NOAA | Office of Response and Restoration | Emergency Response Division

Physical Transport

Flower Garden Banks NRPT Workshop

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NOAA Office of Response and Restoration
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5/24/2016 1

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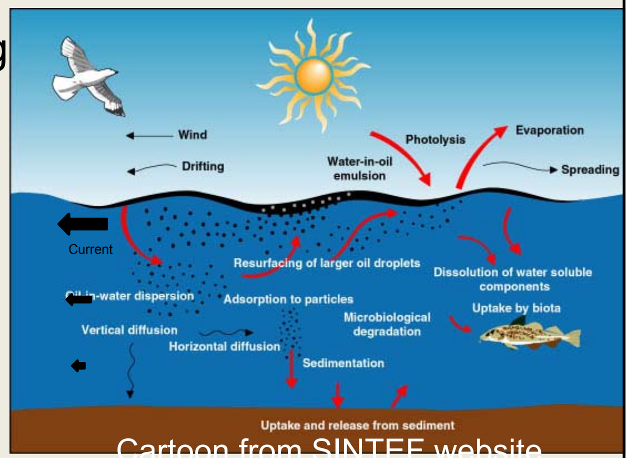
Oil Spill Transport: Takeaways:

- Oil properties play a major role in determining physical processes.
- Oceanographic and atmospheric conditions change with time and location.
- Need onshore winds to beach oil.
- As a spill progresses, oil concentration decreases.
- Because oil usually floats on the surface, it can collect in areas of surface convergence or along shoreline.
- Floating oil transport often dominated by winds
- Subsurface oil doesn't "feel" the wind.

5/24/2016 2

What happens to oil when it is spilled in the marine environment?

- Oil Weathering
- Spreading
- Transport



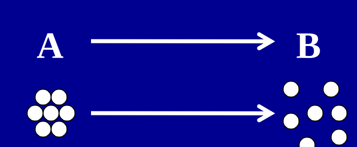
Cartoon from SINTEF website
http://www.sintef.no/static/ch/environment/oil_weathering_model.htm

Surface oil transport

Spreading due to gravity generally complete within first few hours then…

Subsequent oil movement results from:

- Winds
- Currents
- Turbulence

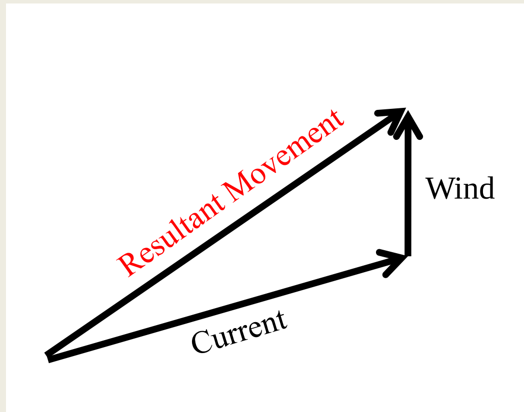


Example of horizontal dispersion.
Why does this happen?

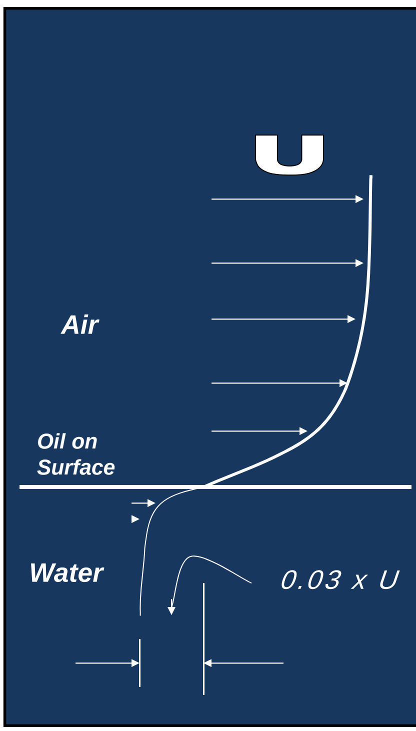
Advection

Can be estimated as the vector sum of:

