Near real-time estimates of the mixing of oil and seawater using polarimetric SAR

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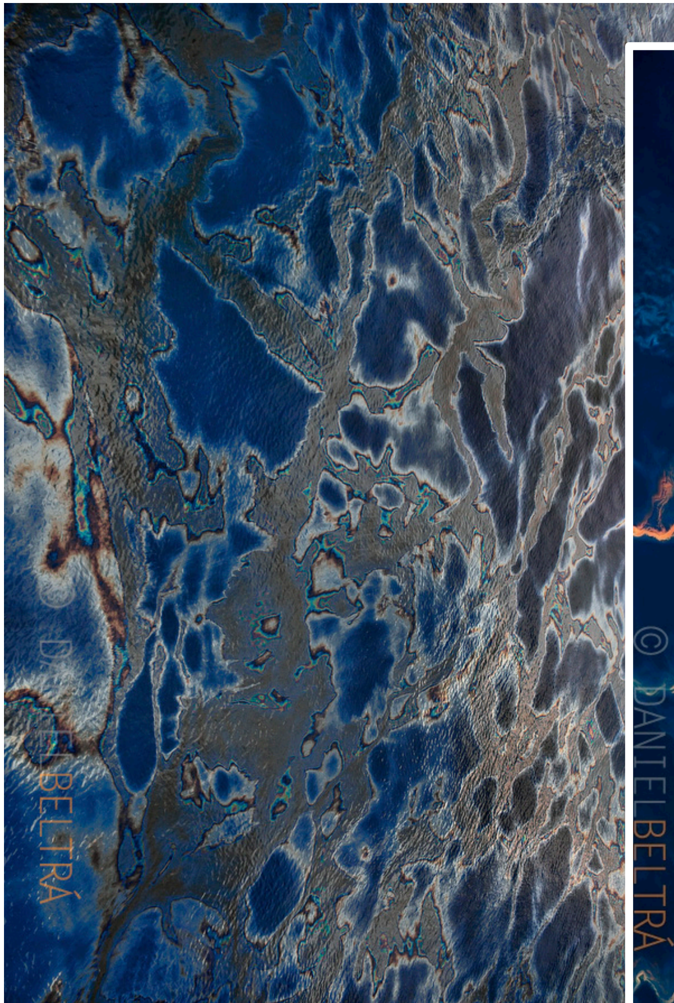
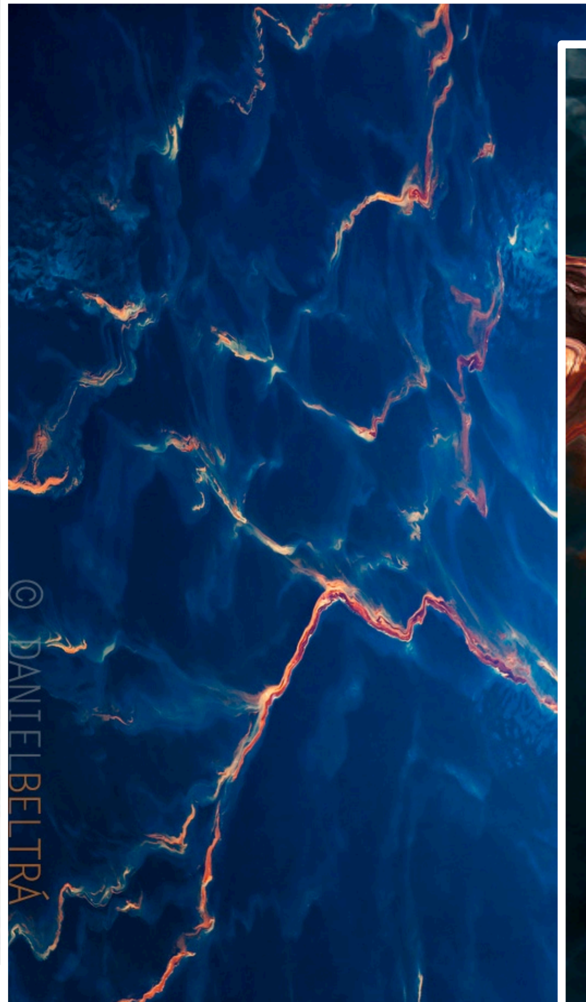
Understanding the problem

- The environmental impact of oil depends on:
  - Type and quantity of oil spilled
  - Properties as a function of time
  - Organisms and environments exposed
  - Nature of the exposure
- Response methods have a time window:
  - Type and quantity of oil
  - Initial spill conditions
  - Weathering and emulsion rates
  - Type of environments that will be affected

