Deepwater Horizon Oil Slick Characterization with UAVSAR

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Mississippi River Delta – June23, 2010 / UAVSAR POLSAR / 7 m resolution

DEEPWATER HORIZON OIL SPILL

THE EVENT

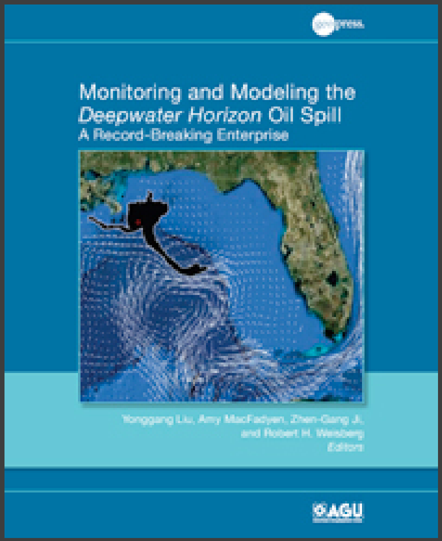
At 9:45 pm on April 20, 2010, a well blowout occurred at the Deepwater Horizon drilling rig in the Gulf of Mexico, 50 miles off the coast of Louisiana. Four days later, the rig sank. On April 30th, oil from the spill made landfall at Venice, Louisiana, in the Mississippi River Delta. By the time the well was capped nearly three months later, ~700,000 m^3 of oil had been released into the Gulf and spread across coastal areas in four states, from Louisiana to Florida.

Study Oil Spill Detection and the Impact of Oil Inundation in Wetland Ecosystems Using High Resolution Polarimetric L-band Radar

- Develop and validate algorithms for improved discrimination of oil slicks on water and collect data that will enable us to better determine oil properties from polarimetric radar backscatter returns.

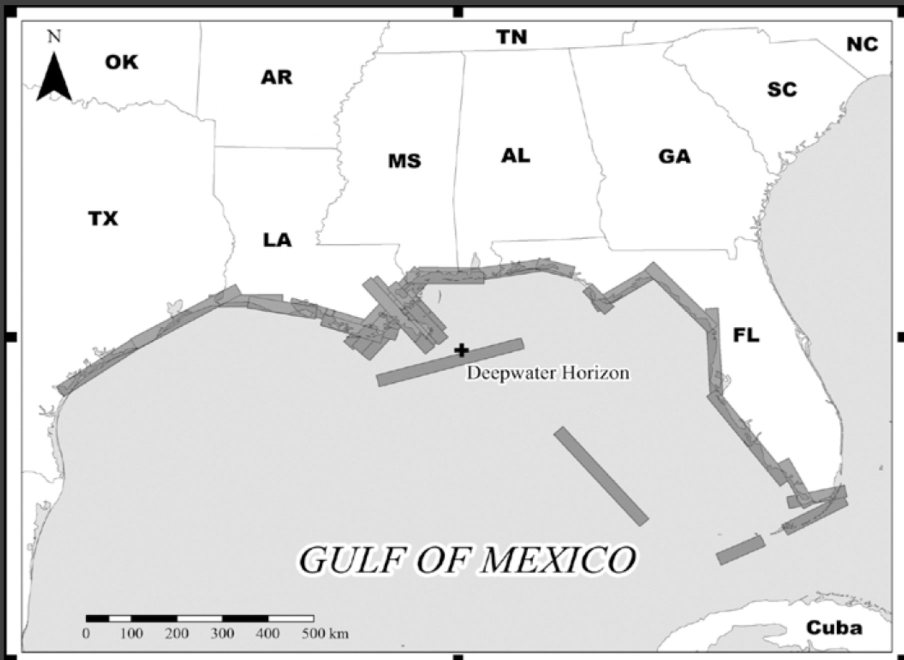
References:

1. Minchew, Brent, Cathleen E. Jones Benjamin Holt (2012), ***Polarimetric analysis of backscatter from the Deepwater Horizon oil spill using L-band radar***, DOI:10.1109/TGRS.2012.2185804, TGRS, Early Access PP:99, p.1-19.
2. Jones, Cathleen E., Brent Minchew, Benjamin Holt, and Scott Hensley (2011), ***Studies of the Deepwater Horizon oil spill with the UAVSAR radar***, in *Monitoring and Modeling of the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise*, Geophys. Monogr. Ser., vol. 195, edited by Y. Liu et al., pp. 33–50, AGU, Washington, D. C.
3. Minchew, B. (2012), ***Determining the mixing of oil and sea water using polarimetric synthetic aperture radar***, GRL, 39, L16607, doi:10.1029/2012/GL052304

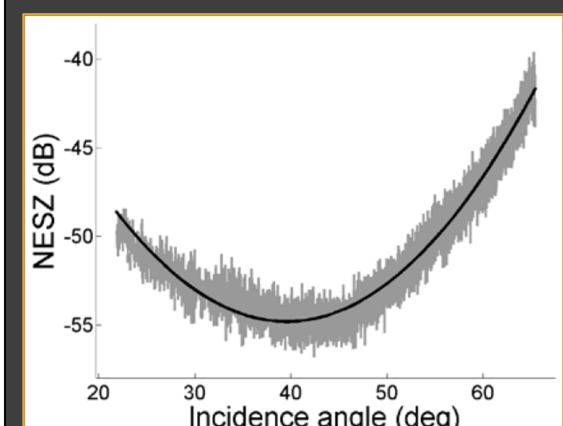


UAVSAR Gulf Oil Spill Campaign

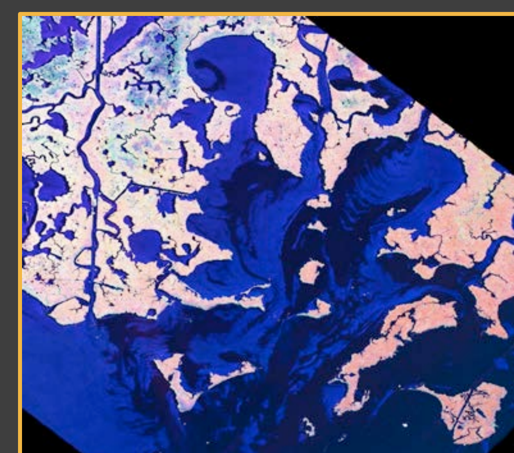
22-23 June 2010



- 2 days, 3 flights, 21 flight hours
- ~5500 km of flight lines
- Imaged an area of 120,000 km^2

