# A multi-sensor assessment of the Deepwater Horizon oil spill: Surface expression and volume

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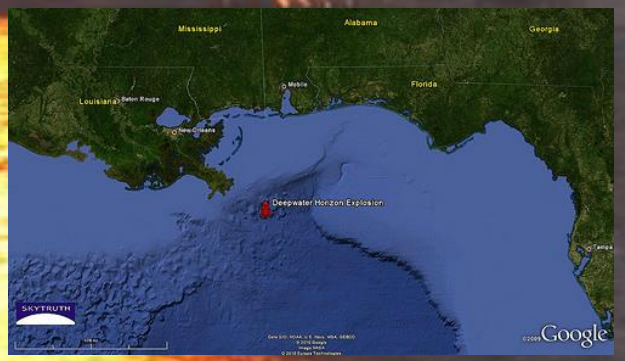
# Gulf of Mexico Oil Spill
# Spring – Summer 2010

Deepwater Horizon
Tragic blowout: April 20, 2010
Final capping: July 15, 2010

## 63,000 barrels per day

Total: 4.4 million barrels = 184.8 Million gallons



# Outline

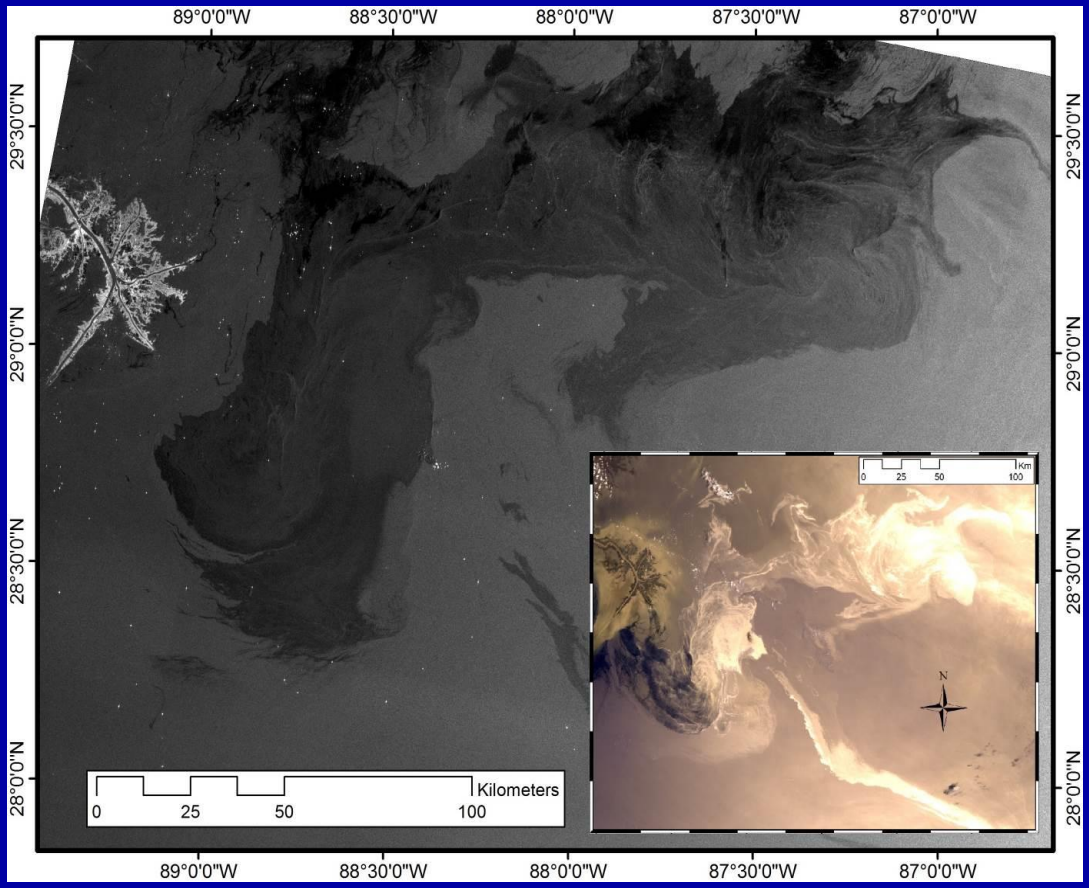
- Optical versus SAR
- Understanding the contrast
- Surface expression
- Volume estimates
- What's next

# Remote Sensing of Surface Oil

## Two fundamental questions: Where is the oil? How much?

**Most used technique:**
- SAR

**Other techniques**
- Optical (UV-VIS-NIR)
- Infrared
- .....

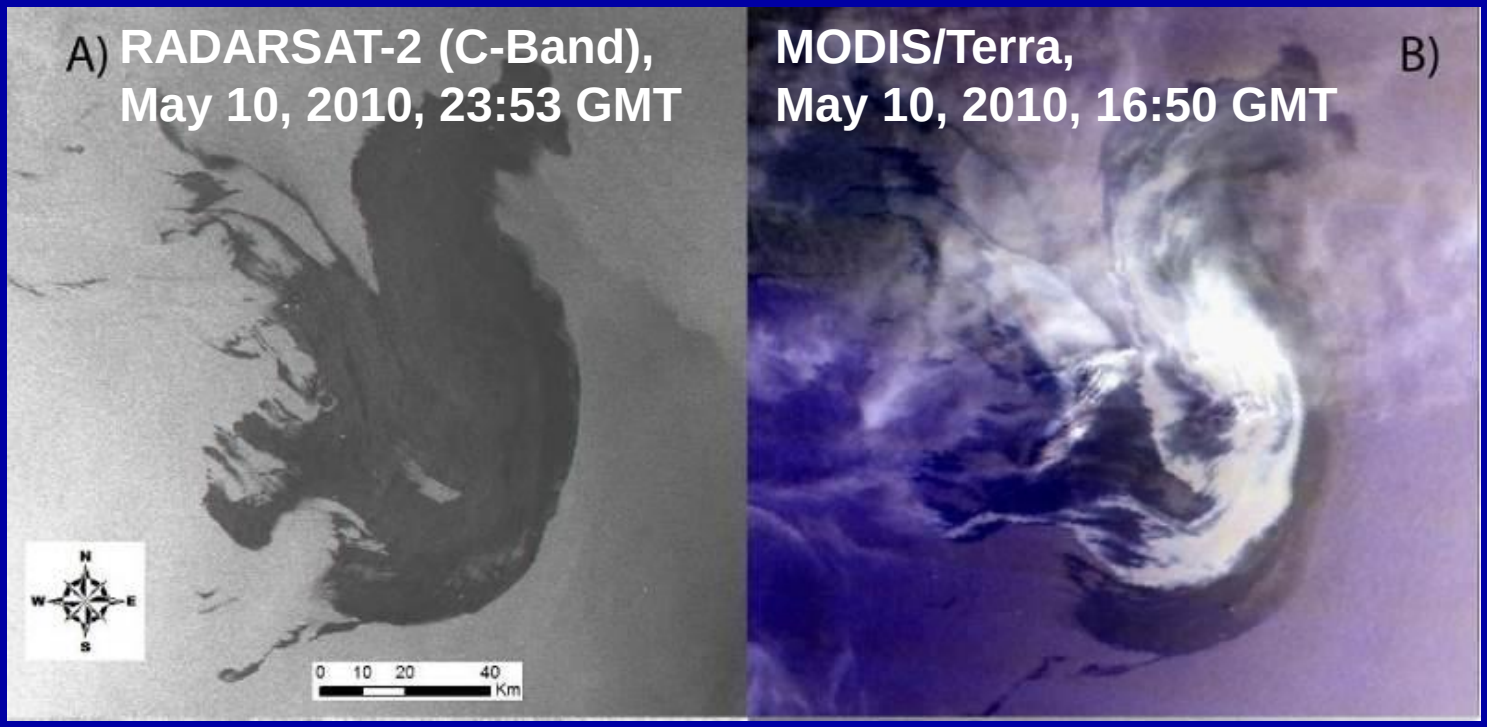



24 May 2010, ALOS (L-Band) SAR, and MERIS

From Garcia-Pineda et al. (2013)

# Remote Sensing of Surface Oil

| SAR (many satellites) | Optical (many satellites) |
|---|---|
| High res (m's to 10s of m's) | Low res (10s – 100s of m's) |
| Small footprint (10s – 100s of km) | Large footprint (100s – 1000s of km) |
| Cloud free | Cloud opaque |
| Often high cost | Low to no cost |

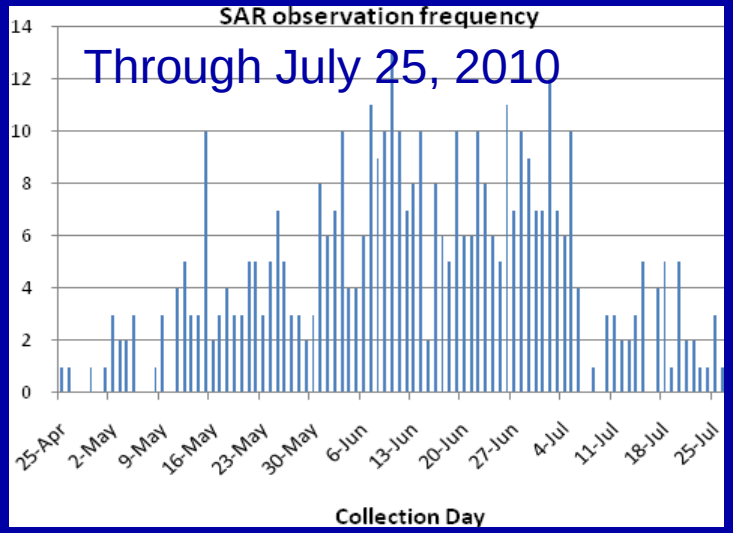



From Garcia-Pineda et al. (2013)

# Remote Sensing of Surface Oil

**Between late April and end of July, 2010**

| SAR Scenes Covering DWHD | |
|---|---|
| Envisat | 123 |
| CosmoSkyMed | 140 |
| ERS2 | 18 |
| ALOS-PALSAR | 70 |
| RADARSAT 1 | 36 |
| RADARSAT 2 | 69 |
| TerraSar-X | 30 |
| Total | 486 |




**MODIS: ~ 57 usable, 19 optimal**

**MERIS: about 1/3 or MODIS**

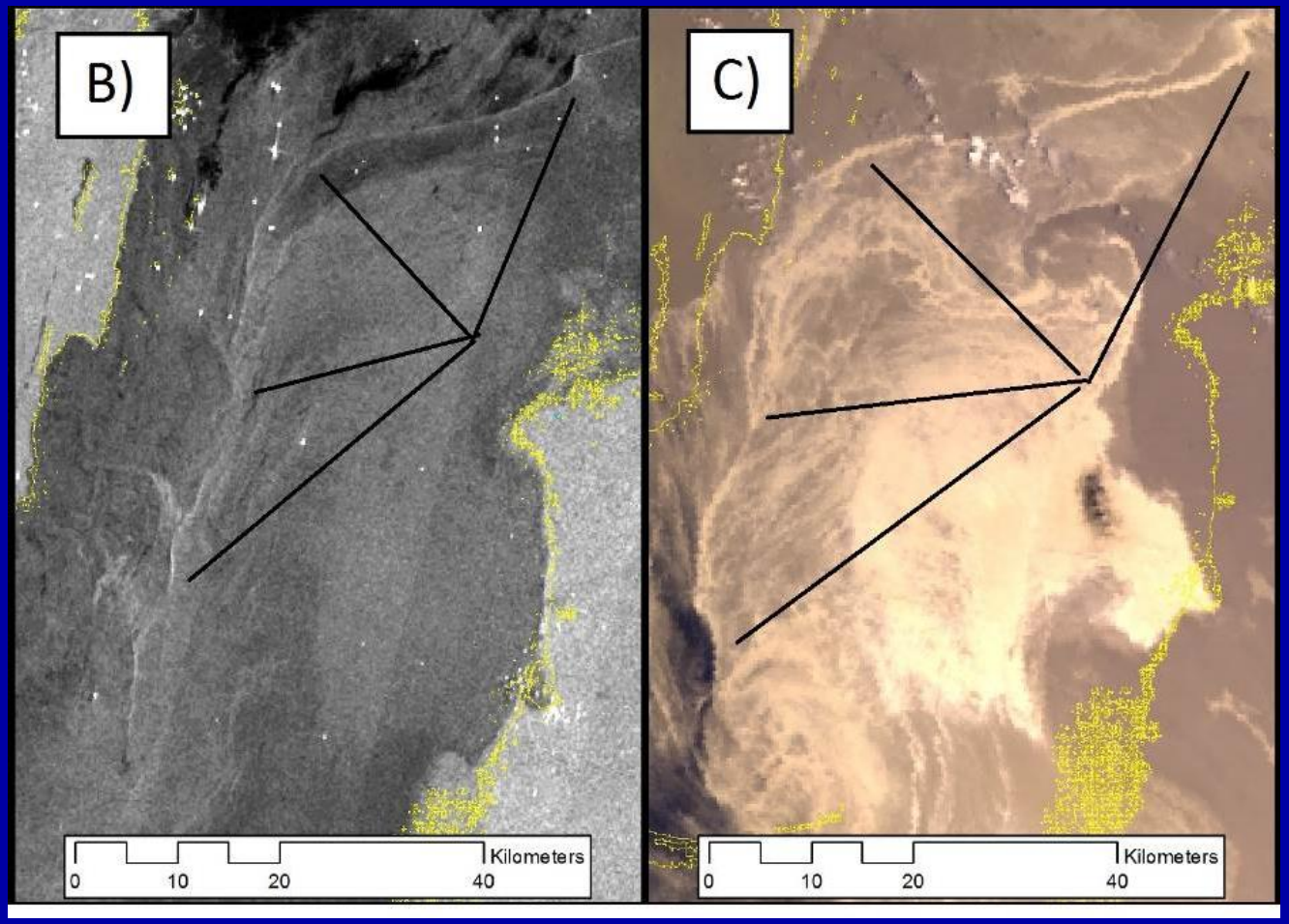
**Landsat: several 10s**

**HICO: 4-5 with oil expressions**

**AVIRIS: > 100 flight lines**

# Remote Sensing of Surface Oil

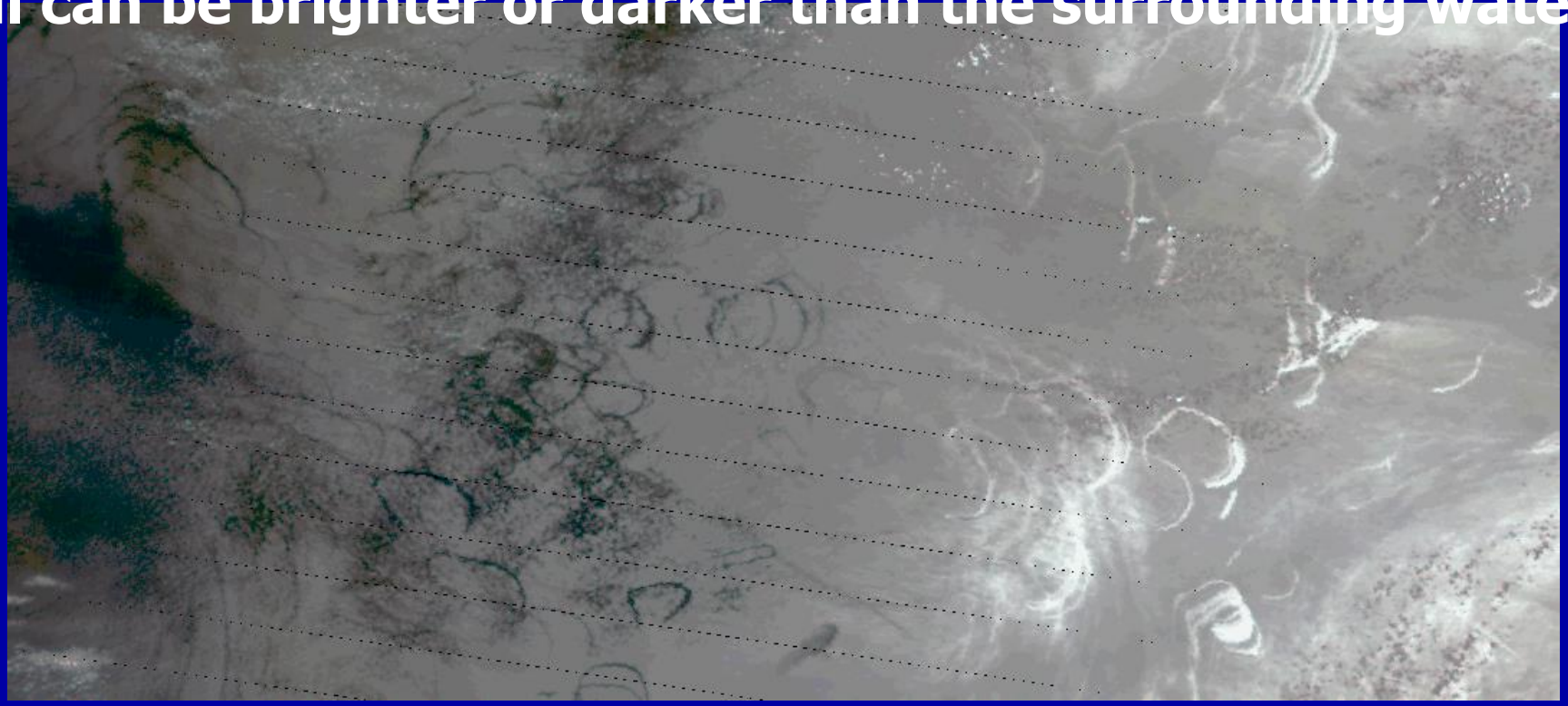
**SAR: primarily for surface expression (yes or no)**
**Optical: more spectral bands, more spatial contrast distributions**

