Remote sensing of film slicks with co-polarized X-C-S-band scatterometer and TerraSAR-X

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Problem and Motivation

A modern approach to the problem of microwave radar backscattering is based on Phillips (1988): radar return = Bragg backscattering + non Bragg (non polarized) scattering due to wave breaking.

This study is focused on

- analysis of experiments with artificial slicks (calibrated films), in particular

Analysis of reduction of Bragg and non Bragg components of radar return in slicks

- studying physical mechanism of reduction of radar return due to film
Satellite/boat experiments on the Gorky Water Reservoir

- X-/C-/S-band dual-pol radar
- Research vessel
- Trimaran Research Laboratory of IAP RAS
### Satellite/boat dual-polarized radar experiments with slicks

<table>
<thead>
<tr>
<th>Date, sensor</th>
<th>Inc. angle</th>
<th>Wind velocity, dir.</th>
<th>Azimuth angle (kV)</th>
<th>Bragg wavenumber $k_{\text{Bragg}}$, rad/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.08.2014, TerraSAR-X</td>
<td>37°</td>
<td>7 m/s, NW</td>
<td>(kV)≈40° (40° from downwind)</td>
<td>2.43</td>
</tr>
<tr>
<td>03.08.2015, TerraSAR-X</td>
<td>32.5°</td>
<td>5 m/s, W</td>
<td>(kV)≈180° (upwind)</td>
<td>2.17</td>
</tr>
<tr>
<td>22 07.2016, 3-band radar, 1st transect</td>
<td>60°</td>
<td>7 m/s, E</td>
<td>(kV)≈80°</td>
<td>1.01, 2.17, 3.63</td>
</tr>
<tr>
<td>22 07.2016, 3-band radar, 2nd transect</td>
<td>60°</td>
<td>7 m/s, E</td>
<td>(kV)≈40°</td>
<td>1.01, 2.17, 3.63</td>
</tr>
<tr>
<td>22 07.2016, 3-band radar, 3rd transect</td>
<td>60°</td>
<td>7 m/s, E</td>
<td>(kV)≈180°</td>
<td>1.01, 2.17, 3.63</td>
</tr>
</tbody>
</table>
Bragg and non Bragg (non polarized) radar return

\[
\sigma_{pp}^0 = \sigma_{BC_{pp}} + \sigma_{NBC}
\]

\[
\sigma_{BC_{pp}}^0 = 16\pi k_{em}^4 R_{pp}(\theta) F(k_B)
\]

\[
\sigma_{PD} = \sigma_{VV}^0 - \sigma_{HH}^0 = \sigma_{BC_{VV}}^0 - \sigma_{BC_{HH}}^0 = (R_{VV} - R_{HH}) F(k_B)
\]

\[
\sigma_{NBC} = \sigma_{VV}^0 - (\sigma_{VV}^0 - \sigma_{HH}^0)/(1 - R_{HH}/R_{VV})
\]

\[
K_{BC} \text{(crosswind)} \approx \gamma_s/\gamma_0 = \frac{1 - x + xy}{1 - 2x + 2x^2}
\]

\[
x = \frac{E k^2}{\rho(2v)^{1/2} \omega^{3/2}} \quad \quad \quad y = \frac{E k}{4 \rho v \omega}
\]

\[
\gamma_s, \gamma_0 \quad \text{wave damping coefficients in slick (s) and nonslick (0)}
\]

Bragg contrast

\[
K_{BC} = K_{PD} = \frac{\sigma_{PD_{nonslick}}}{\sigma_{PD_{slick}}}
\]

Non Bragg contrast

\[
K_{NBC} = \frac{\sigma_{NBC_{nonslick}}}{\sigma_{NBC_{slick}}}
\]

E- film elasticity
Characteristics of surfactant films

Surface tension and Elasticity of OLE film at several wave frequencies as functions of surfactant concentration

Artificial slicks: films of oleic acid (OLE)

OLE film: saturation range
Surface tension $\approx 32\text{mN/m}$
Elasticity $\approx 22-40 \text{mN/m}$
TerraSAR-X satellite experiment of 31.08.2014

- Radar look
- Wind
- OLE slick
- VV
- HH
TerraSAR-X experiment of 31.08.2014

TerraSAR-X NRCS at VV and HH pols with the noise floor deducted (black and red dashed curves);
Contrasts BC (black) and NBC (red);
Contrast ratio KBC/KNBC of radar backscatter
A fragment of VV polarized TerraSAR-X image for the experiment of 03.08.2015.
TerraSAR-X experiment of 03.08.2015

NRCS VV and HH, dB

BC and NBC contrasts

BC contrast / NBC contrast

Distance, m

Distance, m

Distance, m
X-/C-/S scat slick measurements

Radar backscatter at VV and HH polarizations (in arbitrary but the same units). Contrasts for BC, NBC and ratio of BC/NBC contrasts, transect 1. Black curve - S-band, red C-band, blue X-band.
Bragg and NBC contrast in slick

BC and NBC contrasts vs. Bragg wave number for OLE slicks: 3 band radar (● - BC, ▼ - NBC) and with TerraSAR-X (■ - BC, □ - NBC). Curves – theory for BC-contrasts at elasticity 20 mN/m (black), 30 mN/m (red), and 40 mN/m (blue). Radarsat data (Hansen et al., 2016) for crude oil/emulsion (● - BC and ▼ - NBC)
Laboratory experiments. Strong wave breaking in the presence of film

Strong breaking of m-scale waves in a wave tank

Frequency modulated packet of surface waves, focused at a given distance
Surface film mixing due to strong wave breaking. Wave tank experiment.

Theory: film concentration achieves a maximum and the surface tension - minimum at wave crests!

Experiment: for strongly breaking waves the surface tension increases and film concentration drops at wave crests! Film is destroyed.

\[
\frac{\Gamma}{\Gamma_0} = \left[1 - \frac{U(x - Ct)}{C}\right]^{-1}
\]
Laboratory experiments. Micro wave breaking in the presence of film

10 cm wavelength

Bulge/toe
Parasitic ripples

No film

Film

20 cm wavelength

bulge/toe

Author | ESRIN | 18/10/2016 | Slide 15
Summary

Organic slicks of oleic acid on the water surface were observed using dual-pol TerraSAR-X and an X-/C-/S-band microwave radar, and reduction of Bragg and non-Bragg components of radar return was studied.

The Bragg scattering component is reduced in slicks due to enhanced viscous damping of resonant Bragg cm-scale waves by film. The Bragg contrasts are highest for an upwind look direction and grow with wave number. The contrasts for downwind directions grow with wave number, too, but are smaller than for the upwind case. For cross wind observations the Bragg contrast values are comparable with up- and downwind contrasts, but slowly decrease with wave number.

The non Bragg component is significantly reduced in slicks. The effect of reduction of NBC in slicks can hardly be explained by strong wave breaking since wave crest overturning can destroy film. The action of film on micro breaking of cm-dm-scale wind waves and modification of micro breaking features - parasitic ripples, and toe/bulge structures can be mostly responsible for suppression of NBC in slicks.
Thank you for your attention.

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