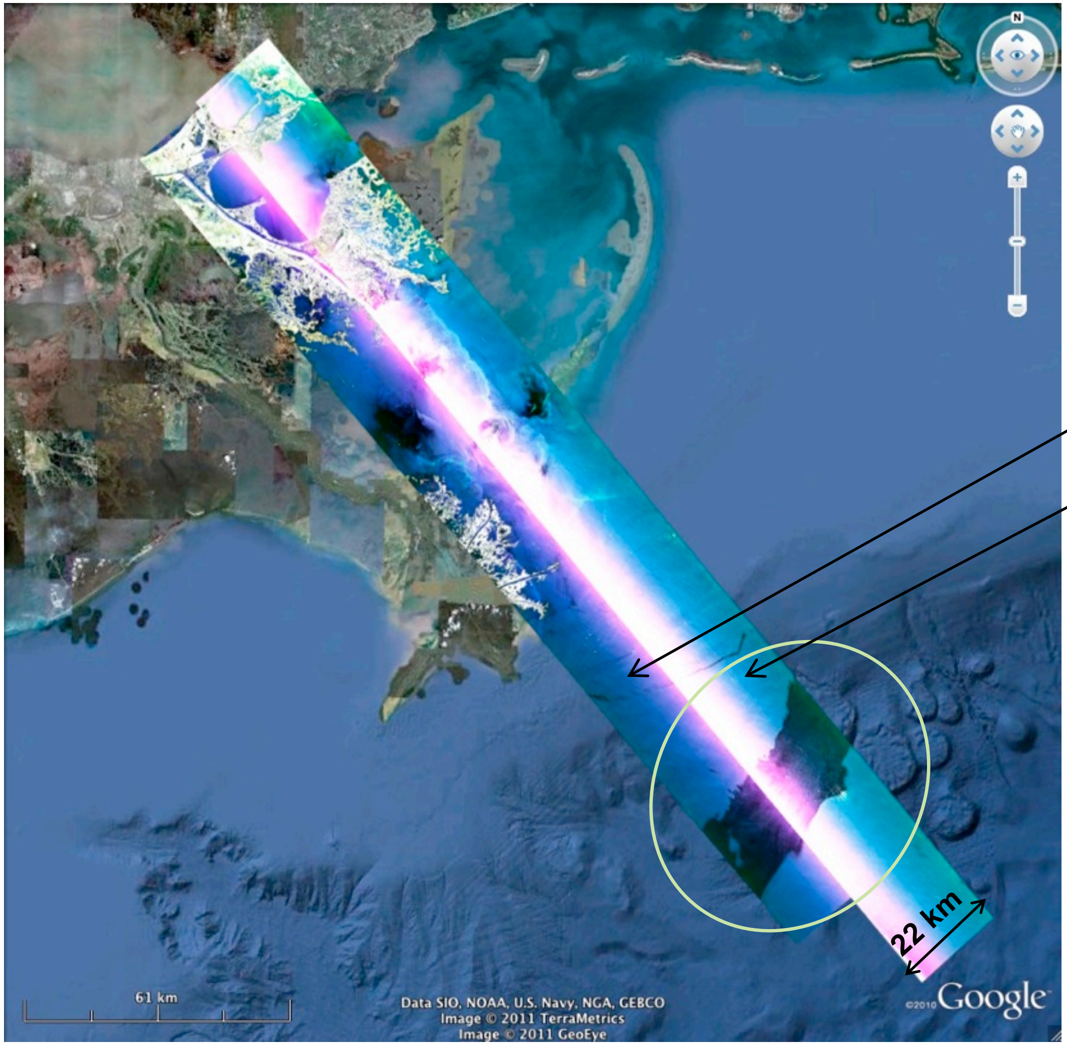


Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz (23.8 cm wavelength)
Resolution	1.7 m Slant Range, 1.0 m Azimuth
Polarization	Quad-Polarization (HH, HV, VH, VV)
Transmit Power	> 3.1 kW



UAVSAR Flight Lines

Covering the Main Slick of the Deepwater Horizon Spill



Two UAVSAR lines viewing the main slick from opposite directions were using in our analysis of the polarimetric response of the oil from the DWH spill.

gulfco_32010_10054_101_100623
collected 23-June-2010 21:08 UTC

gulfco_14010_10054_100_100623
collected 23-June-2010 20:42 UTC

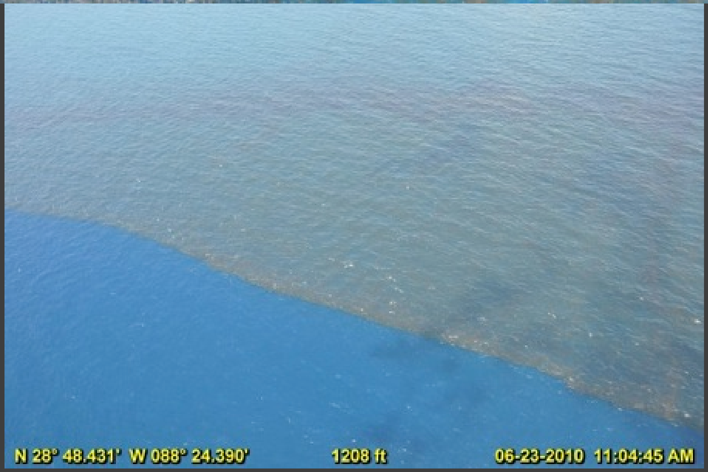
Because of the vast extent of the spill, we are able to measure the radar cross section as a function of incidence angle between 26° -65° using this data set. By looking at different portions of the slick, we could also quantify the variability of the returns from oil.

The Open Ocean Deepwater Horizon Oil Slick

22-23 June 2010

Surface conditions:
Sea state: 1.0-1.3 m SWH
Wind: 2.5-5 m/s from 115° -126°

Photos from 6/23/10, NOAA RAT-Helo, EPA ASPECT, U. S. Florida



EFFECT OF SURFACE LAYER OF OIL
ON RADAR BACKSCATTER FROM WATER

Oil damps the small-scale capillary and gravity-capillary waves on the ocean surface mainly through a reduction in the surface tension at the gas-liquid interface.