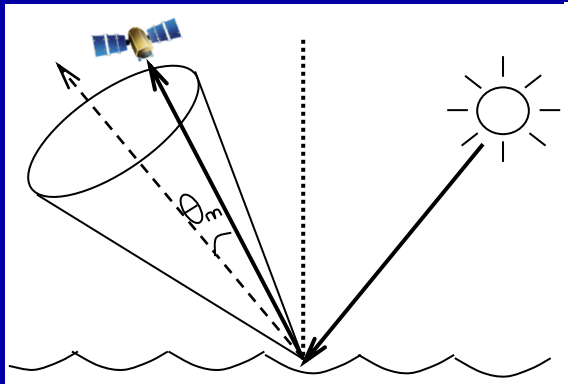



**Images on 24 May 2010, from Garcia-Pineda et al. (2013)**

# Understanding Optical Contrasts

## Oil can be brighter or darker than the surrounding water





$$p_s(z_x, z_y) = \frac{1}{\pi\sigma^2}\exp[-(z_x^2 + z_y^2)/\sigma^2], \text{ Cox and Munk (1954)}$$

$$z_x = \partial z/\partial x,\ z_y = \partial z/\partial y,\ \sigma^2 = 0.00534\,W$$

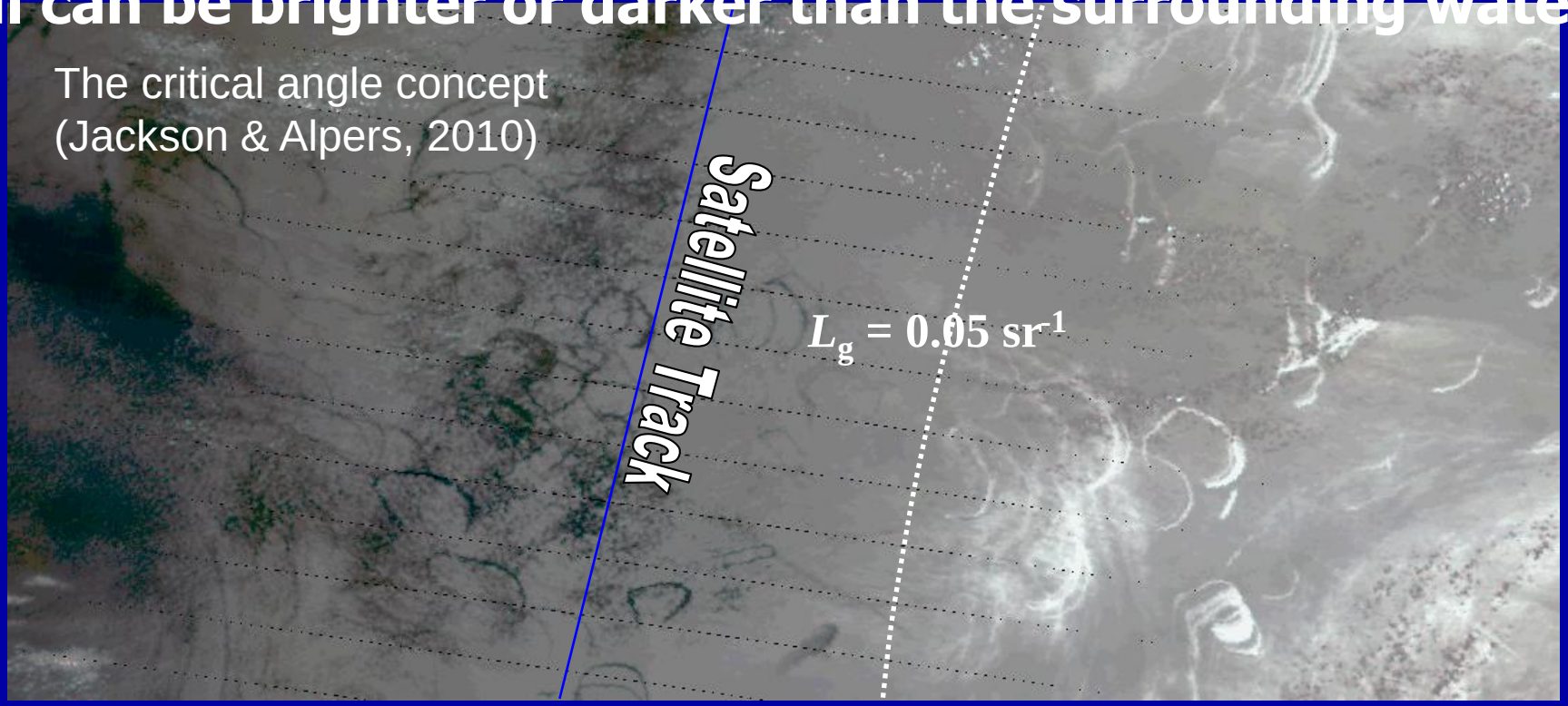
$$L_g = \frac{\rho(\theta_m, \lambda)}{4N(\vartheta_0, \theta, \phi)} p_s(z_x, z_y)$$

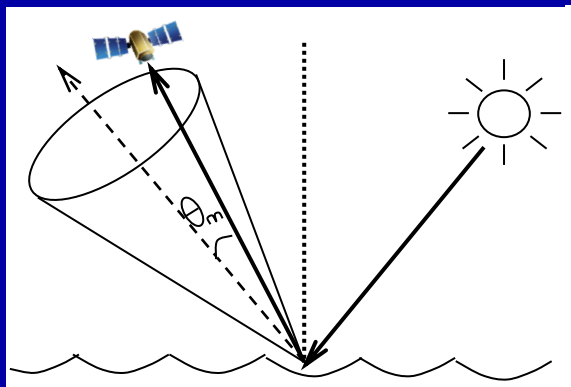
$$\cos(\theta_m) = \cos(\theta_0)\cos(\theta) - \sin(\theta_0)\sin(\theta)\cos(\phi)$$

# Understanding Optical Contrasts

## Oil can be brighter or darker than the surrounding water

The critical angle concept
(Jackson & Alpers, 2010)

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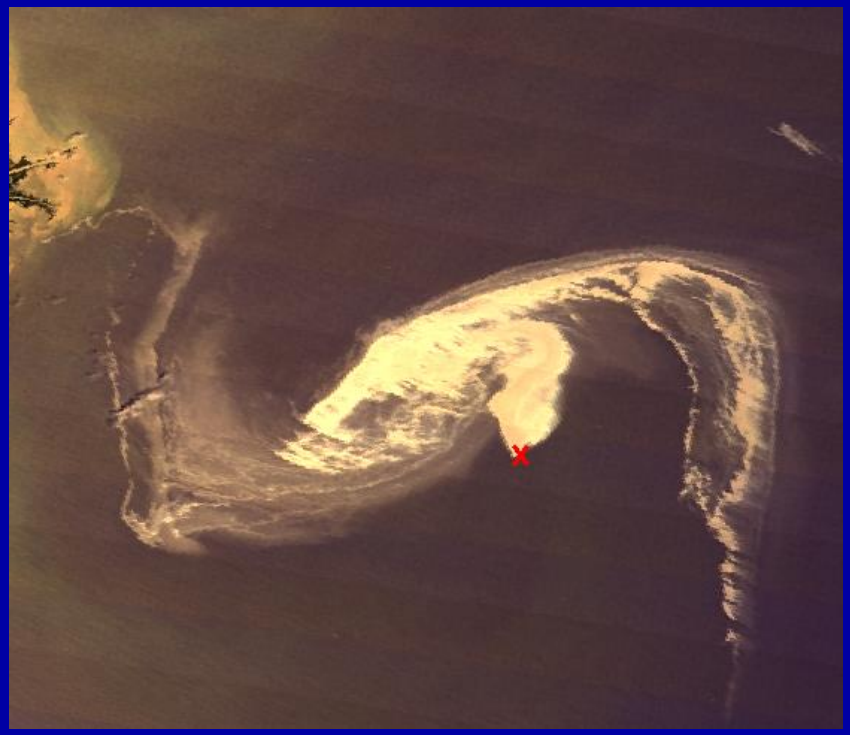
$$L_g = \frac{\rho(\theta_m, \lambda)}{4N(\vartheta_0, \theta, \phi)}\,p_s(z_x, z_y)$$

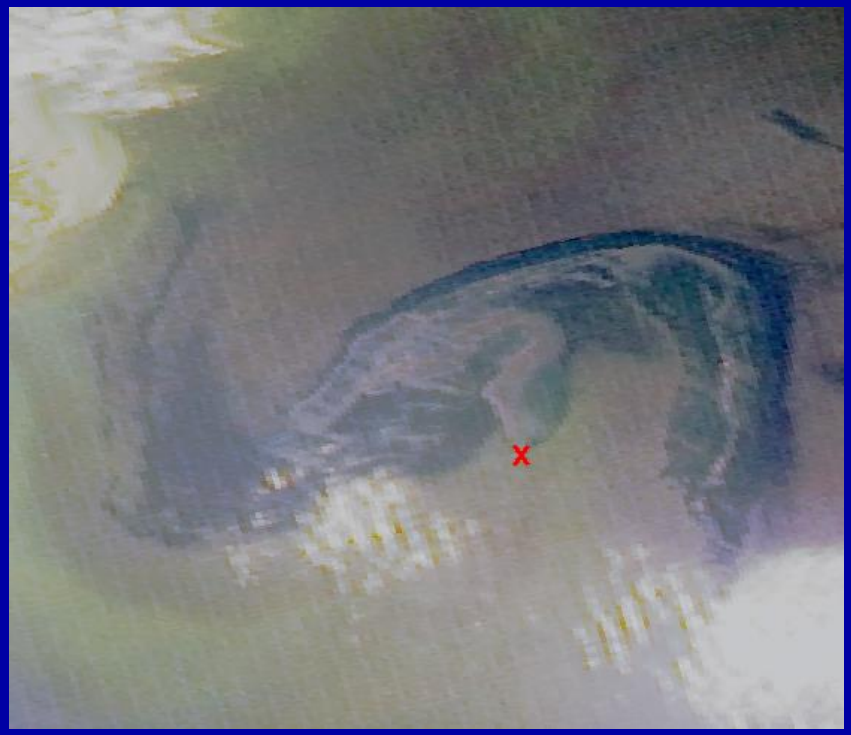
$$\cos(\theta_m) = \cos(\theta_0)\cos(\theta) - \sin(\theta_0)\sin(\theta)\cos(\phi)$$

# Understanding Optical Contrasts

**When oil is thicker, its optical properties also play a role, and the contrasts become more complicated…**

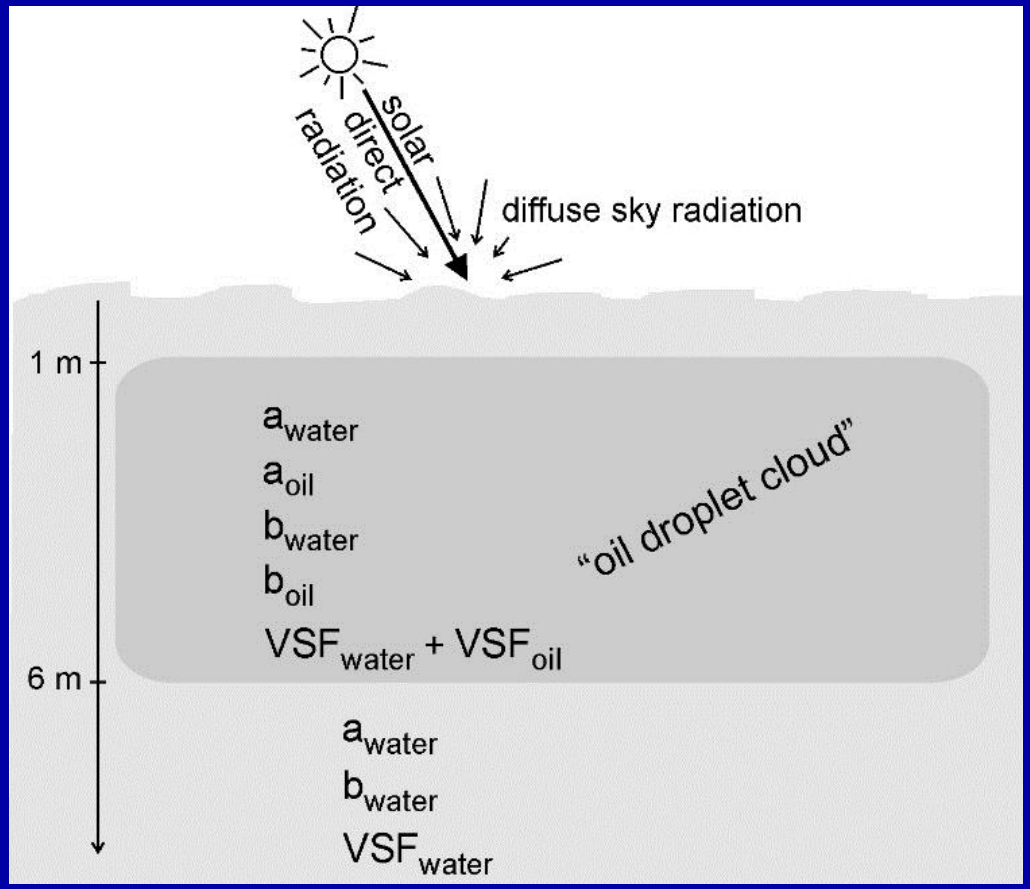
**April 29, 2010, Terra and Aqua, 2.5 hours apart**





# Monte-Carlo Simulations

(Otremba, Zielinski, and Hu, 2013)



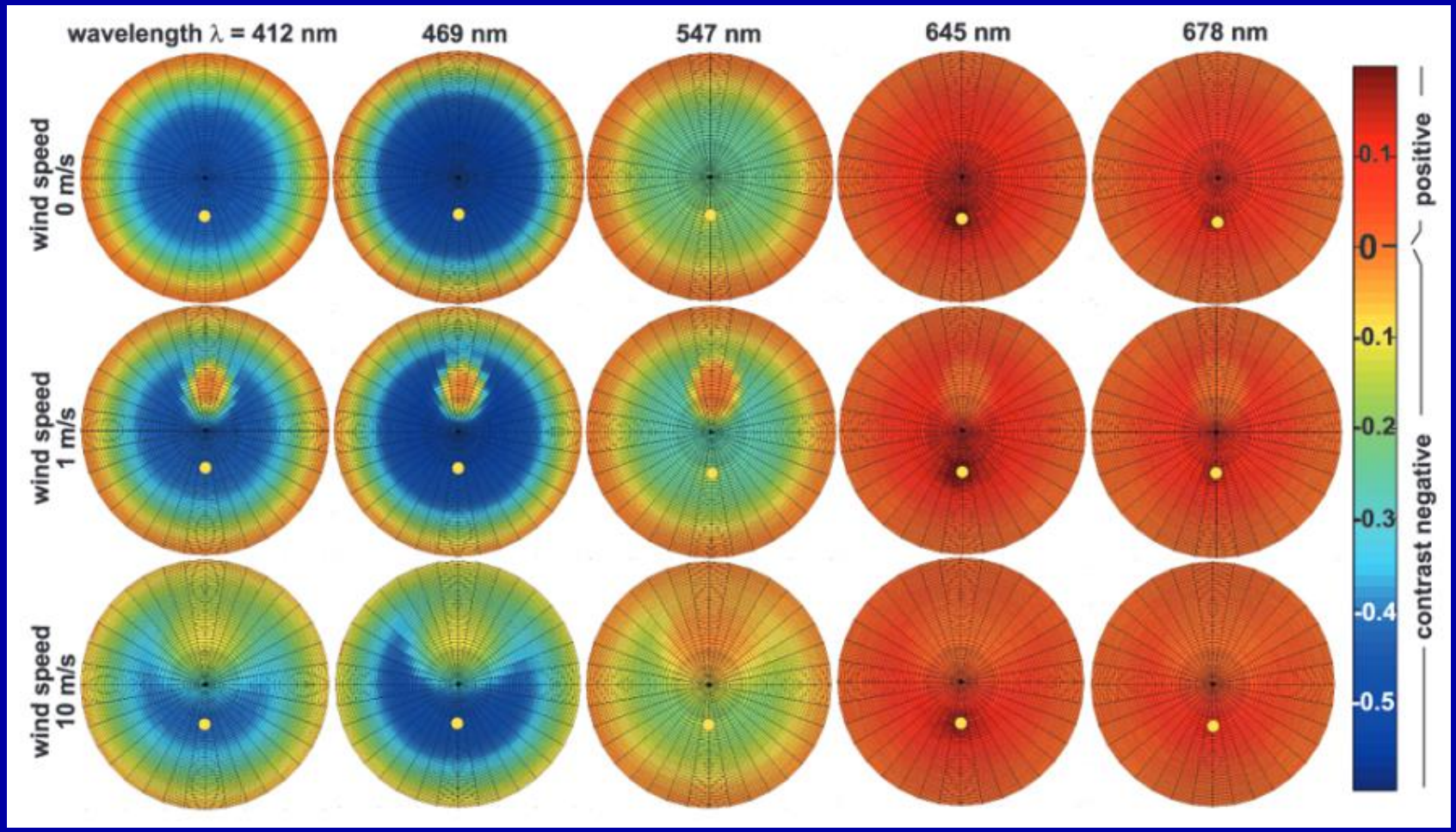

| Suspension in water 10 ppm | | | |
|---|---|---|---|
| CrudeOil | Romashkino | | |
| lambda | a[m-1] | b[m-1] | bb [m-1] |
| 412 | 4.3 | 6.4 | 0.0413 |
| 443 | 3.8 | 6.95 | 0.05 |
| 547 | 2.5 | 8.4 | 0.078 |
| 645 | 2.19 | 9.1 | 0.09 |
| 678 | 1.81 | 9.12 | 0.085 |
| VSF calculated using Mie theory | | | |
| and using n + *i* k of oil + size distribution | | | |

