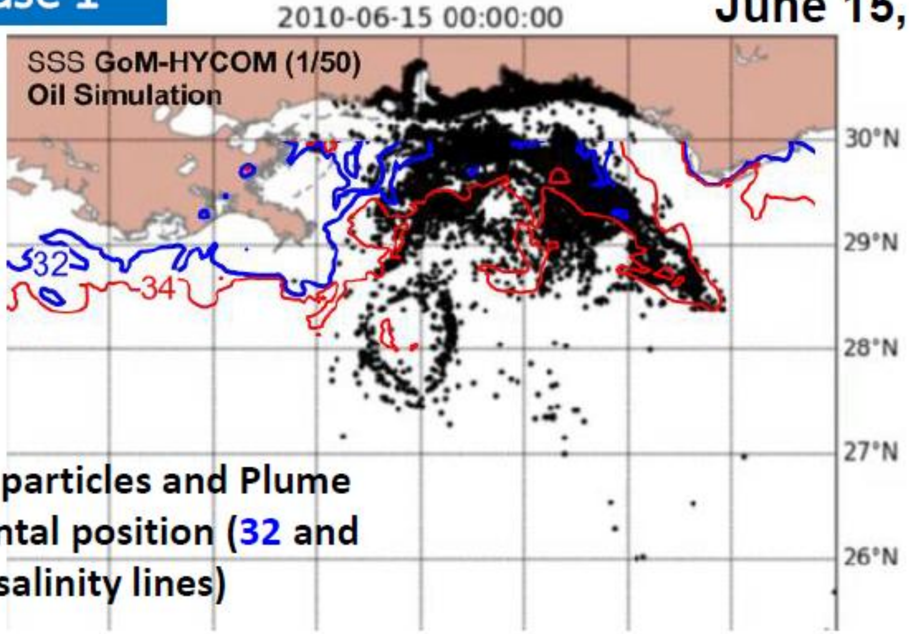




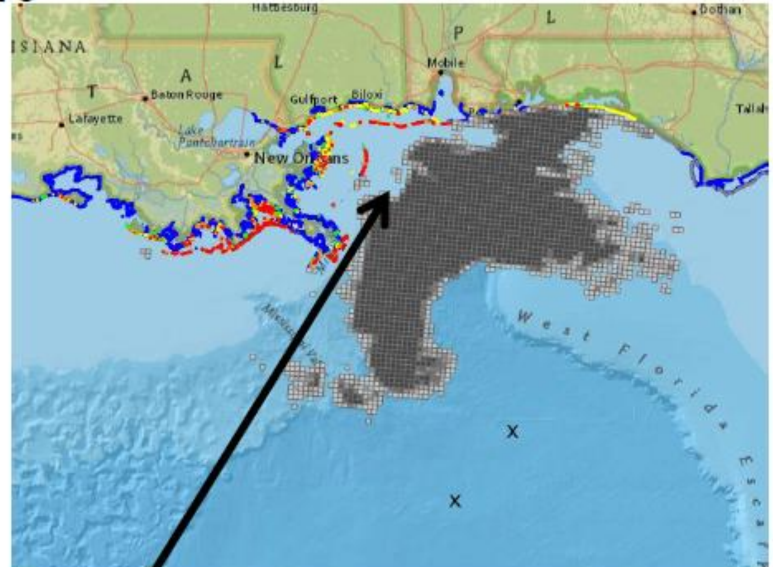
Oil slick simulation without wave forcing

