

Transitioning SAR-derived Oil Spill Thickness Measurements into an Operational Context

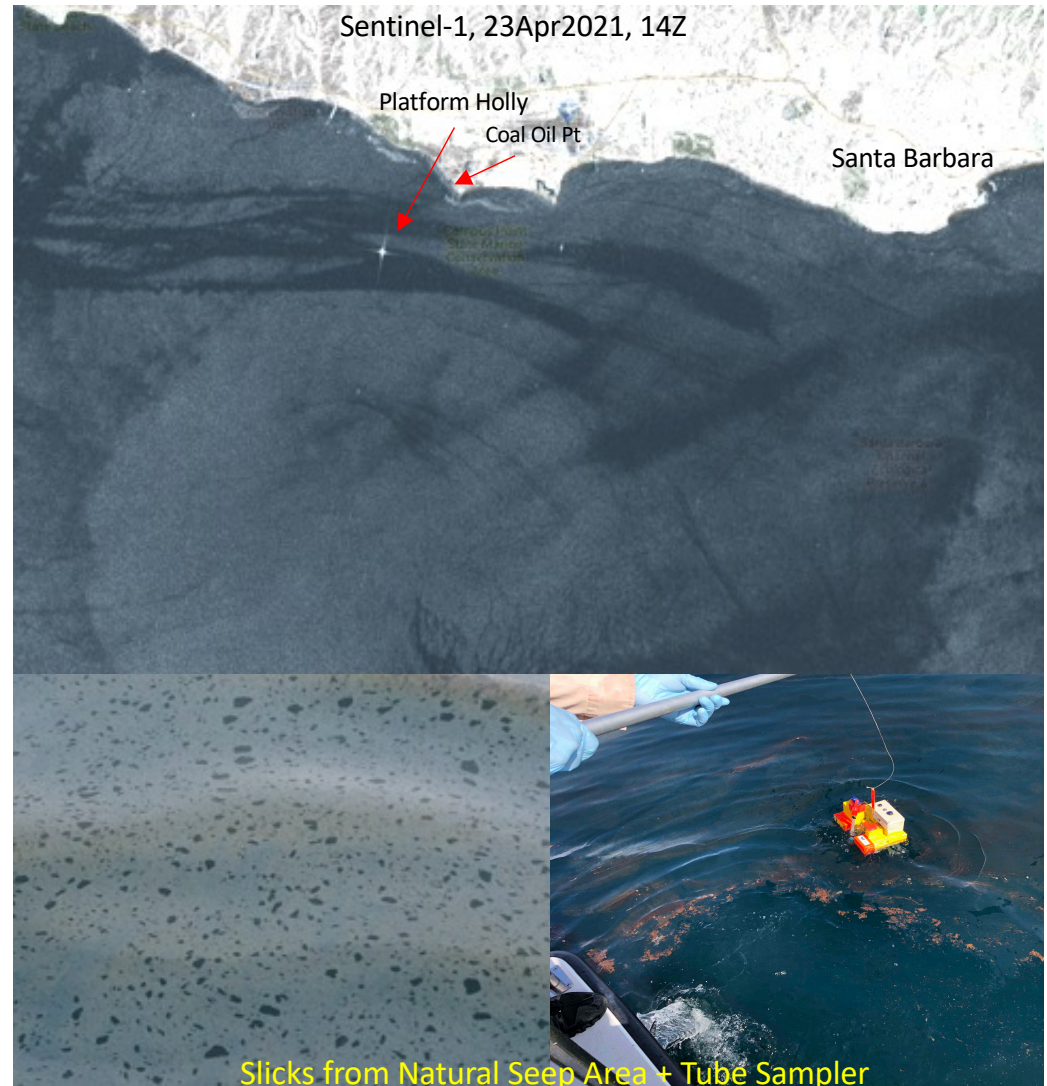
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Project Objective: Develop a quantifiable approach for determining the thicker components of oil spills using SAR imagery (C-band, NISAR) that can be used operationally for clean-up efforts.

Challenges

- Need low noise SAR, with repeat observations
-> UAVSAR
- Effective in situ sampling of a heterogeneous material for validation over broad slick region
-> Tube oil sampler
-> Drones for local areal extent and characterization
- Sampling location for field campaigns
-> Santa Barbara CA natural oil seep area, 2021-22
-> Norway with controlled releases, 2022?
- Multiple satellite remote sensors for effective comparisons – SAR plus Optical
- Algorithm to separate oil from clean water and other low backscatter features
-> Damping ratio, water/oil backscatter using vertical polarization
-> Copolarization ratio – if available



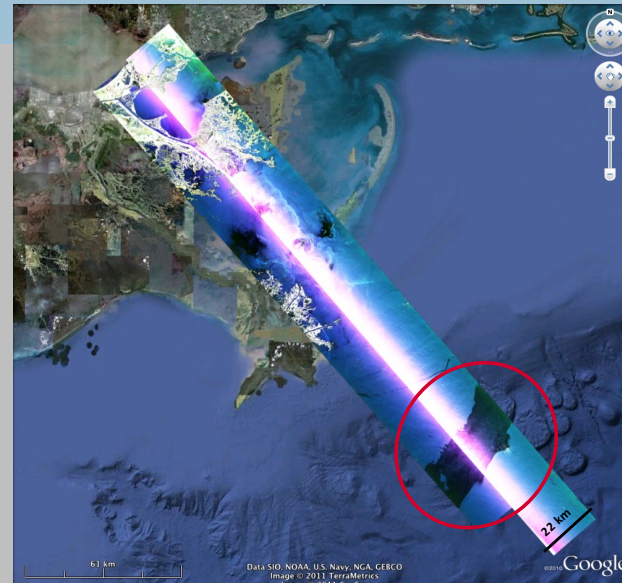


NASA UAVSAR GULF OIL SPILL CAMPAIGN

22-23 JUNE 2010 DEPLOYMENT



- 2 days, 21 flight hours
- ~5500 km of flight lines with 22 km swath width
- imaged an area of 120,000 km²



Main DWH oil slick,
imaged 23 June 2010

Frequency	L-Band 1217.5 to 1297.5 MHz (23.8 cm wavelength)
Intrinsic Resolution	1.7 m Slant Range, 0.8 m Azimuth
Polarization	HH, HV, VH, VV
Repeat Track Accuracy	± 5 meters
Transmit Power	> 3.1 kW
Radiometric Calibration	1.2 dB absolute, 0.5 dB relative channel-to-channel
Noise Floor	-47 dB average