Water column IOPs derived from MODIS over oil-free water

| IOPs of | water | |
|---|---|---|
| lambda | a (1/m) | b (1/m) |
| 412 | 0.066 | 0.516 |
| 443 | 0.050 | 0.395 |
| 547 | 0.059 | 0.198 |
| 645 | 0.345 | 0.121 |
| 678 | 0.520 | 0.106 |

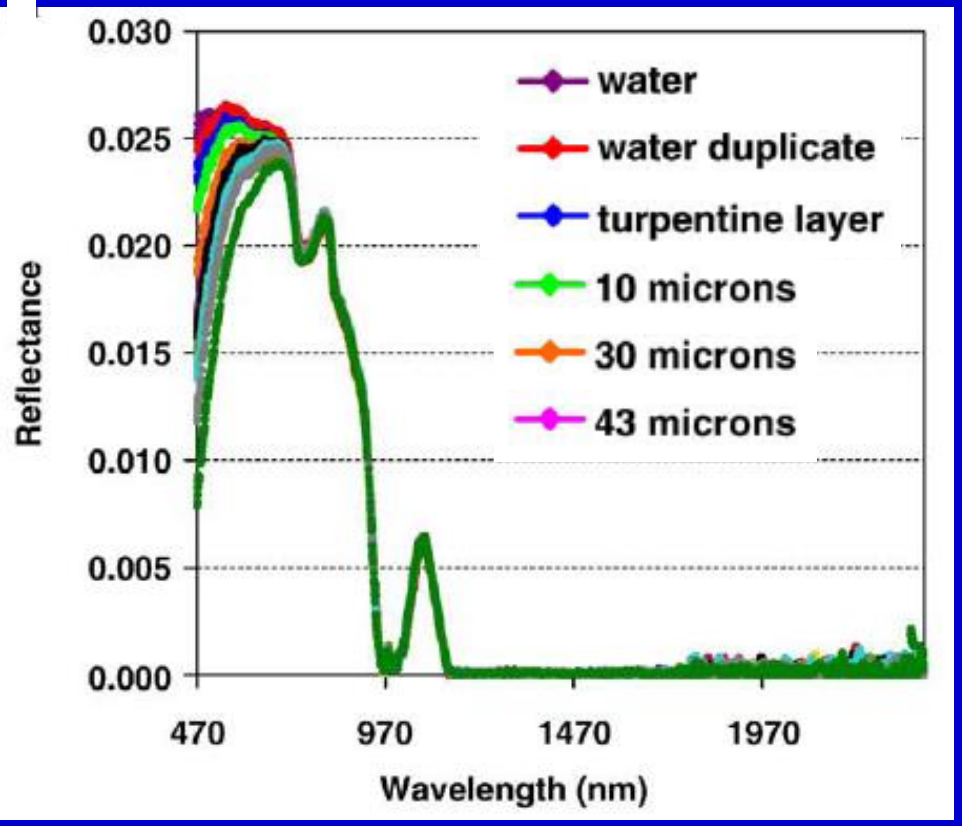
# Monte-Carlo Simulations

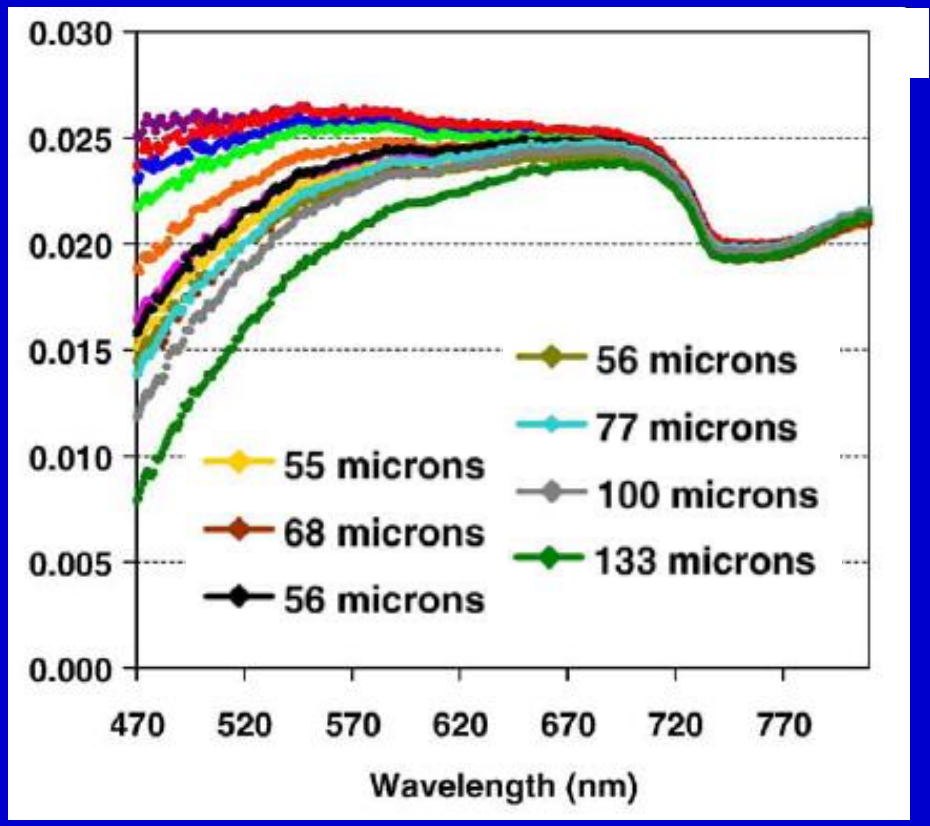
(Otremba, Zielinski, and Hu, 2013)



# Laboratory Measurements

Surface reflectance of oil-free water and oil films with different thickness (Wettle et al., 2009).



# Laboratory Measurements

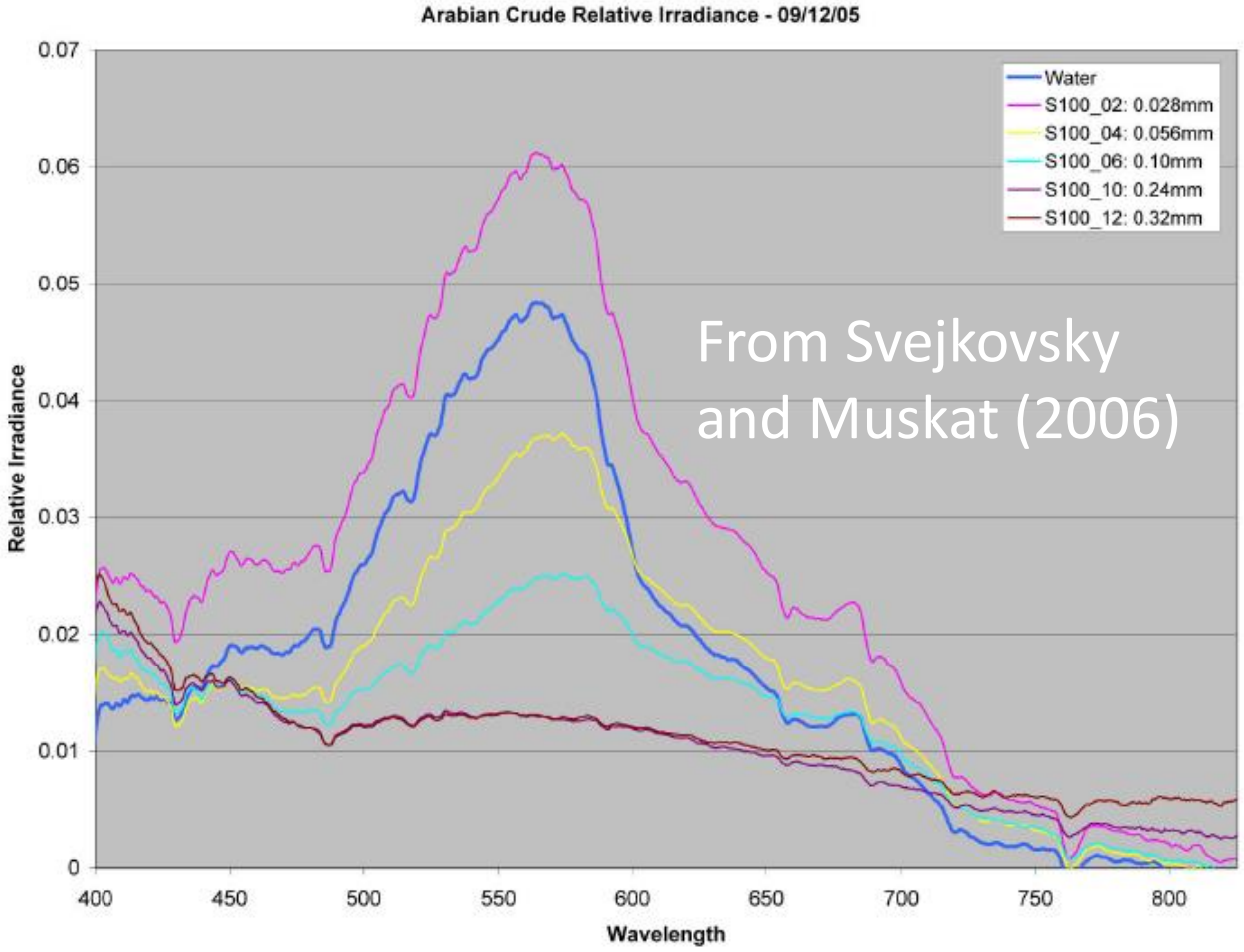
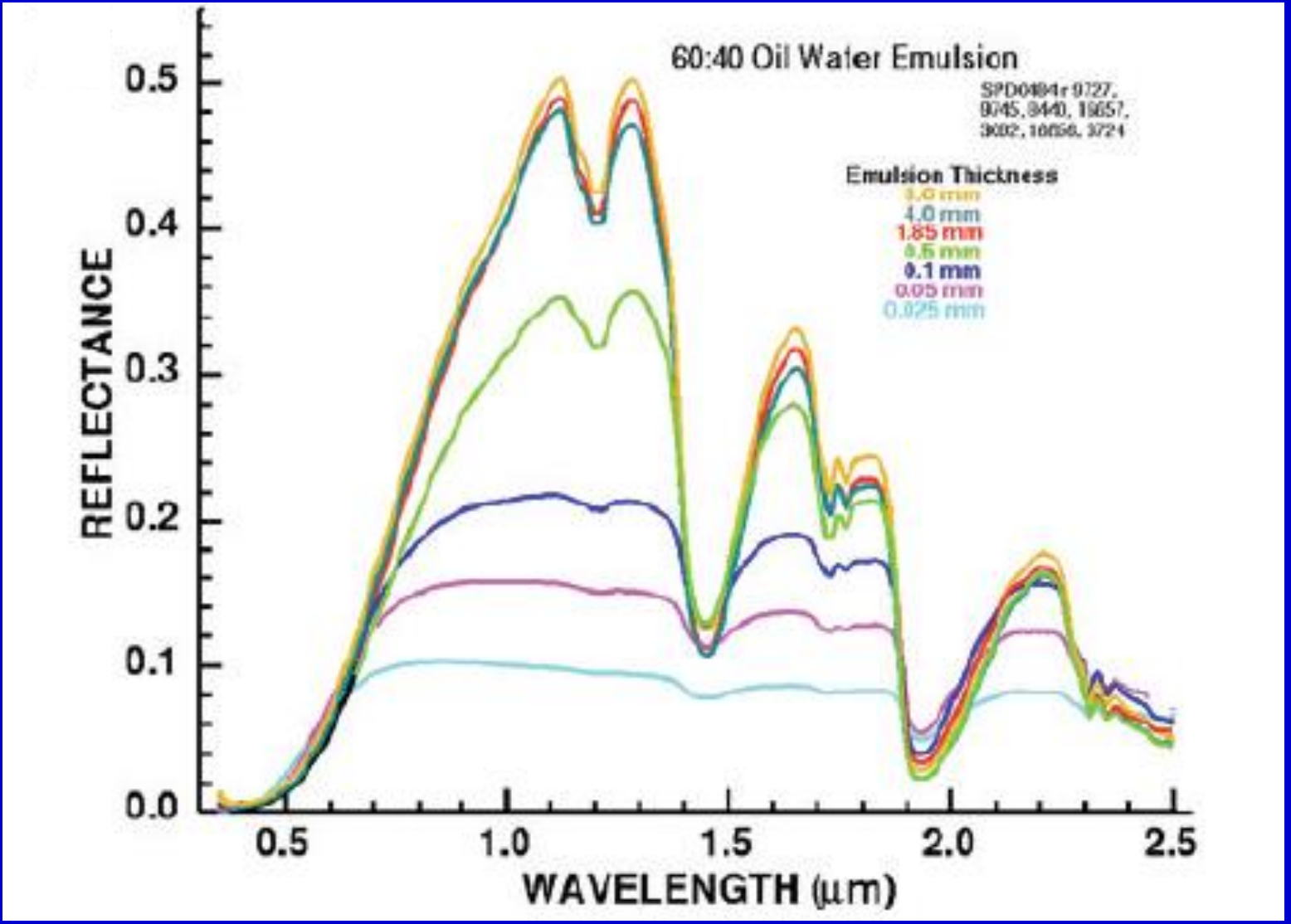


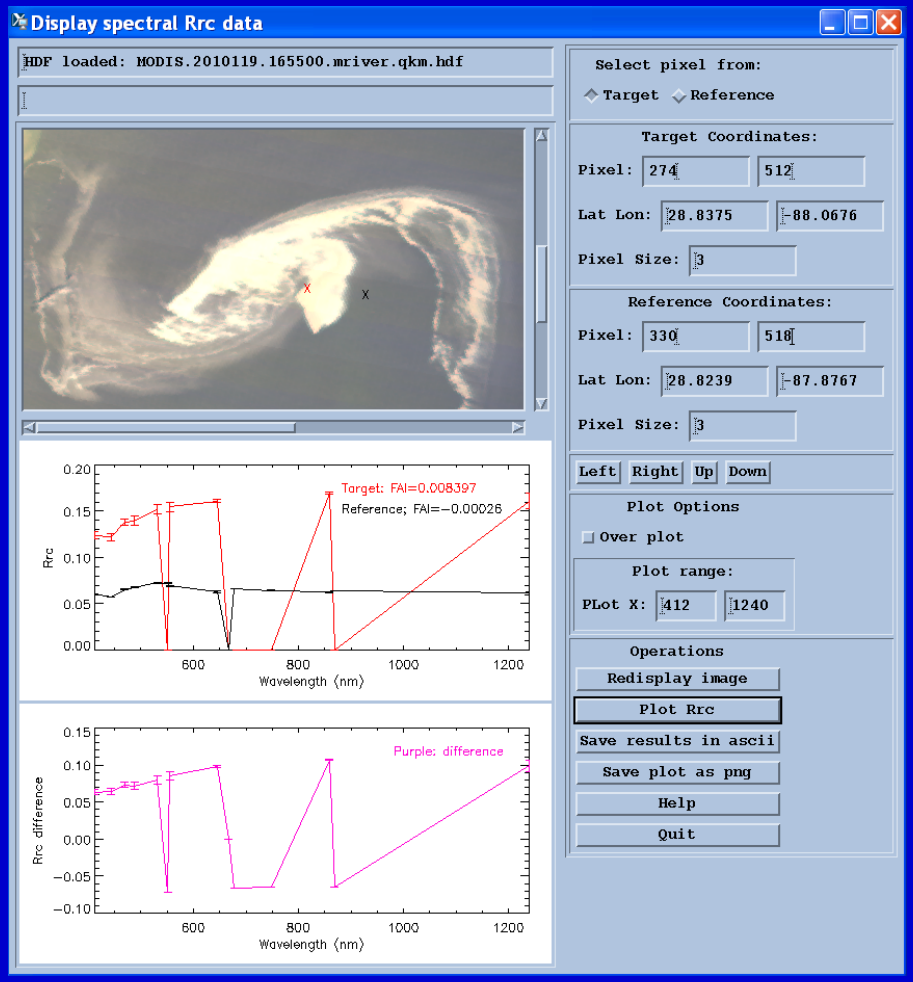

**Figure 3.** Reflectance spectra of Arabian Medium Crude films of various thickness over deep water background in Oceanside Harbor, California. (Note that very thin films actually cause a slight increase in surface reflectance from the clear water/background spectrum.)