- Wind Drift
- Surface Currents



Wind

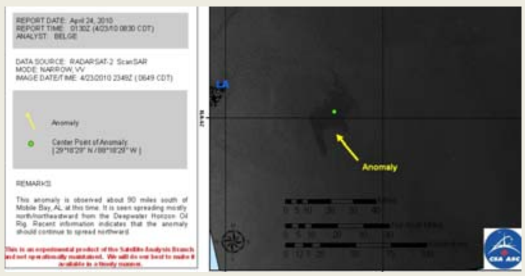


- Surface of the water (and oil) moves at about 3% of the wind speed.
- Example:
  - In a 20 knot wind, the oil moves at about 0.6 knots.
- How might this change as the oil weathers?

Windage

How fast the wind pushes a floating object

Rubber rafts	7%
Large Cabin Cruiser	5%
Raft with drogue	5%
Sailboats, Fishing Vessel	4%
Fresh Oil	3%
Surfboards	2%
Weathered tarballs	1%
Subsurface oil droplets	0%



DWH Satellite analysis of sea surface roughness used to detect oil.

Windage includes energy from small capillary waves which are damped by oil.

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla p + \nabla\cdot(\overline{\overline{\tau}})$$

- 3% of wind speed is a handy "rule-of-thumb" for oil movement most applicable for fresh oil in light to moderate winds
- It parameterizes a number of very complex ocean-atmosphere-wave interactions
- Dependent on oil-type, wind strength, wave climate
- Changes over time due to weathering processes

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0$$

Advection

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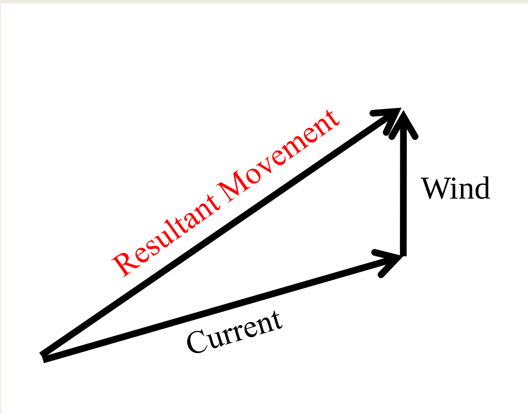


Next look at currents

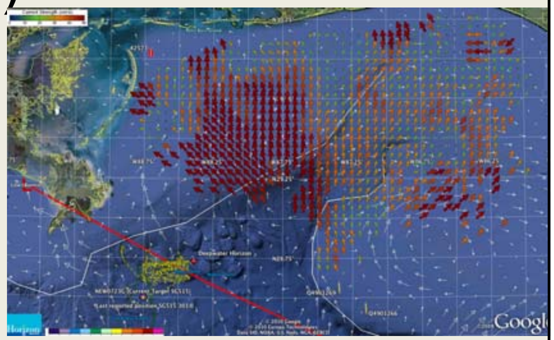
Length and Time Scale for Currents

(or, how far the spill will move or spread over what time period)

Current Type	Length Scale	Time Scale	Uncertainty
River	10s of miles	Hours to days	Lowest
Tides	Miles	Hours	Low
Estuarine Circulation	10s of miles	Days	Medium
Coastal Flow	100s of miles	Days to weeks	High
Ocean Circulation	1000s of Miles	Months to years	Low-High

(but, don't forget weathering!)

Coastal (shelf) currents



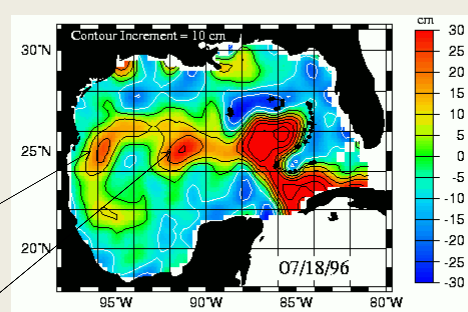
- Complicated dynamics
  - wind-driven flow
  - freshwater influence
  - deep ocean influences
  - tides
  - topographic interactions…
- Strong variability on multiple time scales (seasonal, event-scale)

Snapshot of measured currents (colored vectors) and modeled currents (white vectors) in 2010

Are tides important here?