OIL CHARACTERIZATION FOR DIRECTED RESPONSE

VARIATIONS IN THE AVERAGED INTENSITY

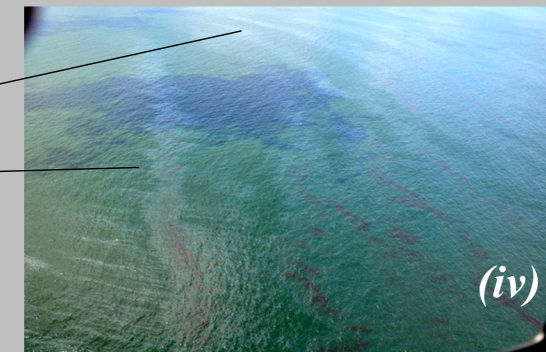
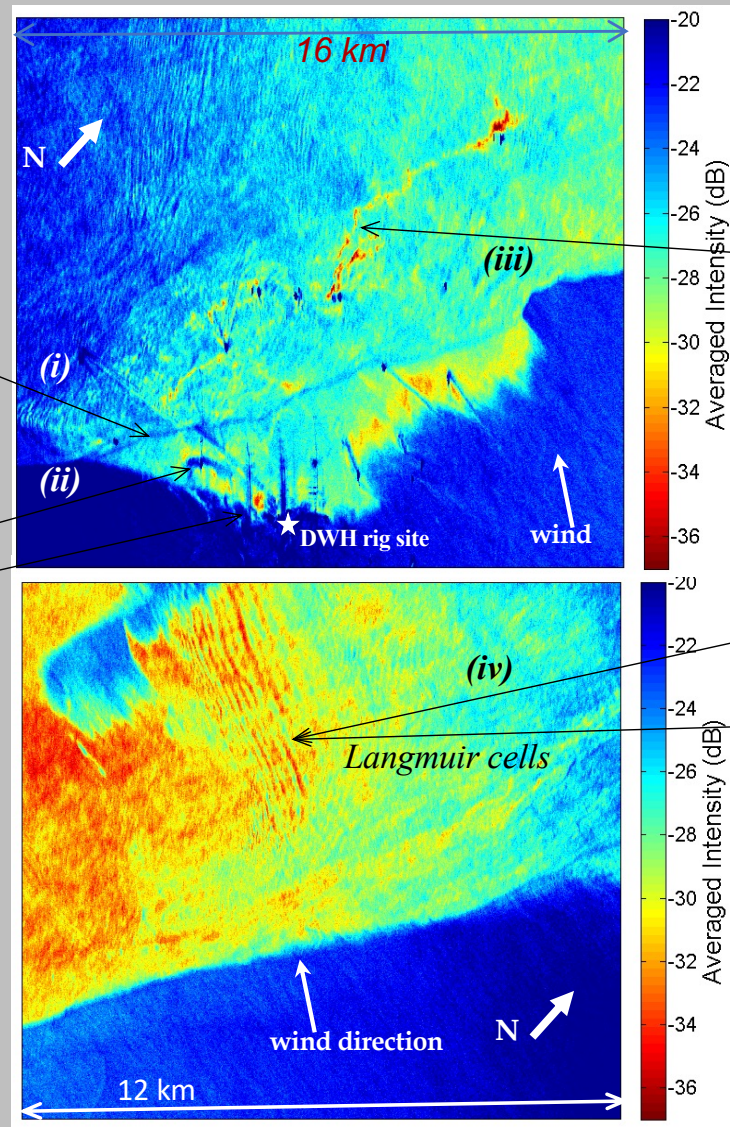
NOT ONLY IS THE OIL SLICK CLEARLY DIFFERENTIATED FROM THE SURROUNDING SEAWATER (DARK BLUE IN THE UAVSAR IMAGE), BUT THE LOW NOISE UAVSAR RADAR BACKSCATTER DIFFERENTIATES VARYING OIL CHARACTERISTICS WITHIN THE SLICK.



Jones, C.E. et al (2011). AGU Geophysical Monograph Series, 195, 33-50.

Leifer et al (2012) RSE

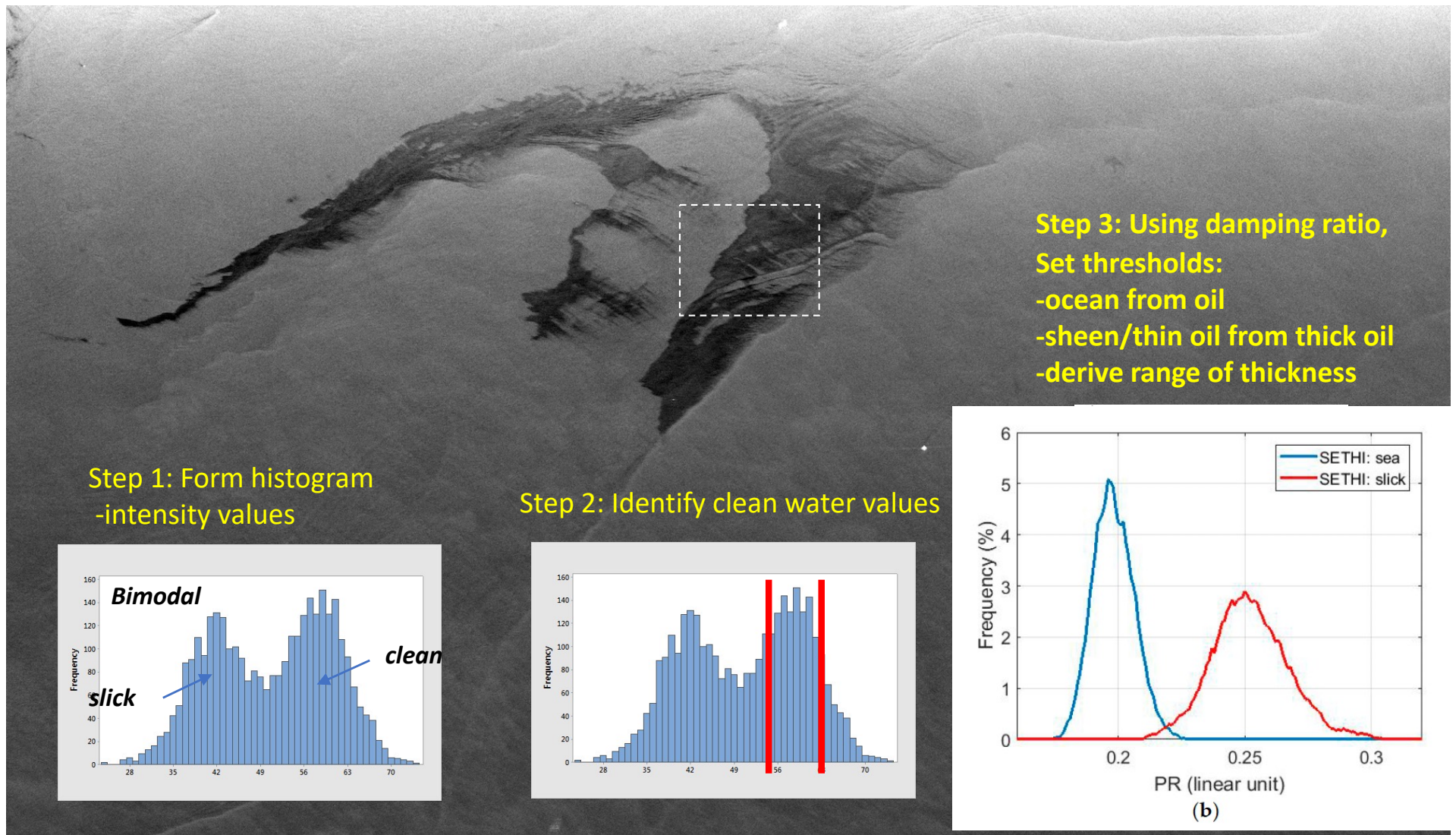
Minchew, Jones, Holt (2012). TGARSS



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

Relate In Situ to Thickness: Methodology Using Damping Ratio – Single Polarization

