Radar Remote Sensing for Identifying and Characterizing Oil Slicks in Coastal & Open Waters

Cathleen E. Jones
Jet Propulsion Laboratory, California Institute of Technology

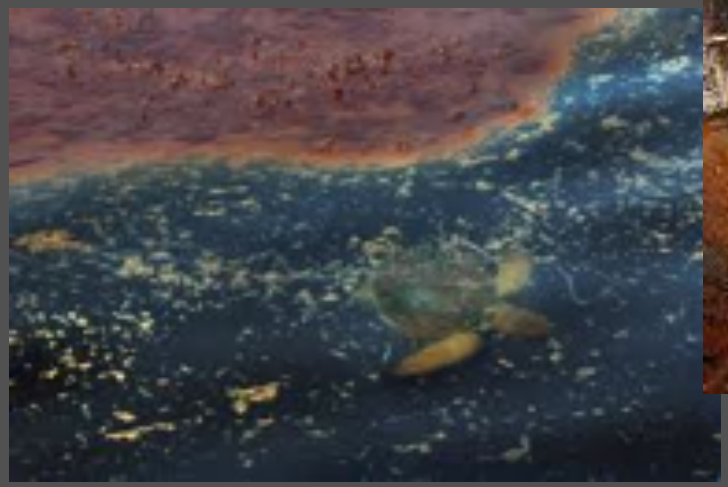
3 May 2016
10th National Monitoring Conference, National Water Quality Management
Tampa, FL

Oil Spills

Information to Guide Response

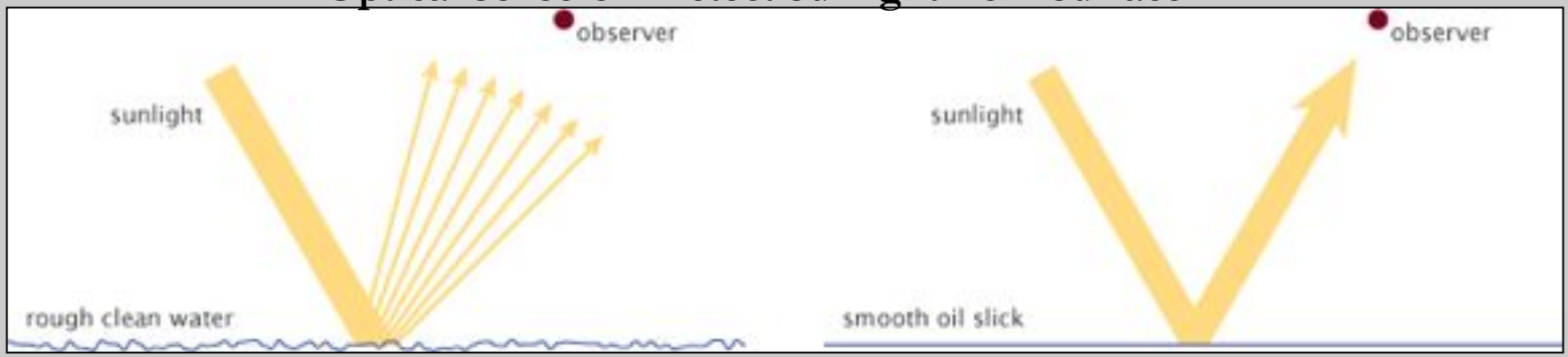
Key Parameters:

- Oil spill position
- Slick type / origin
- Spill extent
- Spill thickness & volume
- Oil-to-water emulsion ratios
- Transport
- Weathering



Radar Remote Sensing of Oil Slicks

Optical Sensors – Detect Sunlight from Surface



RADAR:

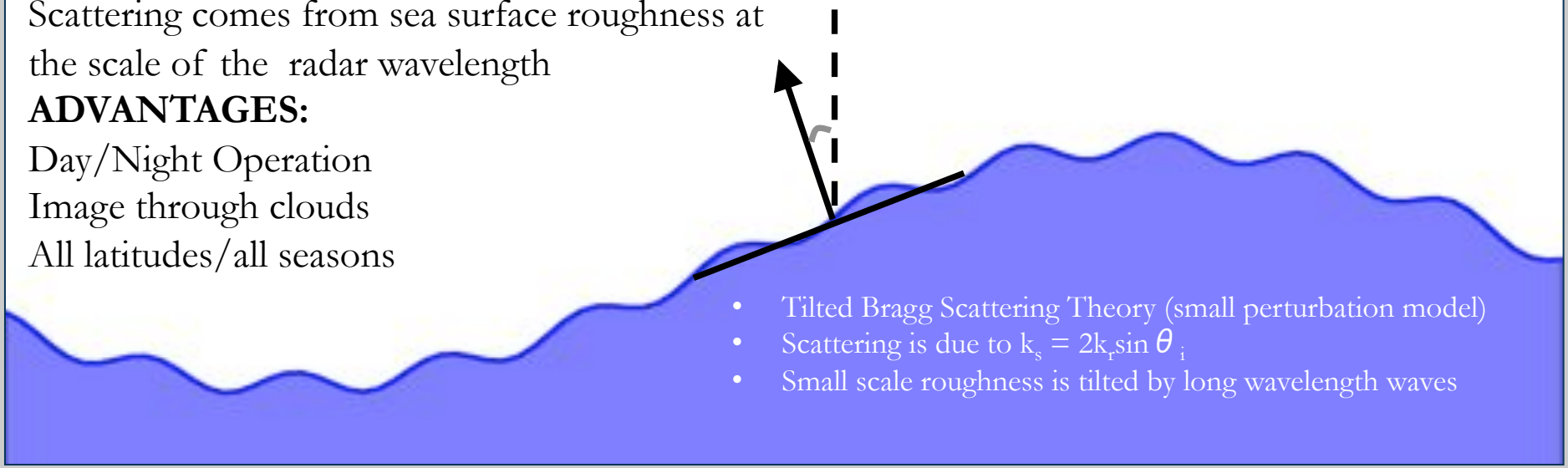
Scattering comes from sea surface roughness at the scale of the radar wavelength

ADVANTAGES:

Day/Night Operation

Image through clouds

All latitudes/all seasons



- Tilted Bragg Scattering Theory (small perturbation model)
- Scattering is due to $k_s = 2k_r \sin\theta_i$
- Small scale roughness is tilted by long wavelength waves

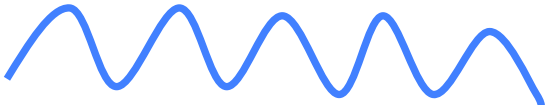
Oil / Water Dielectric Constant

Complex Permittivity
$\varepsilon = \varepsilon' - i\varepsilon''$

Sea water $\varepsilon_{sw} = 80 - i70$
-High conductivity surface

Crude oil $\varepsilon_O = 2.3 - i0.02$
-Low conductivity surface

Ocean Surface (no oil)



$\varepsilon_{SW} = 80 - i70$

-Frequency, temperature dependent

Ocean Surface +Thin Sheen

$\varepsilon_{SW+Sheen} \sim\sim 80 - i70$

-Reduced roughness
-Sheen too thin to change ε_{sw}

Emulsion = Mixture of Oil + Sea water

$\varepsilon_{Mixture} = \varepsilon_{SW} + \varepsilon_O$

-New dielectric layer with ε mixture
–Alters scattering

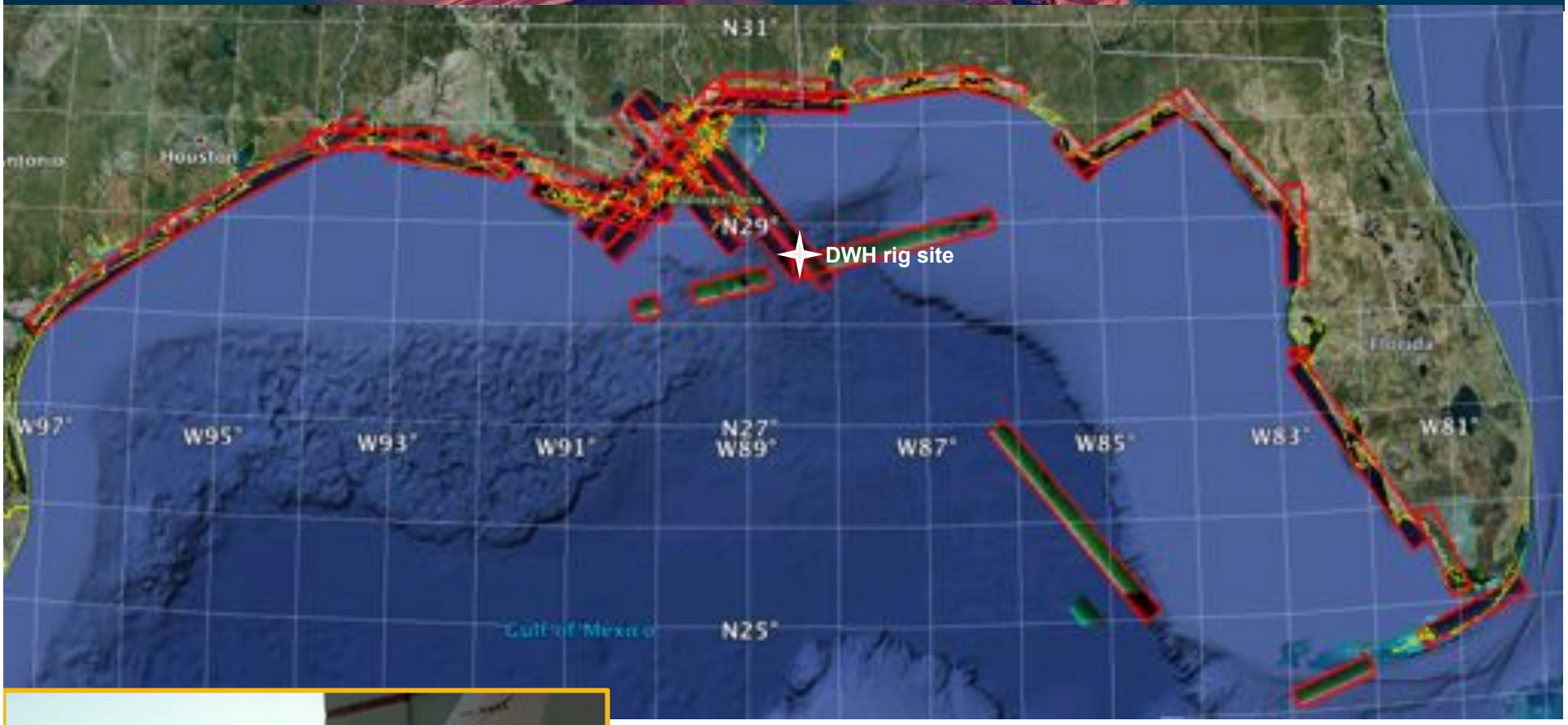
Radar backscattered signal responds to volumetric fraction of emulsified oil as a mixture of oil and seawater