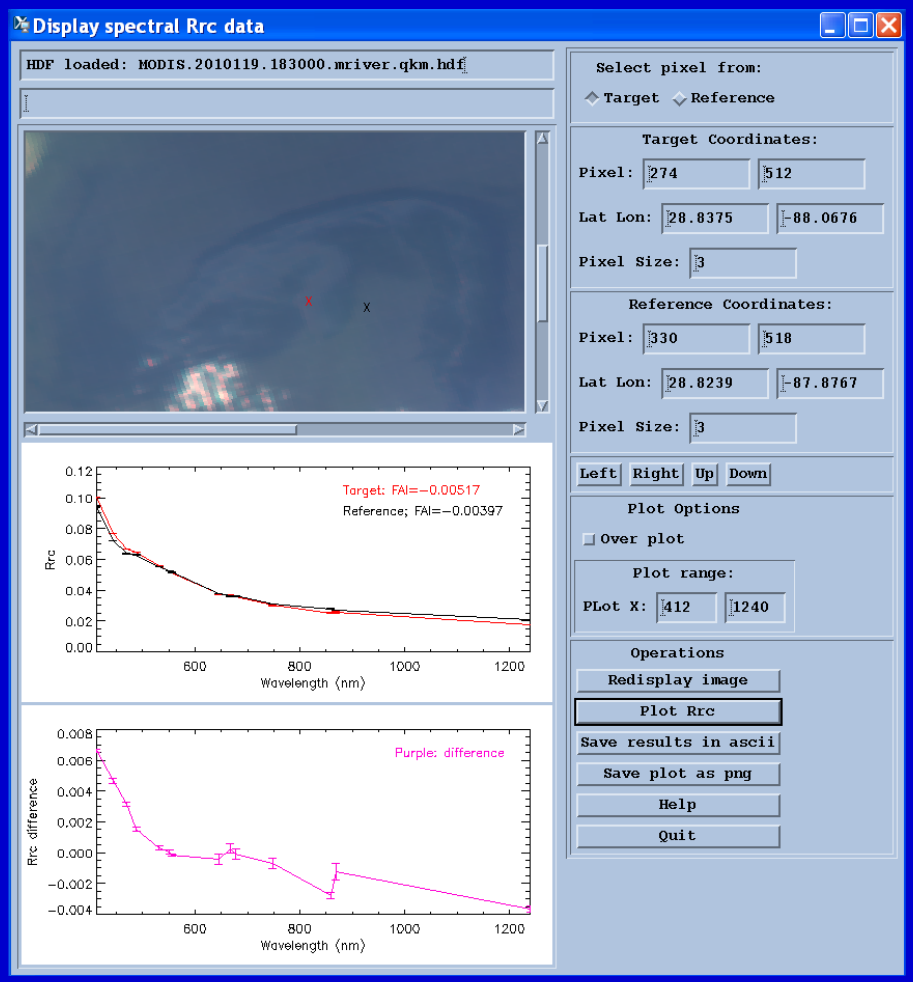
# Laboratory Measurements




From Clark et al. (2010, USGS report)

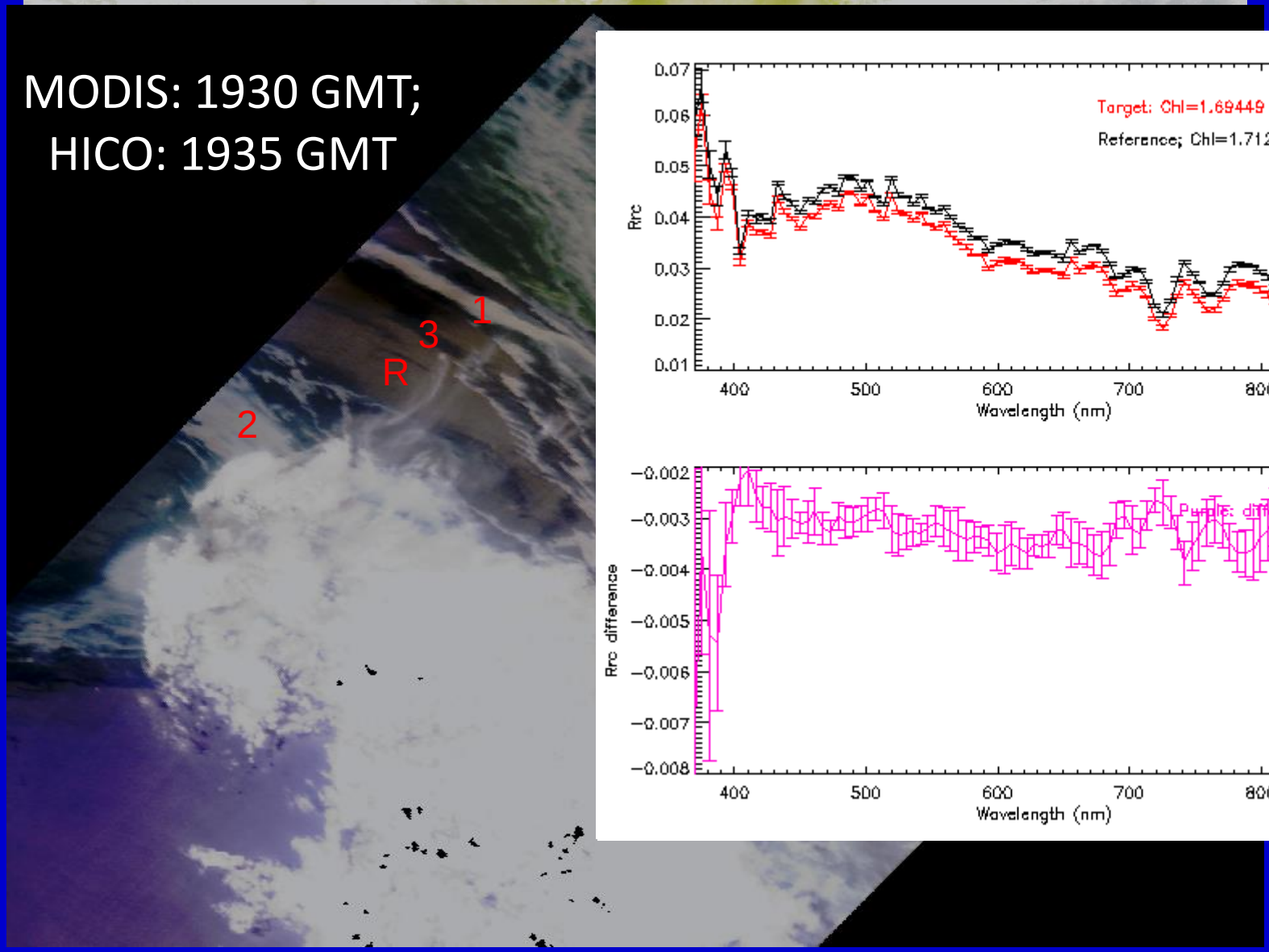
# MODIS shows different optical contrasts



# HICO also shows different optical contrasts

MODIS: 1930 GMT;
HICO: 1935 GMT

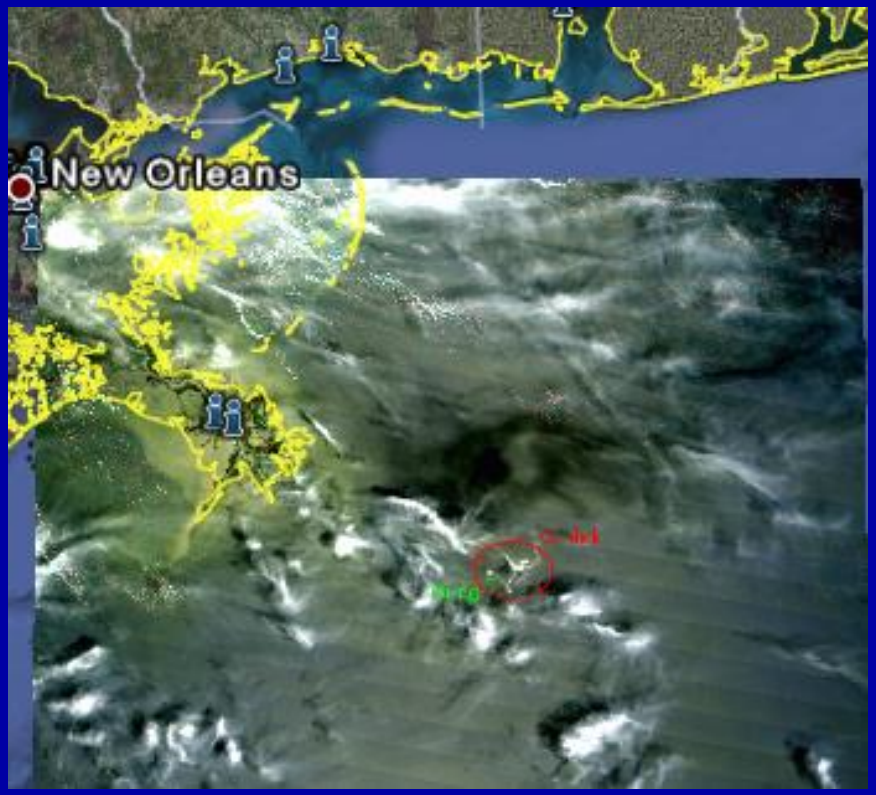


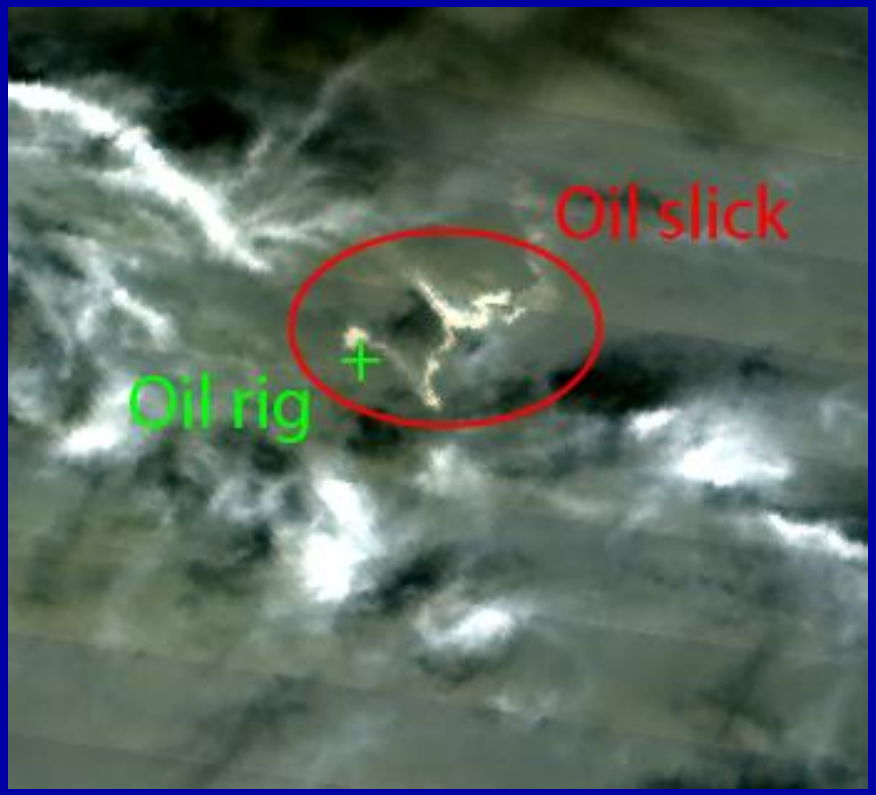
# So, what can we do before we have an optical closure?