Dispersion relationship for waves at the interface between air and a liquid of density ρ with surface tension σ:

$$\omega^2 = gk + (\sigma/\rho)k^3$$

gravity is the restoring force

surface tension and inertia are the restoring forces

$\rho_{oil}/\rho_{water} \approx 0.8 - 0.9$

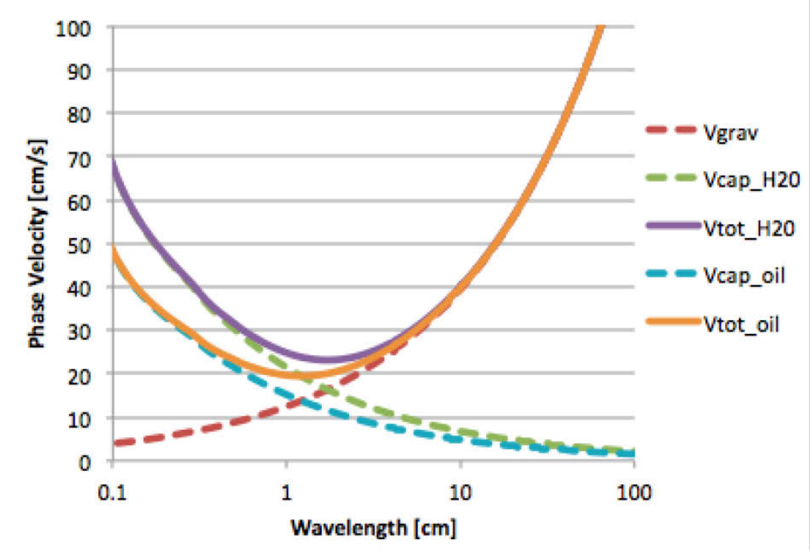
$\sigma_{oil}/\sigma_{water} \approx 0.25 - 0.5$

$$v_{phase} = \sqrt{\frac{g}{k} + \frac{\sigma}{\rho}k}$$

for a given velocity, k increases when the surface tension decreases

Ocean waves are excited by resonant forcing in a turbulent wind field. The wavelength of capillary waves resonantly excited in the presence of oil is smaller than for a clean water-air interface, hence the damping of the smaller wavelengths. This affects the roughness scale of the water surface. In a real slick, the surface characteristics will vary between pure H20 and pure oil, depending upon layer thickness, oil type, and areal coverage.

Also, in viscoelastic fluids gravity waves with short wavelength are damped by restoring forces arising from gradients in the surface tension (Marangoni effect).



Radar backscatter from the ocean surface is dominated by scattering from small scale capillary and gravity-capillary waves that roughen the surface. In Bragg scattering theory, the dominant mechanism is resonant backscatter from surface waves of wave number k_{Bragg}:

$$k_{Bragg} = 2k\sin(\theta_{inc})$$
$$k = \frac{2\pi}{\lambda_{radar}}$$

As the incidence angle increases, the wavelength of the Bragg surface wave decreases to a minimum of $\lambda_{radar}/2$ at grazing angles.

L-band (λ_{radar}=23.8 cm) : λ_{Bragg} = 23.8 cm (30°), 13.7 cm (60°)

$$\sigma_{HH} = 4\pi k^4\cos^4(\theta_i)W(k_{Bragg})\left|\left(\frac{\sin(\theta+\psi)\cos\beta}{\sin\theta_i}\right)^2 R_{HH} + \left(\frac{\sin\beta}{\sin\theta_i}\right)^2 R_{VV}\right|^2$$

ocean wave spectral density

$$\sigma_{VV} = 4\pi k^4\cos^4(\theta_i)W(k_{Bragg})\left|\left(\frac{\sin(\theta+\psi)\cos\beta}{\sin\theta_i}\right)^2 R_{VV} + \left(\frac{\sin\beta}{\sin\theta_i}\right)^2 R_{HH}\right|^2$$

$$\frac{\sigma_{HH}}{\sigma_{VV}}$$

$$\sigma_{HV} = 4\pi k^4\cos^4(\theta_i)W(k_{Bragg})\left|R_{VV} - R_{HH}\right|^2$$