Source: NOAA

Oil on the sea surface



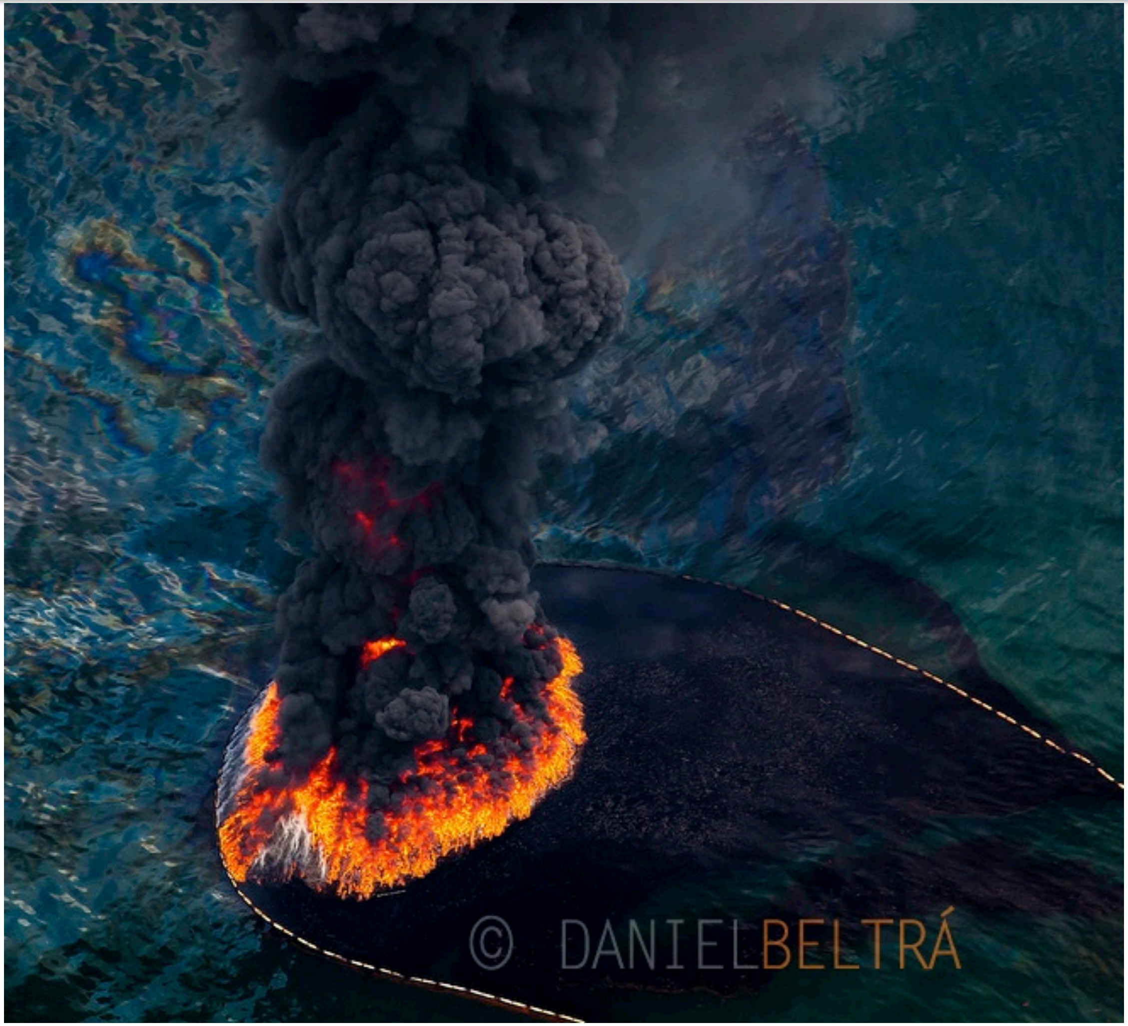


Cleanup methods

Mechanical: Booms, skimmers, vacuums, etc.

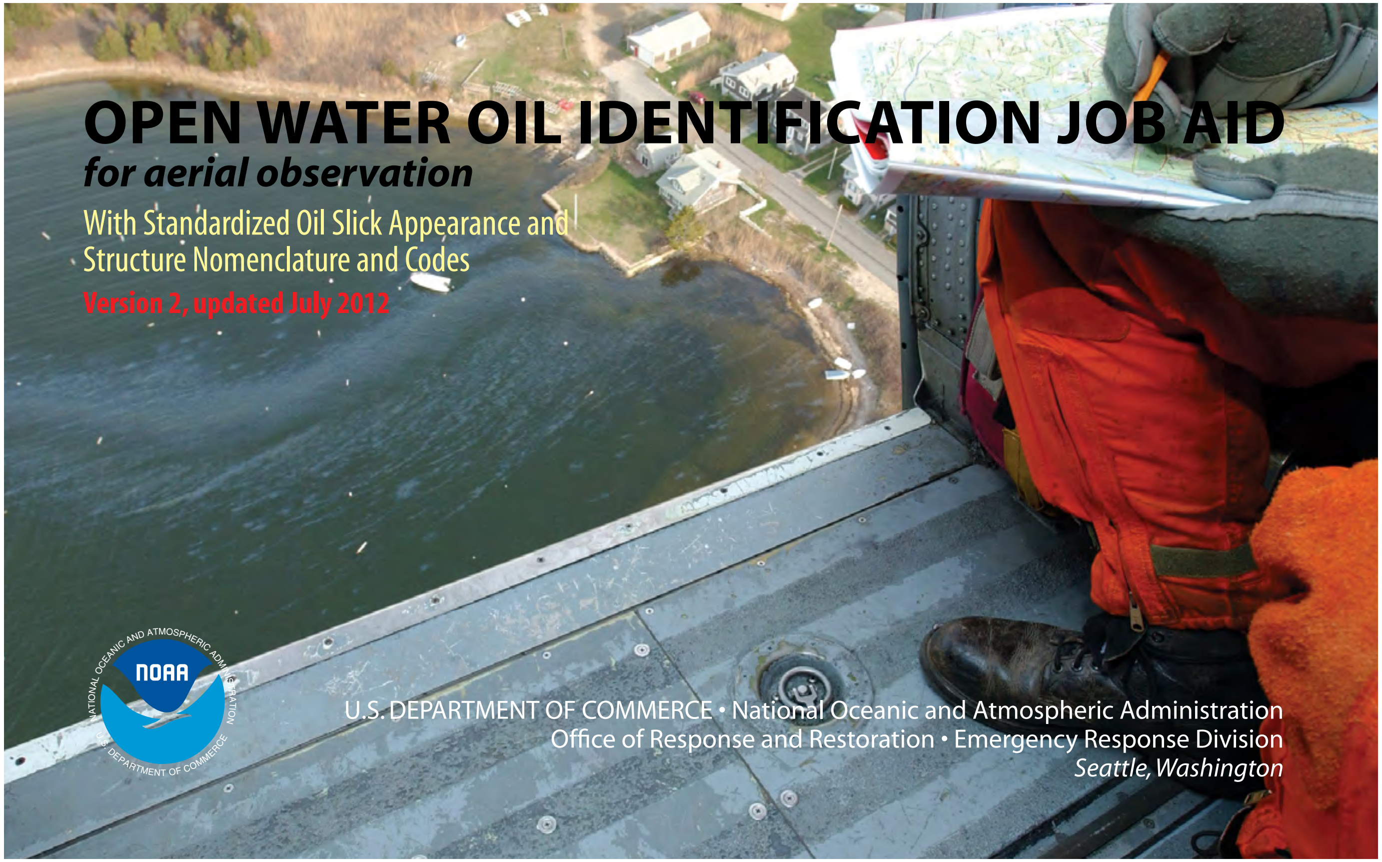
Cleanup methods

Chemical dispersants



***In situ* burning**

Observational strategy



Limitations:

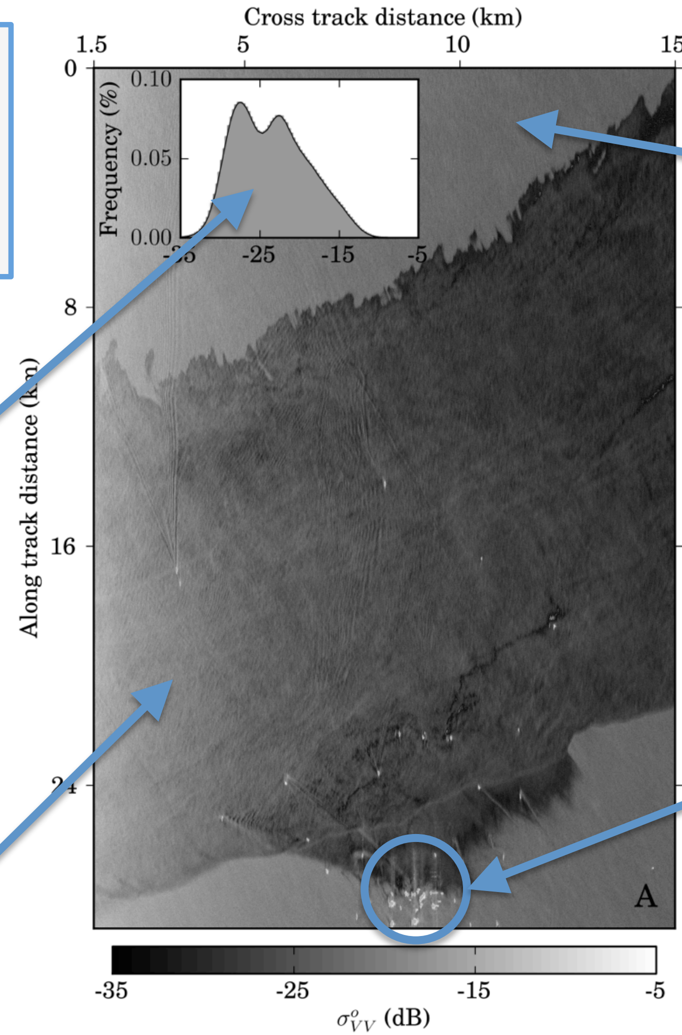
Must be done during the day

Can only be done in good weather

Based on skills and interpretation of the observer

Observing oil with radar

- UAVSAR VV power
- Collected June 2010
- Approximately 24 hours of flow from the well



Relatively clean water

Bimodal histogram

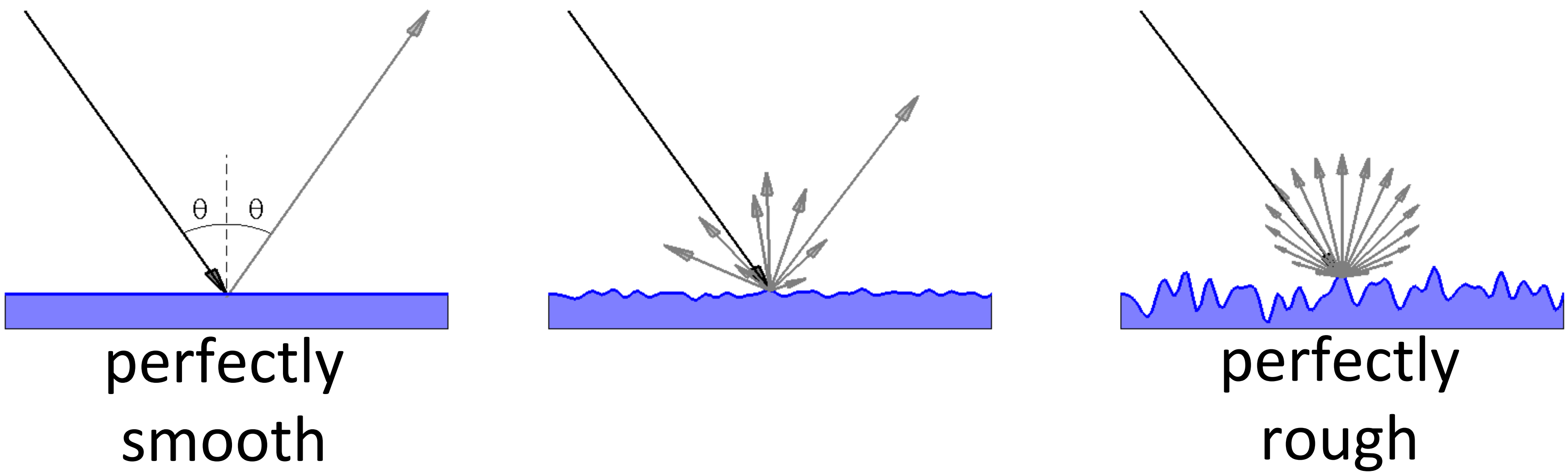
Oil on or near the surface = low backscatter power