…in the GoM

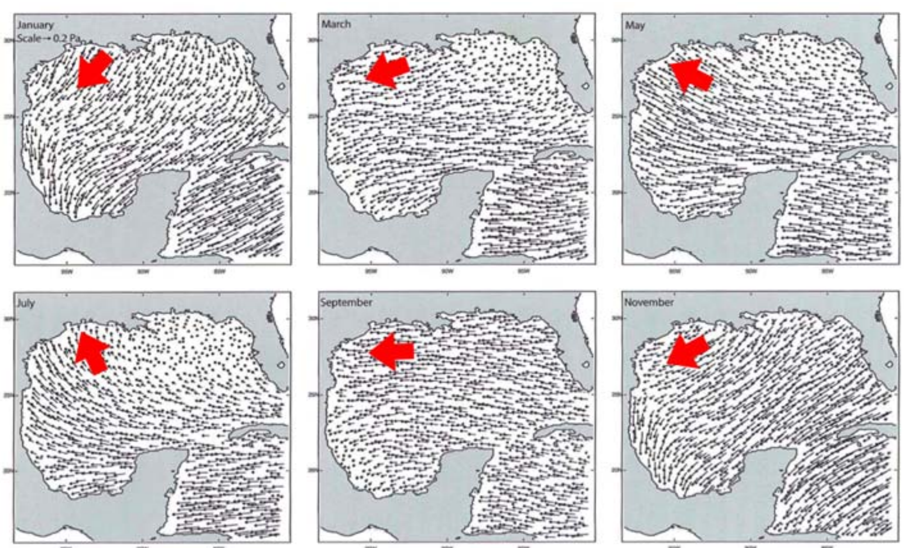
- The Loop Current is a warm ocean current that flows northward between Cuba and the Yucatán peninsula, moves north into the Gulf of Mexico, loops east and south before exiting to the east through the Florida Straits and joining the Gulf Stream



Where did these come from

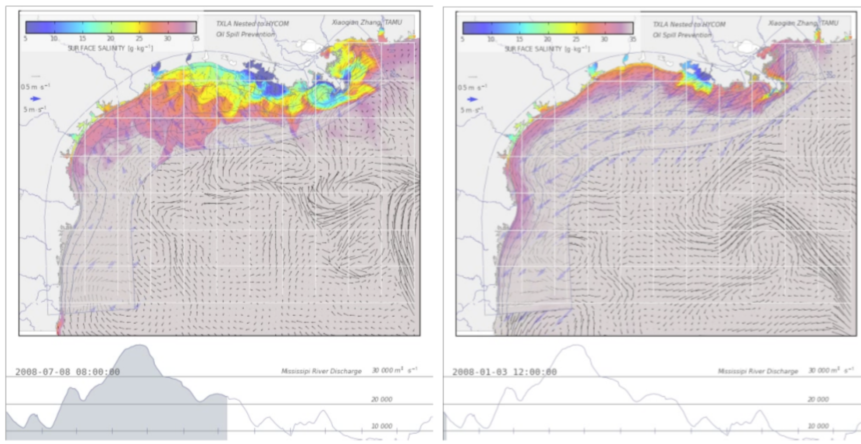
NW Gulf Bathymetry

Seasonal Winds



Morey et al, 2005, AGU Monograph: *Circulation in the Gulf of Mexico: Observations and Models*