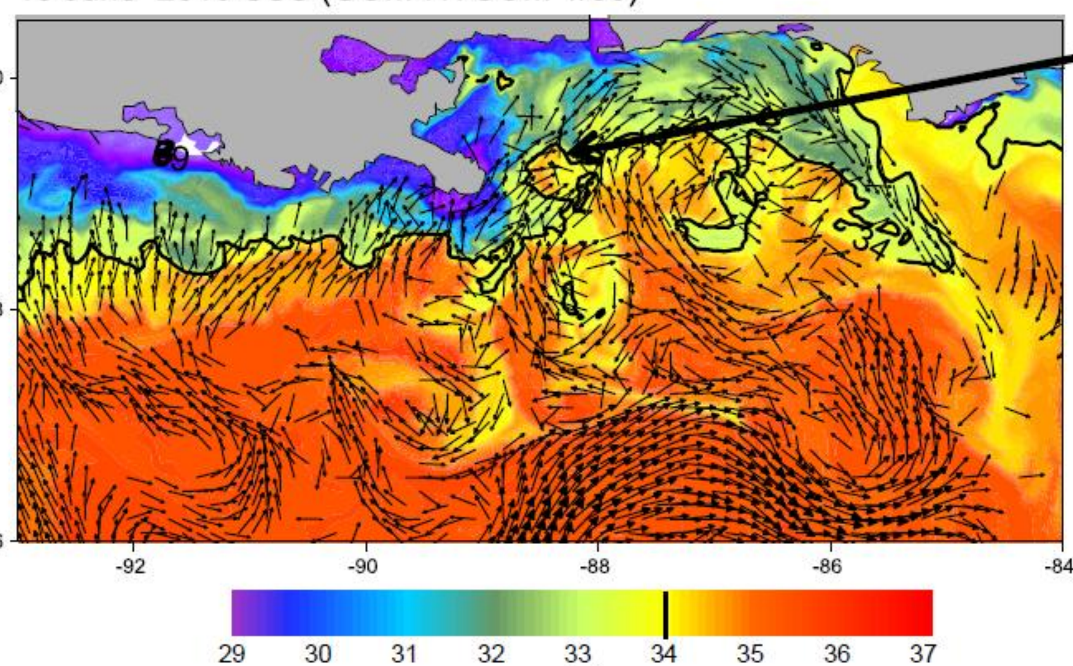
Case 1

June 15, 2010



Oil particles and Plume frontal position (32 and 34 salinity lines)



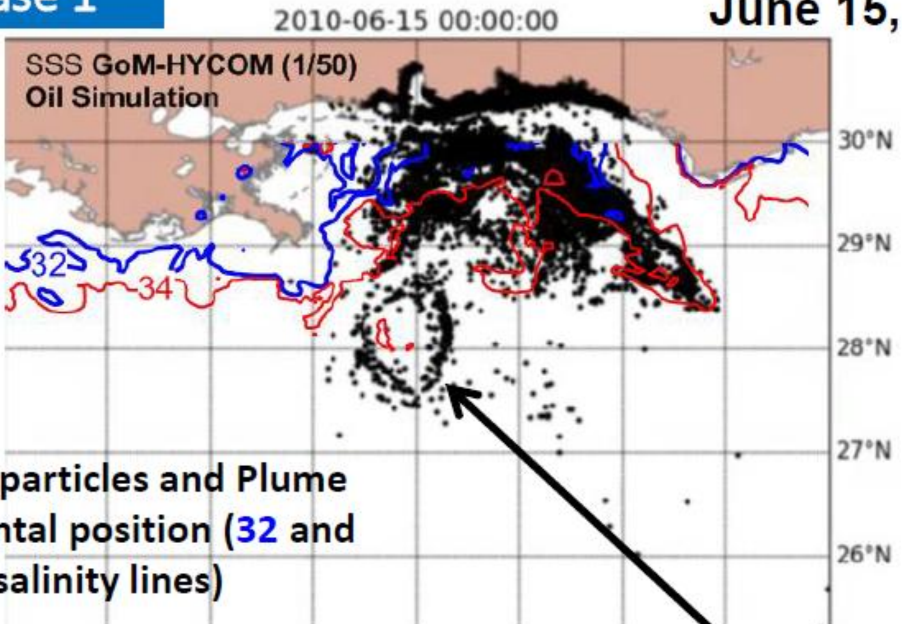


MR induced front and offshore upstream plume currents keep oil away from the Delta