Deepwater Horizon site

How it works

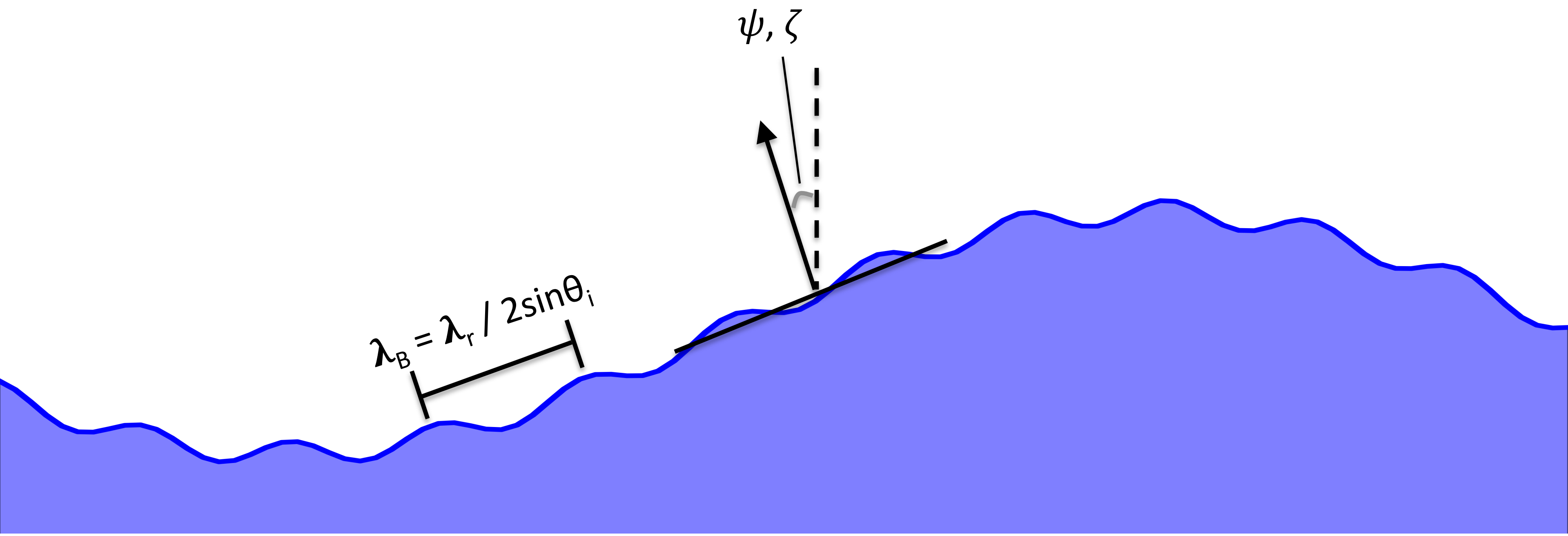
2 ways for oil to reduce radar backscatter power:

- Smoothing surface roughness (decreasing surface tension)



- Reducing total scattered power (only when mixed)

Modeling sea clutter



- Tilted Bragg or small perturbation model
- Scattering is due to waves → $k_B = 2k_r \sin\theta_i$
- Small scale roughness is tilted by long wavelength waves
- Oil only affects small scale roughness

Expanded capability: PolSAR

$$\sigma_{pp}^{o} = \left(4\pi k_r^4 \cos^4\theta_i\right) \Gamma_{pp} W$$

- Reflectivity is polarization dependent

$$\Gamma_{pp} = \Gamma_{pp}(\varepsilon_r, \psi, \zeta)$$

- Roughness is polarization independent

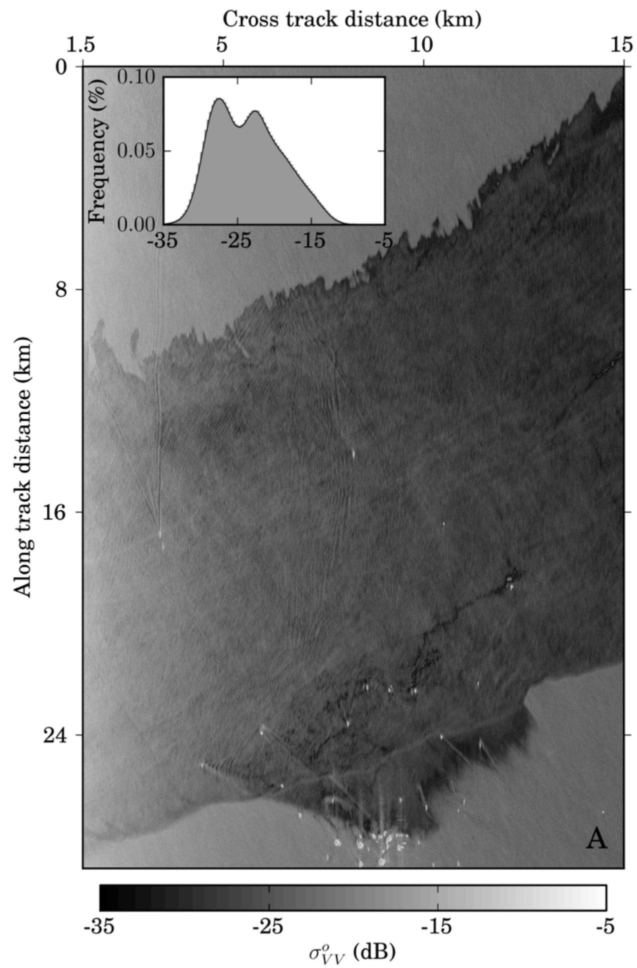
$$W = W(h_B, \ell_B, \psi, \zeta)$$

Meeting a need

- Need: Collect data on oil properties
- Assume: Binary oil/water classification is a solved problem
- Goal: Distinguish mixed oil from thin films
- Connect radar-derived characteristics with standard optical classification systems