River Plume



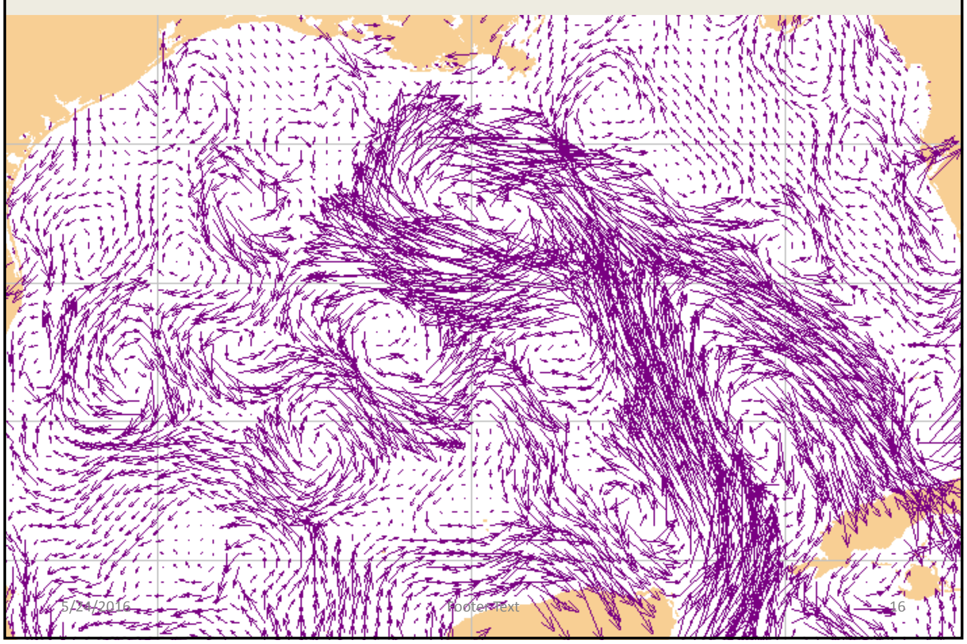
(a) Summer (b) Winter

Xiaoqian Zhang, http://pong.tamu.edu/∼zhangxq/

5/24/2016 Footer Text 15

Kristen M. Thyng (Texas A&M) NASA 2014 May 28, 2014 10 / 39

SSH-Derived Currents



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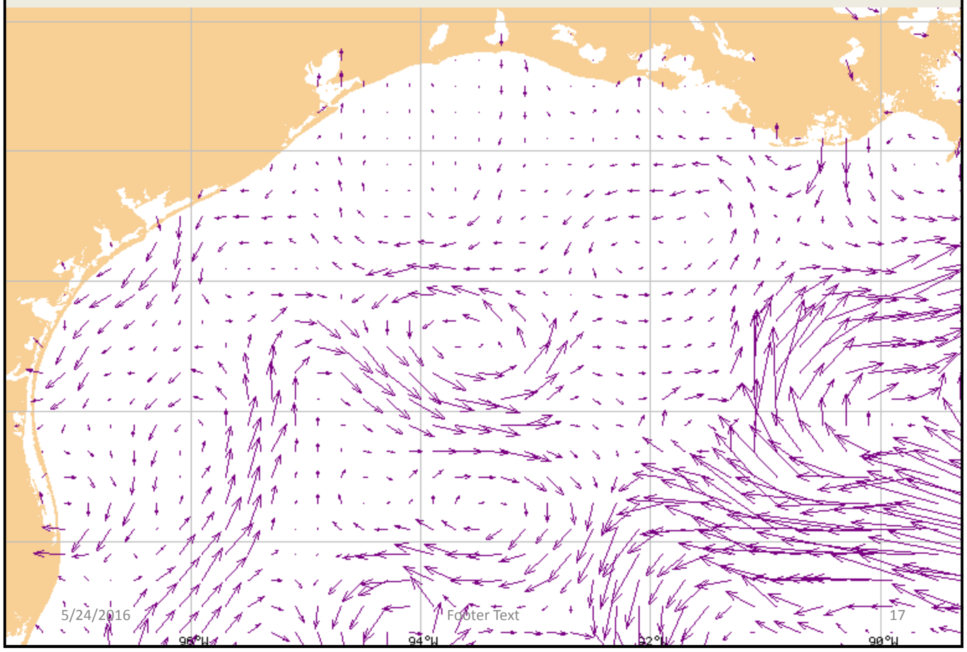
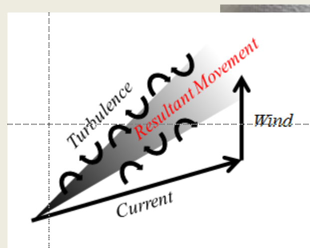
SSH-Derived Currents