ψ = *in-plane facet tilt angle*

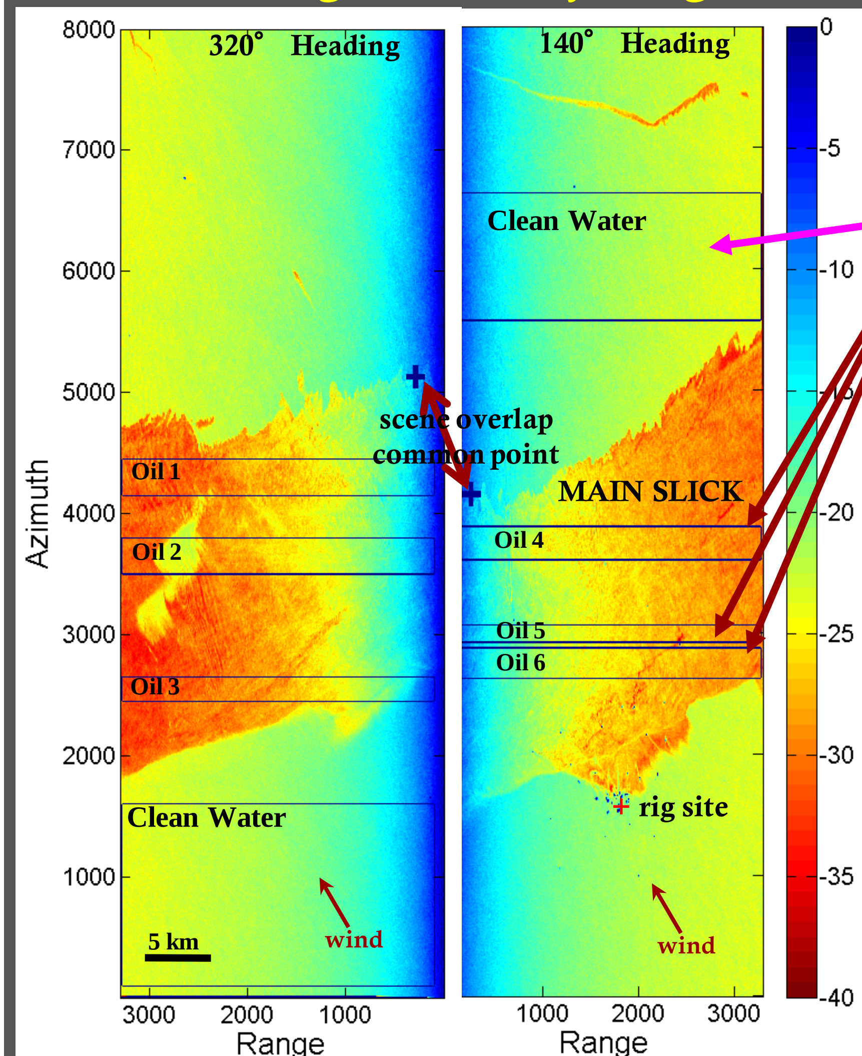
β = *out-of-plane facet tilt angle*

$$\theta_i = \cos^{-1}[\cos(\theta+\psi)\cos(\beta)]$$

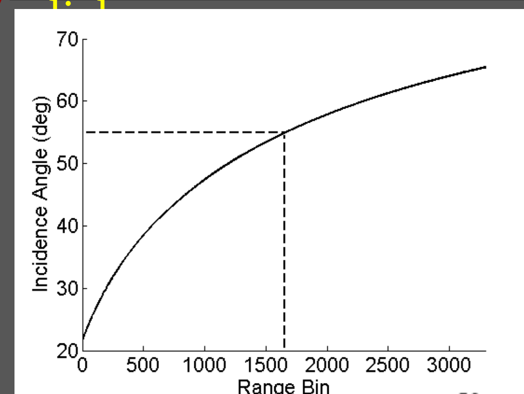
complex dielectric constant

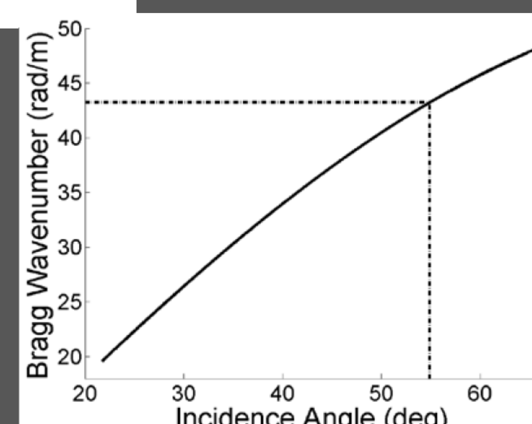
$$R_{VV} = \frac{(\varepsilon_r - 1)(\varepsilon_r(1+\sin^2(\theta_i)) - \sin^2(\theta_i))}{\left(\varepsilon_r\cos(\theta_i) + \sqrt{\varepsilon_r - \sin^2(\theta_i)}\right)^2} \qquad R_{HH} = \frac{\varepsilon_r - 1}{\left(\cos(\theta_i) + \sqrt{\varepsilon_r - \sin^2(\theta_i)}\right)^2}$$

Averaged Intensity Images



In the following slides, for each UAVSAR line the parameters are averaged in the along track direction and plotted as a function of incidence angle for a clean water region and for three strips within the slick.