Inferring oil properties

- Step 0: Mask relatively clean water

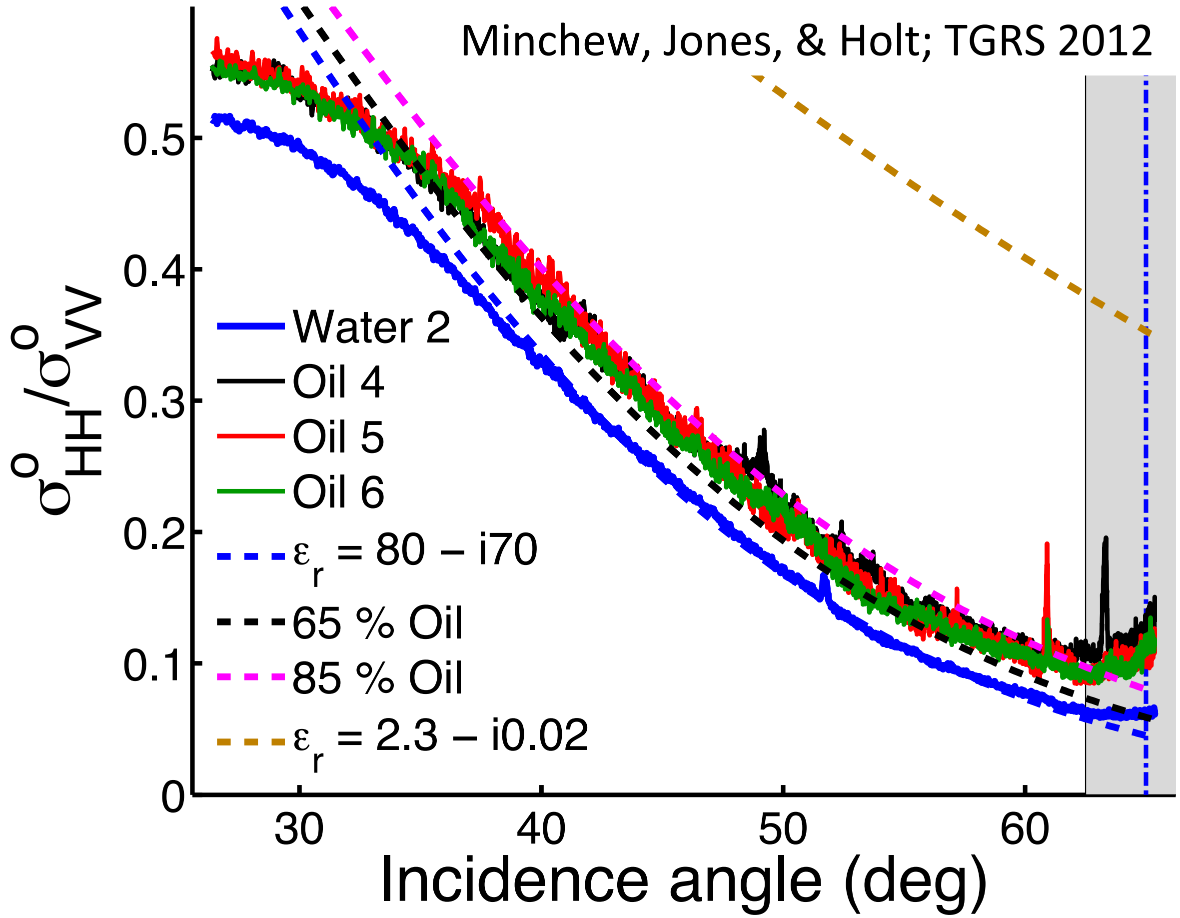


Inferring oil properties

- Step 1: Estimate surface slope (long wavelength)

$$\frac{\sigma^o_{HH}}{\sigma^o_{VV}} = \frac{\Gamma_{HH}}{\Gamma_{VV}}$$

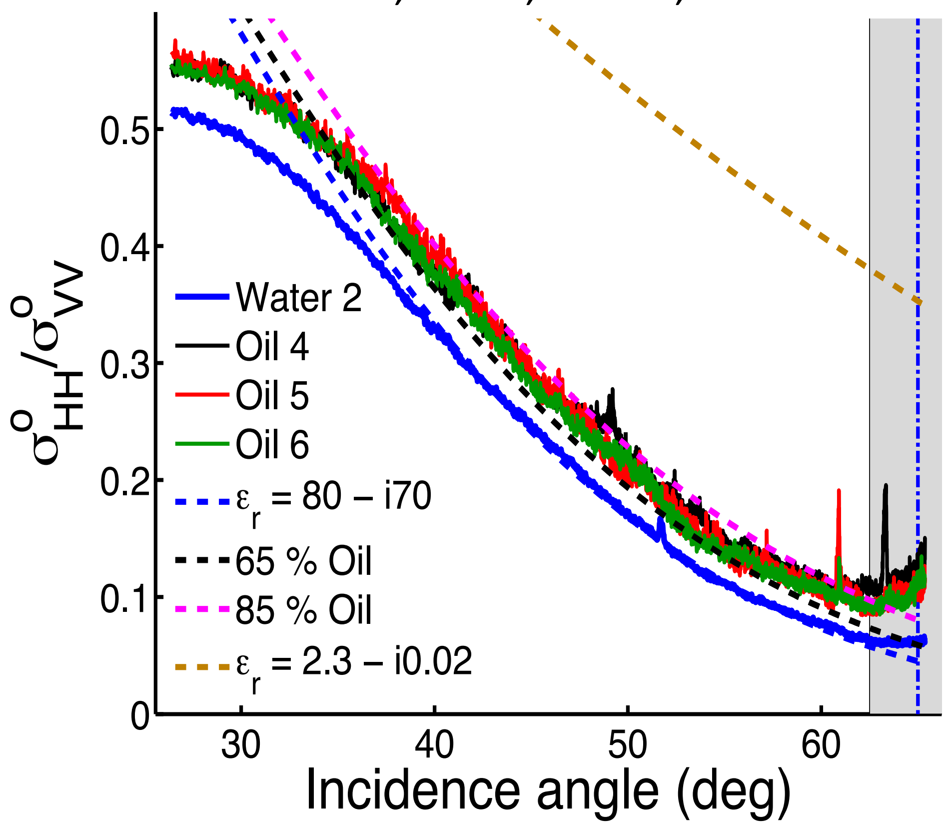
$$\Gamma_{pp} = \Gamma_{pp}(\varepsilon_r, \psi, \zeta)$$