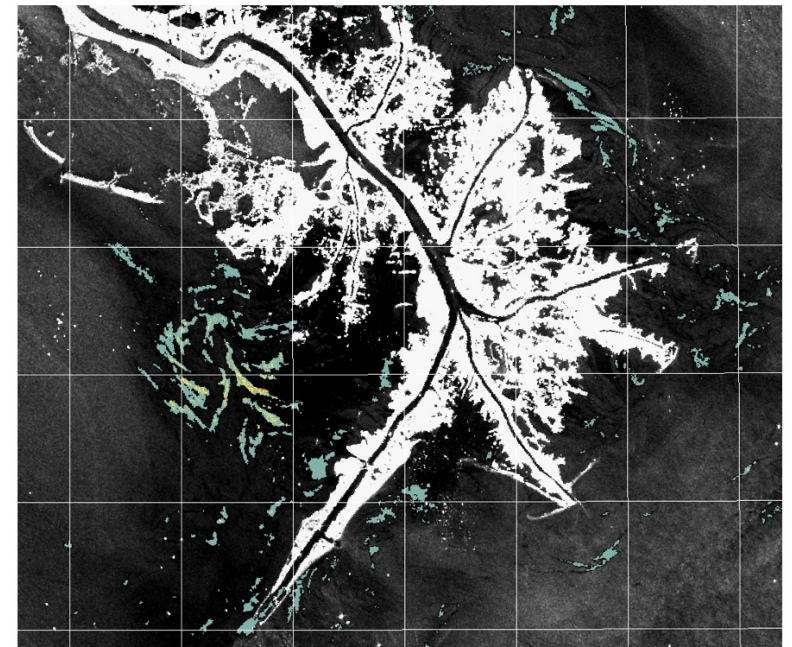
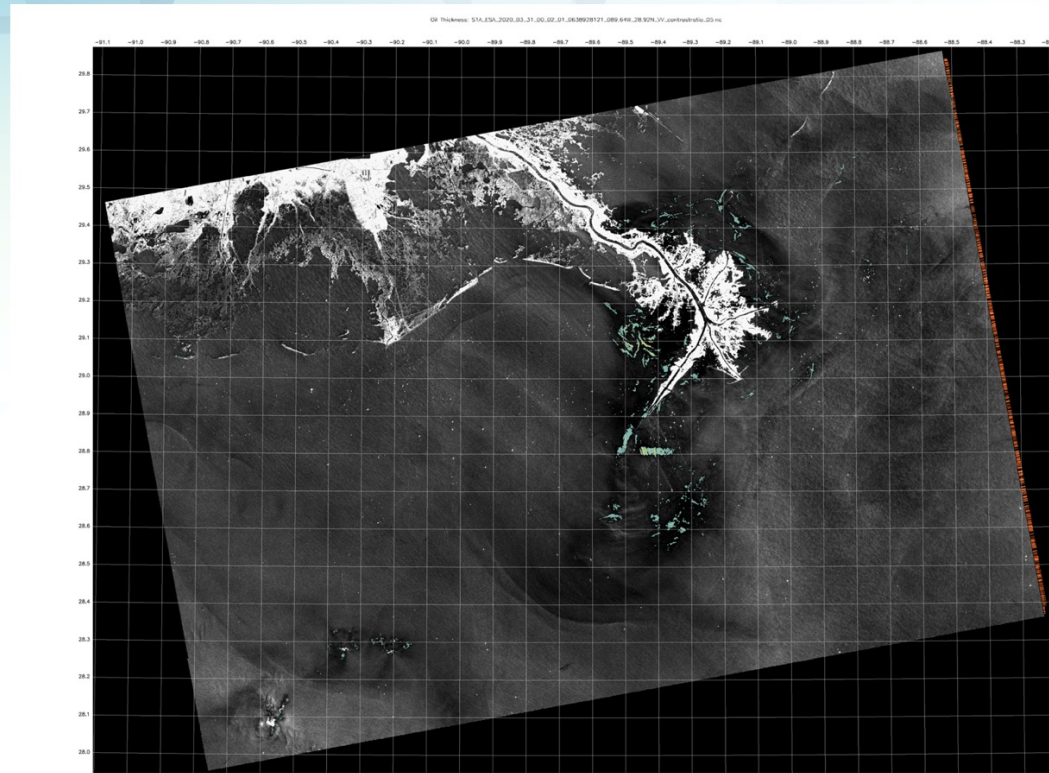
$$\text{Damping Ratio (Contrast in Backscatter dB)} = \frac{VV_{\text{ocean}}}{VV_{\text{oil}}}$$



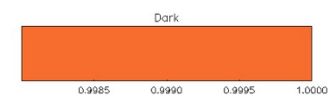
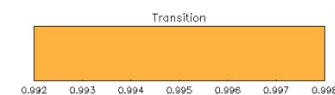
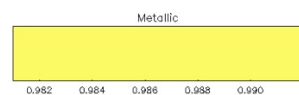
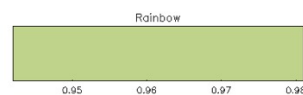
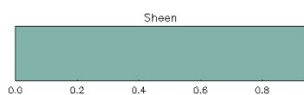
- Impacted by environment (wind, temperature), oil heterogeneity and varying properties

Goal- SAR-derived Oil Thickness Maps in an Operational Framework

Sample Oil Thickness Classification Using Contrast Ratio as a Baseline Algorithm



Sentinel-1A SAR C-band imagery 2020-03-31 00:02:01 UTC



Note: Contrast Ratio is opposite of damping ratio – so oil/ocean

Taylor Energy Persistent Seep, Gulf of Mexico

November 2016

- Main exercise was funded by DOI/Bureau of Safety & Environmental Enforcement (BSEE)

- Participants & Data

- NOAA Office of Response & Restoration
- Boat crew collecting samples for thickness, oil-water ratio analysis
- Ocean Imaging, Water Mapping, Fototerra
- On Wings of Care
- Airborne visual observers & cameras, IR, SLAR
- Satellite WorldView, Radarsat-2

Goal - i) identify best in situ sampling method for oil thickness
- ii) compare in situ with multiple remote sensors