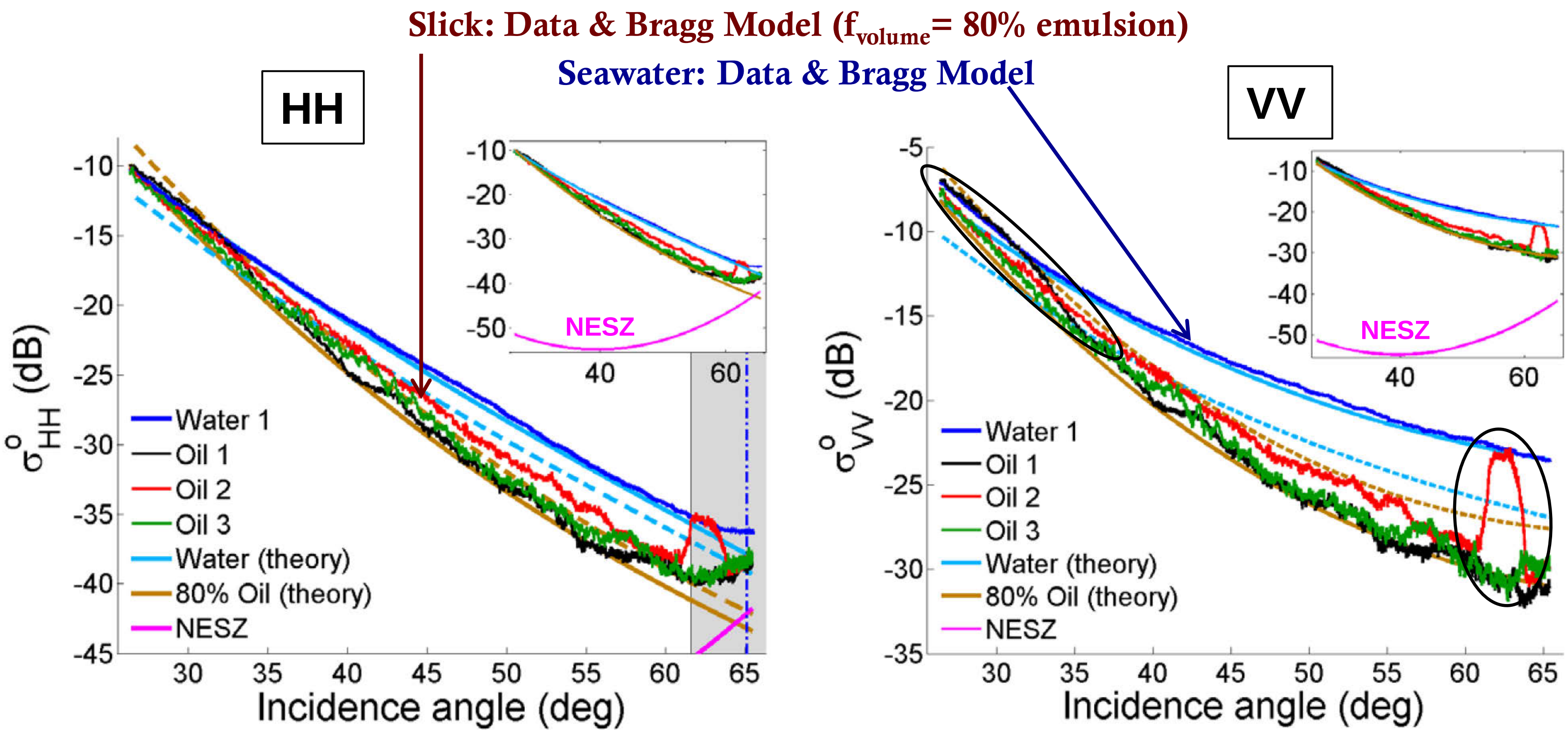




Bragg Scattering – Seawater & Slick

Polarization-Dependent Normalized Radar Cross Section

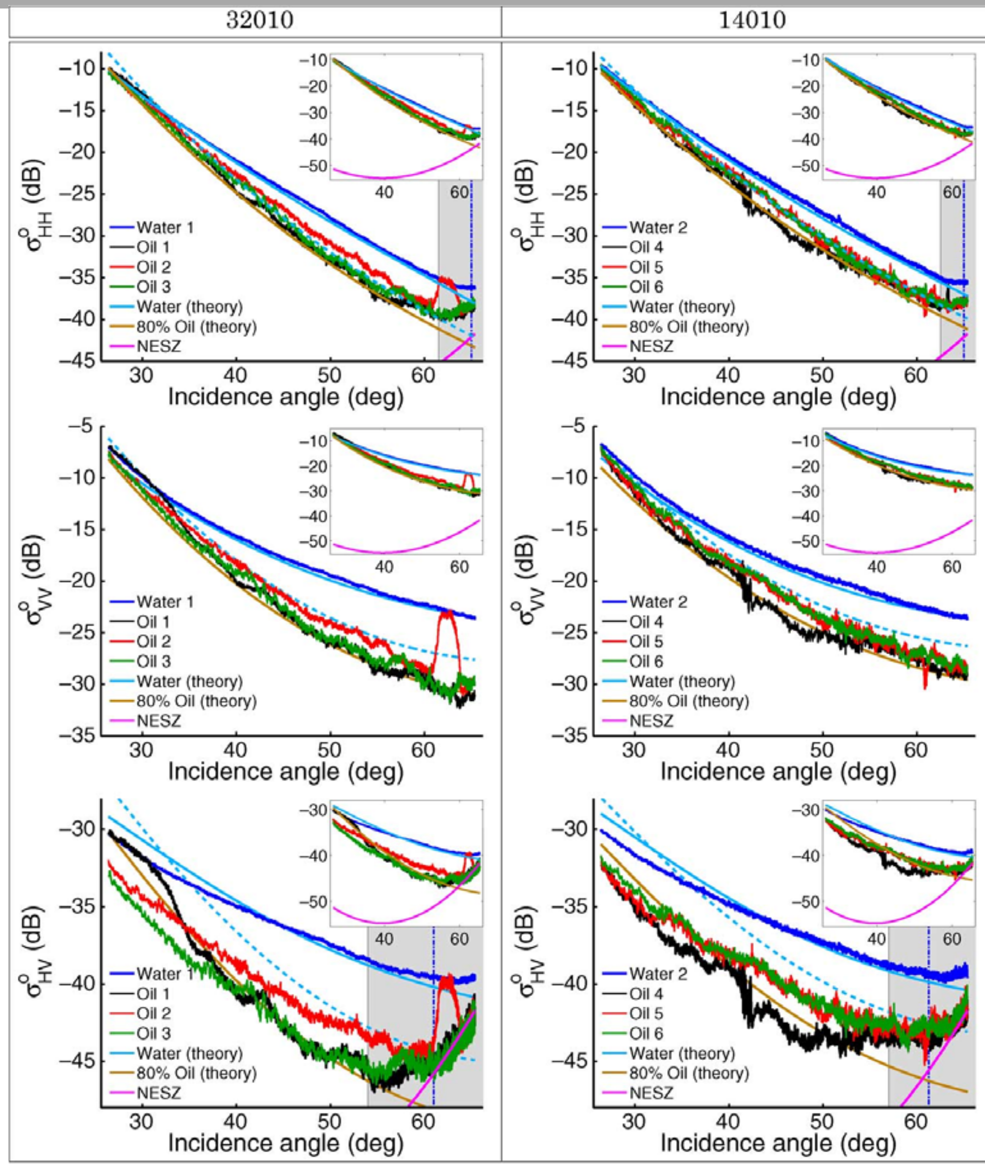
Bragg scattering theory describes well both scattering from unslicked seawater and from the Deepwater Horizon oil slick:



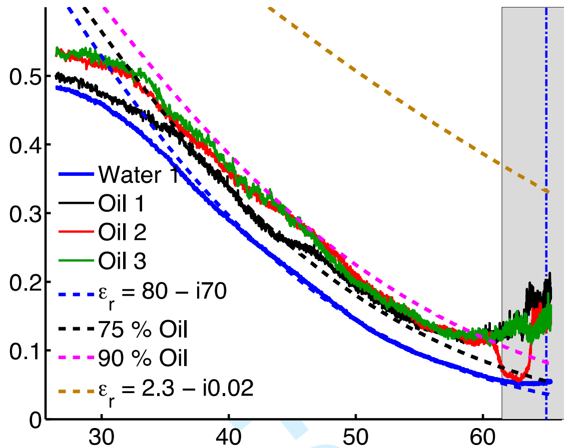
**We used a linear mixing model for the oil-in-water emulsion dielectric constant. $\varepsilon_{mix} = f_{volume}\varepsilon_{oil} + (1 - f_{volume})\varepsilon_{seawater}$