Inferring oil properties

- Step 2: Find oil weighting factor

Minchew, Jones, & Holt; TGRS 2012



$$\frac{\sigma^o_{HH}}{\sigma^o_{VV}} = \frac{\Gamma_{HH}}{\Gamma_{VV}}$$

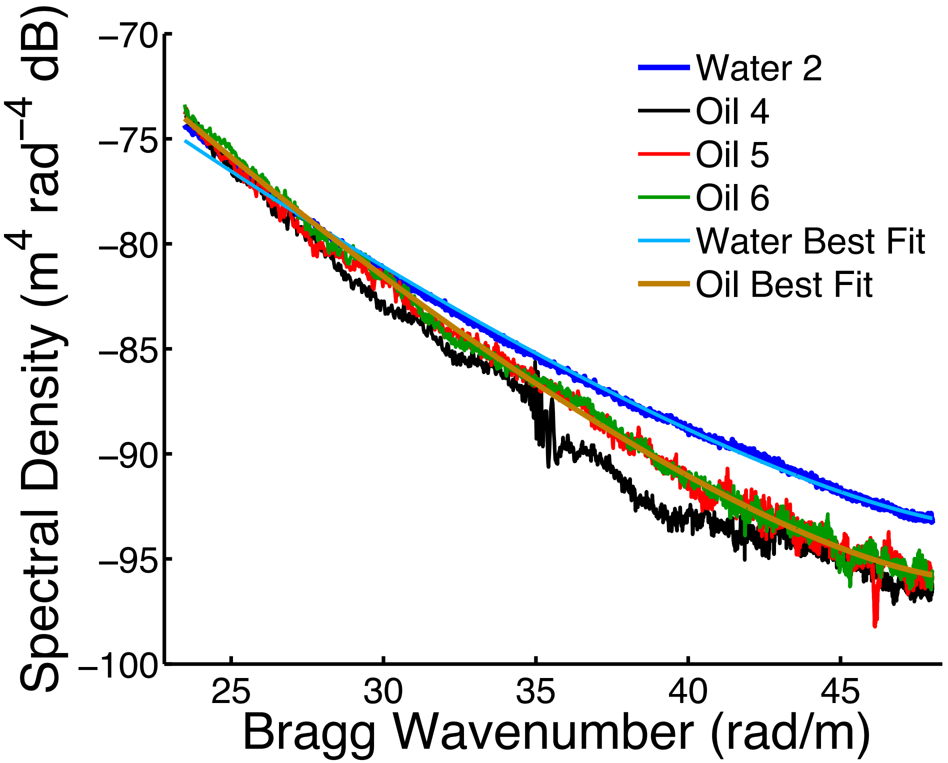
$$\Gamma_{pp} = \Gamma_{pp}(\varepsilon_r, \psi, \zeta)$$

$$\varepsilon_r = w_o \varepsilon_r^{oil} + (1 - w_o)\varepsilon_r^{water}$$

Inferring oil properties

- Step 3: Calculate roughness spectrum

$$W = \frac{\sigma^o_{VV}}{(4\pi k_r^4 \cos^4\theta_i)\,\Gamma_{VV}}$$



Minchew, Jones, & Holt; TGRS 2012

Inferring oil properties

- Step 4: Oil/water mixing index

$$M = \frac{1}{\sigma_{VV}^{o(water)}}\left[\frac{\partial \sigma_{VV}^{o}}{\partial W}\Delta W - \frac{\partial \sigma_{VV}^{o}}{\partial \Gamma_{VV}}\Delta \Gamma_{VV}\right]$$

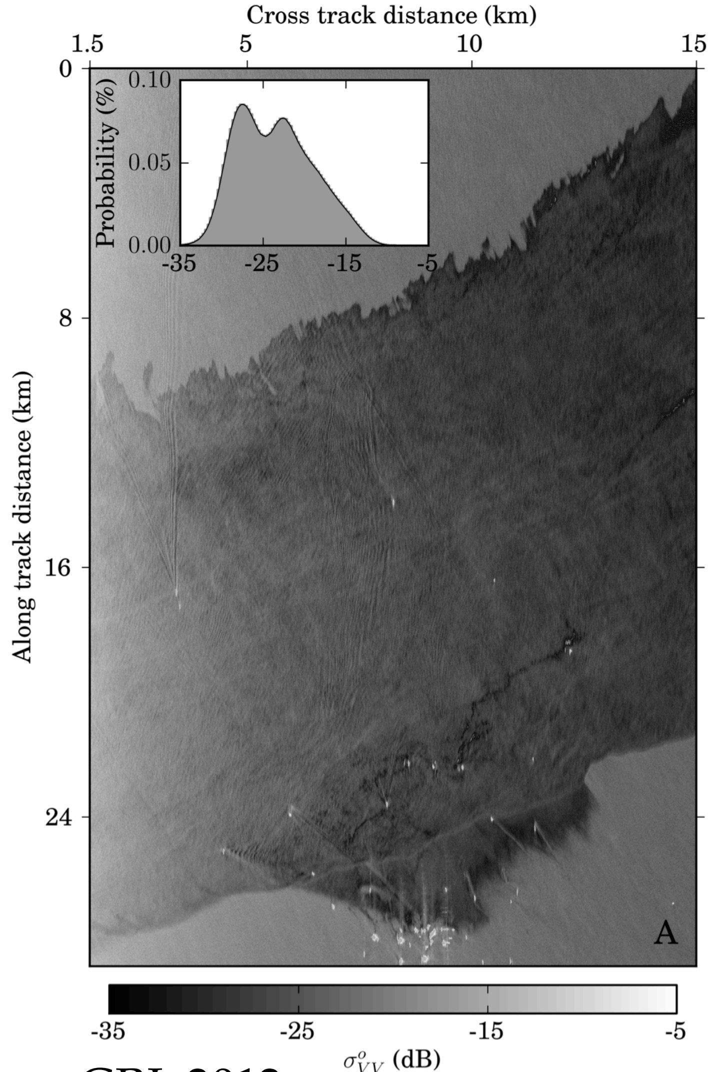
$$\approx \frac{W^{water} - W^{oil}}{W^{water}} - \frac{\left|\alpha_{VV}^{water}\right|^2 - \left|\alpha_{VV}^{oil}\right|^2}{\left|\alpha_{VV}^{water}\right|^2}$$