Source: Benjamin Holt, JPL

NASA UAVSAR Airborne Radar

UAVSAR Gulf Oil Spill Campaign

22-23 June 2010 Deployment



- Covered main slick & Gulf coastline
- 2 days, 3 flights, 21 flight hours
- ~5500 km of flight lines
- Imaged an area of 120,000 km^2

UAVSAR Gulf Oil Spill Campaign

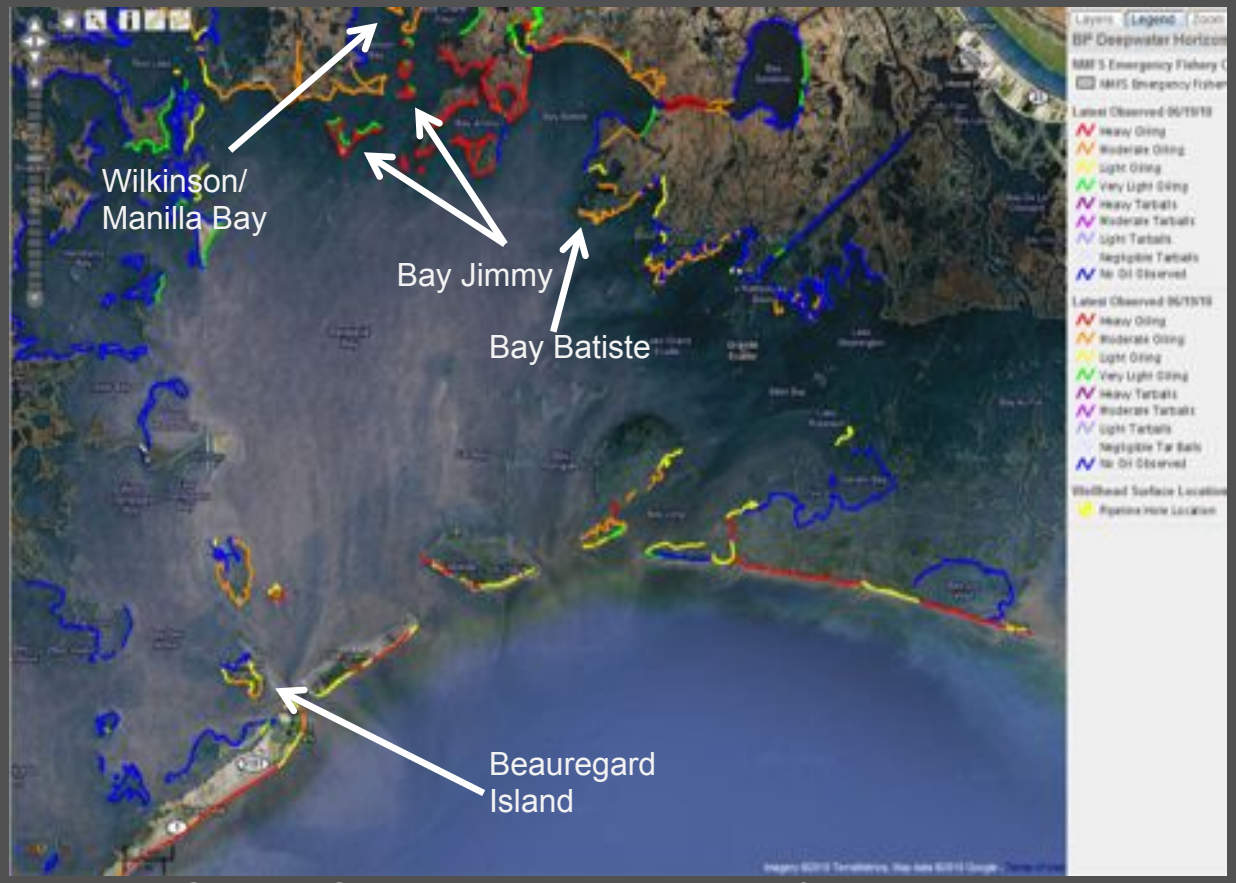
Science Goals

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 with radar.
- Study the use of radar for determining the extent of oil penetration into sensitive coastal ecological zones, in particular, to map the spread of oil from the coastline into coastal wetlands.
- Use the radar data to determine the extent and nature of the damage to different coastal ecosystems and to track ecosystem recovery.
- Determine how SAR can better be used during oil spill response, either in open water, on the coast, or in inland waters.

UAVSAR Gulf Oil Spill Campaign

22-23 June 2010 Deployment



Shoreline Cleanup Assessment Team Map for June 23, 2010

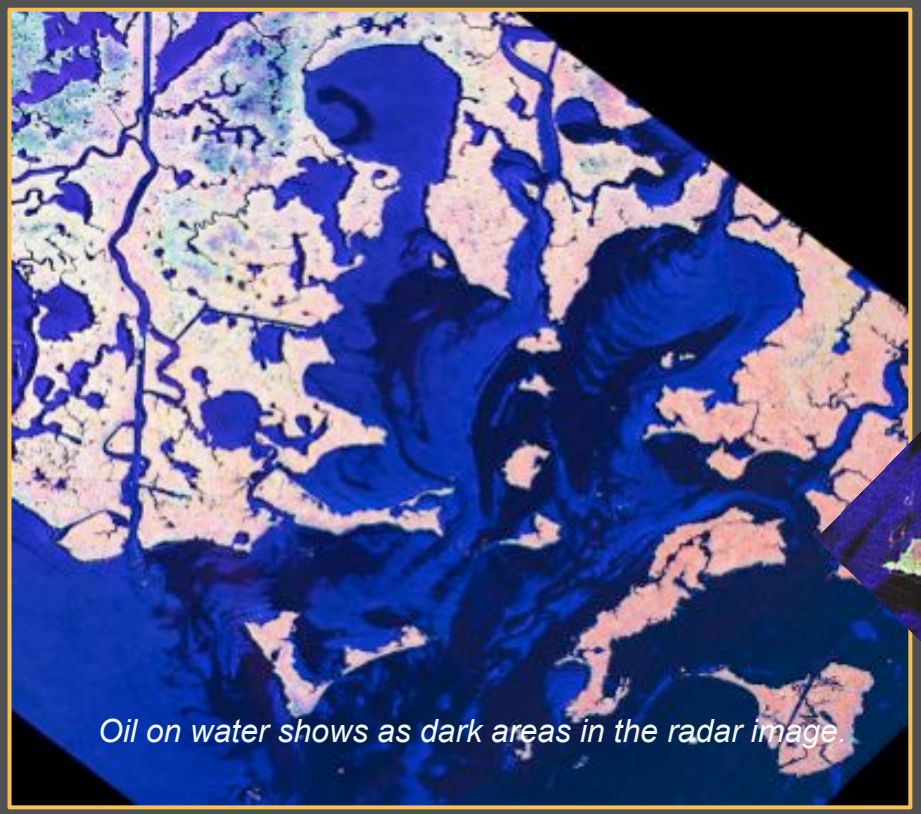
UAVSAR Validation Shoreline Impact Assessment, June 23-24, 2010

Bruce Davis *(DHS, Science and Technology Directorate),* **Philip Kuper and Kara Holekamp** *(Computer Science Corp., Stennis Space Center),* **Steve Tate** *(ASRC Research and Technology Solutions, Stennis Space Center)*