- Surface expression
- Surface volume

# MODIS Captured the 1st Spill Image

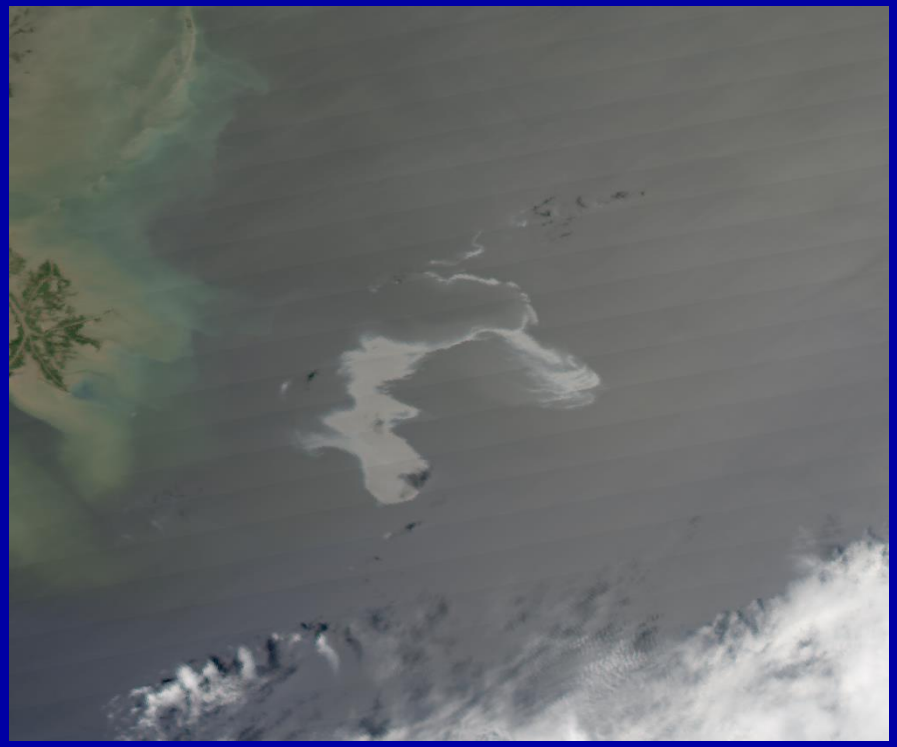
April 22, 2010



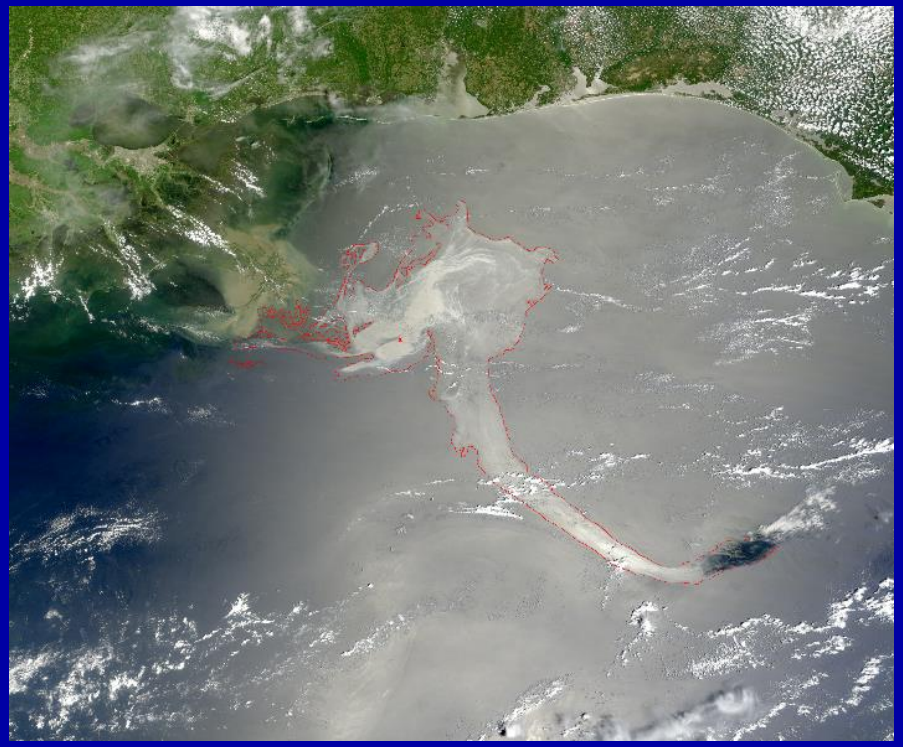



# MODIS Image Series

April 25, 2010

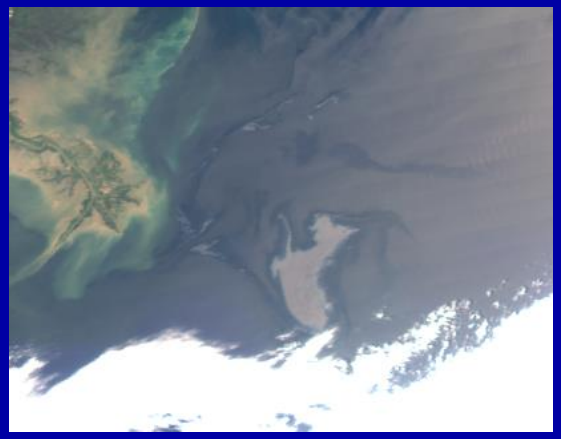


May 17, 2010

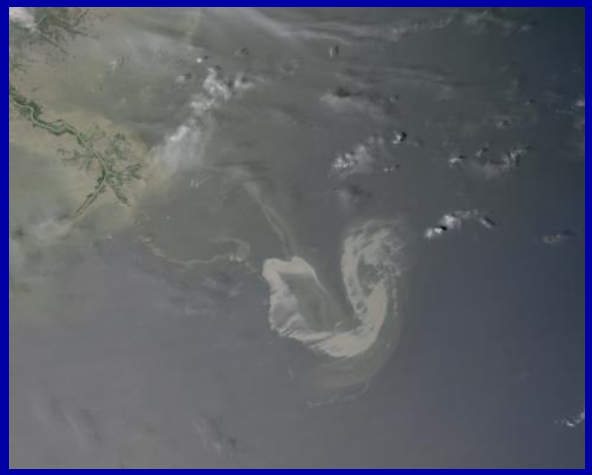


# MODIS Image Series

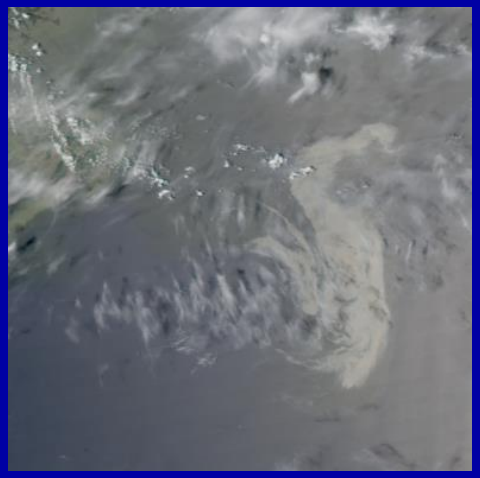
May 4



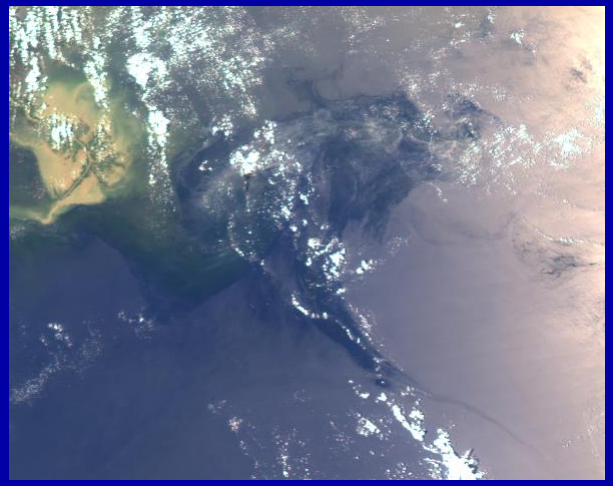
May 9



May 11

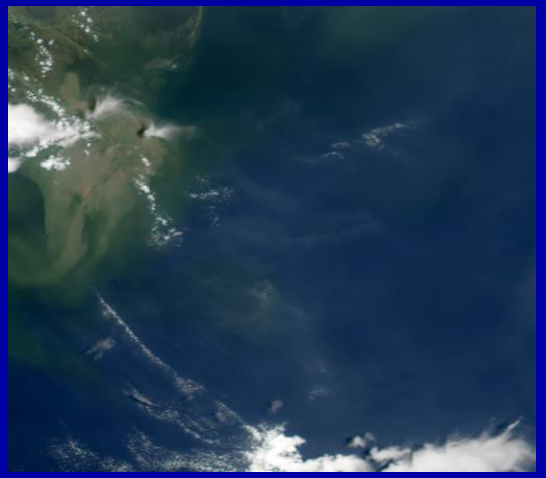


May 20



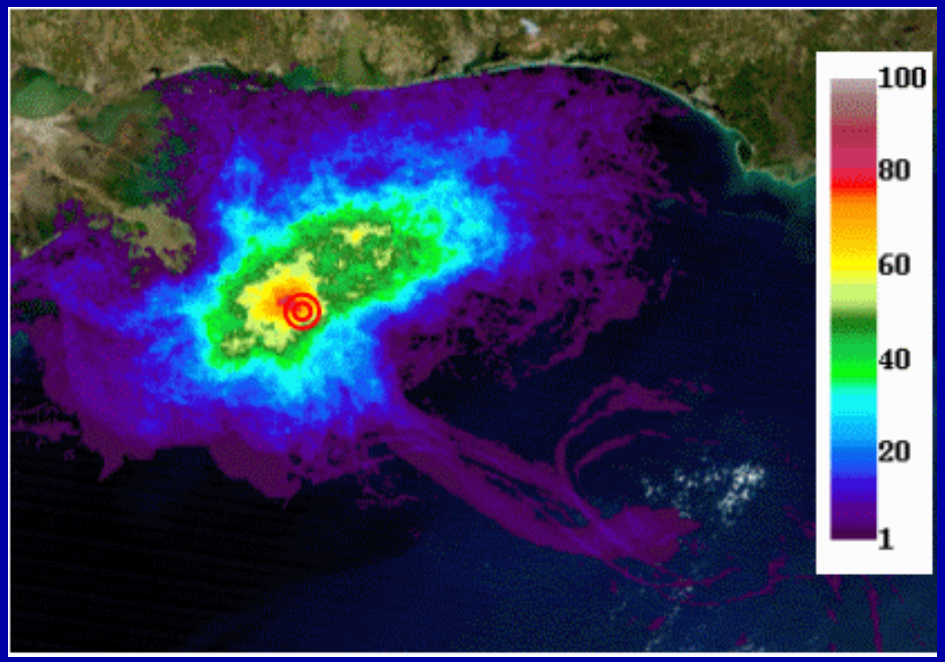
May 23

May 28

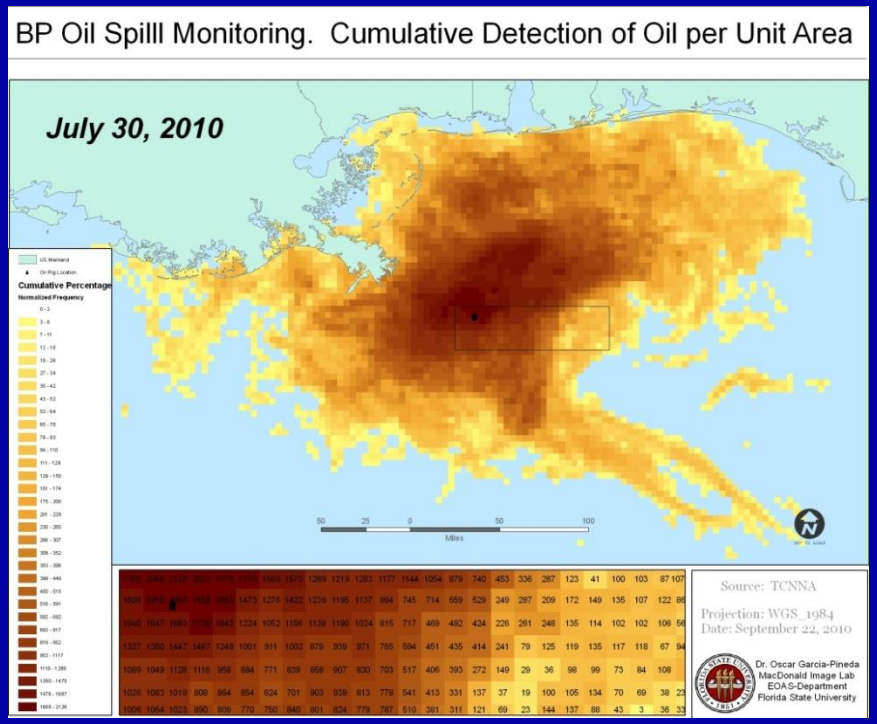


# Summary Statistics

**% of MODIS images showing oil presence, 4/22/2010 – 7/30/2010**



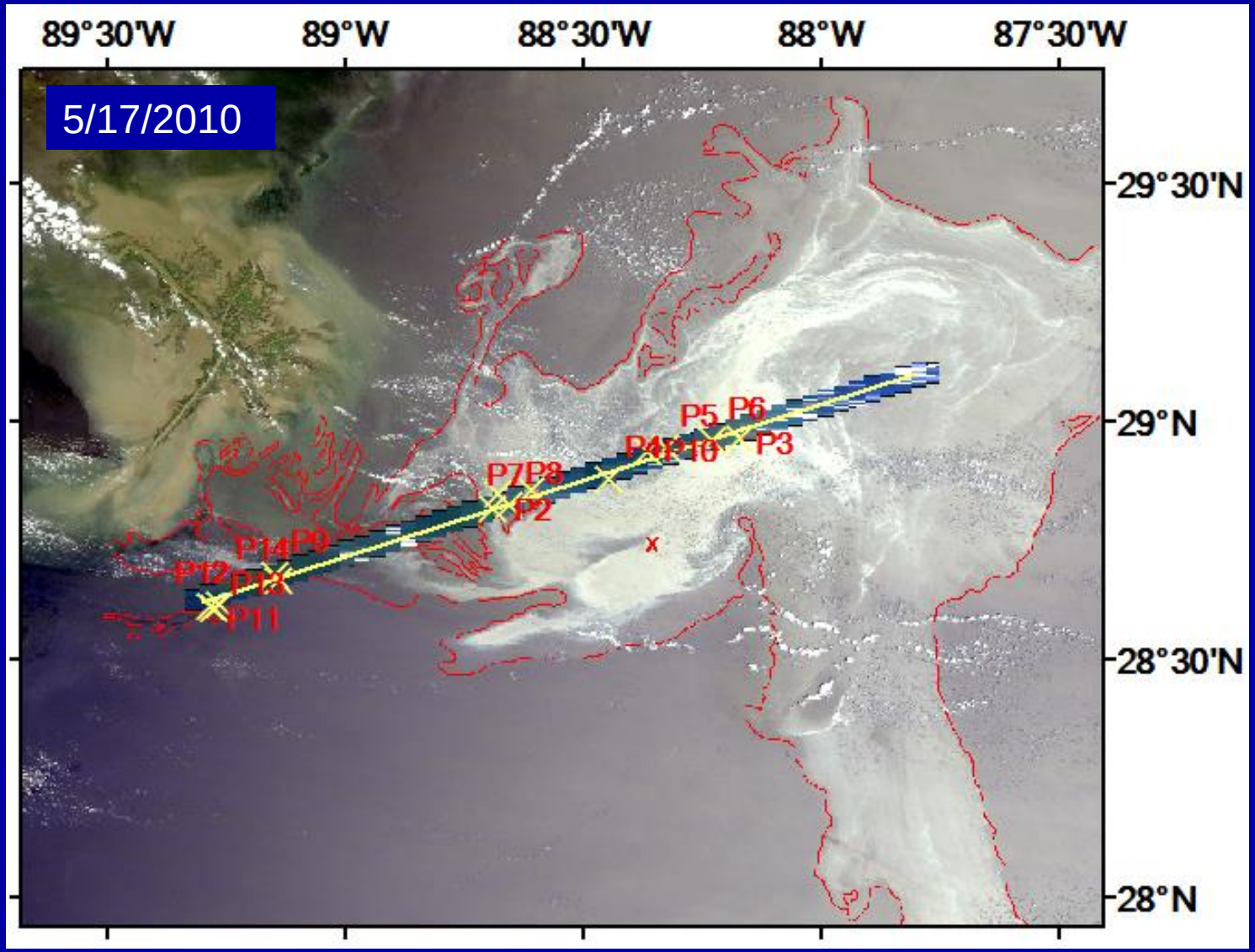

**% of SAR images showing oil presence, 4/25/2010 – 7/30/2010**




**SAR results from Oscar Garcia-Pineda (FSU)**

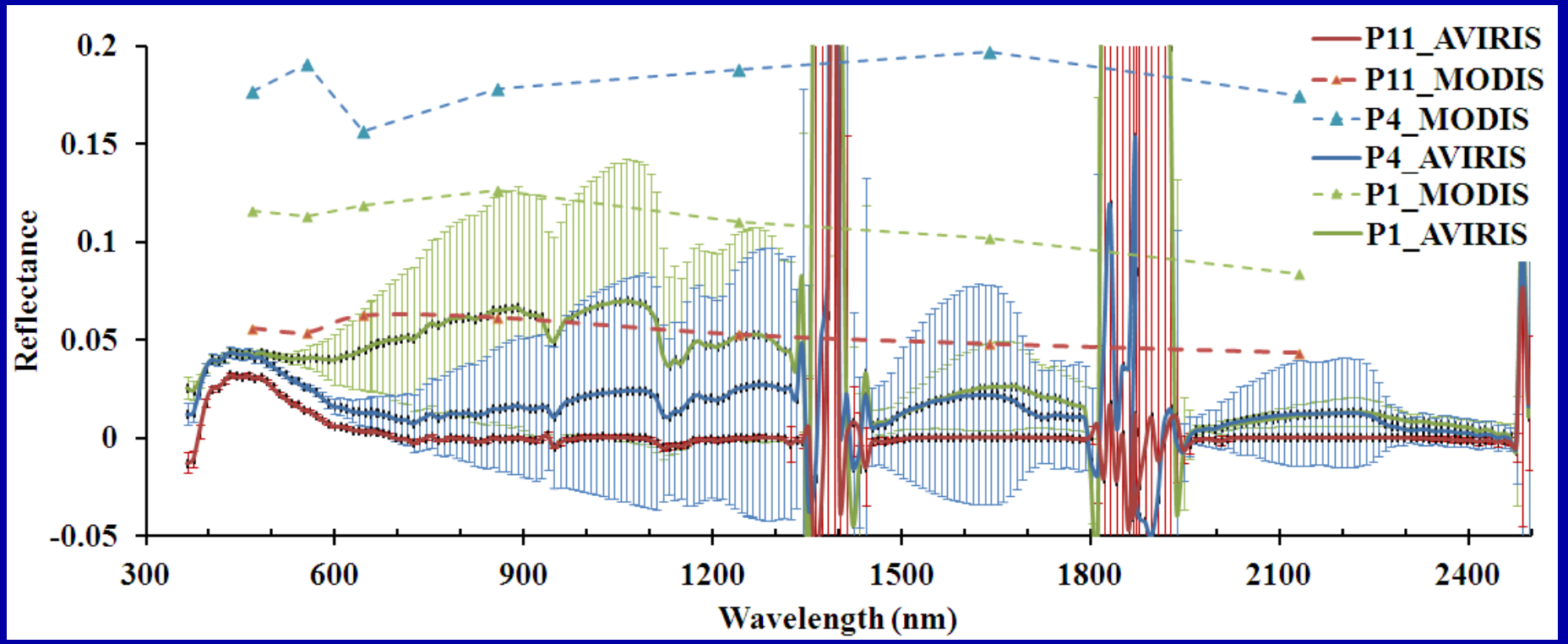
# What about surface oil volume

# Approach: Scale up AVIRIS-derived oil thickness using CONCURRENT MODIS



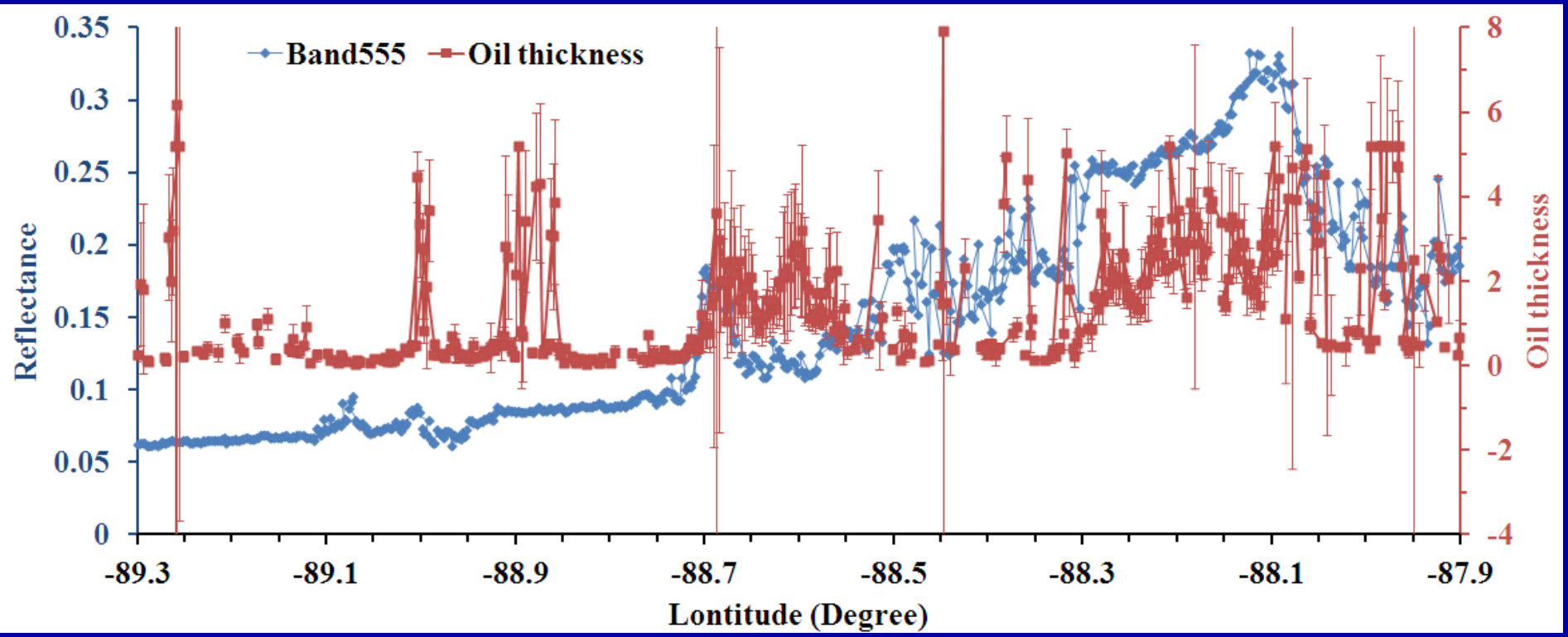
# MODIS-AVIRIS Spectral Comparison

MODIS and AVIRIS (std) reflectance at several pixels



# MODIS Reflectance versus AVIRIS-derived Oil Thickness

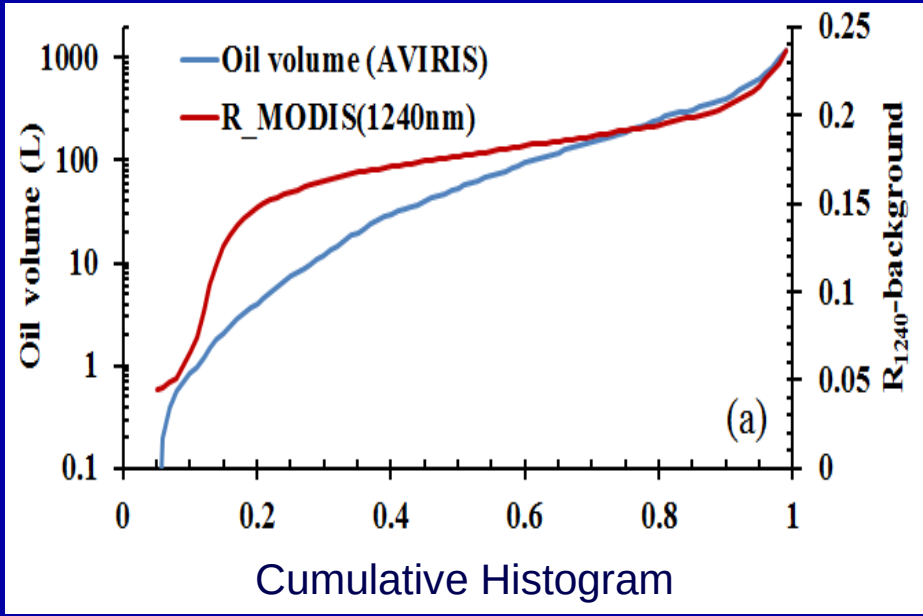
AVIRIS data products provided by USGS



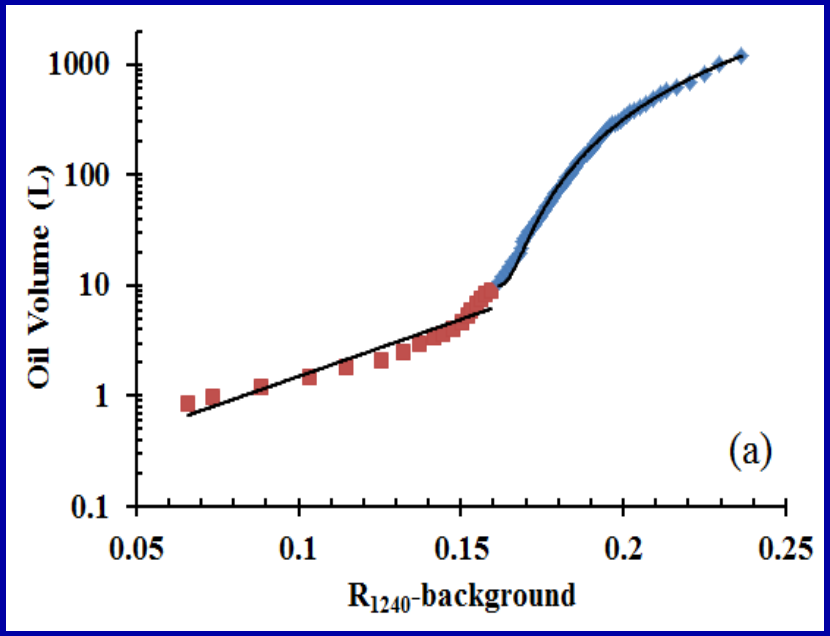

AVIRIS mean and std did not include 0-oil pixels

So, for a number of reasons, pixel-wise AVIRIS-MODIS regression did not work well.
Then, how can we derive oil volume?

