Oil Slick Characterization
Using Synthetic Aperture Radar

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Effective response to oil spills requires specific information about the slick’s characteristics:

Key Parameters:
- Oil spill position
- Slick type / origin
- Spill extent
- Spill thickness & volume
- Oil-to-water emulsion ratios
- Transport
- Weathering
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)
\[ \epsilon_{SW} = 80 - i70 \]
- Frequency, temperature dependent

Ocean Surface + Thin Sheen
\[ \epsilon_{SW+Sheen} \approx 80 - i70 \]
- Reduced roughness
- Sheen too thin to change \( \epsilon_{sw} \)

Emulsion = Mixture of Oil + Sea water
\[ \epsilon_{Mixture} = \epsilon_{SW} + \epsilon_O \]
- New dielectric layer with \( \epsilon \) mixture
- Alters scattering

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

Day 2, controlled experiment for radar remote sensing

- Controlled releases of emulsions with a range of oil fractions
- 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: Norwegian Spill Experiment (Day 2. 10 June 2015)

<table>
<thead>
<tr>
<th>Release</th>
<th>Time (UTC)</th>
<th>Substance</th>
<th>Volume</th>
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</thead>
<tbody>
<tr>
<td>P</td>
<td>04.48</td>
<td>Plant oil: Radiagreen ebo</td>
<td>0.2 m³</td>
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<tr>
<td>E40</td>
<td>04.59</td>
<td>Emulsion (40% oil): 300 L water + 100 L Troll + 100 L Oseberg + 0.2 L One-Mul</td>
<td>0.5 m³</td>
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<tr>
<td>E60</td>
<td>05.15</td>
<td>Emulsion (60% oil): 200 L water + 150 L Troll + 150 L Oseberg + 0.2 L One-Mul</td>
<td>0.5 m³</td>
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<tr>
<td>E80</td>
<td>05.30</td>
<td>Emulsion (80% oil): 100 L water + 200 L Troll + 200 L Oseberg + 0.2 L One-Mul</td>
<td>0.5 m³</td>
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</tbody>
</table>

Mineral oil: 3 barrels each

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Time (UTC)</th>
<th>Mode</th>
<th>Freq. band</th>
<th>Polarization</th>
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<tbody>
<tr>
<td>UAVSAR (16 scenes)</td>
<td>05.32-08.53</td>
<td>PolSAR</td>
<td>L-band</td>
<td>Quad-pol.</td>
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<tr>
<td>TSX</td>
<td>06.24</td>
<td>SM</td>
<td>X-band</td>
<td>Dual-pol. (HH, VV)</td>
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<td>RS2</td>
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<td>WFQ</td>
<td>C-band</td>
<td>Quad-pol.</td>
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<td>RISAT-1</td>
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<td>FRS</td>
<td>C-band</td>
<td>Compact pol. (RH, RV)</td>
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<tr>
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<td>PolSAR</td>
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<td>ALOS-2</td>
<td>23.53</td>
<td>HS</td>
<td>L-band</td>
<td>Single-pol. (VV)</td>
</tr>
</tbody>
</table>

UAVSAR: Repeated imaging of released slicks for ~8 hours following release
Satellite / Airborne SAR Comparison – 2015 Norway

Wind speed ca. 9 - 12 m/s

Best contrast in
1. UAVSAR
2. TSX
3. RS2

Different from low wind conditions

Wind speed ca. 1.6 - 3.3 m/s

Slick / Clean Water Variation in Intensity with Frequency

400 pixel average profile:

TSX-VV

RS2-VV

uav-VV

Wind speed ca. 9 - 12 m/s

Slick / Clean Water Single-Pixel Variability

Wind speed ca. 9 - 11 m/s

Drifters:
2 iSphere (wind drift)
2 Self Locating Datum Marker Buoy (submerged)

Released with plant oil & 80/20 emulsion
5 & 5:30 AM, 10 Jun 2015
Slick Development

5:46 AM UTC

6:52 AM UTC

7:44 AM UTC

8:53 AM UTC

11:45 AM UTC

13:18 PM UTC

Intensity-VV_{oil}  
Intensity-VV_{water}
NORSE2015: Norwegian Spill Experiment (Day 3. 11 June 2015)

Release of 16 m$^3$ of emulsion into a boom

Unrecovered Oil Plume:

Photo: Øyvind Breivik (Met).
Summary

Low-noise SAR:

- Characterize oil within a spill
- Use radar backscatter and temporal development of the slicks
- Qualitatively relate to volumetric fraction of oil for a thick layer
- Relate intensity to zones with more oil coverage
- Infer thickness from oil fraction for emulsions
- Infer % coverage and zoning from polarimetric or radiometric parameters
- Quantify separability of slicks from clean water and different types of slicks from each other