UAVSAR Results

- First cut at comparing damping ratios to oil thickness showed promising results (in situ measurements primarily near source)

- Used SAR time series to identify, based on the damping ratio, stable and varying oil over duration of SAR collection



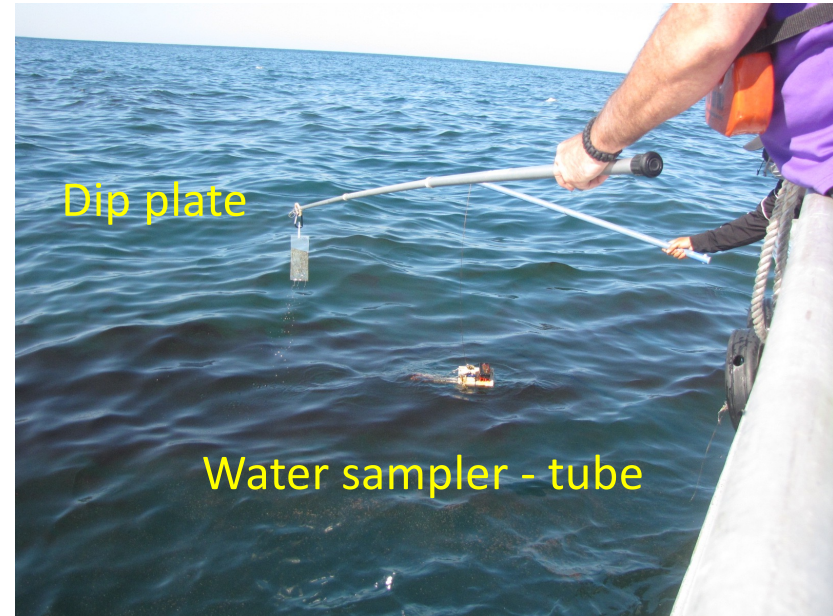
UAVSAR participated in the November 2016 campaign.

(ROSES RRNES proposal, funded by NASA)

MC-20 NOAA Field and Sensors Campaign, Nov. 14-17, 2016



Nov. 15, 09:15:23 am CST



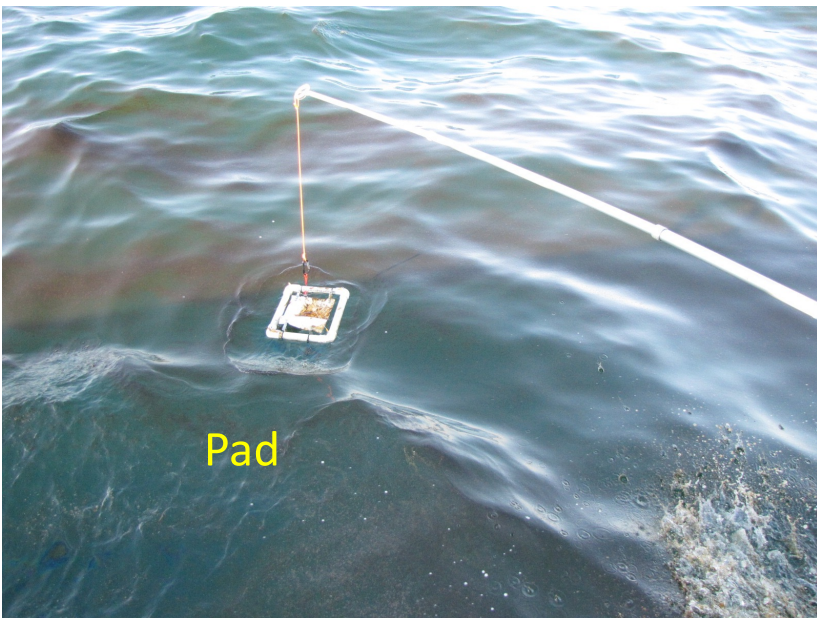
Nov. 15, 10:01:37am CST

Sample - In situ thickness measurements- 3 devices

Nov. 15, 09:49 to 10:02 CST, μm

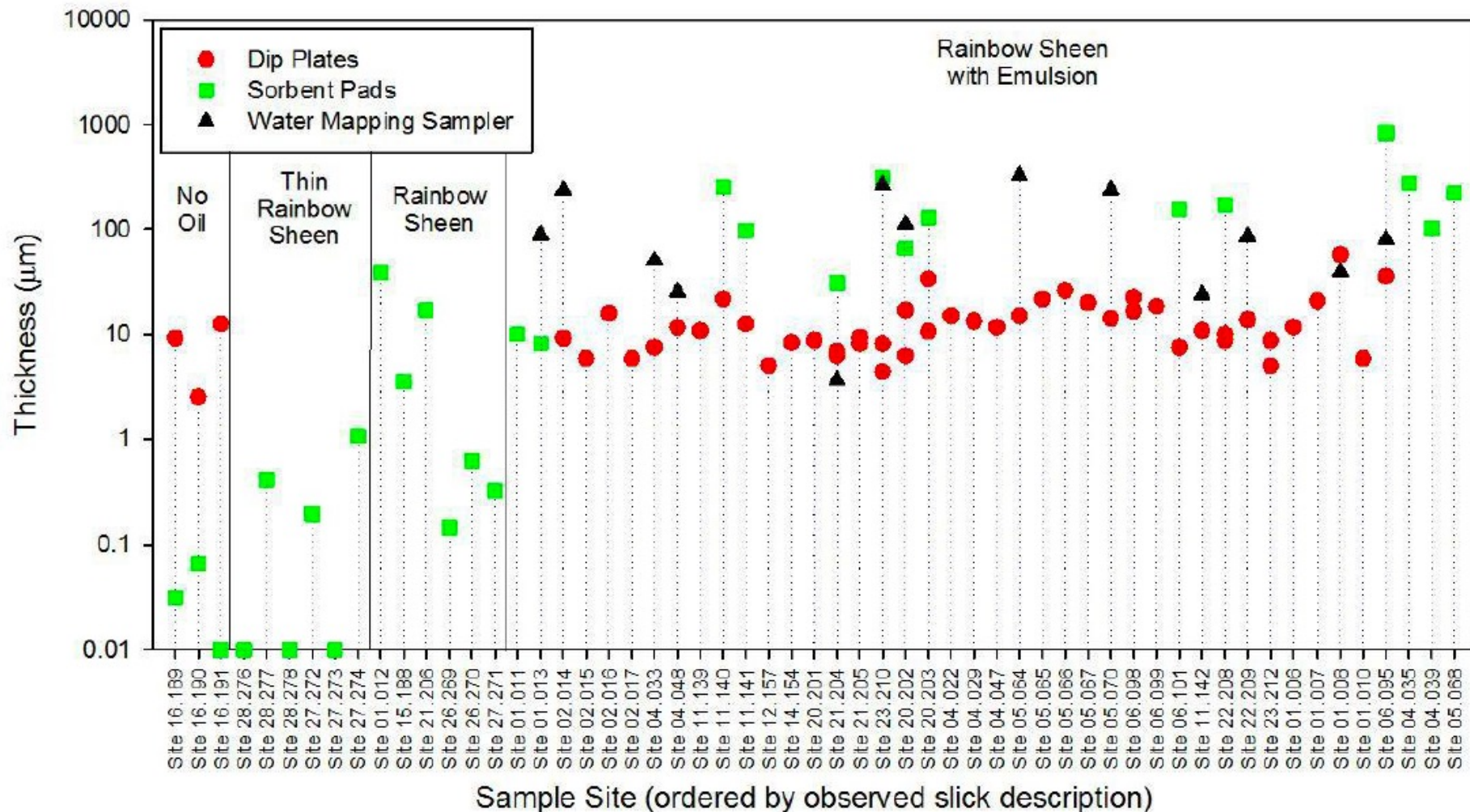
Water Mapping Sampler Slick Thickness	320.0
Dip Plate Slick Thickness (4x)	15
Dip Plate Slick Thickness (4x)	21.6
Dip Plate Slick Thickness (4x)	26.2
Dip Plate Slick Thickness (4x)	20
Pad Slick Thickness	203.3
Water Mapping Sampler Slick Thickness	210.0
Dip Plate Slick Thickness (4x)	14.1