QUAD POLARIZATION, OIL SLICK IN BOTH FLIGHT LINES

POLARIZATION-DEPENDENT NORMALIZED RADAR CROSS SECTION



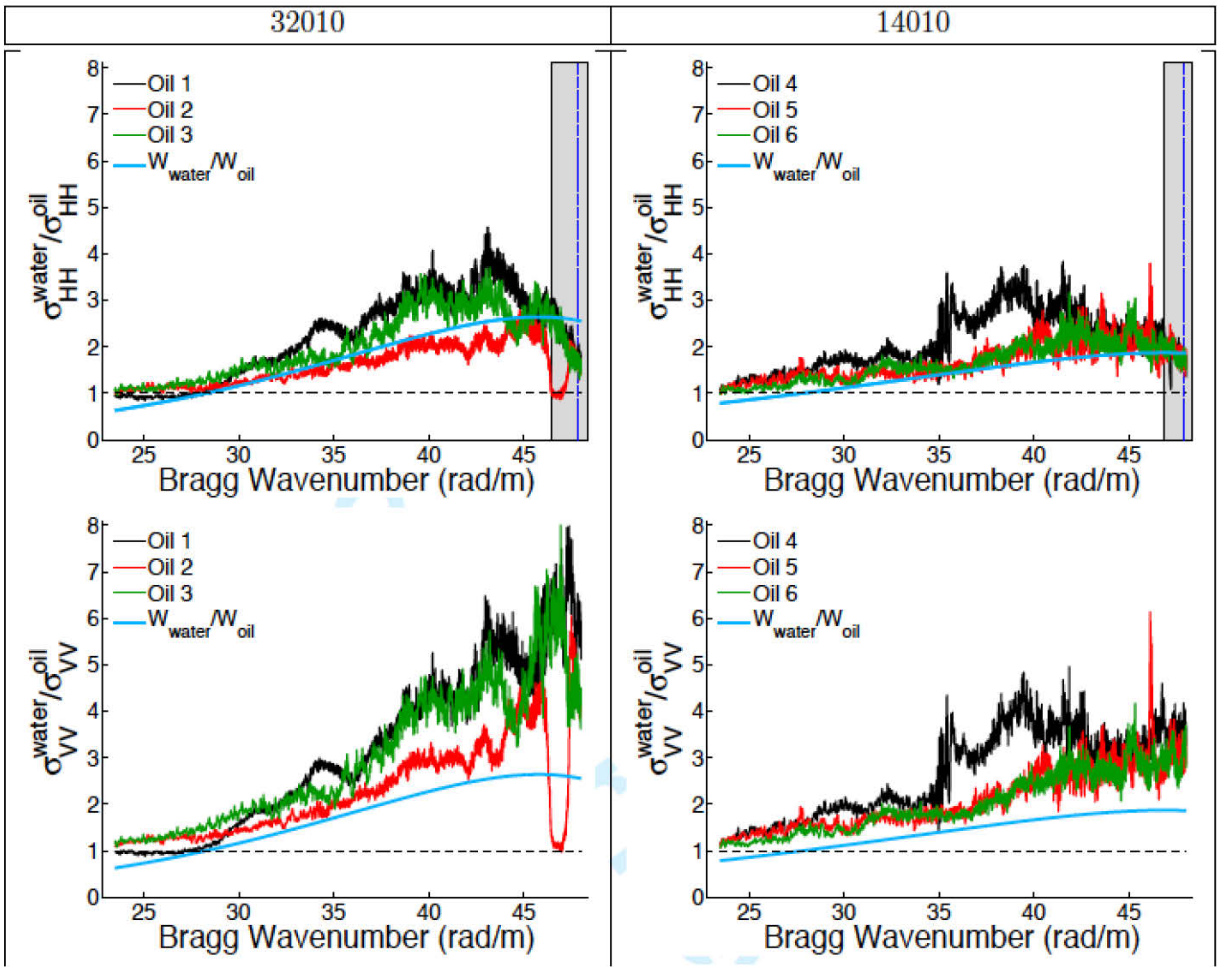
We derive the volumetric fraction of oil in the emulsion layer of the main oil slick using a fit to the co-polarized cross section ratio data for the dielectric coefficient within the Bragg scattering model:



**We used a linear mixing model for the oil-in-water emulsion dielectric constant.

$$\varepsilon_{mix} = f_{volume}\varepsilon_{oil} + (1 - f_{volume})\varepsilon_{seawater}$$

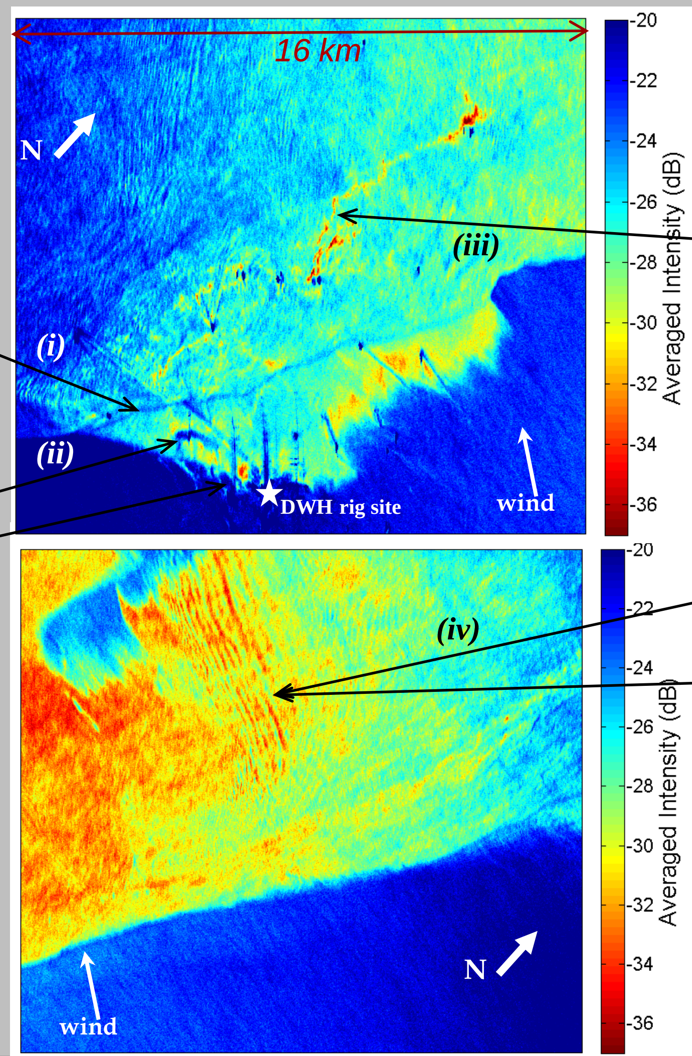
Oil Slick Wave Spectral Damping:

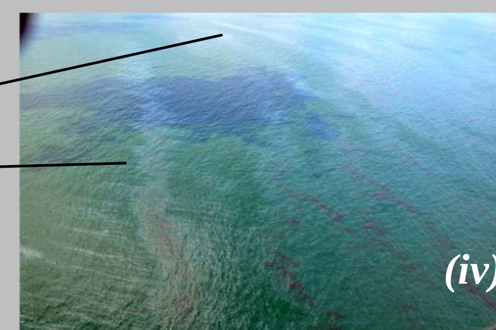


Beyond Oil Detection to Oil Characterization

Variations in the Averaged Intensity

Not only is the oil slick clearly differentiated from the surrounding water (dark blue in the UAVSAR image), but the low noise UAVSAR radar backscatter can differentiate some oil characteristics within the slick.