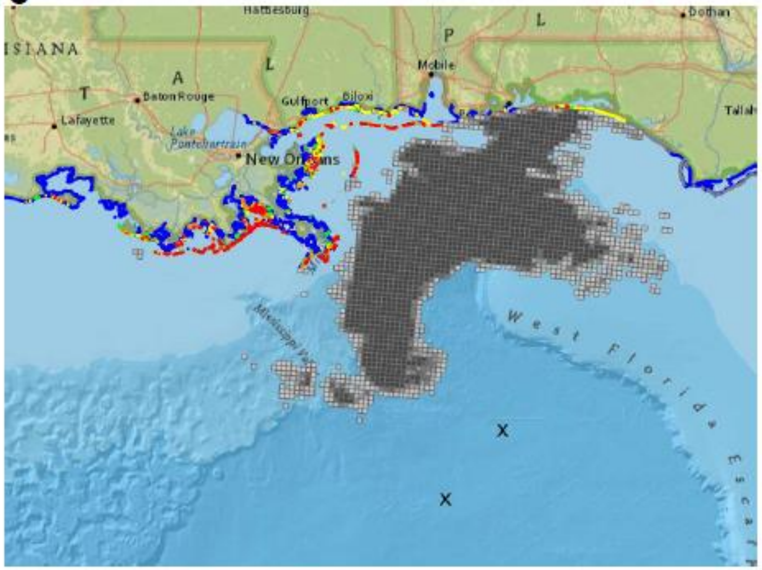
Slide from V.Kourafalou et al.

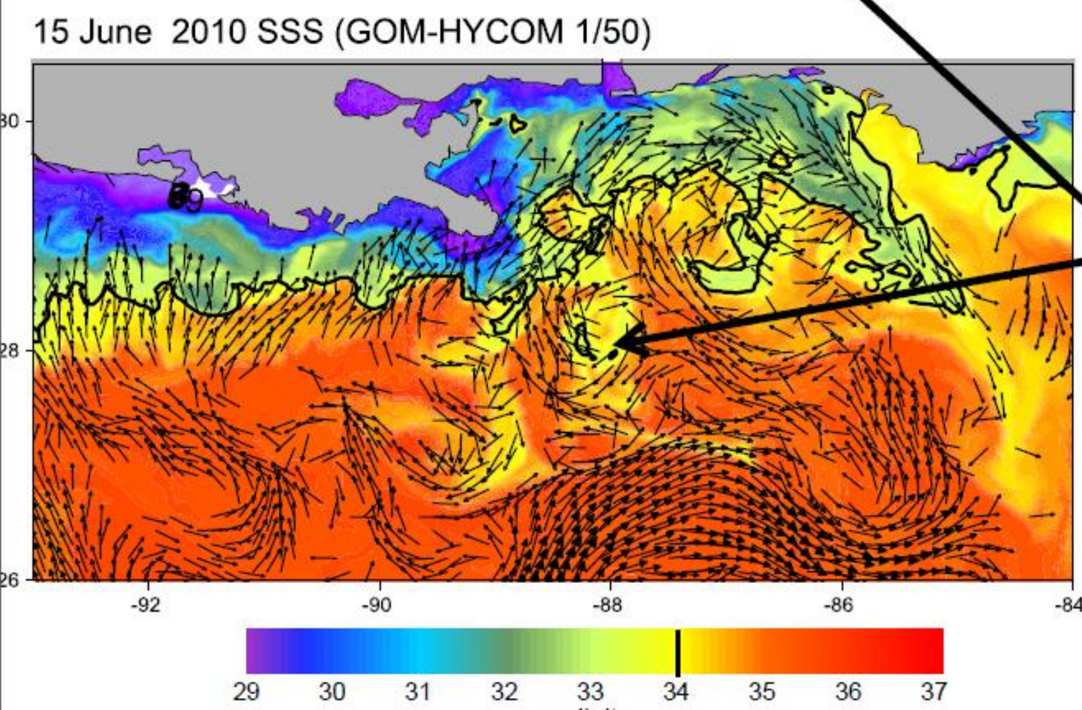
Case 1

June 15, 2010



Oil particles and Plume frontal position (32 and 34 salinity lines)