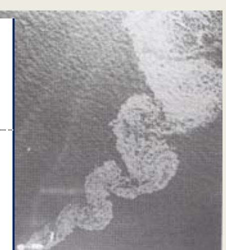


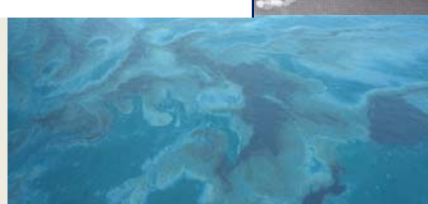
Turbulence

- These are small scale currents that ocean models may not resolve
- Turbulence will tear apart a slick and result in a patchy distribution spread over a larger area

- Response challenge: encounter rate
- Volume?

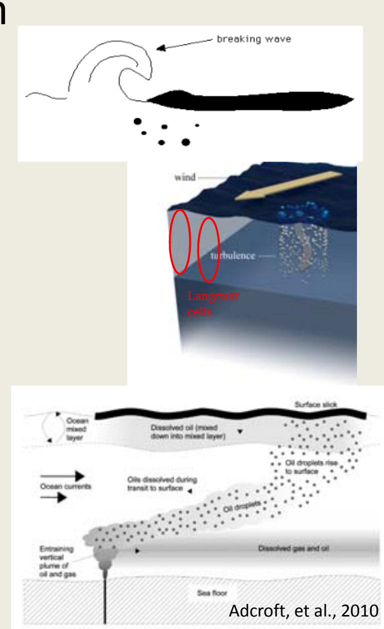






The missing 3rd dimension (dispersion)

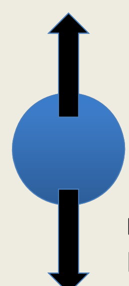
- Driven by wave energy – breaking waves
- Dependent upon oil type (viscosity, surface tension)
- Mixed to depth of ocean mixed layer
- Subsurface oil also subject to advective and diffusive transport, but:
  - No "wind-drift"
  - Diffusing in 3-dimensions
  - Vertical shear of currents
  - Less potential for convergence – i.e. concentrations reduce with time



Adcroft, et al., 2010

Rise Velocity

- Rise velocity is the balance between Buoyancy and Drag
- Radius is cubed in Buoyant force, squared in Drag force
- Larger Droplets: Faster rise velocity.



Buoyant Force:
$F_B = 4/3\pi r^3 (\rho_W - \rho_O)$

Drag Force:
$F_D = C_D \pi r^2 V^2$

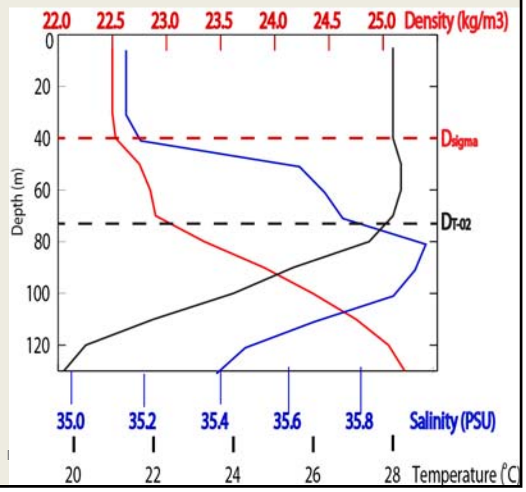
- Small Droplets stay in the water column longer
- In a turbulent environment – they can stay under water forever

5/24/2016 Footer Text 20

The Mixed Layer

- Region of relatively well mixed water:
  - Fairly constant temperature and salinity

- Dispersed Oil will mix relatively fast within this layer
- Very slow process for dispersed oil to get below the mixed layer.