Photos taken over the slick on 23-June-2010 between 16:00 and 20:00 UTC (NOAA RAT-Helo and EPA/ASPECT)

The Scattering Matrix relates the incident and scattered electric field vectors:

$$\begin{pmatrix} E_H \\ E_V \end{pmatrix}_{scattered} = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} E_H \\ E_V \end{pmatrix}_{incident}$$

The scattering matrix is expressed in the Pauli basis as

$$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \xrightarrow{Pauli} k = \frac{1}{\sqrt{2}} \left[S_{HH} + S_{VV} \quad S_{HH} - S_{VV} \quad 2S_{HV} \right]^T$$

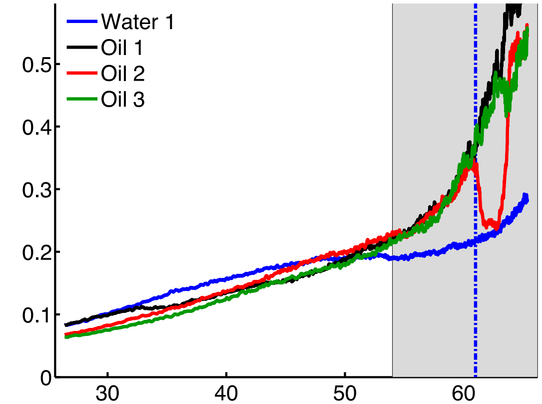
Diagonalization of the coherency matrix T=kk* gives 3 eigenvalues, λ, and eigenvectors, u. Those define the scattering mechanisms and their backscattered power.
The Cloude-Pottier polarimetric decomposition yields 4 variables derived from the eigenvalues and eigenvectors:

Entropy: $$H = \sum_{i=1}^{3} \left(\frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \right) Log_3 \left(\frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \right) \quad 0 \le H \le 1$$

Anisotropy: $$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3} \quad 0 \le A \le 1$$

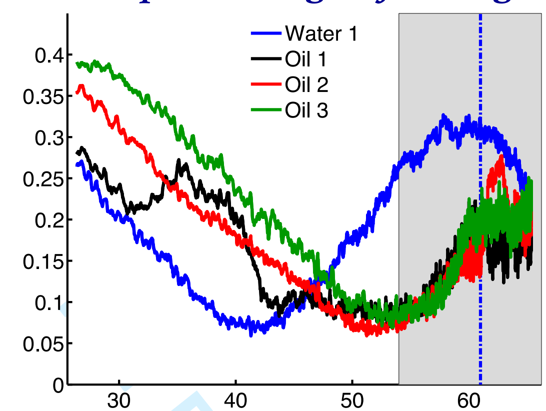
Mean angle: $$\overline{\alpha}(u)$$

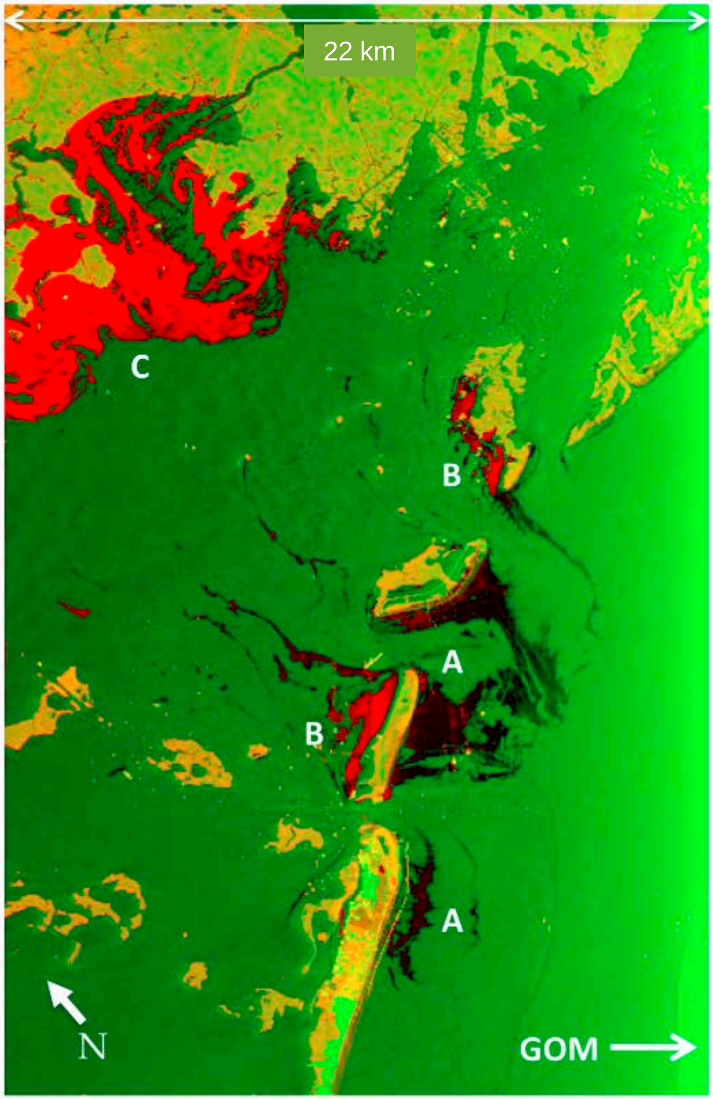
Averaged intensity: $$\Lambda = \sum_{i=1}^{3} \left(\frac{\lambda_i^2}{\lambda_1 + \lambda_2 + \lambda_3} \right)$$

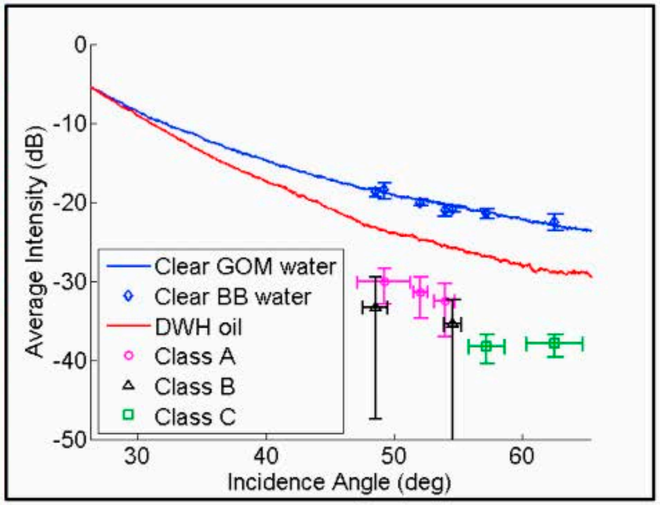


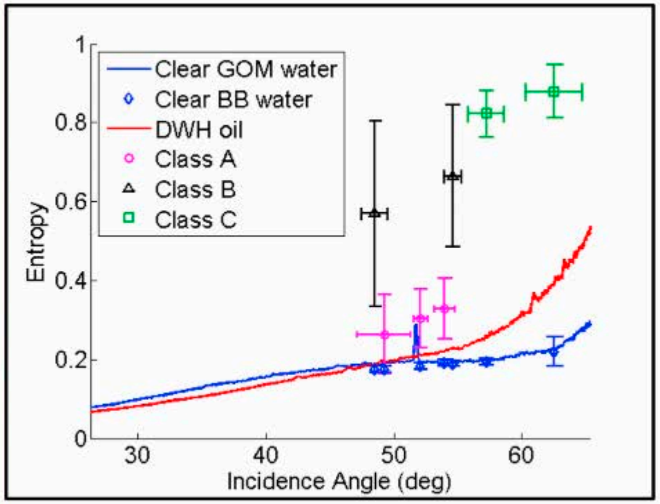
Entropy: Values are low (Bragg) except for low SNR regions (SNR < 6 dB grey band - oil; blue line - H_2O)

Anisotropy: Shows greatest variation in the oil slick, but is only measurable with quad-pol, low noise instrument. We are studying the statistical significance and possible origin of this signal.