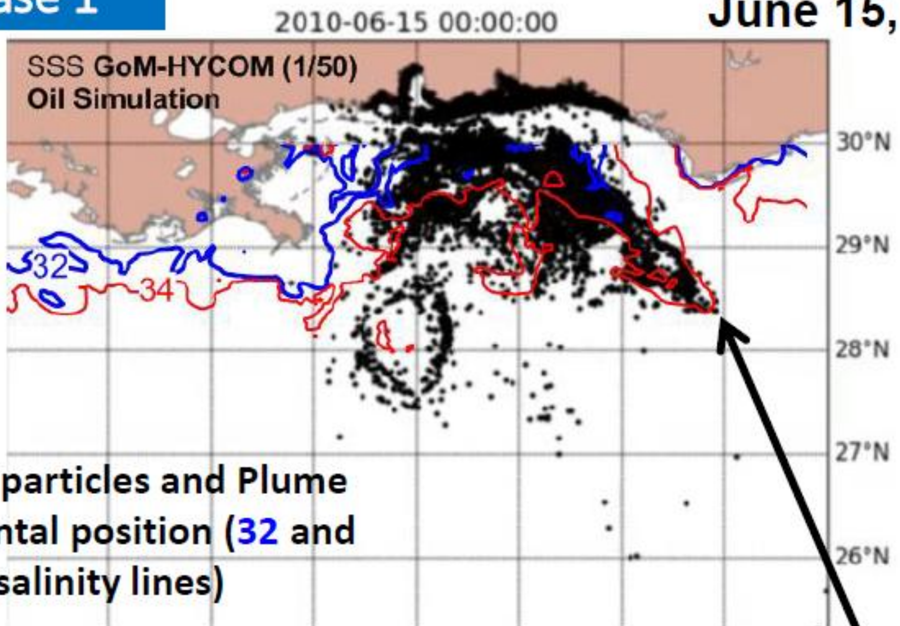
MR induced front and offshore upstream plume currents keep oil away from the Delta

Oil trapped in anticyclonic eddy

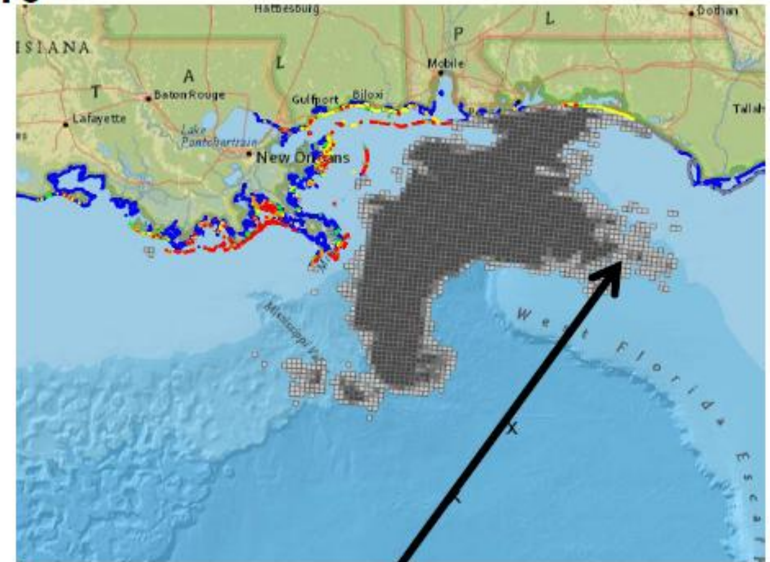
Slide from V.Kourafalou et al.