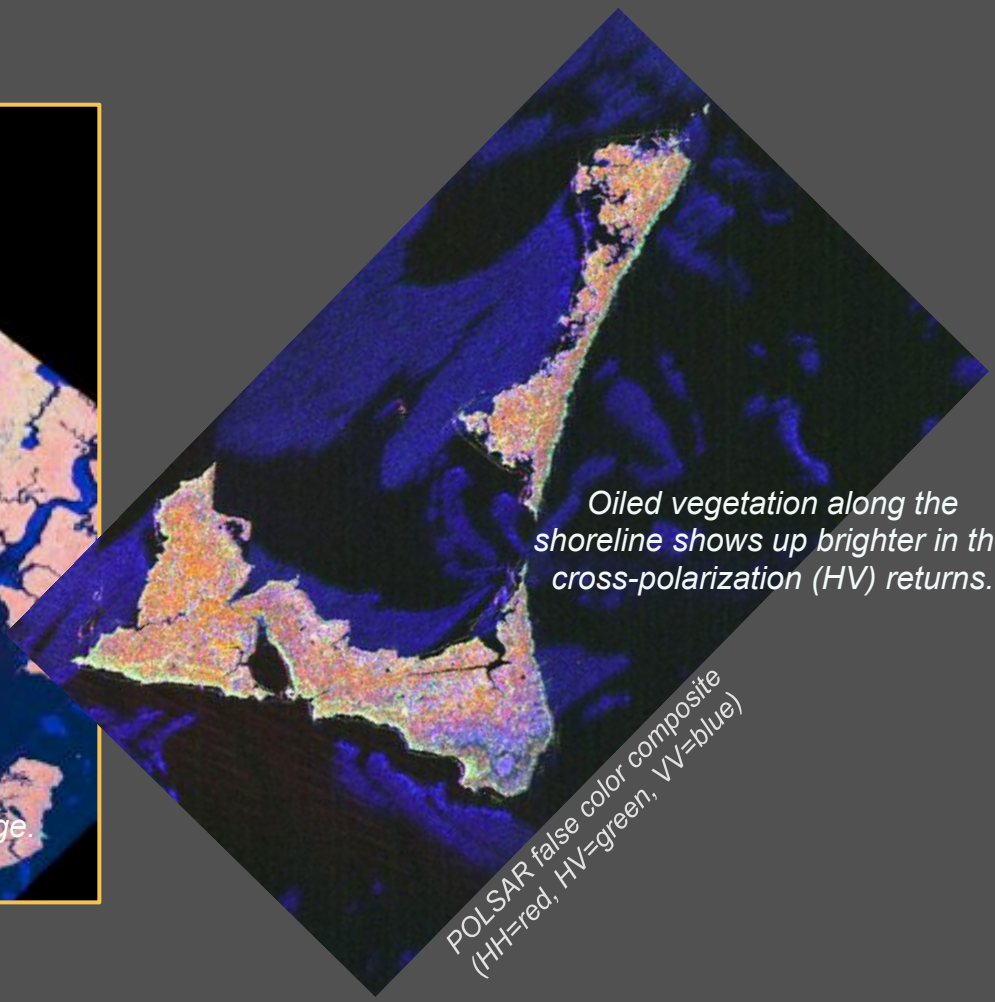
Oil Intrusion Into Coastal Waterways

Barataria Bay, Louisiana

Barataria Bay, Louisiana:



Oil on water shows as dark areas in the radar image.



Oiled vegetation along the shoreline shows up brighter in the cross-polarization (HV) returns.

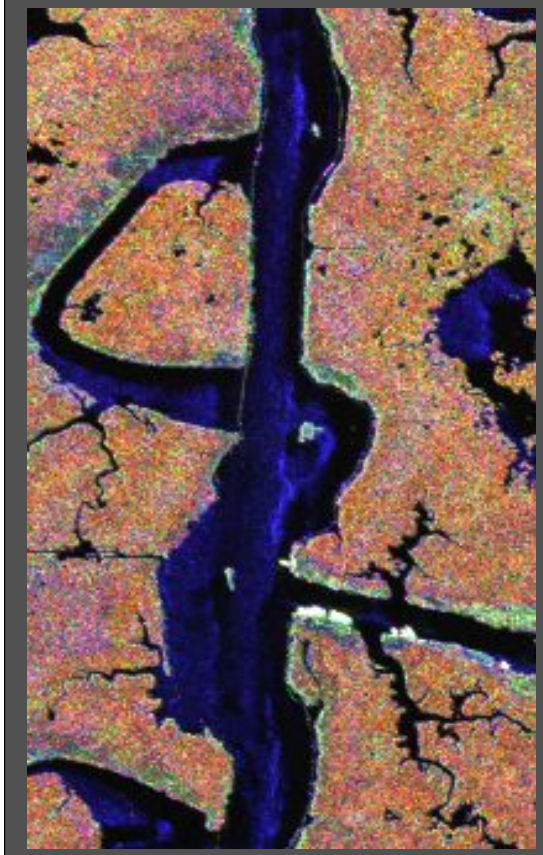
POLSAR false color composite (HH=red, HV=green, VV=blue)

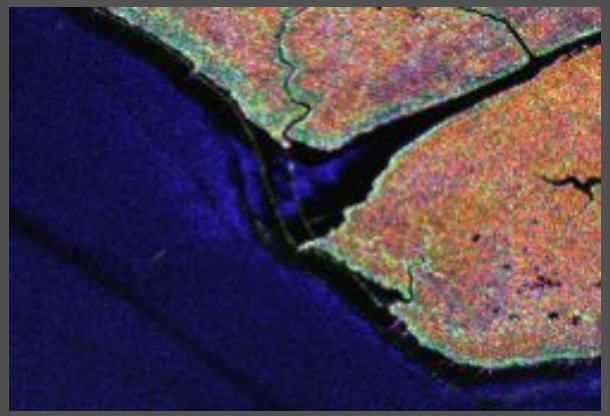
1. Ramsey, E., A. Rangoonwala, Y. Suzuoki, and C. E. Jones (2011). Oil detection in a coastal marsh with polarimetric synthetic aperture radar (SAR). Remote Sensing, 3, 2630-2662.

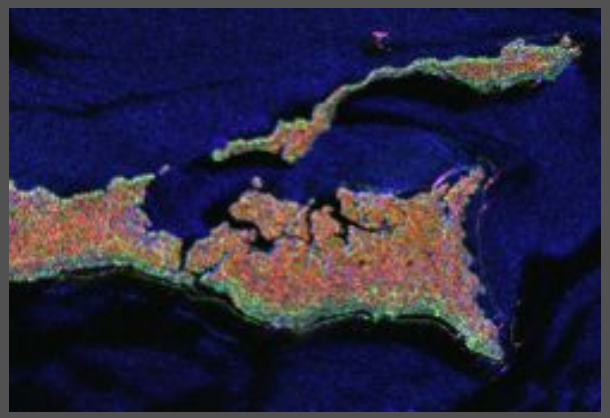
2. Jones, C.E., B. Minchew, B. Holt, and S. Hensley (2011). Studies of the Deepwater Horizon oil spill with the UAVSAR radar. In *Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise*, Geophysical Monograph Series, 195, 33-50.