# Histogram Matching

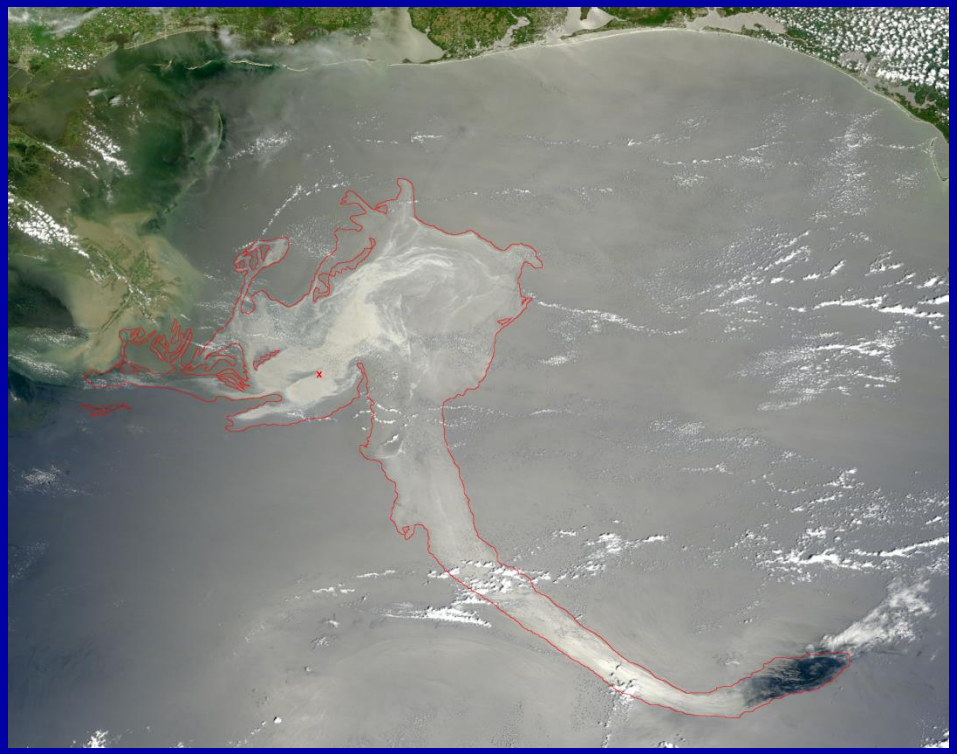


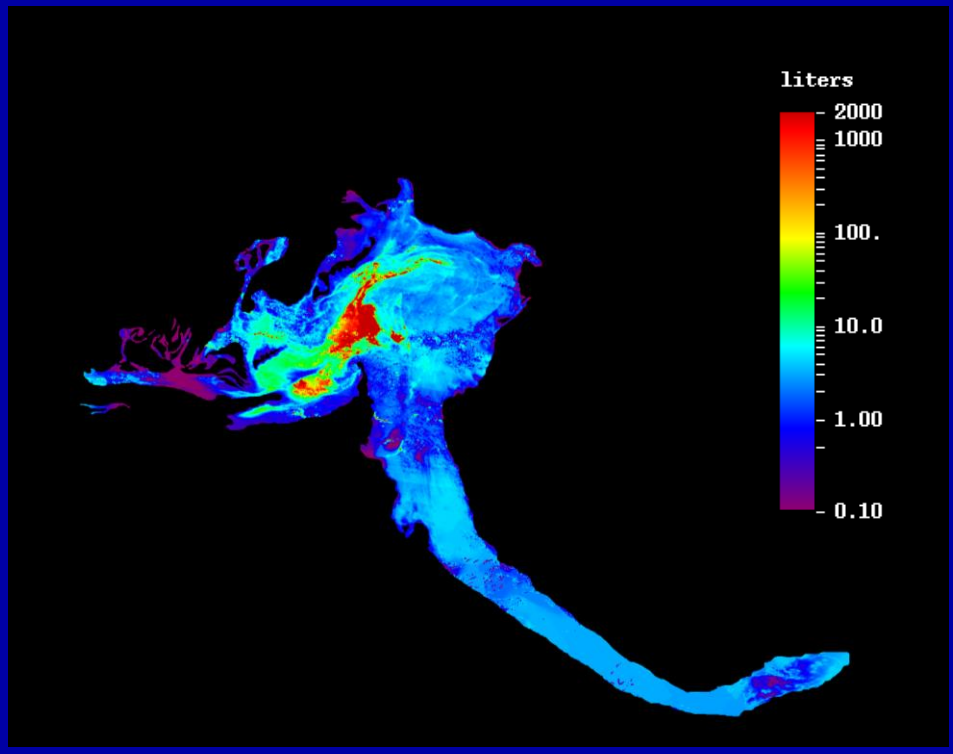

Cumulative Histogram



# Histogram Matching

May 17, 2010

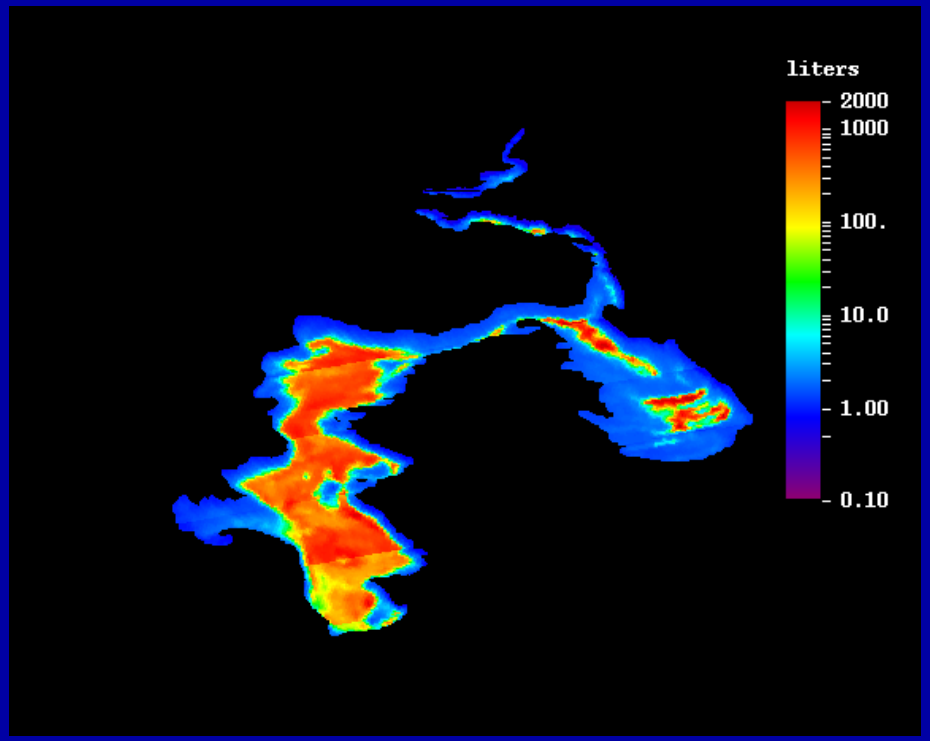





1000 liters per MODIS pixel are equivalent to 18 μm in oil thickness

# Histogram Matching

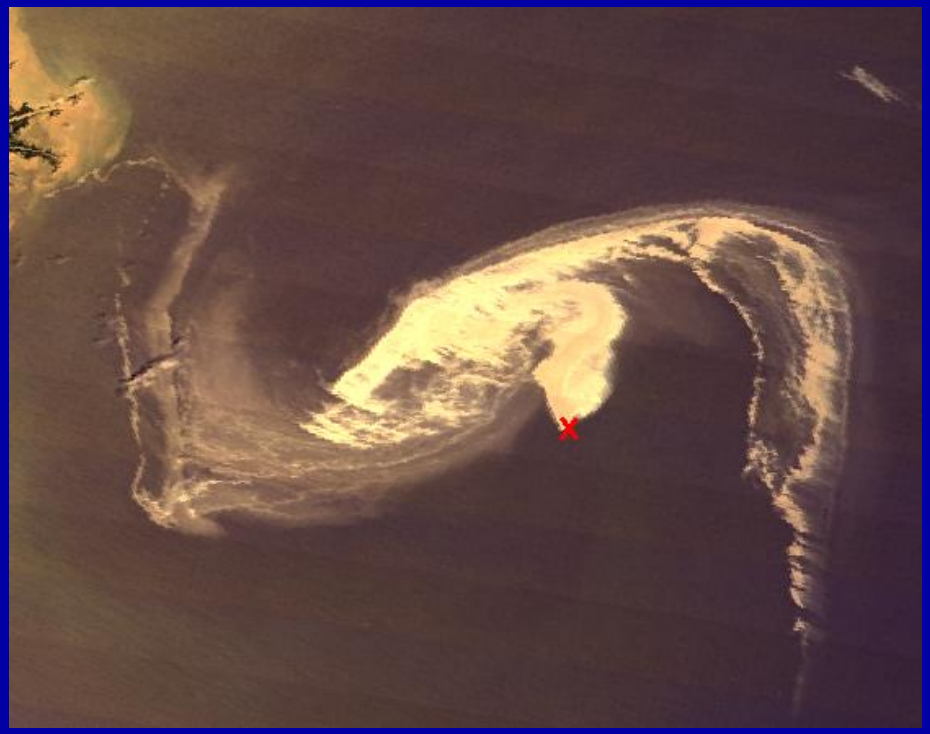
April 25, 2010

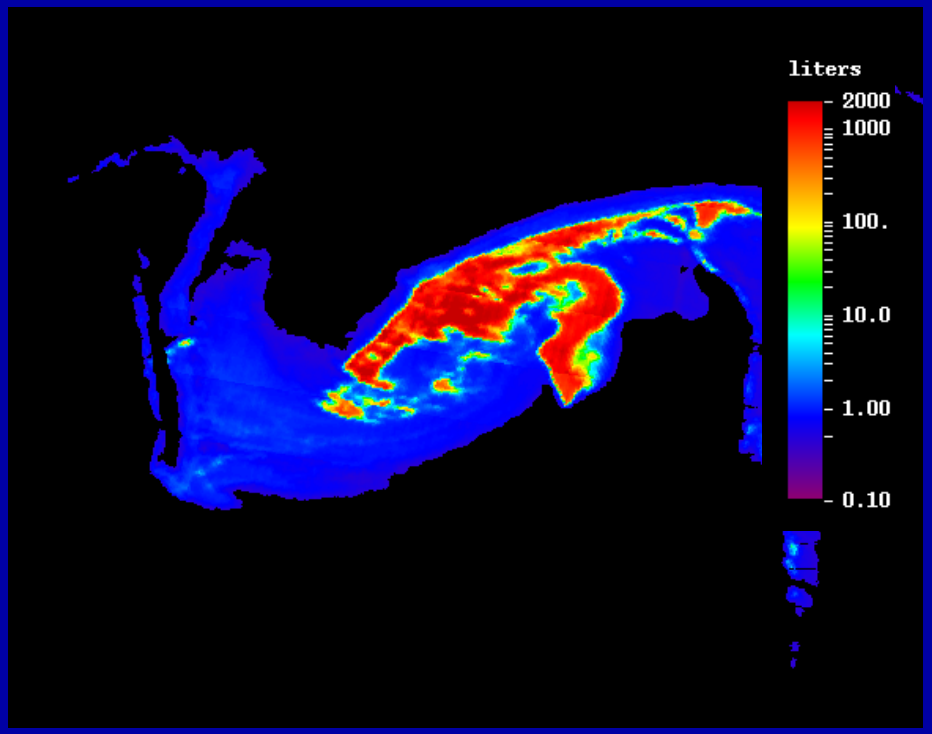



1000 liters per MODIS pixel are equivalent to 18 μm in oil thickness

# Histogram Matching

April 29, 2010





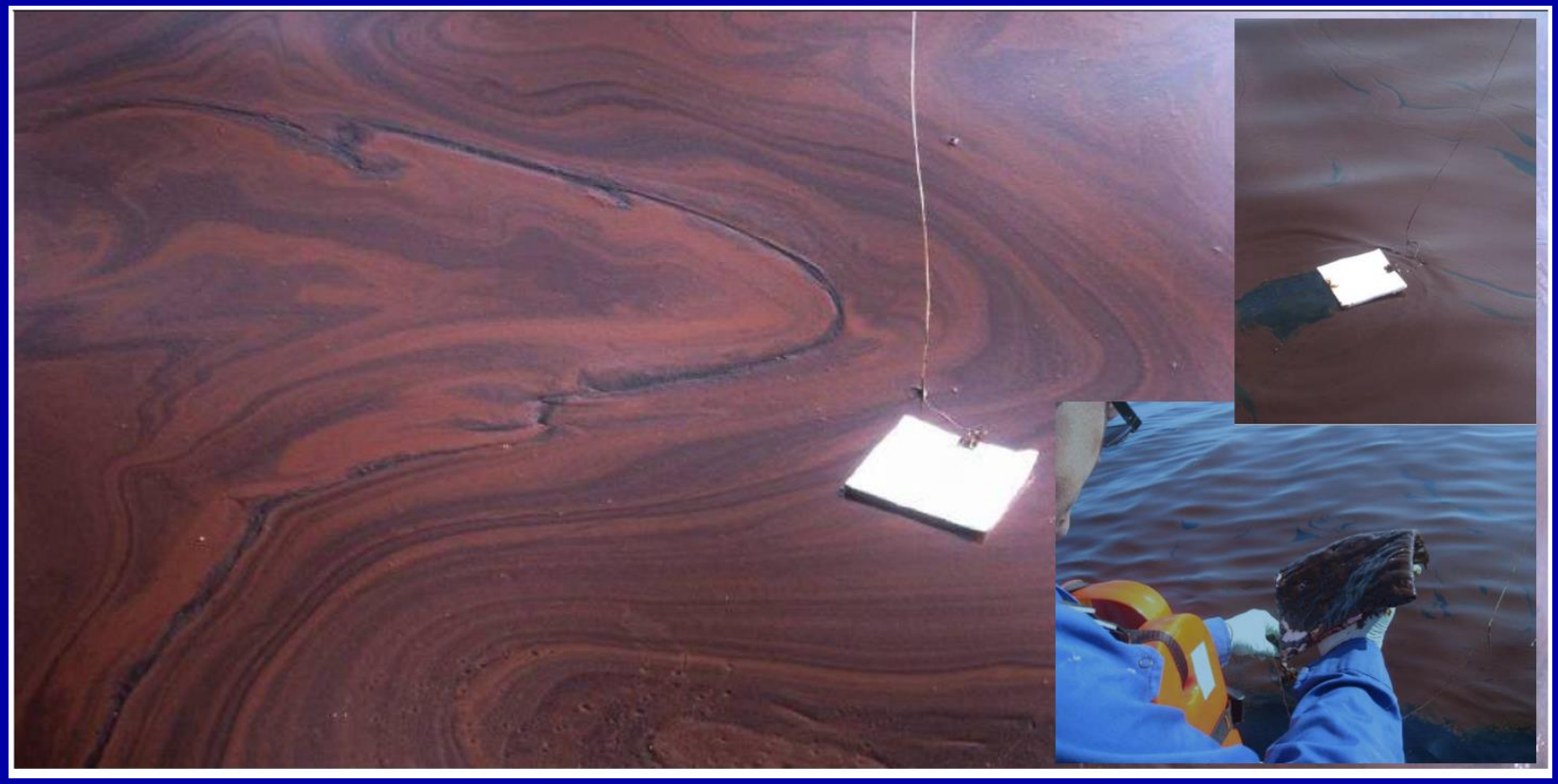

1000 liters per MODIS pixel are equivalent to 18 μm in oil thickness

In total, 19 MODIS images were used to derive surface oil volume using histogram matching

# What have we learned so far?

- Optical detection of surface oil is relatively easy under optimal observing conditions (cloud free, optimal wind speed, some degree of sun glint, Lg > 0.0001 $sr^{-1}$)
- Quantifying oil volume is difficult for a number of reasons, for example the fundamental difficulty in accurate measurements