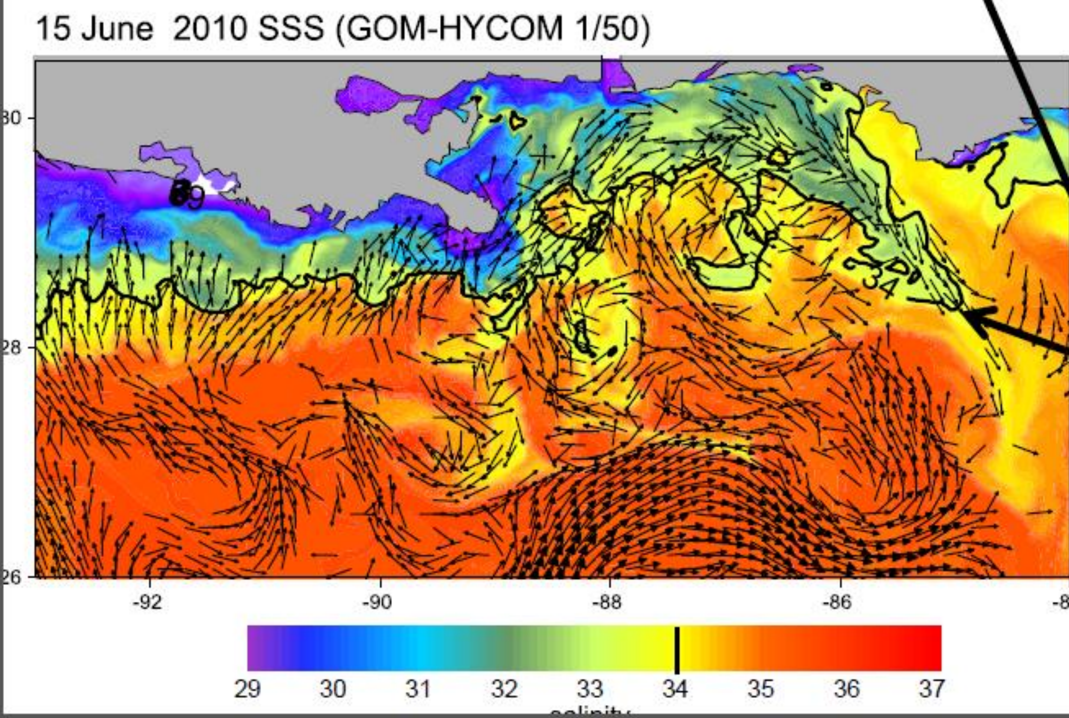
Case 1

June 15, 2010



Oil particles and Plume frontal position (**32** and **34** salinity lines)





MR induced front and offshore upstream plume currents keep oil away from the Delta