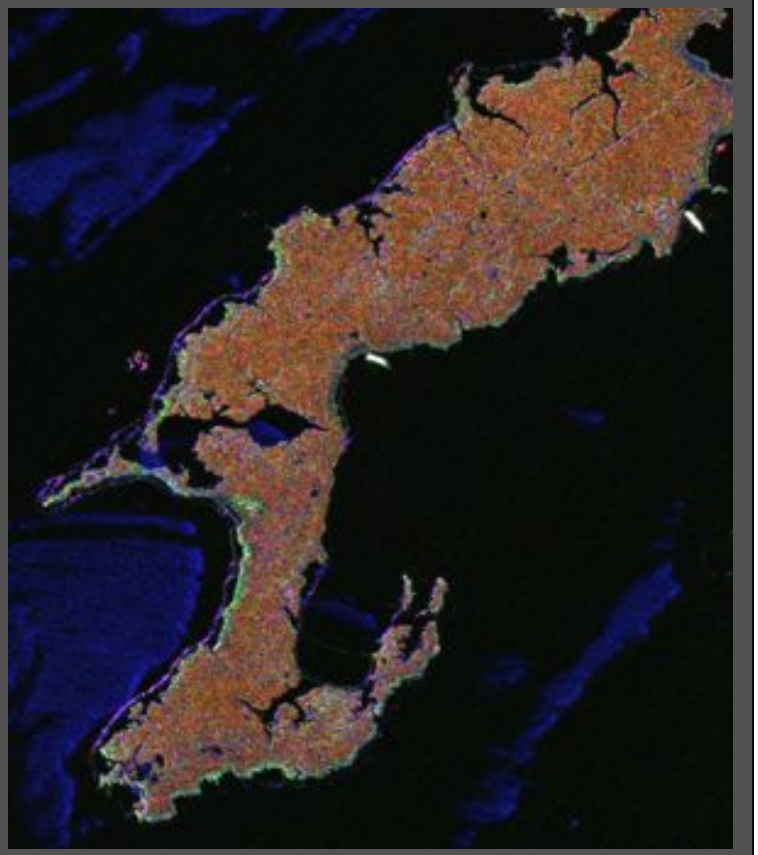
Oil Impact to Wetlands

Barataria Bay, Louisiana









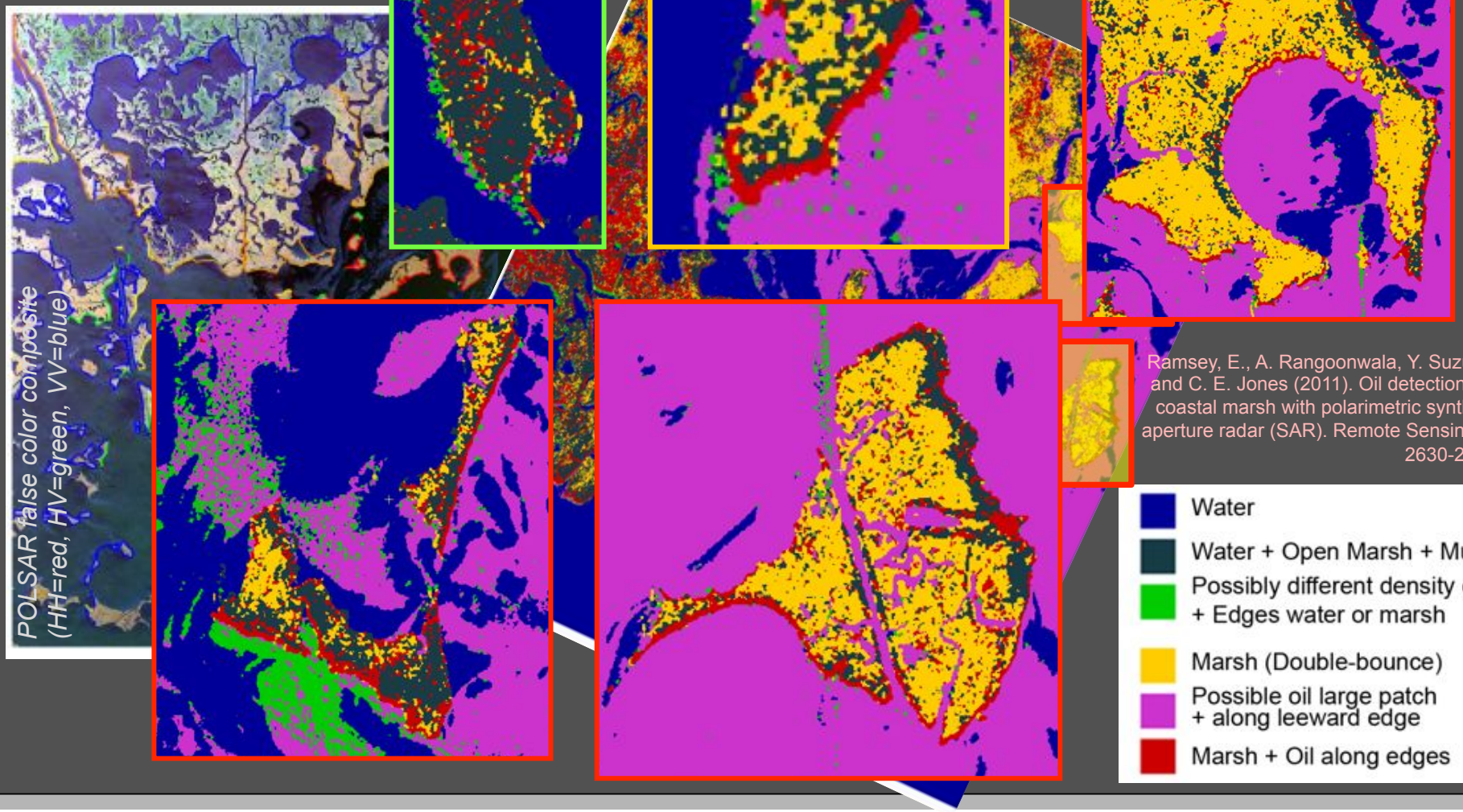
UAVSAR, 1.7 m resolution (HH-red, HV=green, VV=blue)

Automated Oil Mapping in Coastal Waters

Barataria Bay, Louisiana

Unsupervised Wishart Classification using Freeman-Durden Classes

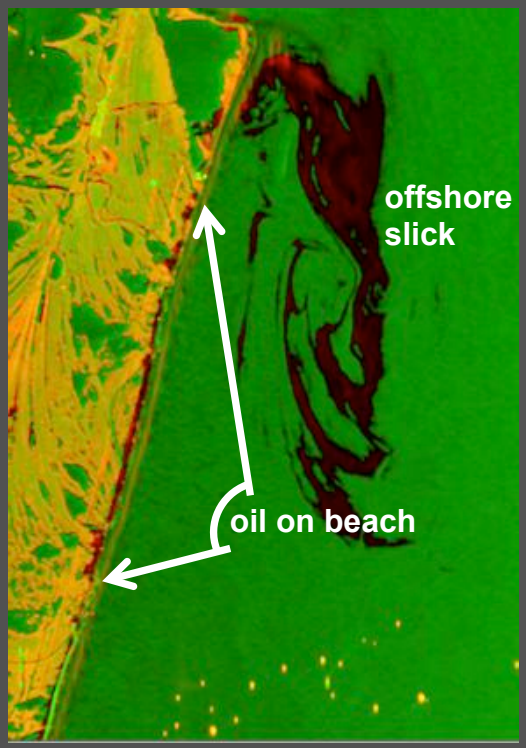
USGS



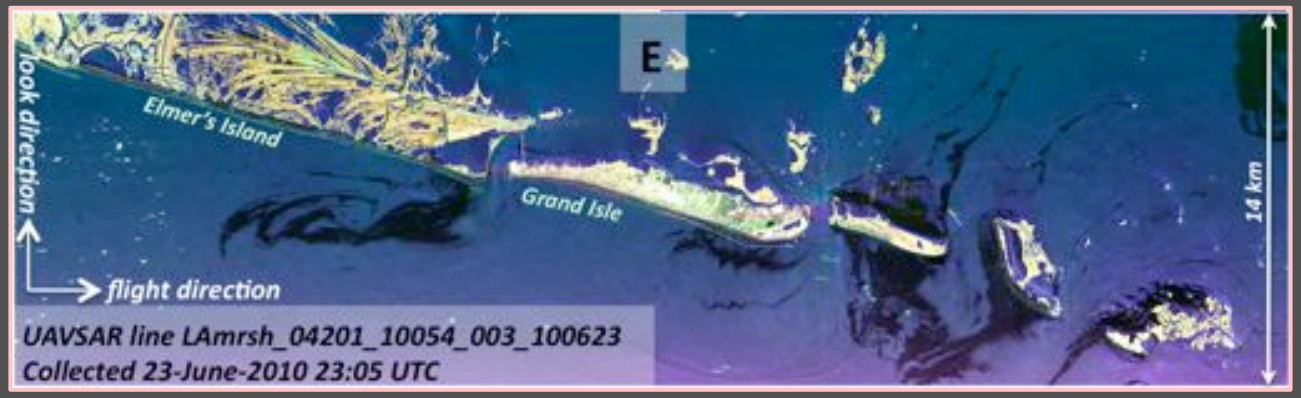
Ramsey, E., A. Rangoonwala, Y. Suzuoki, and C. E. Jones (2011). Oil detection in a coastal marsh with polarimetric synthetic aperture radar (SAR). Remote Sensing, 3, 2630-2662.