•Coincident measurements of same area produced wide range of thicknesses -> oil is heterogeneous



Nov. 15, 08:15:43 am CST

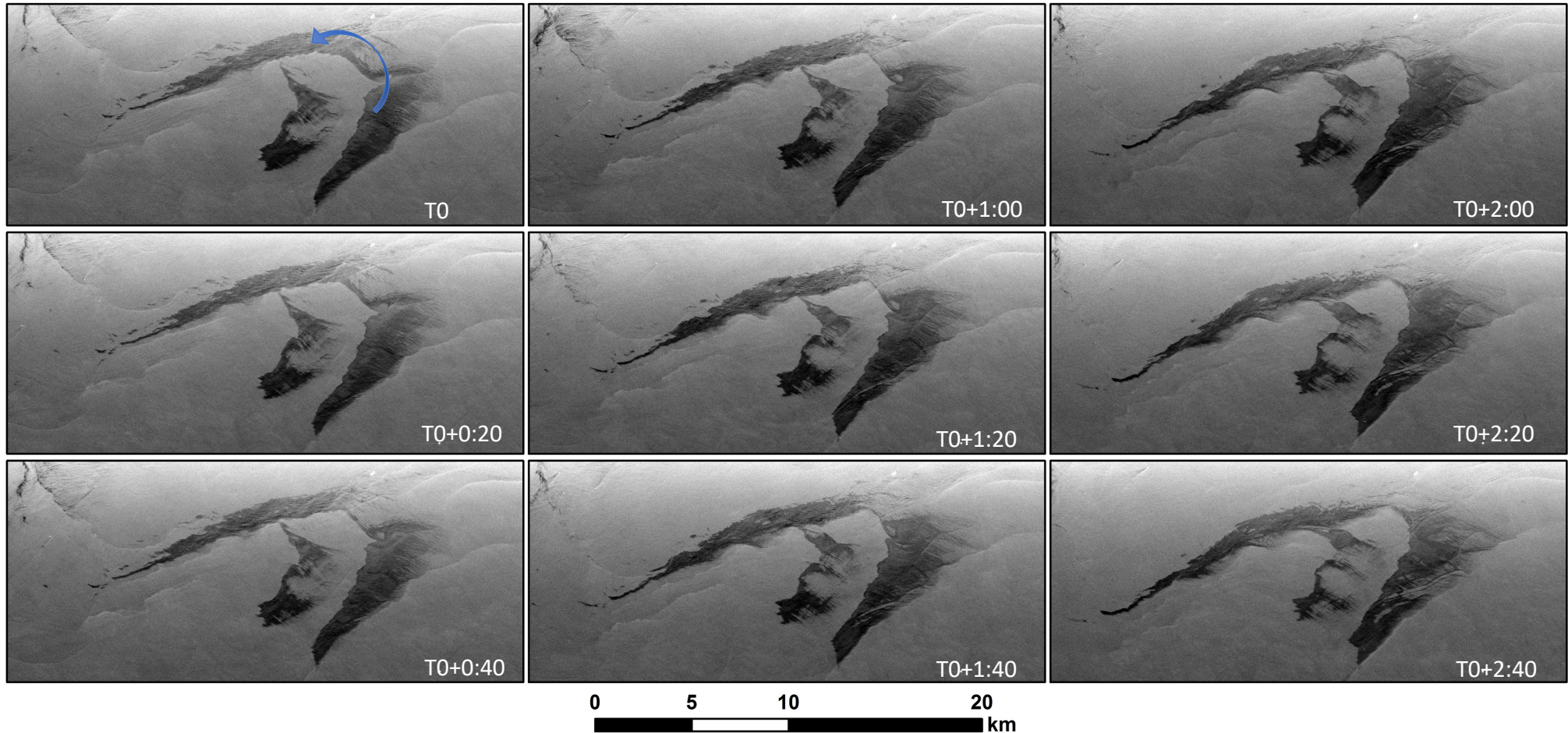
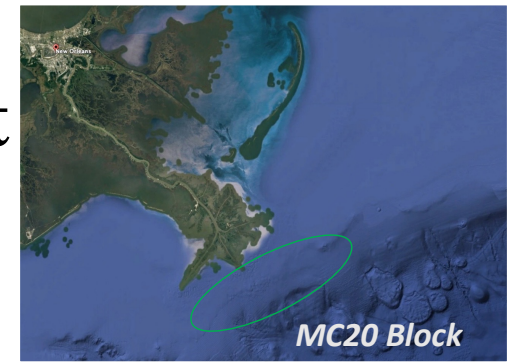
Summary – In Situ Oil Thickness November 14-18, 2016