# The fundamental difficulty in measuring oil thickness



Oil thickness sampling on June 3, 2010. Image courtesy of SINTEF (www.sintef.com). About 2-4 mm thick.

# The fundamental difficulty in measuring oil thickness

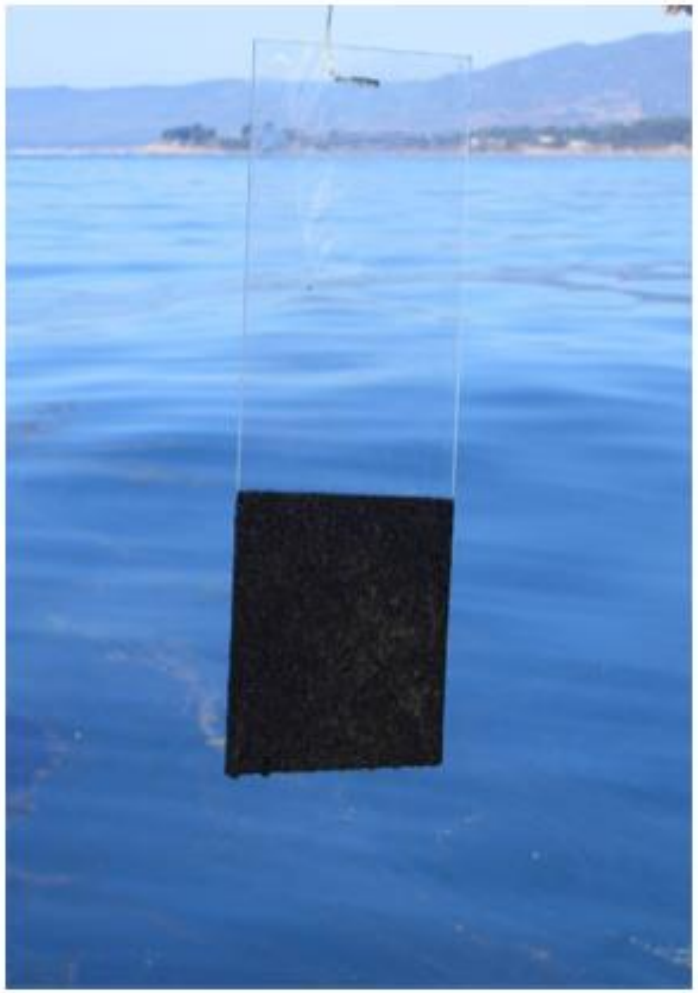


**Figure 5.** The oil thickness sampling plate being lowered into a Santa Barabara Channel oil slick (left); The same plate after being raised from the slick (right).

From Svejkovsky and Muskat (2006)

# Other Difficulties

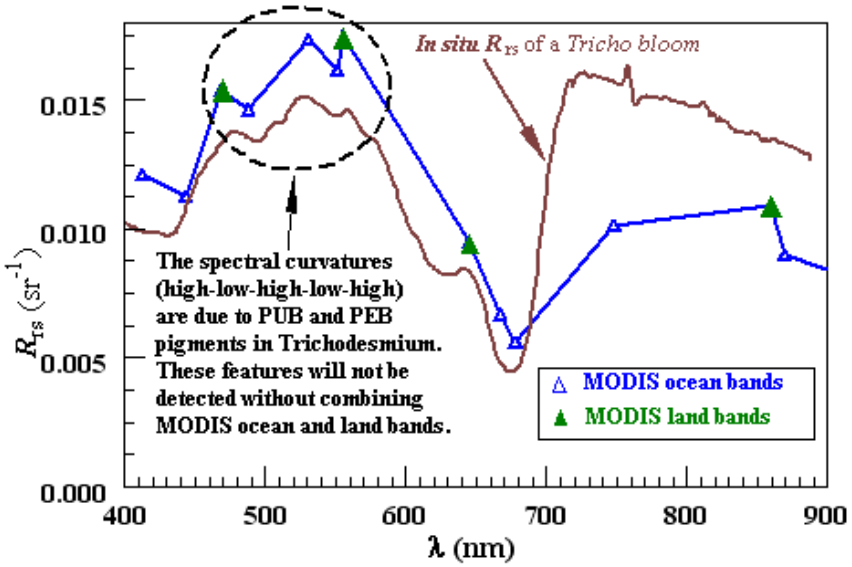
- Mixed pixels
- Cloud contamination
- Look-alikes

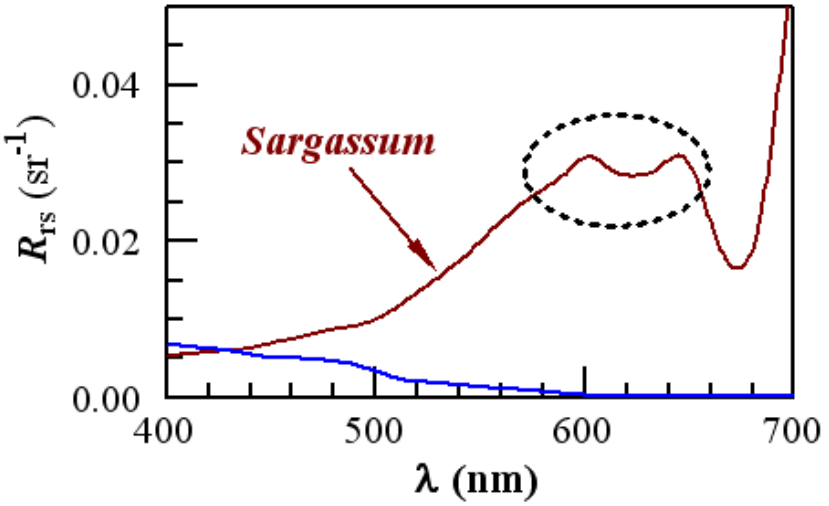
From the RGB image or from the multi-band spectra alone, it is very difficult to determine whether a feature is oil.

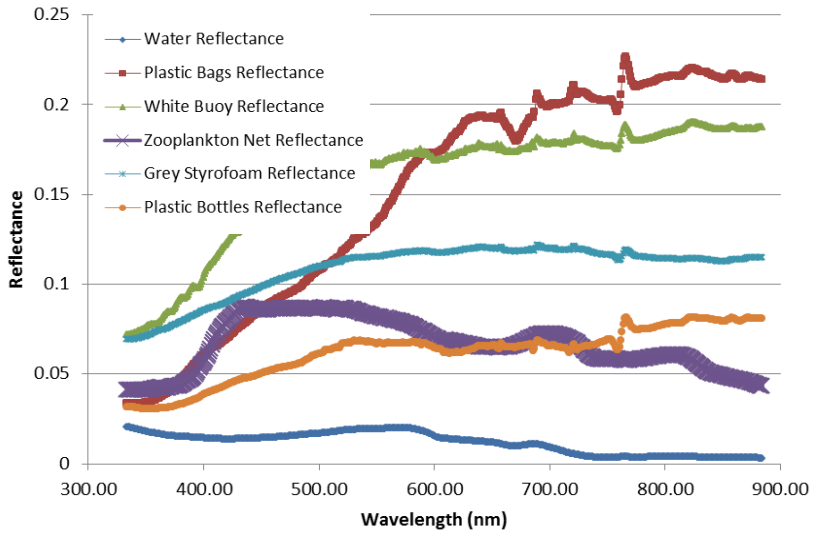
# Look-alikes

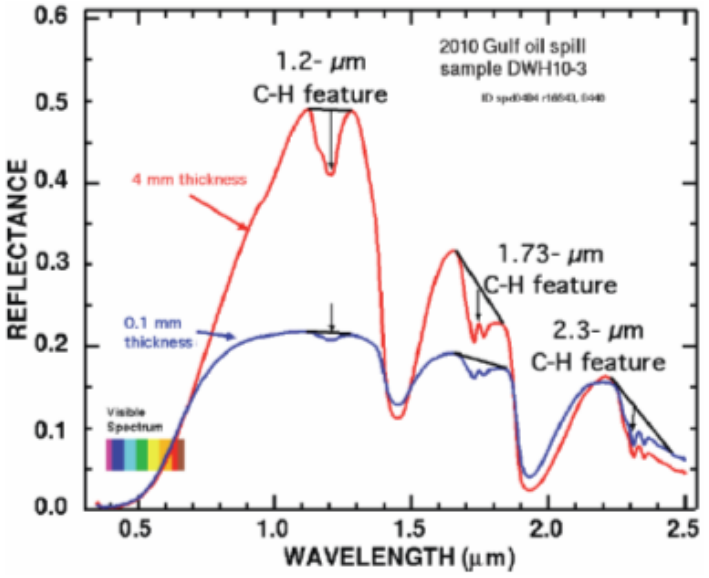



# Spectral Characteristics



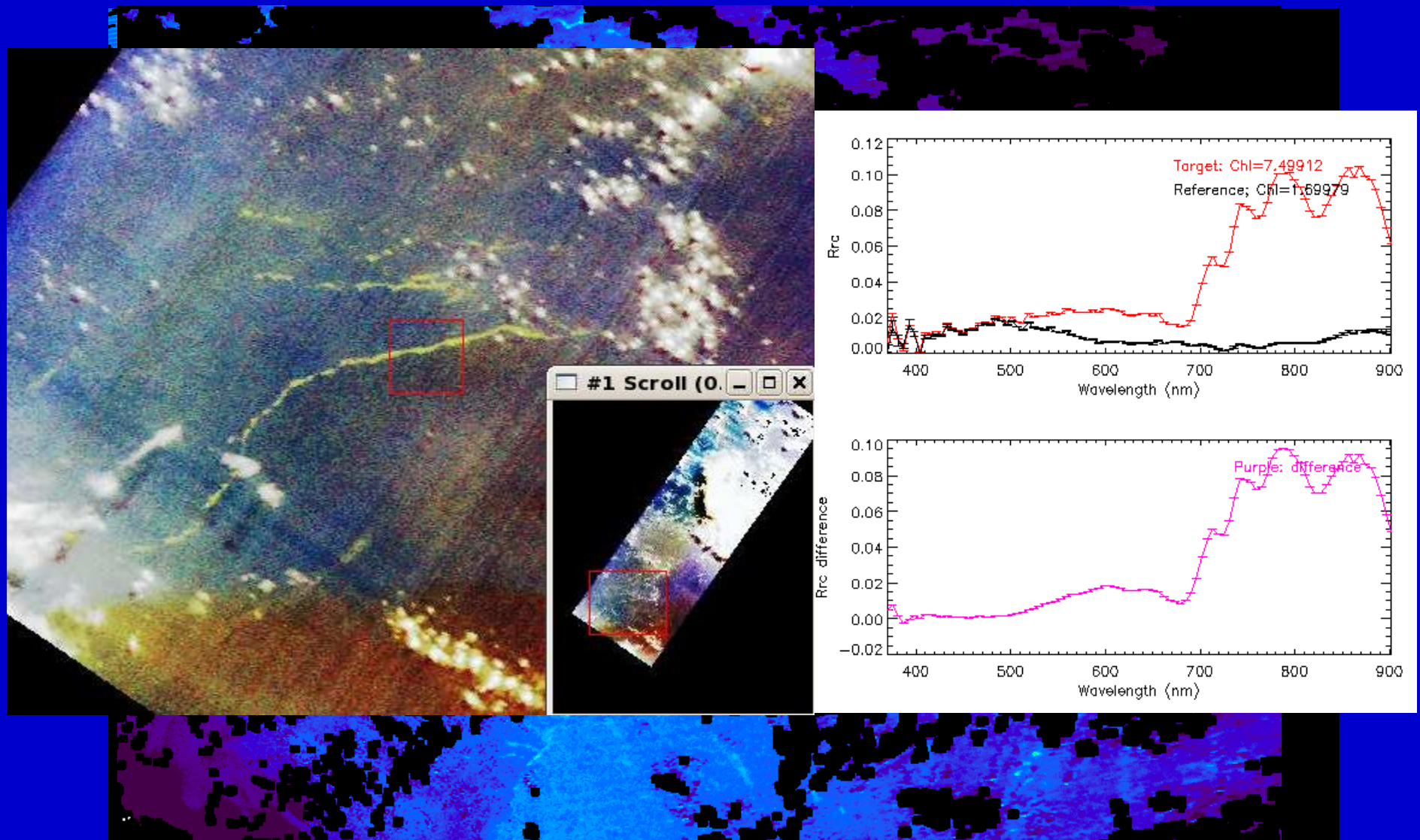



# Spectral Characteristics

## HICO shows *Sargassum* in the mid Atlantic



# Application to MH370 Search

Reference: From New York Times


**Expanded search area**
Malaysian authorities announced Monday that they were expanding the search zone, including areas in the Strait of Malacca.