Oiled Beaches

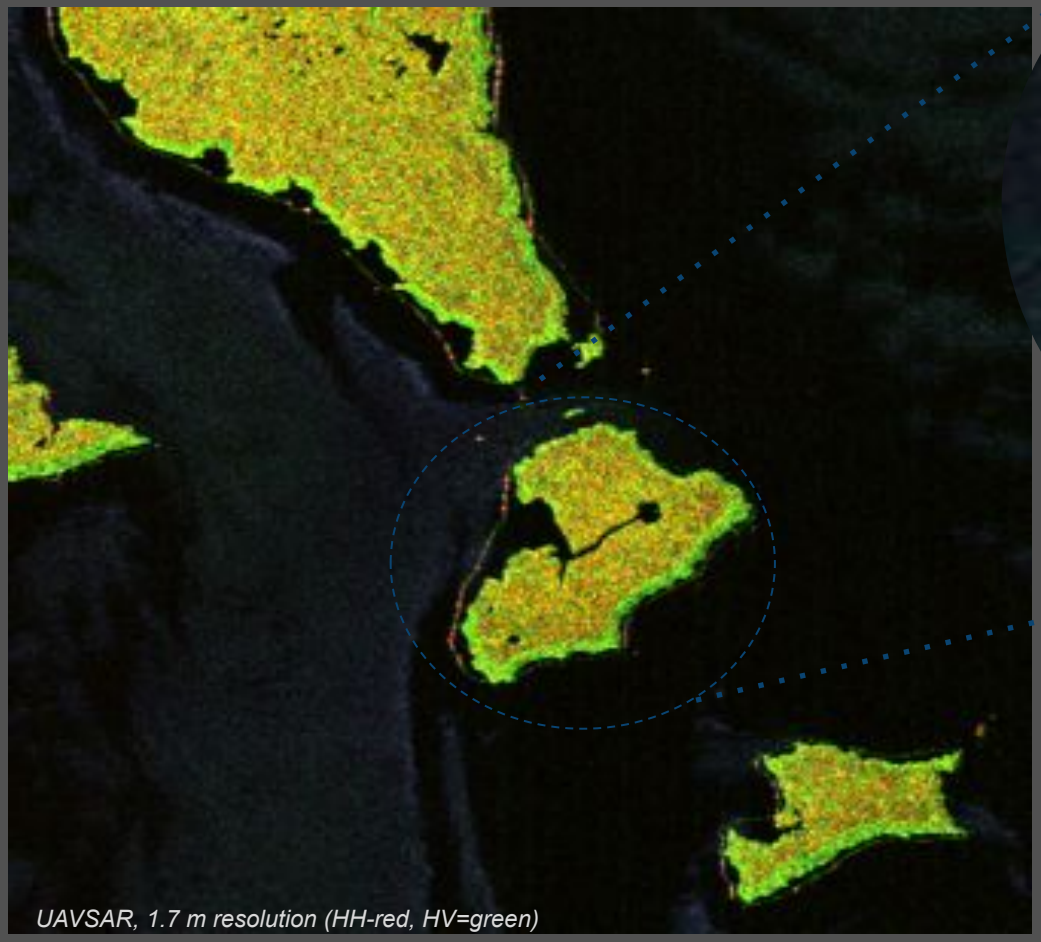
Elmer's Island, Louisiana
June 23, 2010



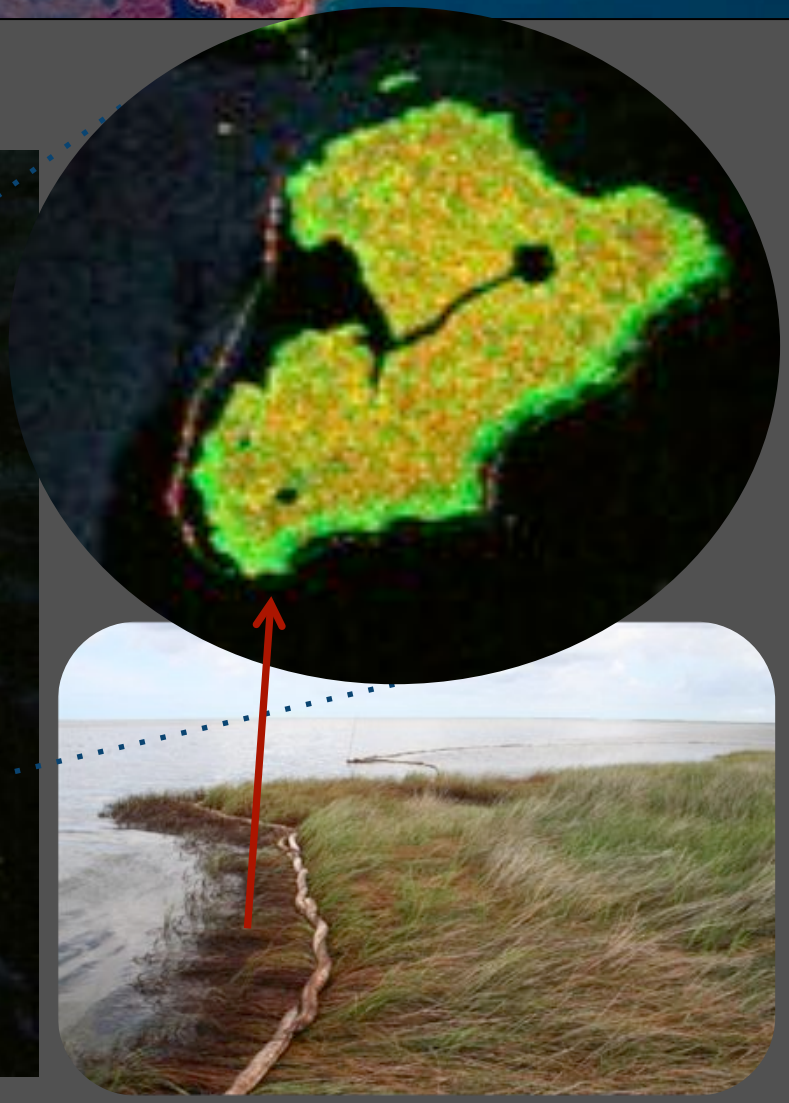
High resolution L-band radar can be used to identify newly oiled areas overnight to direct response crews the following day.



Containment Boom Monitoring



UAVSAR, 1.7 m resolution (HH-red, HV=green)



Cathleen E. Jones and Bruce A. Davis (2011), ***High resolution radar for response and recovery: Monitoring containment booms in Barataria Bay***, *PE&RS, 77(2),* 102-105.

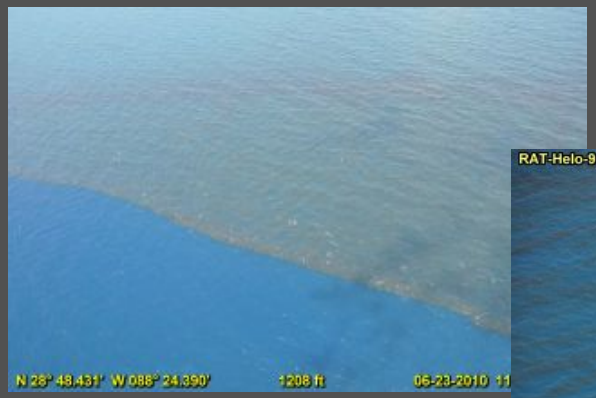
Oil Characterization in Open Waters

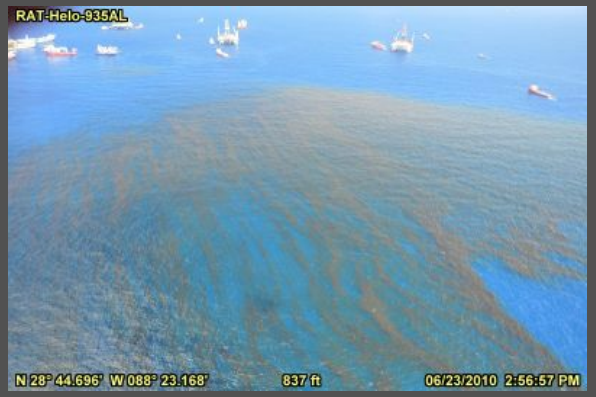
Main Slick, Deepwater Horizon Oil Spill

Polarimetric Backscatter from the ocean surface is dominated by Bragg scattering from surface capillary waves.

$$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \xrightarrow{Bragg} m \begin{pmatrix} R_{HH} & 0 \\ 0 & R_{VV} \end{pmatrix}$$

Oil damps the small-scale waves, causing a departure from Bragg scattering.





Polarimetric Decomposition Methods Studied:
- **Entropy/Anisotropy/Alpha (Cloude-Pottier)**
- **Shannon Decomposition (information theory)**

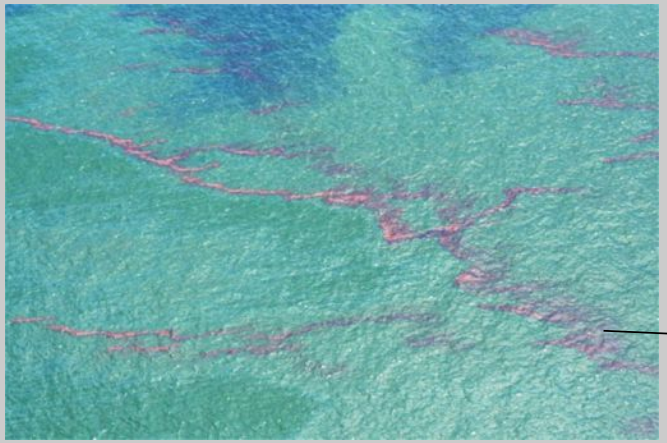
Weather conditions: sea state 0.8-1.0 m SWH, winds 4-6 m/s @ 110°

1. Minchew, B., Jones, C. E., & Holt, B. (2012). Polarimetric analysis of backscatter from the Deepwater Horizon oil spill using L-band synthetic aperture radar. IEEE Transactions on Geoscience and Remote Sensing, 50(10), 3812-3830.
2. Latini, D., Del Frate, F., Jones, C. E. (2016). Multi-frequency and polarimetric quantitative analysis of the Gulf of Mexico oil spill by means of different SAR systems. Remote Sensing of Environment, in review.
3. Jones, C., Minchew, B., & Holt, B. (2011, July). Polarimetric decomposition analysis of the Deepwater Horizon oil slick using L-band UAVSAR data. In Geoscience and Remote Sensing Symposium (IGARSS), 2011 IEEE International (pp. 2278-2281). IEEE.