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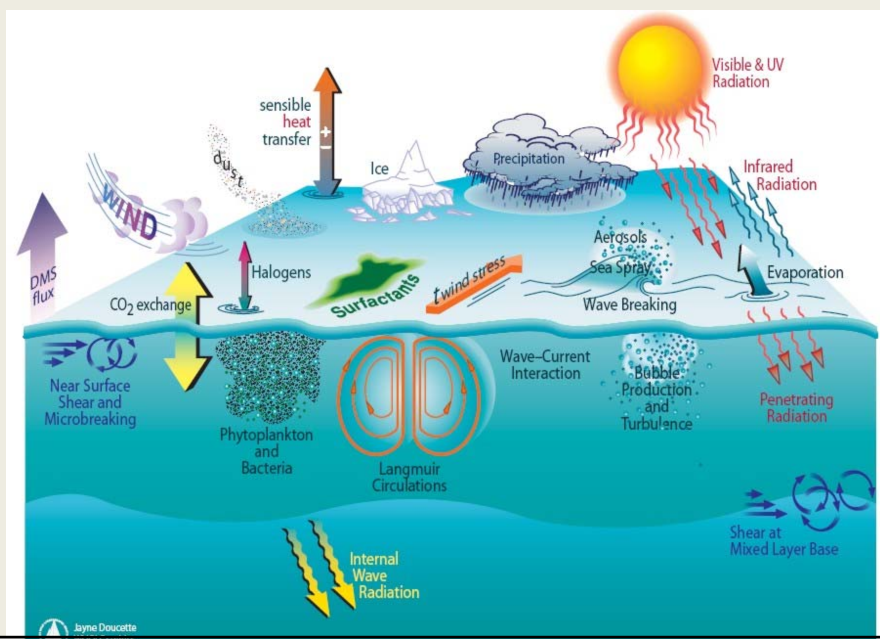


The Mixed Layer

- So how thick is the mixed layer?
- Function of:
  Wind, Sun, Waves, Salinity, Currents – lots more.
- Regional, Seasonal, even Diurnal fluctuations
- Rule of thumb: ~ 10 m on the shelf.
- Offshore NW Gulf of Mexico:
  – Maxima of about 90–120m in February, and minima of about 20m from about May through October.
- Only way to know is to measure it.

Mass Conservation Always Holds

- The more water oil is mixed into, the lower the concentrations.
- You can have high concentrations in a small region, or effect a large region with low concentrations.
- You can not have high concentrations *and* a large region effected.
- In 3d there are no convergences – concentration always goes down.

0-D to 2-D to 3-D to 1-D

- Concentration of oil changes with how it spreads or converges
  - From a point
    - →Initial release
  - To 2-D
    - →Spreading
  - to 3-D
    - →Dispersion
  - To 1-D
    - →Convergence / Beaching

1 barrel = 42 gallons = 159 liters

2-D: Surface Slick

– 100 microns thick ("black oil"; ~2.5 barrels per acre)

Area = Vol/Th = 0.159 m^3/1e-4 m = 1590 m^2

~22 meter diameter sheen (~1/3 football field)

– 1 micron thick ("dull sheen", ~0.025 barrels per acre)