**Last radar signal**
On Wednesday, a military official said the last radar signal, which may have been from the missing plane, was 200 miles northwest of Penang at 2:15 a.m.

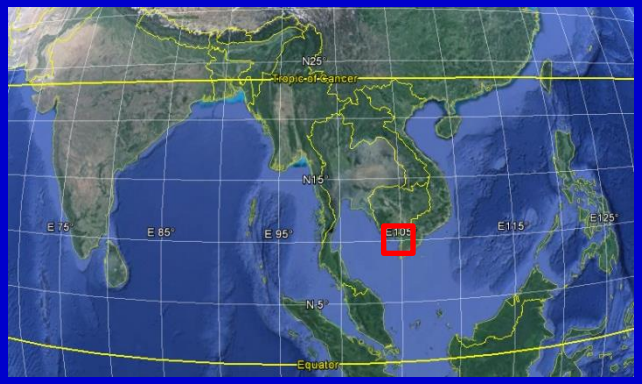
**Pulau Perak island**
A Malaysian military official was quoted in a local newspaper on Tuesday saying the military had received signals from the plane near this island at 2:40 a.m. Saturday.

**Subang airport**
Malaysia Airlines said authorities were "looking at a possibility" that the plane was headed to Subang, an airport that handles mainly domestic flights.

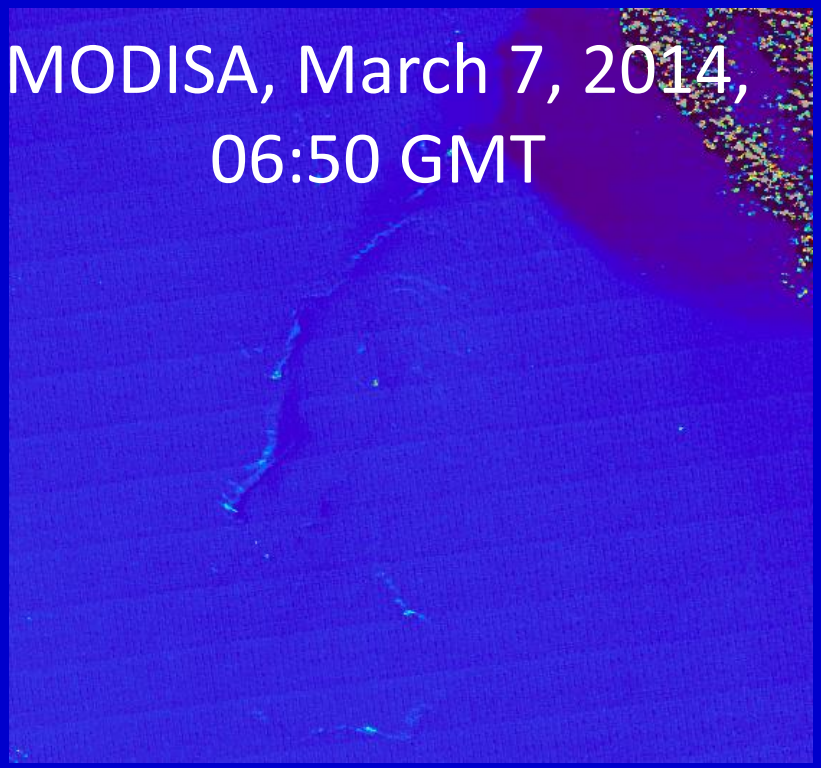
Malaysia is UTC+8 hrs
March 08, 2:40am time at Pulau Perak Island = March 07, 1640 UTC

# Application to MH370 Search

Some suspicious features published in news media are indeed seaweeds

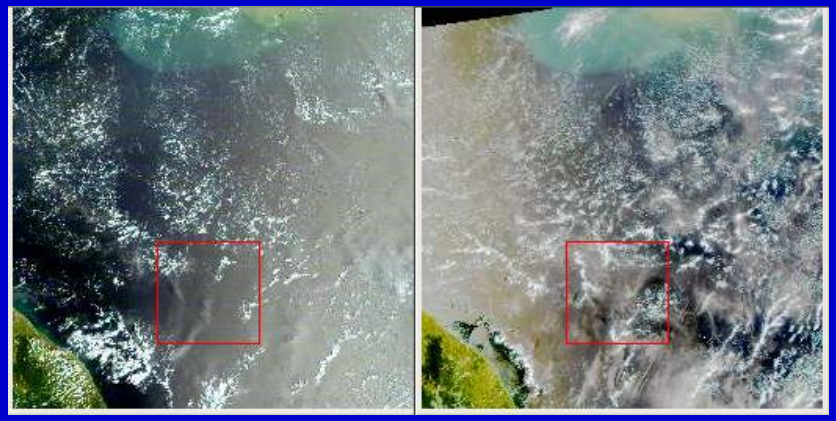


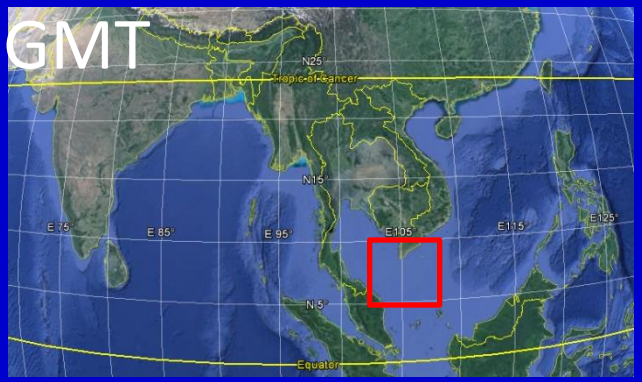




# Application to MH370 Search

March 9, 2014, 03:35 and 06:35 GMT






# March 8, 2014, 07:30GMT, MODIS

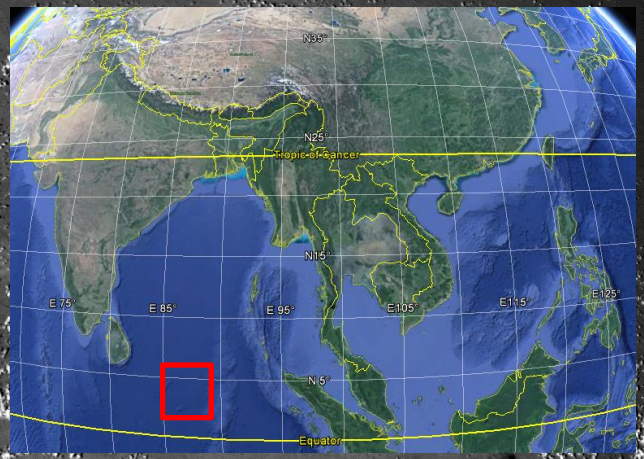
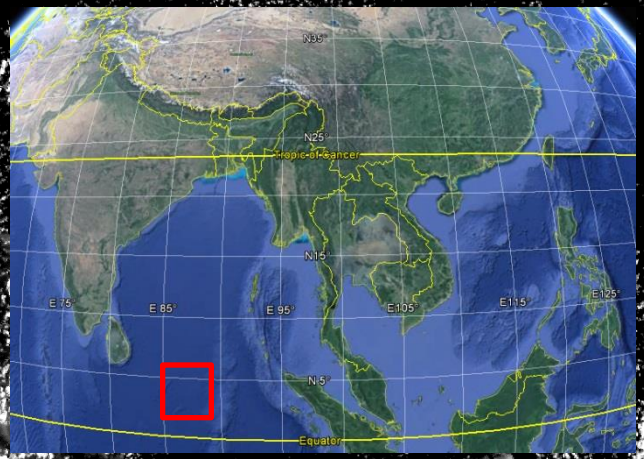



Image Courtesy: Ben Holt, NASA JPL

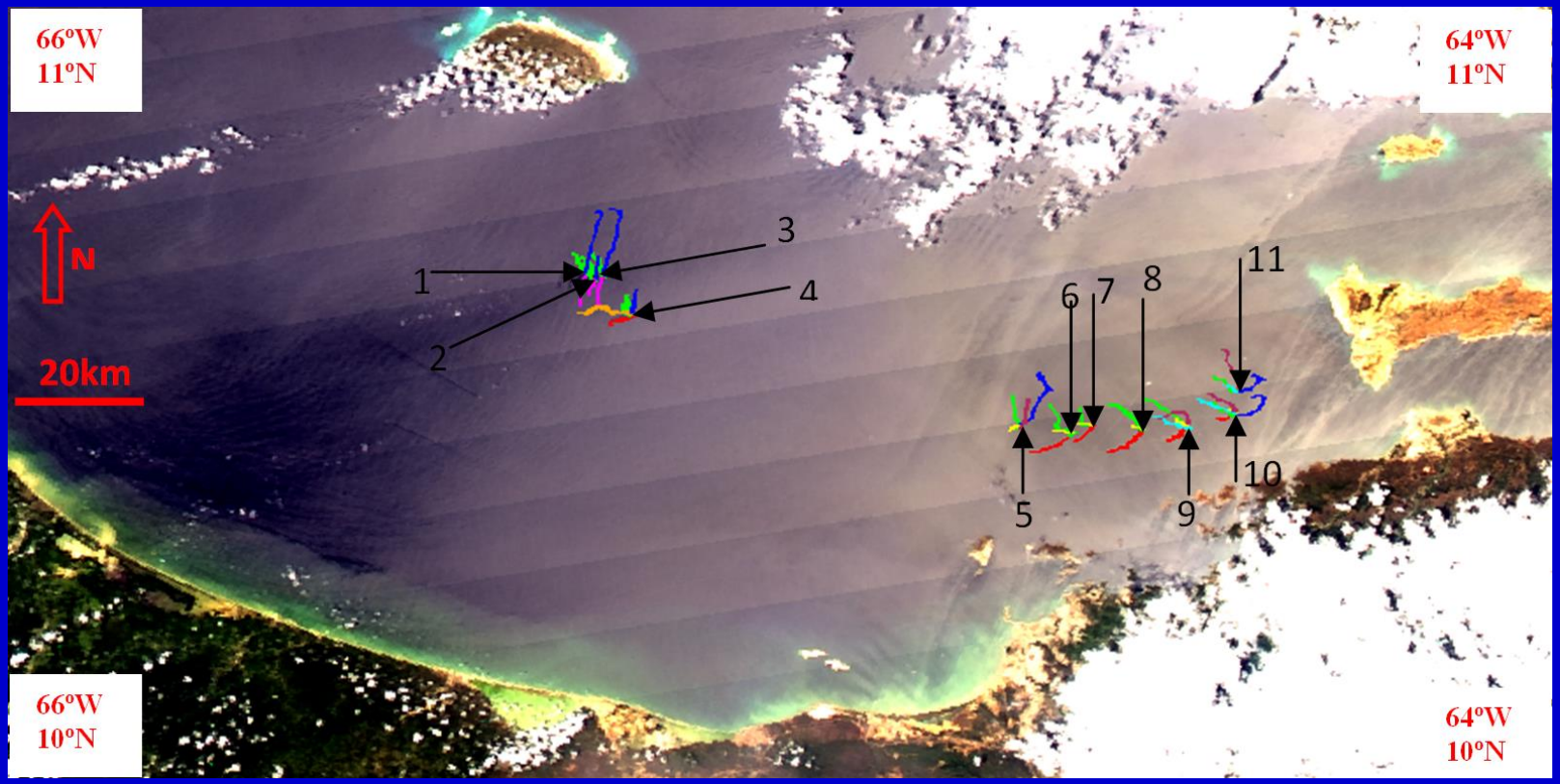
# March 8, 2014, 07:36 GMT, VIIRS



# Summary

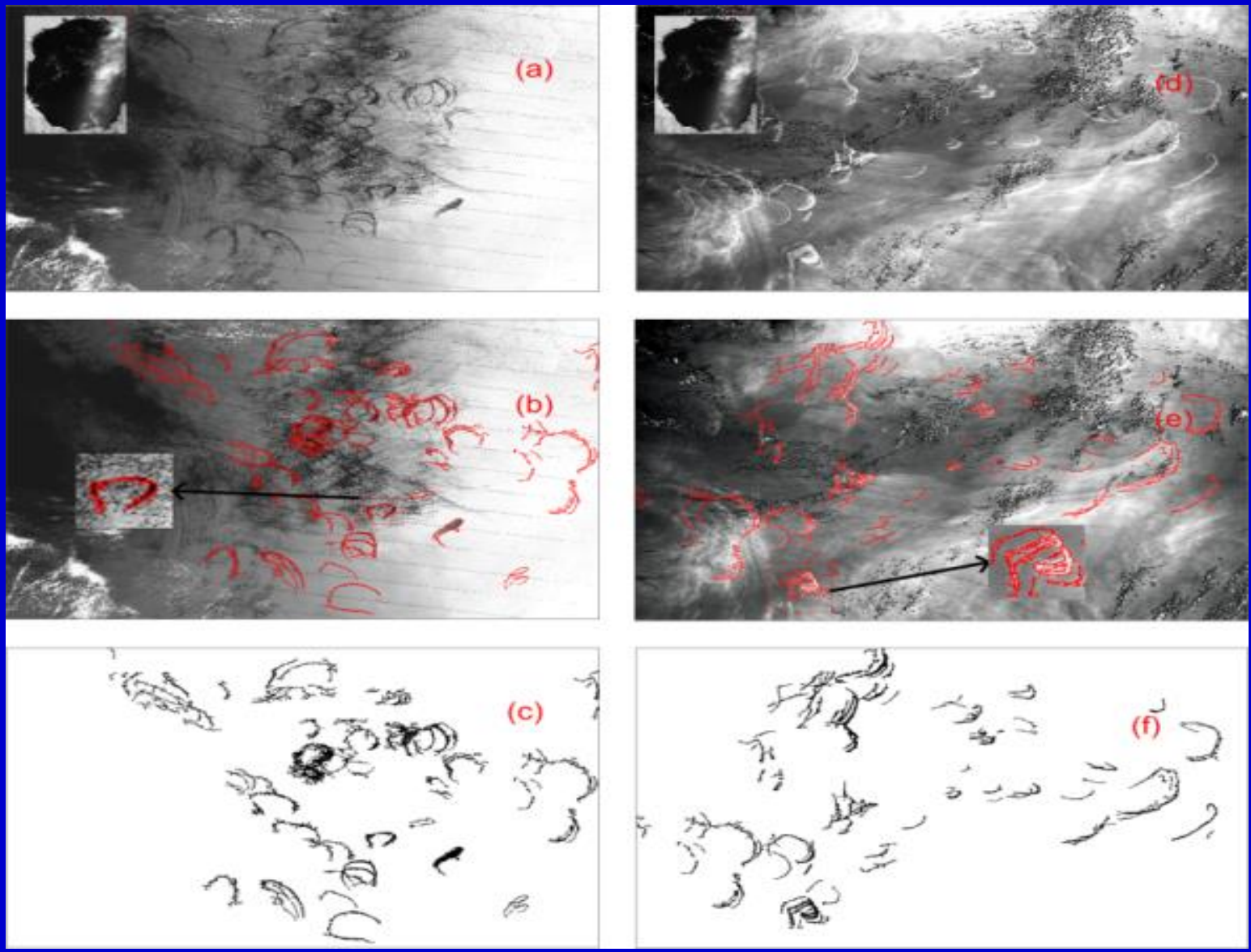
- Optical remote sensing provides complementary data to SAR for spill monitoring
- More spectral bands show advantage of differentiating oil from other look-alikes and show potentials in estimating oil volume
- Surface oil volume is currently estimated by scaling up AVIRIS observations
- Two challenges still need to be addressed: optical closure (model versus remote sensing measurements) and thickness measurements in the field

# Application in Identifying Natural Oil Seeps


From Chen and Hu (in press)

# Feature extraction




From Wang and Hu (to be submitted)