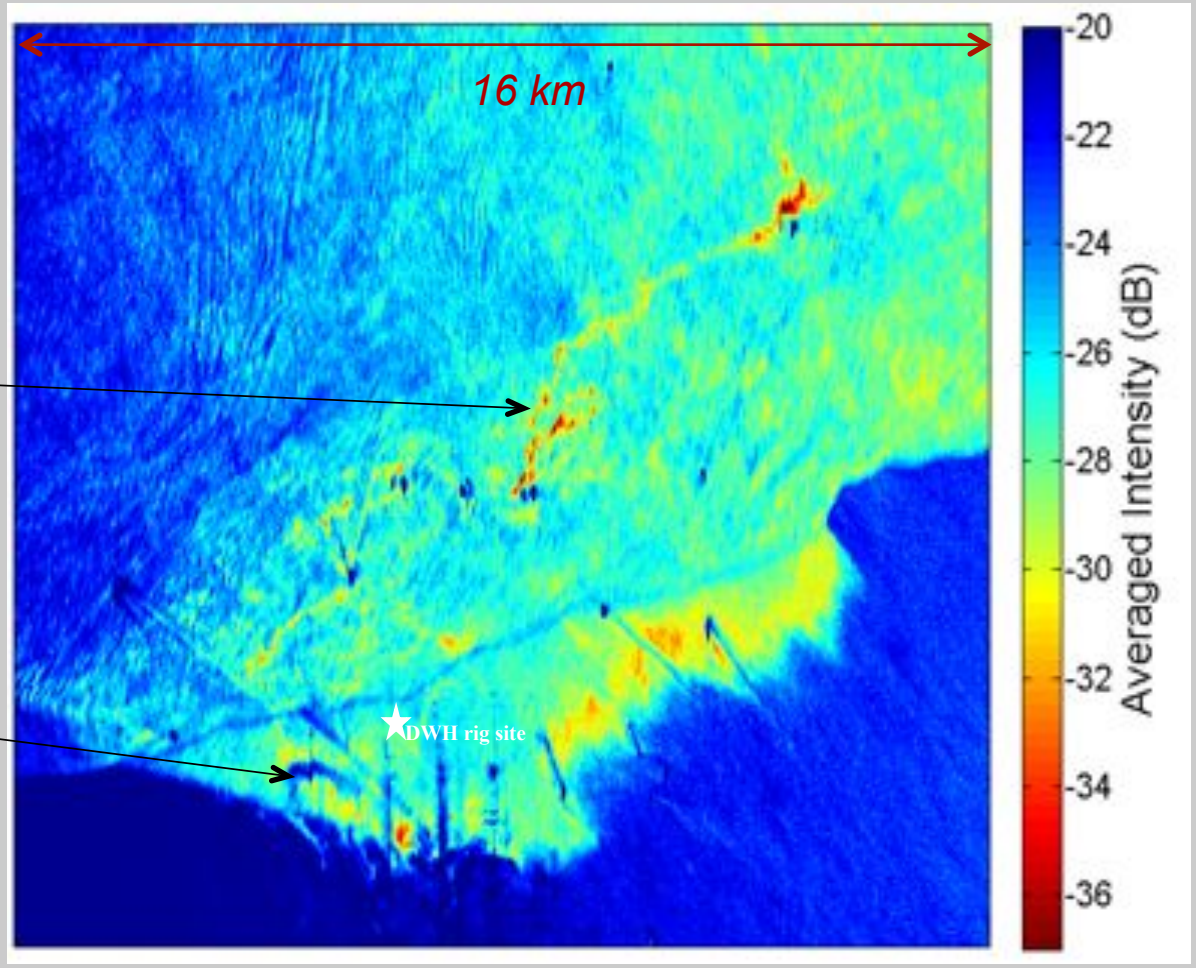
Oil Characterization with Radar Remote Sensing

From the NASA / UAVSAR Airborne Radar --- Deepwater Horizon Spill

Emulsion stringers:



Dispersants application:



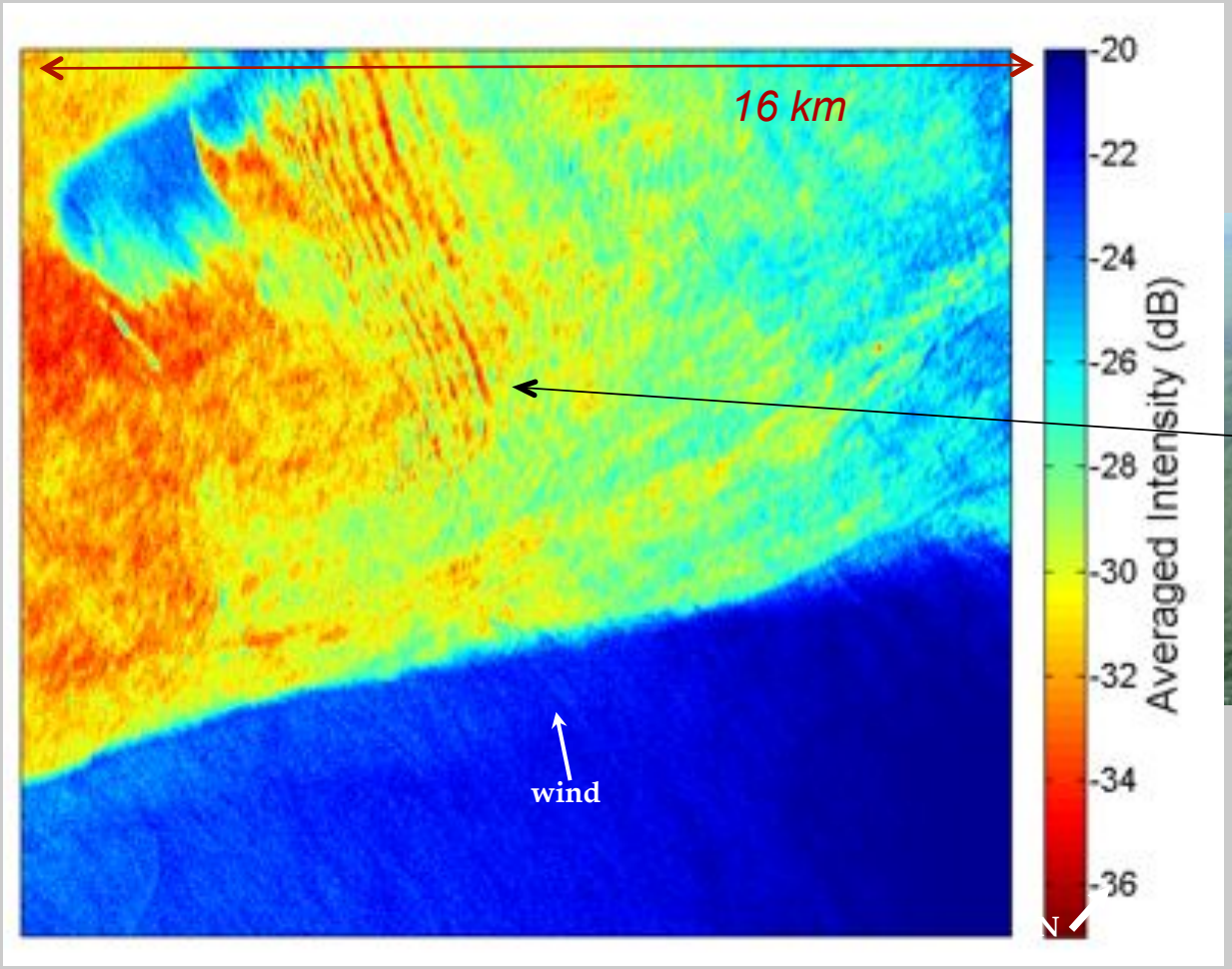
Photos taken over the slick on 6/23/2010 between 16:00 and 20:00 UTC (NOAA RAT-Helo and EPA/ASPECT)

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

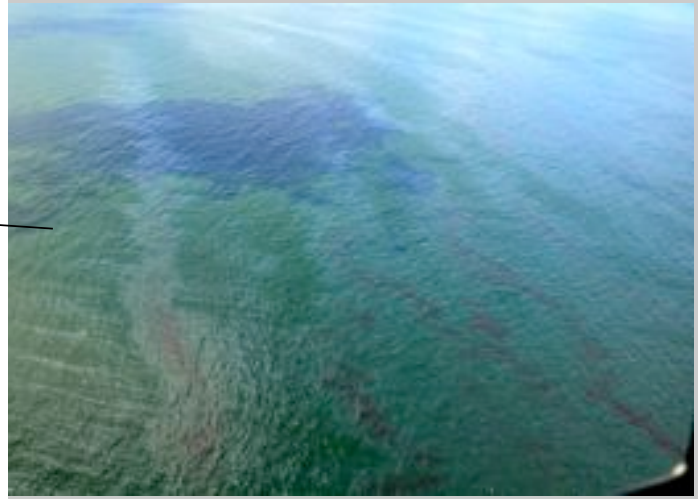
Oil Characterization with Radar Remote Sensing

From the NASA / UAVSAR Airborne Radar --- Deepwater Horizon Spill

Oil concentrated along wind rows:



Photos taken over the slick on 6/23/2010 between 16:00 and 20:00 UTC (NOAA RAT-Helo and EPA/ASPECT)

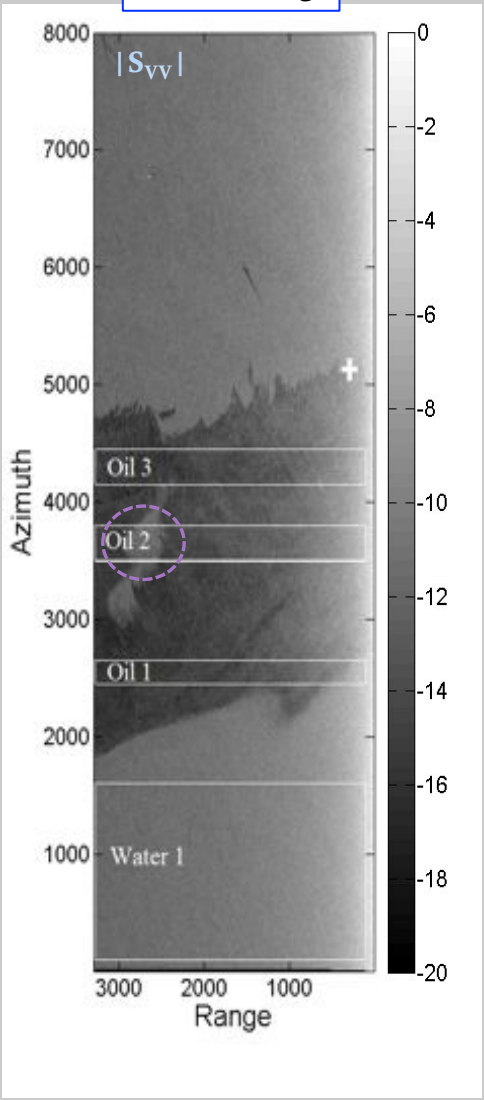


C. Jones, B. Holt, S. Hensley (JPL/Caltech), B. Minchew (Caltech), Studies of the Deepwater Horizon Oil Spill with the UAVSAR Radar, AGU Monograph Series, 2011.