Area = Vol/Th = 0.159 m^3/1e-6 m = 159,000 m^2

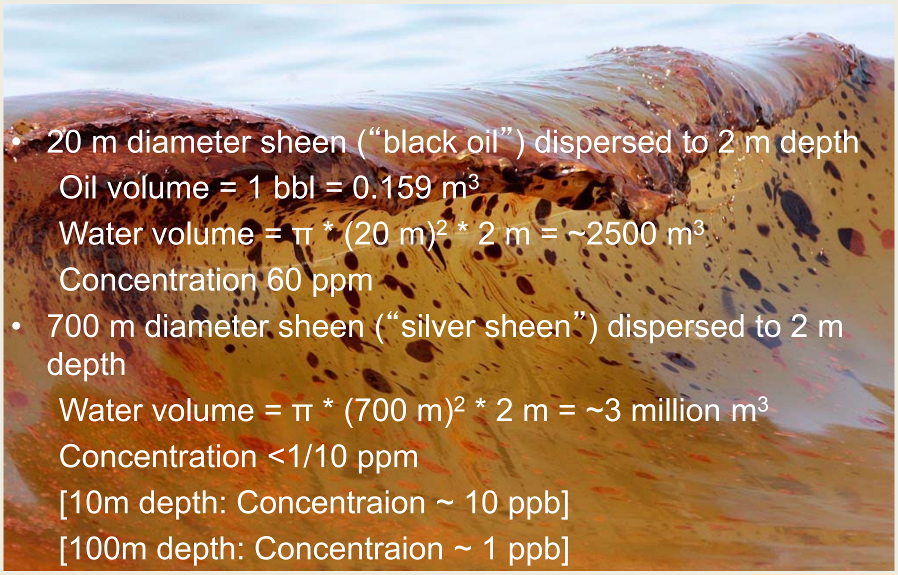
~225 meter diameter sheen (~30 football fields)

– 1/10 micron thick ("silver sheen", ~0.0025 bpa)

Area = Vol/Th = 0.159 m^3/1e-7 m = 1,590,000 m^2

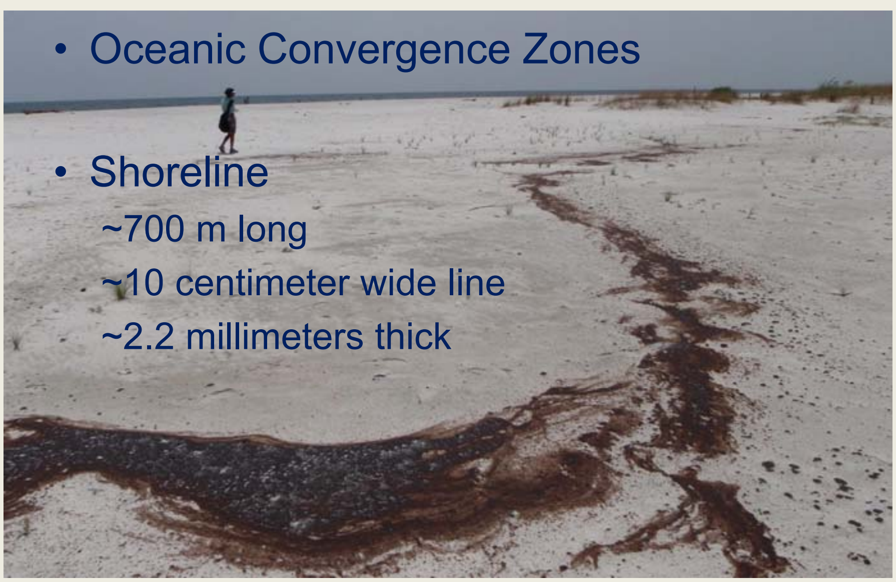
~700 meter diameter sheen (~300 football fields)

3-D: Dispersion



- 20 m diameter sheen ("black oil") dispersed to 2 m depth
  - Oil volume = 1 bbl = 0.159 m^3
  - Water volume = π * (20 m)^2 * 2 m = ~2500 m^3
  - Concentration 60 ppm
- 700 m diameter sheen ("silver sheen") dispersed to 2 m depth
  - Water volume = π * (700 m)^2 * 2 m = ~3 million m^3
  - Concentration <1/10 ppm
  - [10m depth: Concentraion ~ 10 ppb]
  - [100m depth: Concentraion ~ 1 ppb]

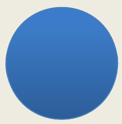
1-D: Convergence



- Oceanic Convergence Zones
- Shoreline
  - ~700 m long
  - ~10 centimeter wide line
  - ~2.2 millimeters thick

Other Droplet Size Considerations

Spherical Droplets:



Volume: $4/3\pi r^3$ Surface Area $4\pi r^2$

Surface Area : Volume Ratio: $3/r$

The Smaller the droplet:

The more exposed surface area.