•Highly variable oil within same small patches

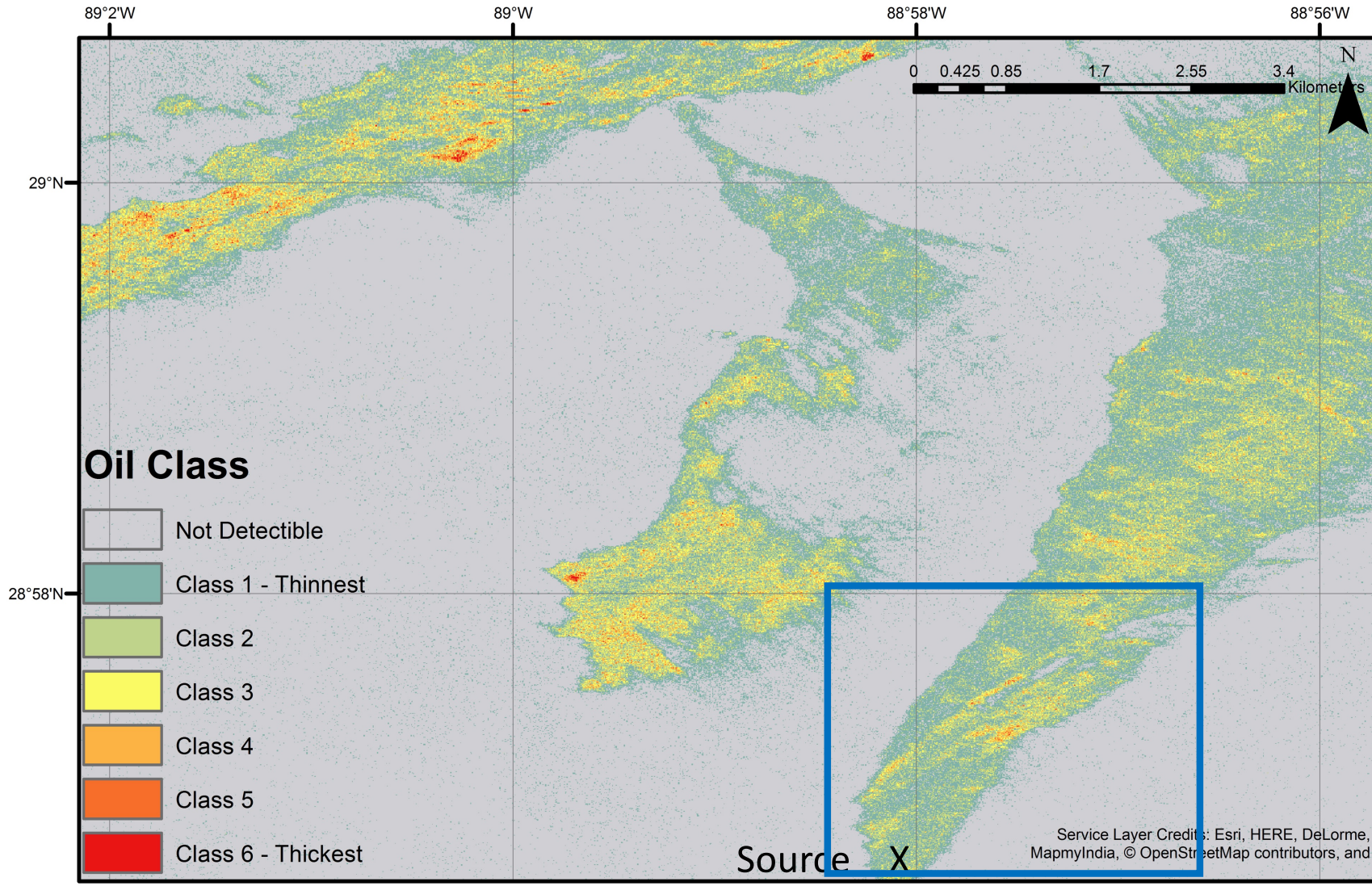
Observed Short-Timescale Slick Transport

November 17am, 2016. Acquisitions separated by 20 minutes



Radar Backscatter: Intensity

Damping Ratios As Range of Estimated Relative Thickness Values



Next Step: What is the threshold between sheens and thicker oils ?



Development and Implementation of Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context

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(Coast Guard)