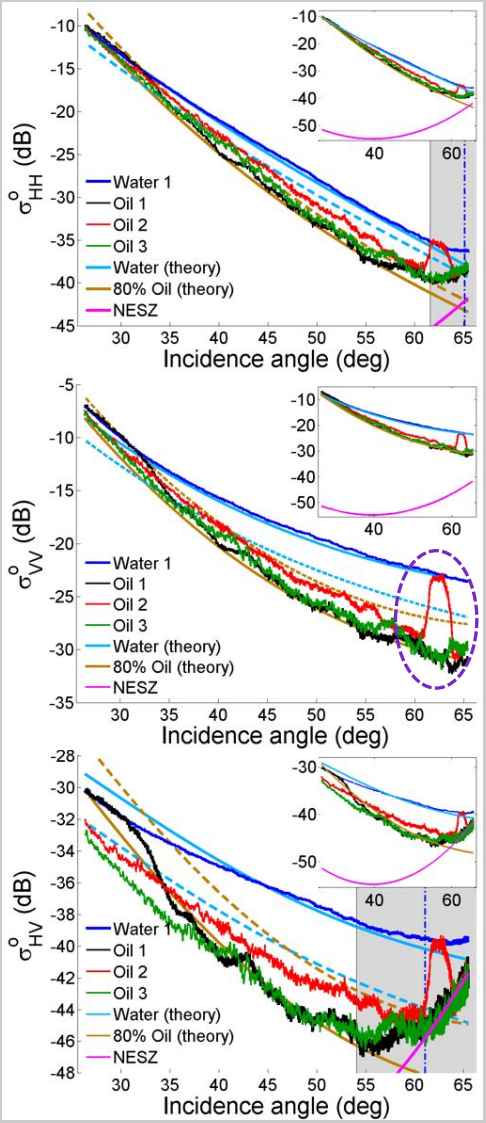
Volumetric Concentration of Oil in Emulsion

From the NASA / UAVSAR Airborne Radar --- Deepwater Horizon Spill

320° Heading



Polarimetric Returns vs. Incidence Angle

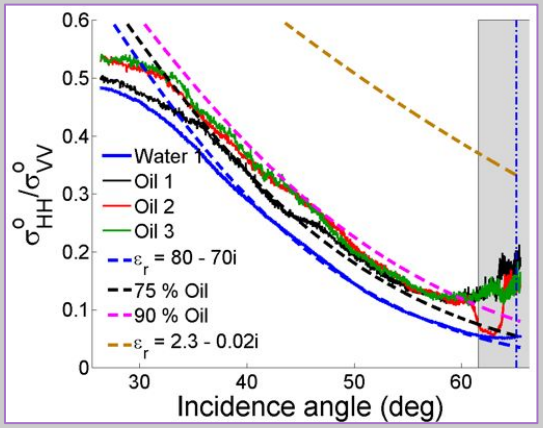


Bragg scattering theory describes well both scattering from clear water and from the oil slick.

We derive the volumetric concentration of oil within emulsion in the main oil slick using a fit for the dielectric coefficient within the Bragg scattering model.

For thick oil slicks we can estimate the volumetric oil concentration from the change in dielectric of the scattering surface.

Copolarized Ratio



B. Minchew, C. E. Jones, B. Holt, Polarimetric analysis of backscatter from the Deepwater Horizon oil spill using L-band radar, TGRS, 2012.

Norwegian Oil-on-Water Exercise 2015

June 2015 Oil-on-Water Controlled Release at the Frigg Field, North Sea, Norway

Controlled experiment for radar remote sensing

- Controlled releases of emulsions with a range of oil fractions (40%, 60%, 80% OIL)
- Plant oil used as biogenic slick simulator
- All slicks left untouched on sea surface
- Radars used: UAVSAR/Radarsat-2/TerraSAR-X/ RISAT-1/ALOS-2

Collaborators: Camilla Brekke, Stine Skrunes, Øyvind Breivik (Norway), Ben Holt (JPL)

NORSE2015, Emulsion Releases

NORSE2015: Norwegian Spill Experiment (June 2015)

Release of Plant Oil & 4 different emulsions (40:60, 60:40, & 80:20 Oil-to-Water ratio)

Stril Mariner: vessel conducting the releases and met/ocean observations.

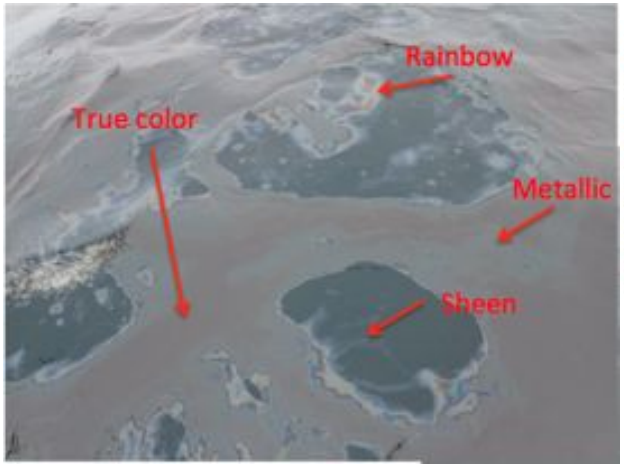
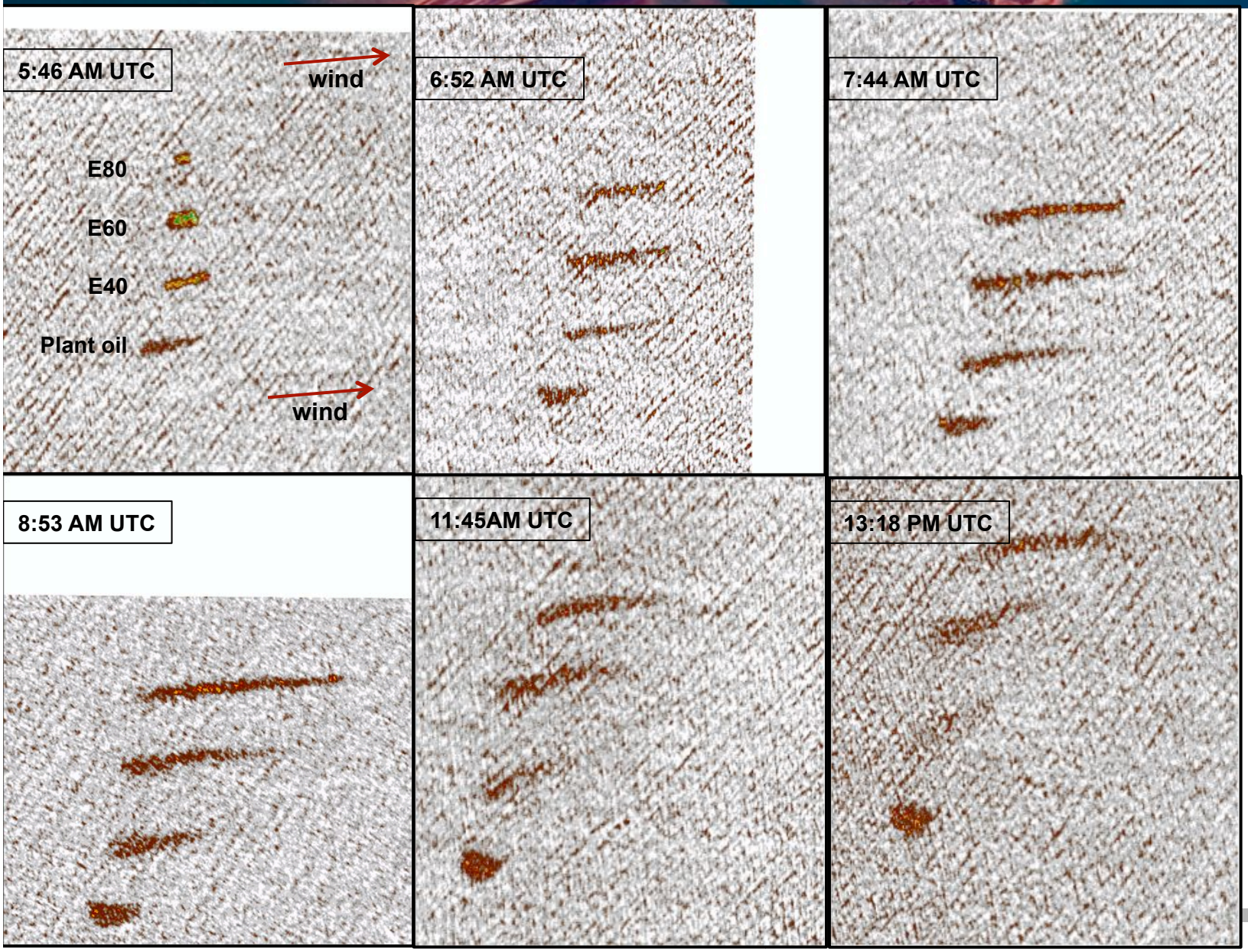


Photo: Øyvind Breivik (Met).