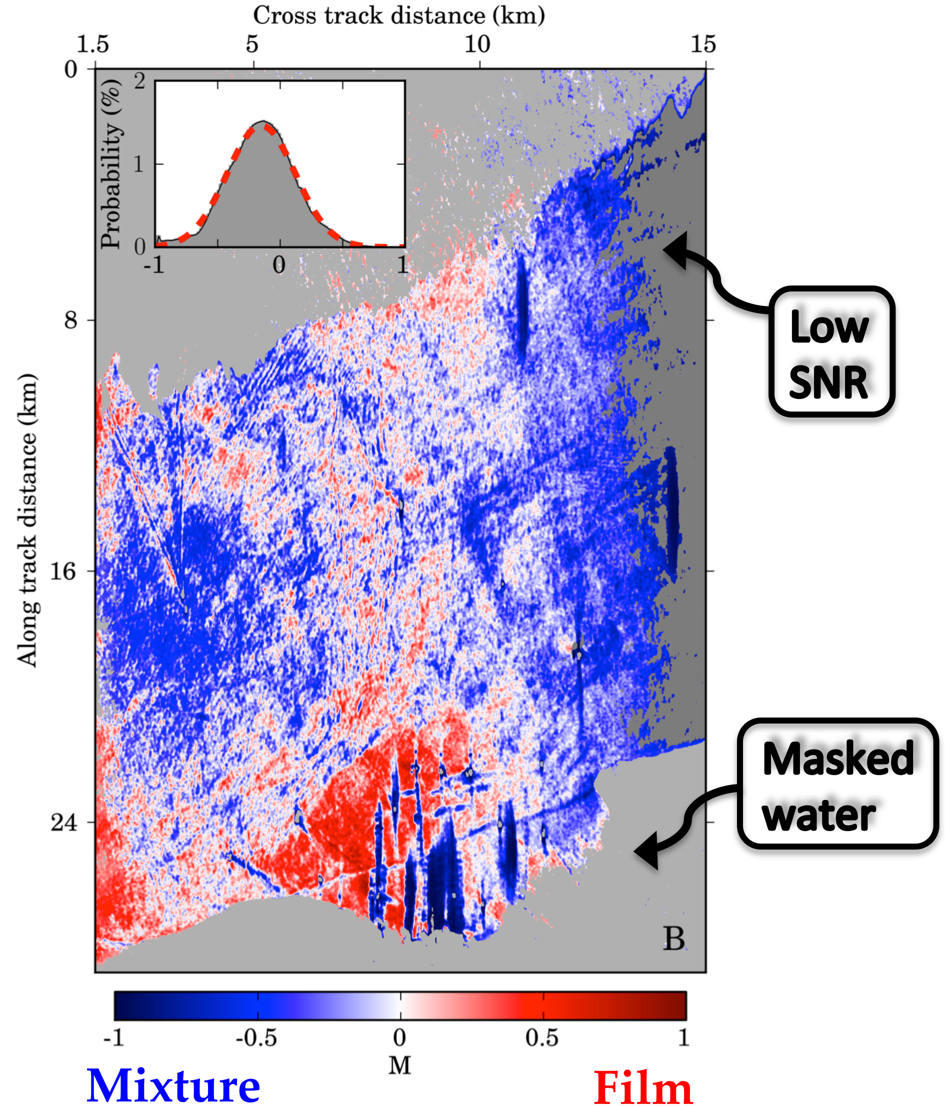
fully mixed $-1 \leq M \leq 1$ thin film

$$\alpha_{VV} = \frac{(\varepsilon_r - 1)\left\{\sin^2\theta_i - \varepsilon_r\left[1 + \sin^2\theta_i\right]\right\}}{\left(\varepsilon_r\cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}\right)^2}$$