Santa Barbara Coal Oil Point Seep Field

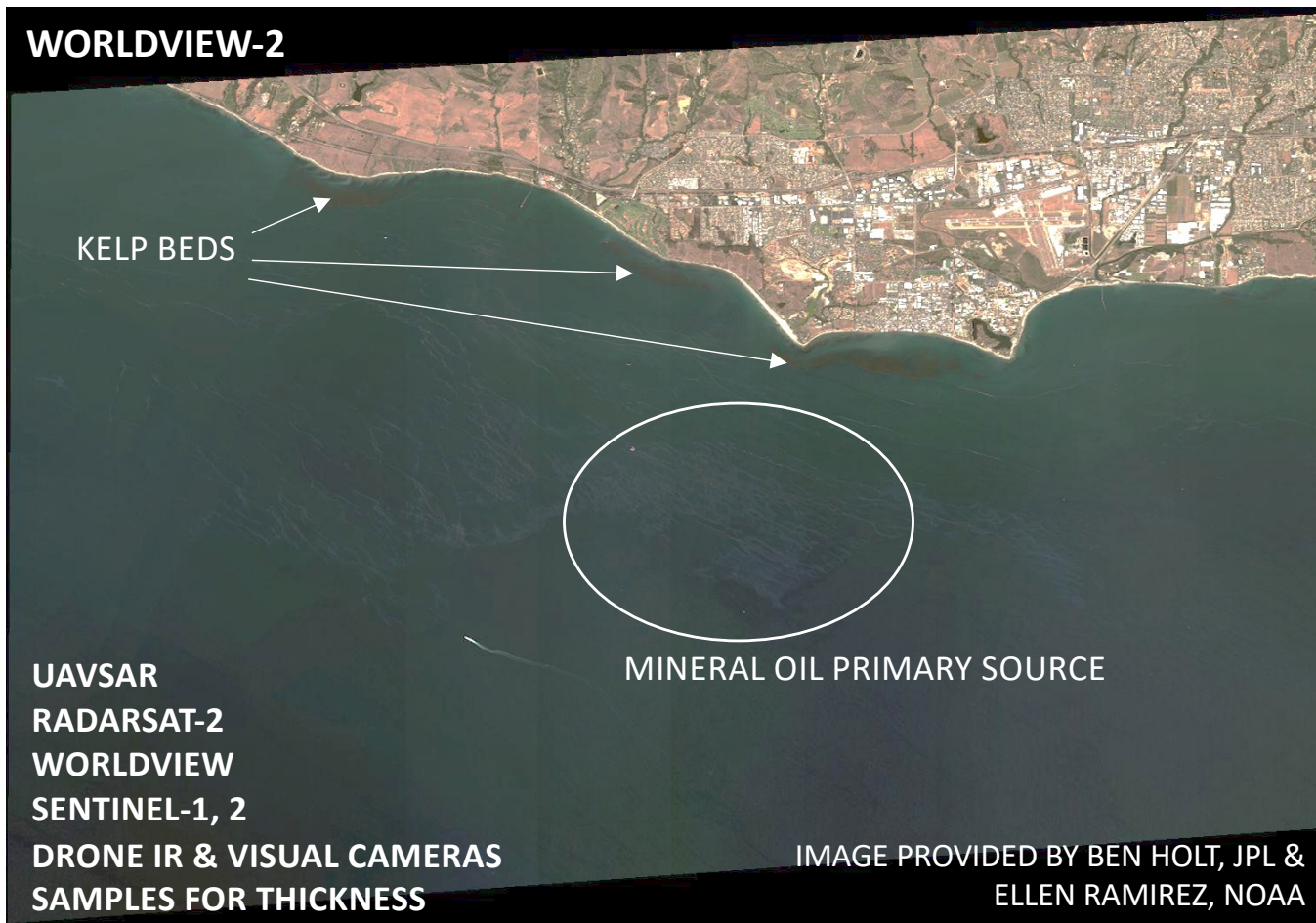
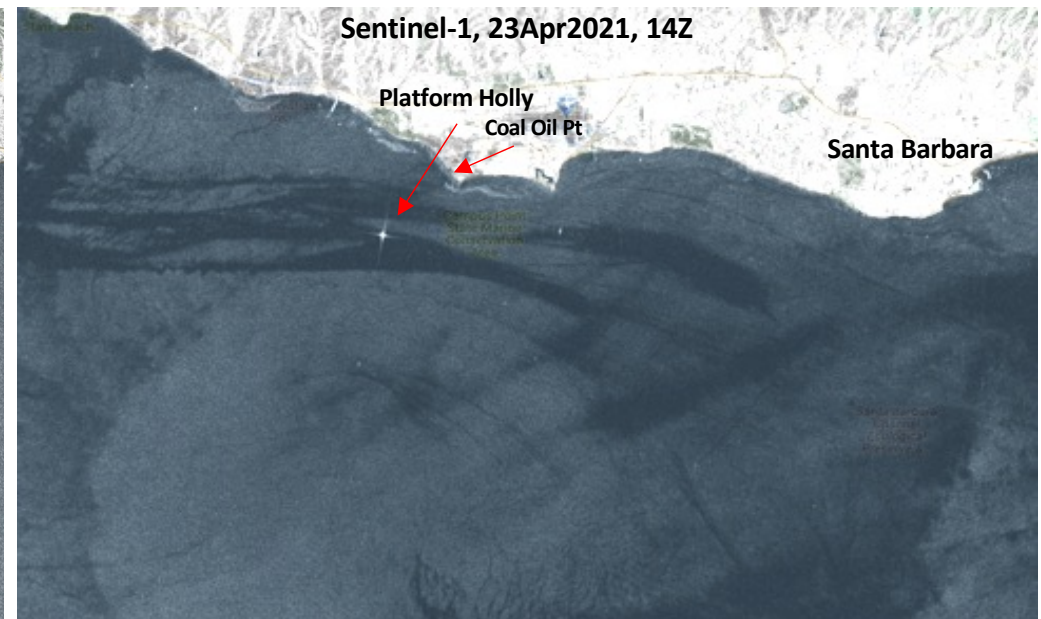
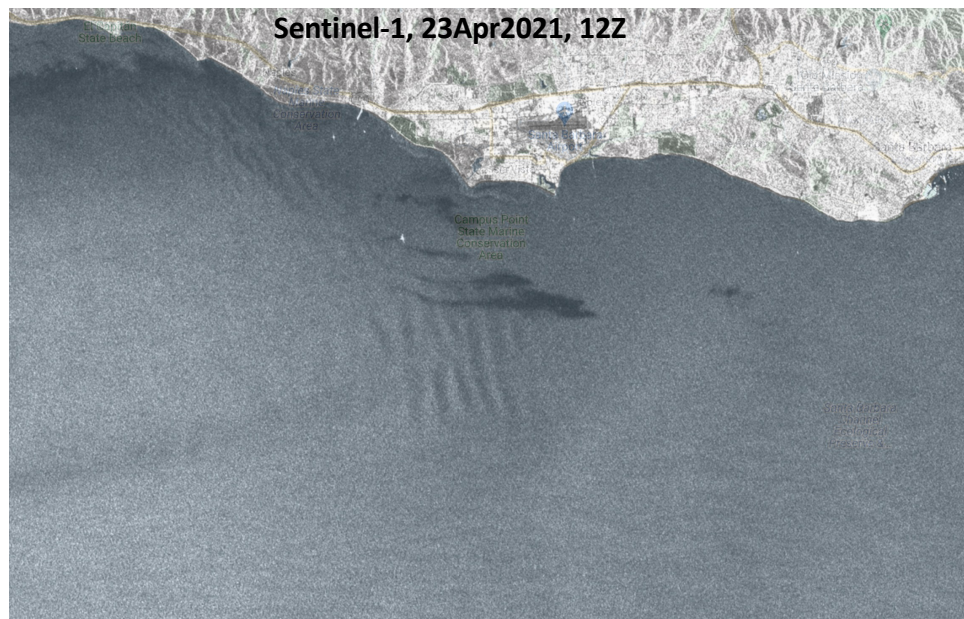
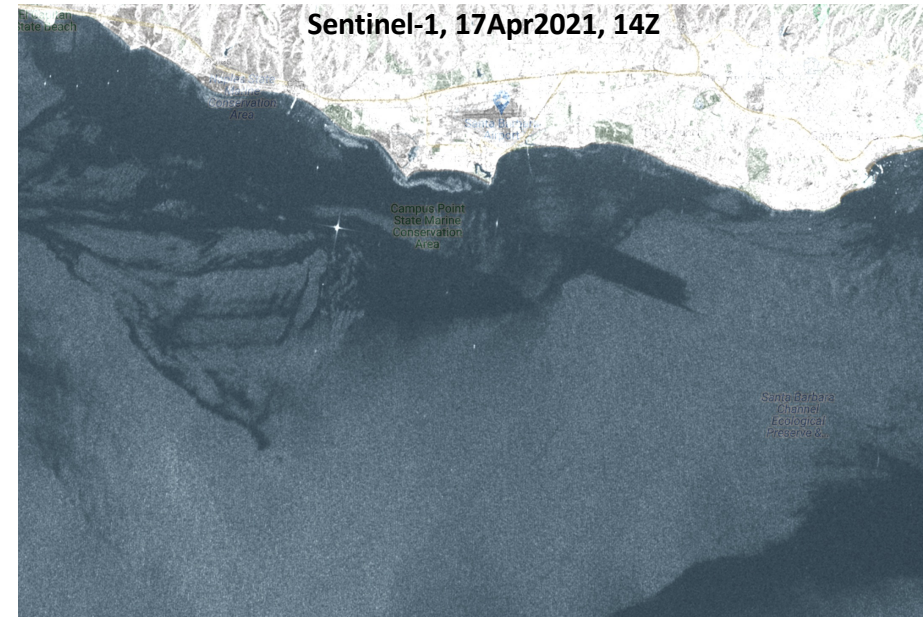


IMAGE FROM DRONE, 2018
(PHOTO & IMAGE CREDIT: OSCAR
GARCIA-PINEDA)

Santa Barbara Natural Seeps Field Campaign, May 10-21, 2021



- Upcoming field campaign will be on a Coast Guard Cutter, with UAVSAR overflights
- Field tests will be designed to provide broad-scale in situ measurements across a considerable extent of slick area – requires knowledge of slick locations and weather/current information both before and during sampling.