80:20 Emulsion During Release:

Photo: Øyvind Breivik (Met).

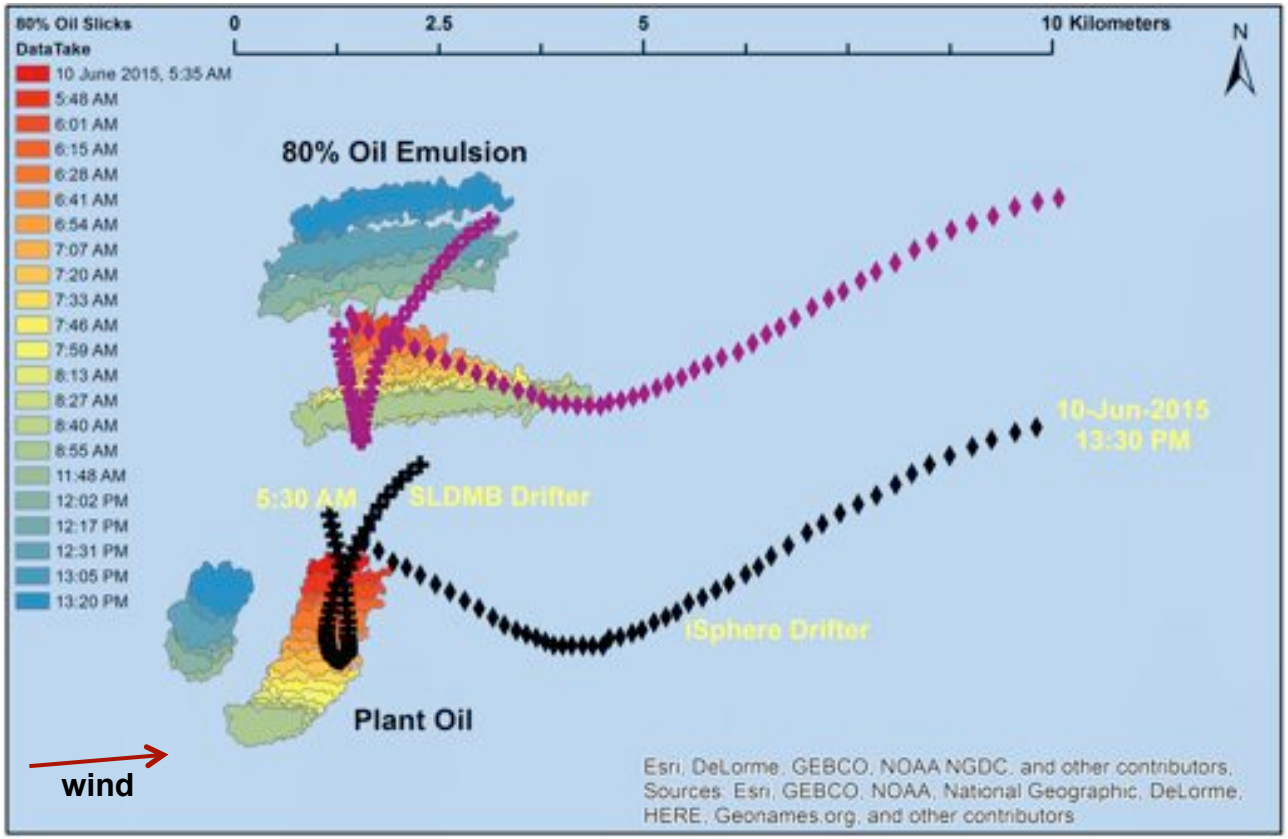
Slick Development



Slick Development

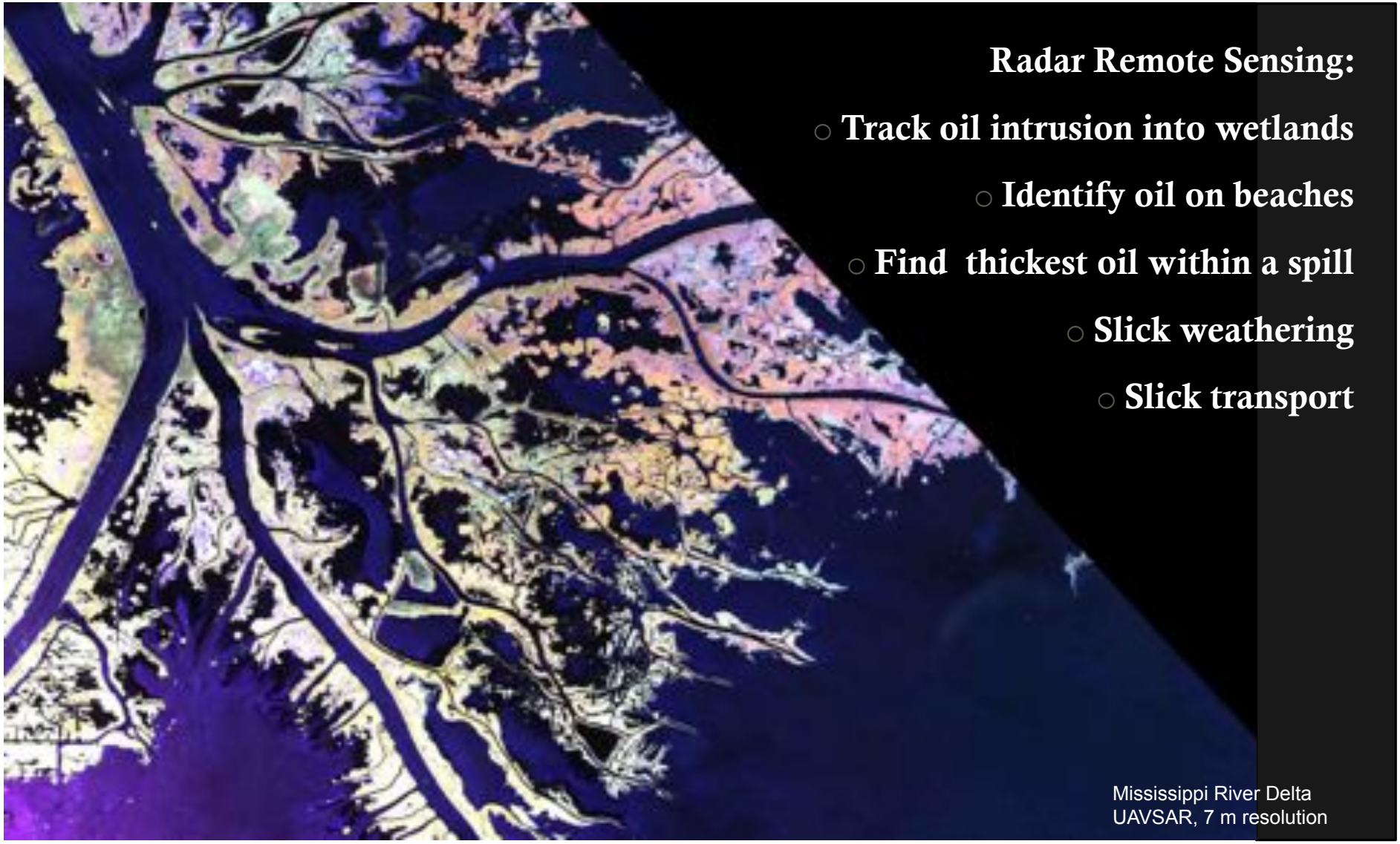
1. All slicks initially expand primarily along the wind direction.
2. The plant oil forms a circular shape & radar doesn't measure further expansion.
3. Emulsion with highest oil fraction persists on the surface the longest of the 3 mineral slicks.
4. Plant oil persists on the surface the longest of all the slicks.
5. The slicks are transported more like the submerged buoy than the wind drift buoy.

High Wind Conditions (9-12 m/s)



Reference: C. E. Jones et al., Measurement and Modeling of Oil Slick Transport, manuscript in preparation.

Summary



Radar Remote Sensing:

- **Track oil intrusion into wetlands**
- **Identify oil on beaches**
- **Find thickest oil within a spill**
- **Slick weathering**
- **Slick transport**

Mississippi River Delta
UAVSAR, 7 m resolution