Minchew, GRL 2012

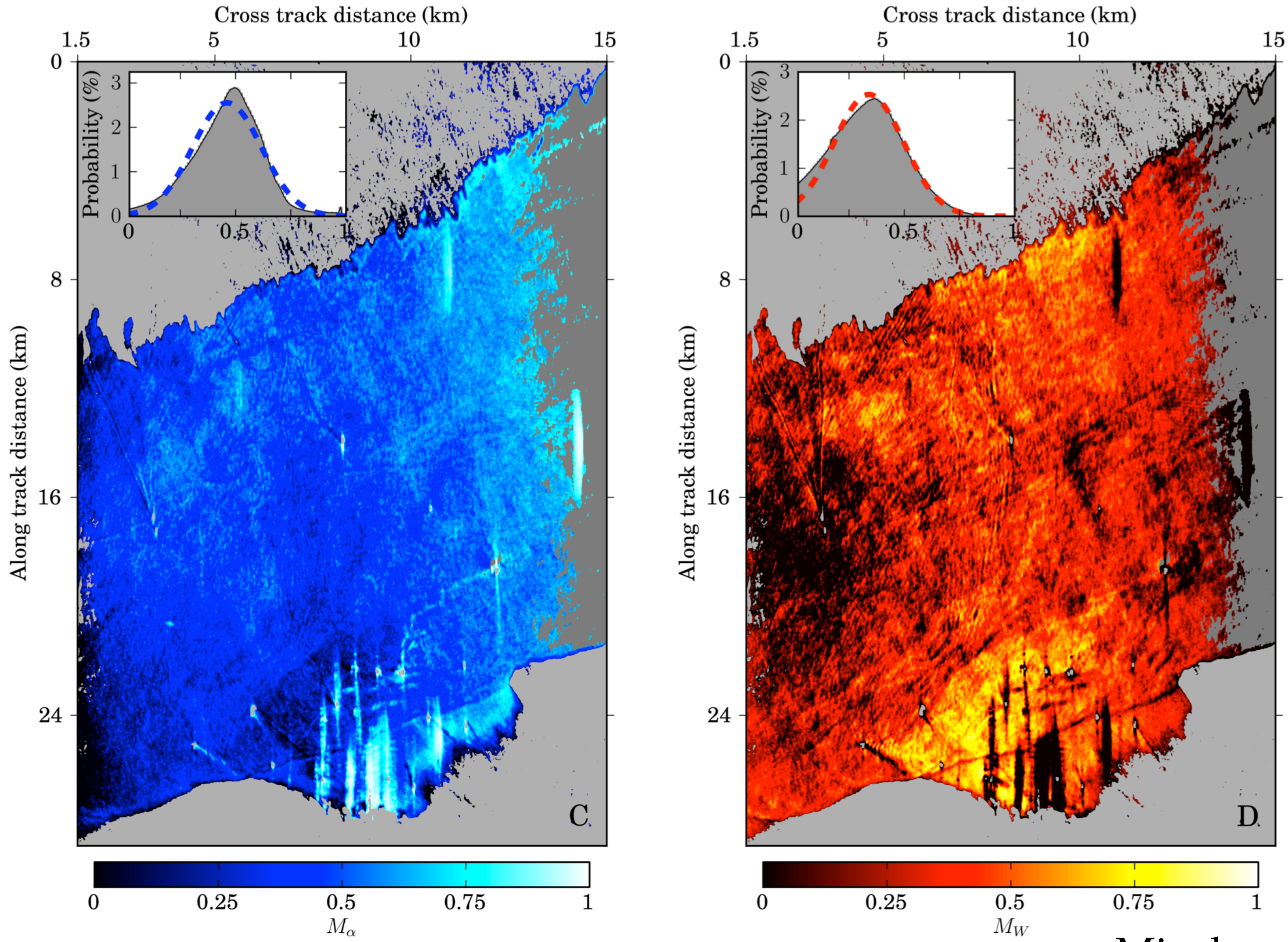
Results





Minchew, GRL 2012

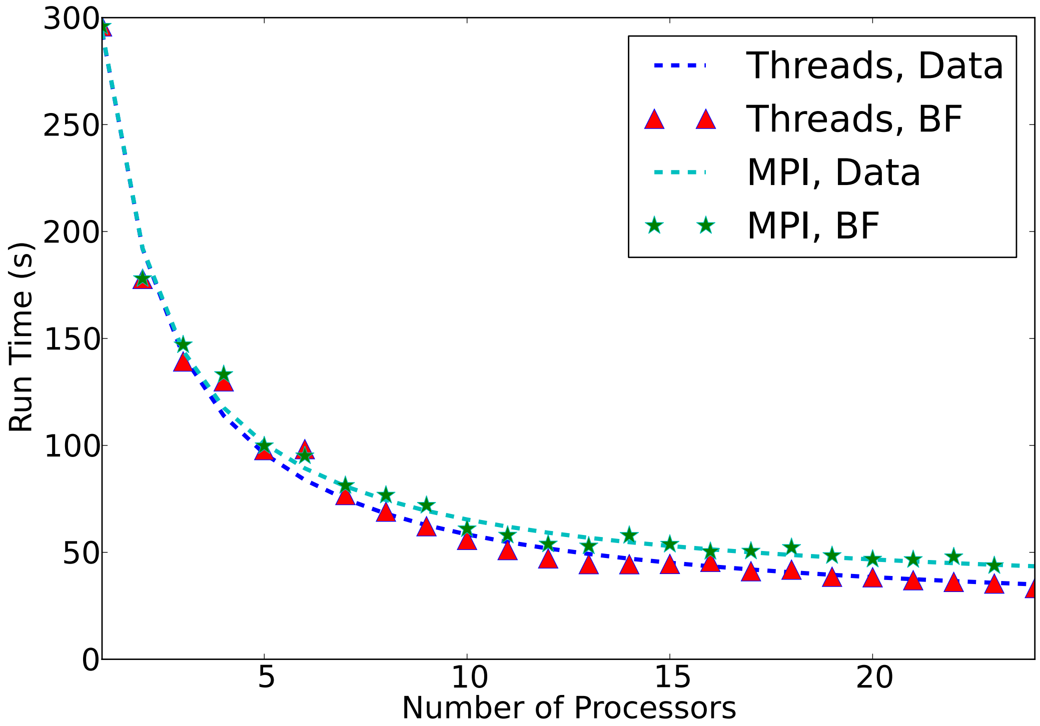
Results



Minchew, GRL 2012

Implementation

- Mdex: software suite implemented in C++ with Python bindings (Minchew)
- 'Hybrid' parallelization
  - Distributed memory: OpenMPI
  - Shared memory: POSIX threads
- Standard libraries
- Some human interface



Readiness

- Beyond binary
- PolSAR → oil properties
- Existing classification system
- Can be done in near real-time

Questions?

Thanks: Cathleen Jones, Ben Holt, and the entire UAVSAR team
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