Faster Dissolution and Bio-degradation

Blowout Plume Dynamics

- A well blowout can be a very energetic plume
- Driven primarily by Buoyancy:
  - Oil is less dense than water
  - Usually has a lot of gas – much less dense.
- In this turbulent environment, droplets are formed
- Dispersants: smaller droplets
- The resulting Droplet Size Distribution (DSD) determines where the oil goes.

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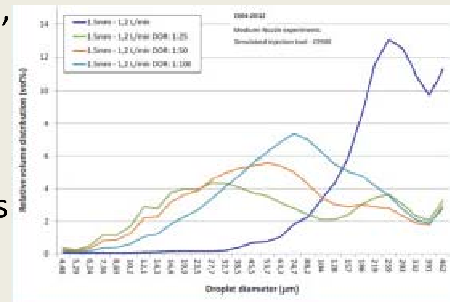

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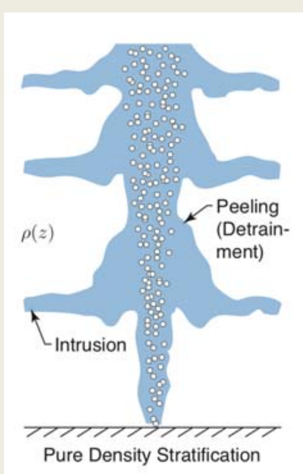
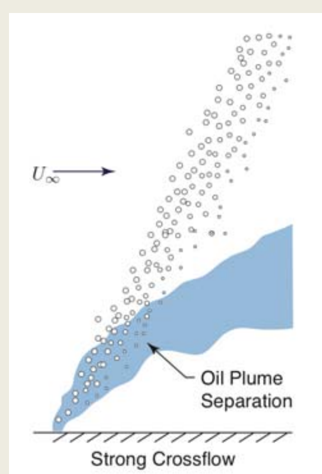




Blowout Plume Dynamics

- “layer” of dissolved constituents and tiny droplets

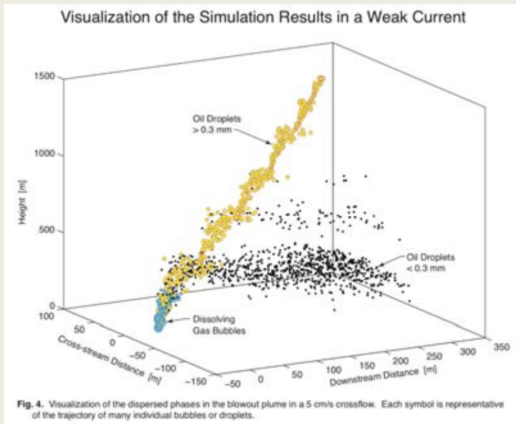
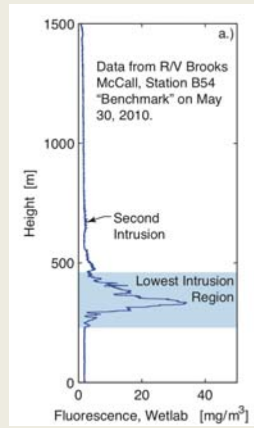


Fig. 4. Visualization of the dispersed phases in the blowout plume in a 5 cm/s crossflow. Each symbol is representative of the trajectory of many individual bubbles or droplets.



- Larger Droplets rise to the surface

Blowout Plume Dynamics

- Deep Gulf is much less energetic than the surface
- Less Mixing
- Slower Transport
- The “layer” will remain more or less at that depth.

- Concentration will decrease with:
  - Diffusion
  - Biodegradation