Summary

- **Quantitative oil spill properties can be derived with SAR**
 - Need improved in situ validation with coordinated campaigns
 - Focus is on using simple parameters (one polarization, simple ratio of ocean/oil)
 - Need to separate mineral oil from biogenic film, may require two copolarizations.
- **Need to determine thresholds for**
 - ocean vs oil for extent
 - sheen/thin oil vs thicker/emulsified oil
 - range of derived estimated thickness
- **Need radar scattering model to estimate effects of wind, temperature, radar frequency, radar parameters, key oil properties, water content to help predict derived oil thickness and understand sensitivities to above.**
(work underway at JPL but not discussed).
- **Field campaigns with comprehensive in situ sampling and UAVSAR key to moving towards operational algorithms for oil slick thickness.**

Oil Thickness Estimate with SAR→

Consider Dielectric Constant of Water and Oil

Complex Permittivity

$$\epsilon = \epsilon' - i\epsilon''$$

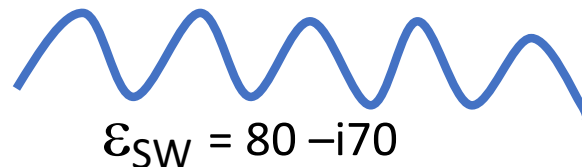
Sea water $\epsilon_{sw} = 80 - i70$

-High conductivity surface

Crude oil $\epsilon_o = 2.3 - i0.02$

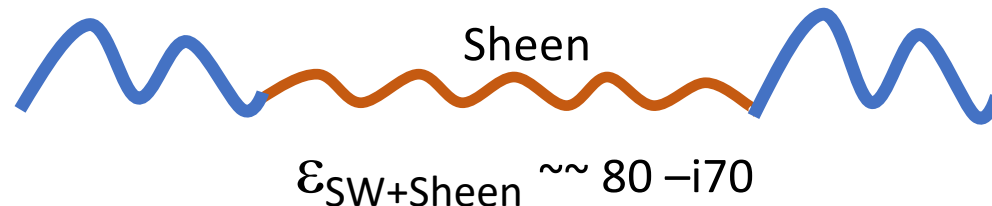
-Low conductivity surface

Ocean Surface (no oil)



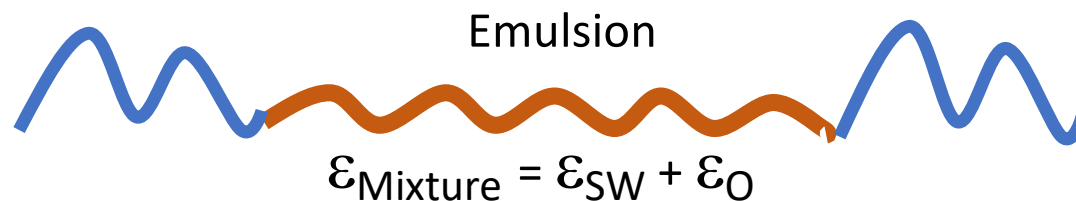
ϵ - frequency, temperature dependent
-Small-scale ocean roughness

**Ocean Surface
+Thin Oil, Sheen**



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

**Emulsion =
Mixture of Oil
+ Sea water**

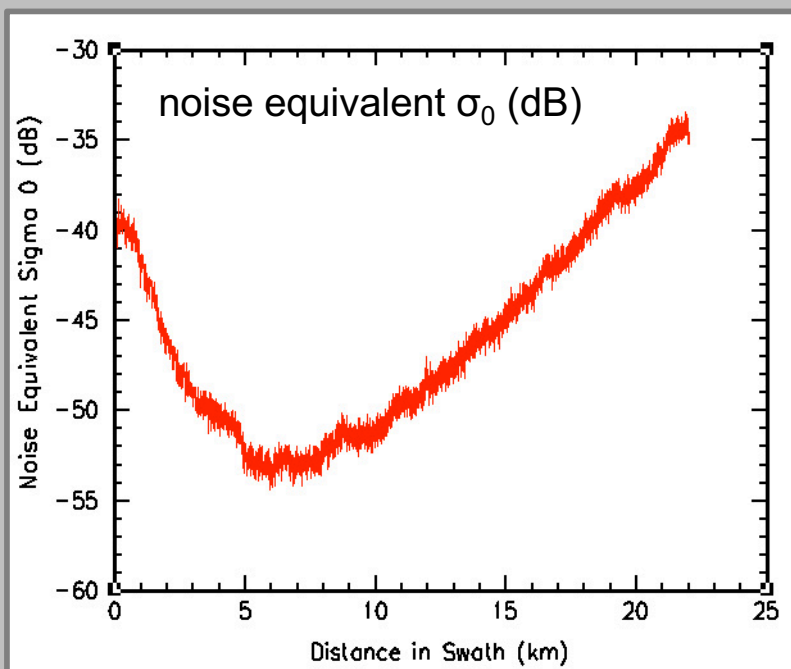


-New dielectric layer with ϵ mixture
-Reduces scattering

Radar backscattered signal responds to volumetric fraction of emulsified oil as a mixture of oil and seawater - an intermediate conductive layer

UAVSAR INSTRUMENT NOISE FLOOR

UAVSAR NOISE FLOOR



The low noise floor of the UAVSAR instrument makes it possible to measure the radar cross section from water with an L-band radar, even with oil damping the surface waves. We find that the instrument noise floor is reached only at the far edge of the swath for the HV returns from oil.

Comparison with other RADAR instruments

Sensor	Description (type, band, wavelength, polarization)	NESZ
UAVSAR	Airborne SAR; L-band (24 cm); quad polarization	-35 to -53 dB
ERS1/2	Satellite SAR; C-band; VV polarization	-20 to -29 dB ¹
Radarsat-2	Satellite SAR; C-band; single or dual polarization	-29 dB ²
ENVISAT ASAR	Satellite SAR; C-band; single or dual polarization	-20 to -29 dB ¹
ALOS PALSAR	Satellite SAR; L-band; single, dual, or quad polarization	avg -23 dB (HH or VV), -26 dB (HV) ³
TerraSAR-X	Satellite SAR; X-band;	avg -23 dB ⁴
AIRSAR	Airborne SAR; C-, L-, and P-band; quad polarization	-34 to -50 dB (L); -40 to -48 dB (P); -26 to -34 dB (C) ⁵

¹ <http://envisat.esa.int/handbooks/asar/CNTR3-2-1.htm>

² RadarSAT-2 Product Description, RN-SP-52-1238, 2-Nov-2009

³ ALOS PALSAR Cyclic Report – Cycle 13, PALSAR_CR_13_070723_070907, 10-Jan-2008

⁴ TerraSAR-X Ground Segment Basic Product Specification Document, TX-GS-DD-3302, 2008

⁵ <http://airsar.jpl.nasa.gov/documents/instrument.htm>