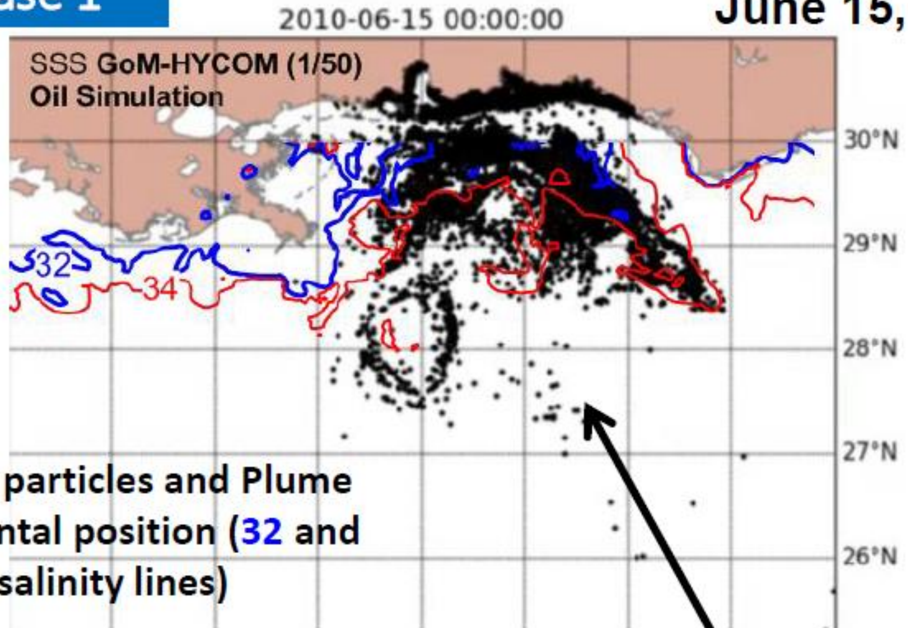
Oil trapped in anticyclonic eddy

Oil and river waters guided over the west Florida escarpment

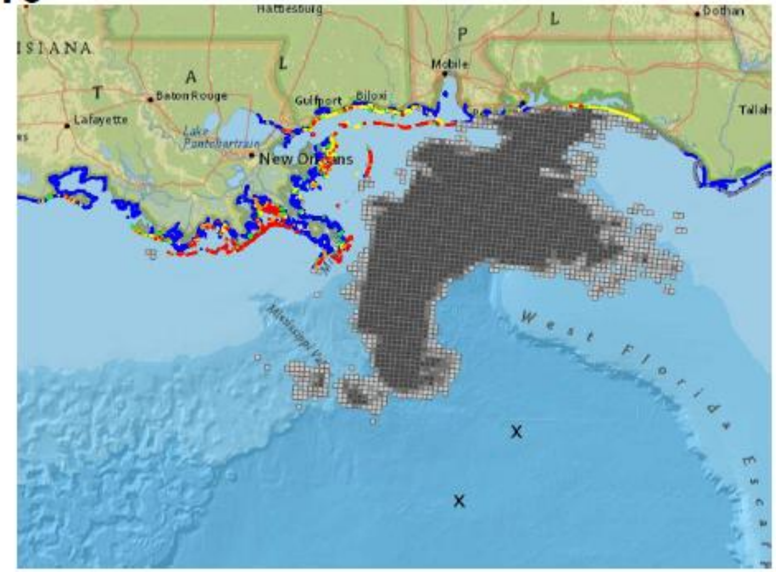
Slide from V.Kourafalou et al.

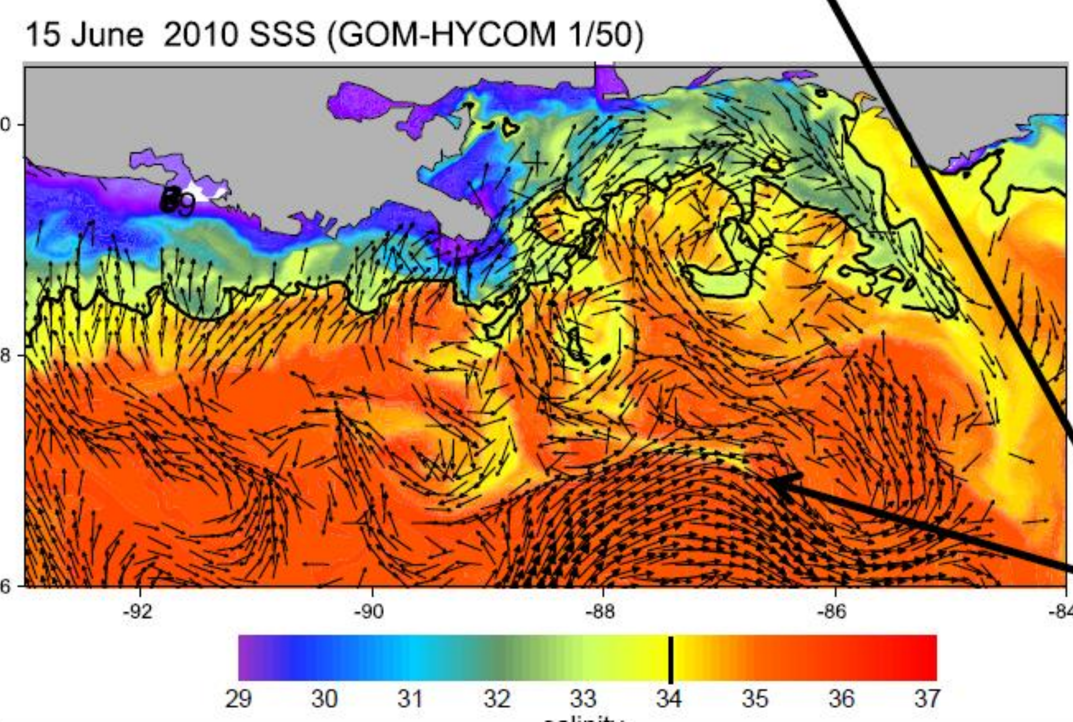
Case 1

June 15, 2010



Oil particles and Plume frontal position (32 and 34 salinity lines)





MR induced front and offshore upstream plume currents keep oil away from the Delta

Oil trapped in anticyclonic eddy

Oil and river waters guided over the west Florida escarpment

Small quantities of oil escaped eddy and moved southwards along the LC front

Slide from V.Kourafalou et al.

Summary

* The oil spill trajectory model is able to reproduce the movement of actual slicks, getting both transportation time and extent of spill correct
* The oil spill model is as good as its input: i.e. depends on good, high-resolution ocean and atmosheric forcing
* Stokes drift may have a considerable impact, especially in scenarios with strong wind
* The role of vertical mixing through several processes is very important for the transportation of the oil slick – a 3D model is therefore essential
* Oil slick trajectory model:
  OpenDrift (open source available at https://github.com/OpenDrift/)


Thank You!