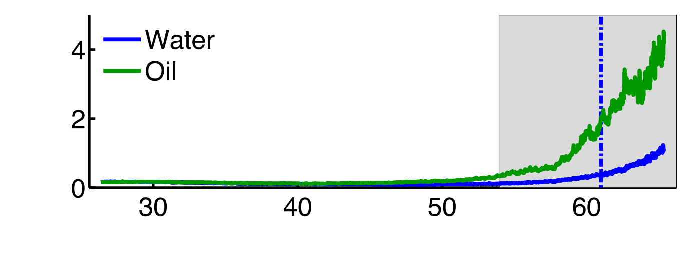


Large amounts of oil moved far into Barataria Bay in SE Louisiana on 16-17 June 2010, with oil remaining in the area until after the UAVSAR over-flight.

Weathered oil in the interior of Barataria Bay shows a significantly higher entropy than oil around the rig site or in the Gulf of Mexico approaching the Louisiana shoreline.

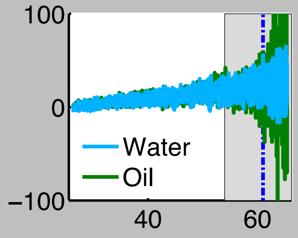
C. E. Jones, B. Holt, S. Hensley (JPL/Caltech), B. Minchew (Caltech), Studies of the Deepwater Horizon Oil Spill with the UAVSAR Radar, 2011, AGU Monograph Series

Noise Power / Total Power



Noise <u>at the worst</u> contributes only a few percent of the total measured power at the high incidence angles.

Co-Polarized Phase Difference

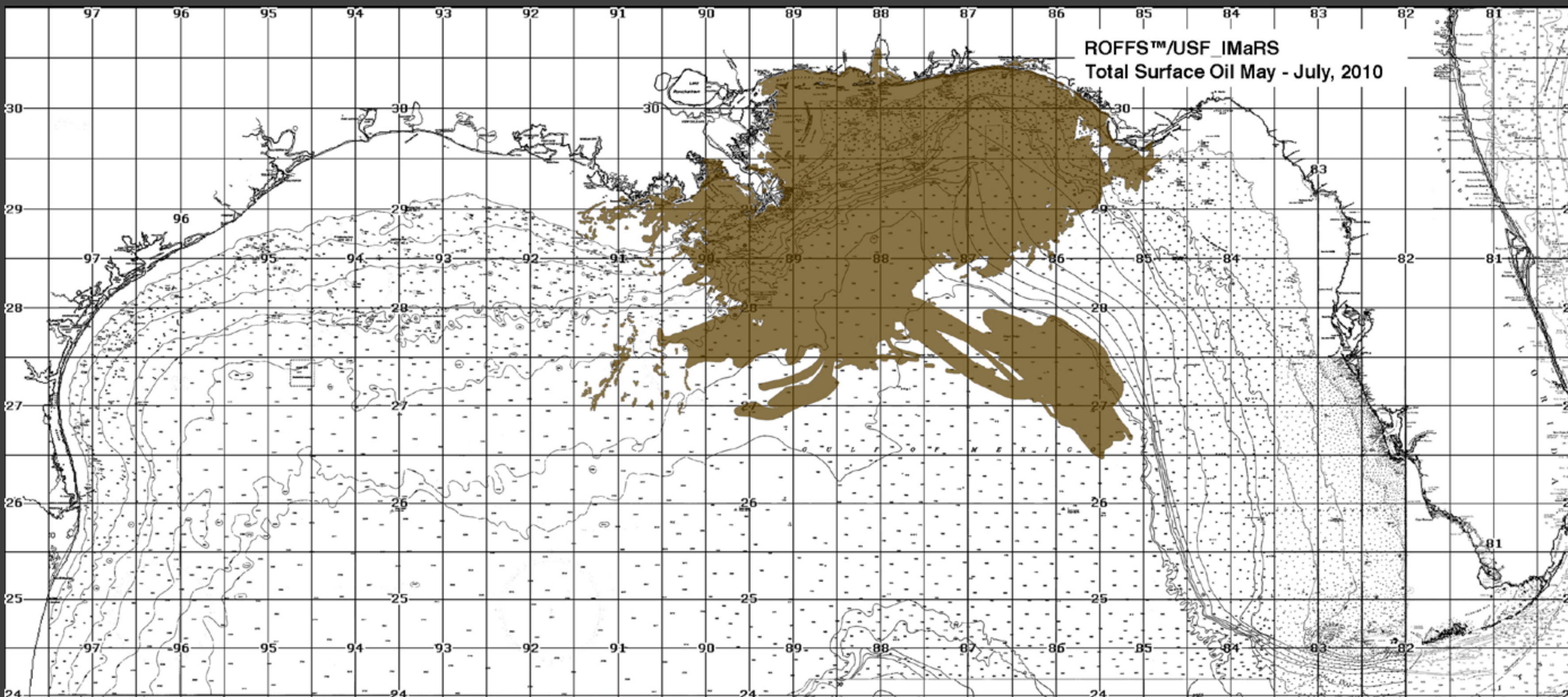


We are not able to distinguish between oil and water using the co-polarized signals' phase difference. The only significant difference occurs in the region where the SNR is low for the radar return from the slick.

Main DWH Oil Slick in Open Waters

Summary of the Results

- Bragg scattering theory well describes L-band radar backscatter from both clean water and the oil in the main DWH slick.
- The most reliable indicator of oil is the backscattered power, which is significantly less than from clean water.
- Assuming Bragg scattering and linear mixing for the emulsion's dielectric properties, we were able to quantify the oil volumetric concentration in the emulsified oil of the DWH slick, placing limits between 65% and 90% across the slick.
- Of the H/A/alpha polarimetric decomposition parameters, the anisotropy appears to offer the most potential for oil classification. However, more analysis is needed to quantify the effect of noise on this parameter.



ROFFS™/USF_IMaRS
Total Surface Oil May - July, 2010