Field experiments on SAR detection of film slicks

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Motivation

Better understanding of possibilities to use SAR for detection and characterization of surface films (including oil spills) on the sea surface.

Previous experiments:


New experiments:
SAR contrasts in a wide range of wind velocities, comparison with simultaneous scatterometer measurements from a boat
IAP RAS experiments on slick remote sensing. GWR, 2011

X-, Ka- band scatterometers on board a research vessel

GWR: width 15 km, length 70 km, mean depth 10 m
Physical characteristics of artificial surfactant films

<table>
<thead>
<tr>
<th>Substance</th>
<th>Emk</th>
<th>VO</th>
<th>OLA</th>
<th>OLE</th>
<th>DA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface tension, mN/m</td>
<td>39</td>
<td>40</td>
<td>36</td>
<td>32</td>
<td>22</td>
</tr>
<tr>
<td>Elasticity, mN/m</td>
<td>2-5</td>
<td>12</td>
<td>15</td>
<td>22</td>
<td>70</td>
</tr>
</tbody>
</table>
Terra SAR-X, 26/06/2009

Slicks of OLE and DA. Inc. angle 36°. Wind velocity 3 m/s, N.(350 deg)
Incidence angle 22.5°. Wind 4.5m/s, 270°
TS-X 16.08.2011. 14.44 UTC  inc.angle 36-39°  Bragg wavenumber k~2.5 rad/cm, Wind 5-6 m/s, East. Boat dir West-East, and East-West
Experiments with slicks on the Gorky Water Reservoir, 2011

TS-X 17.08.2012, 03.40 UTC, inc. angle 20-23°, Bragg wavelength ~4 cm, k~1.57 rad/cm
Experiments with slicks on the Gorky Water Reservoir, 2011

TS-X 22.08.2012, 14.35 UTC inc. angle 22-25°, Bragg wavelength ~3.8 cm  k~1.63 rad/cm
### Contrasts in experiments of 2011 on GWR

<table>
<thead>
<tr>
<th>Experiment</th>
<th>TS-X contrast</th>
<th>X-band scat contrast (inc. angle 60°)</th>
<th>Ka-band scat contrast (inc. angle 60°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/08/11, 14.44 UTC, Wind 5-6 m/s, East</td>
<td>3 (k</td>
<td></td>
<td>V), inc. angle~37°</td>
</tr>
<tr>
<td>17/08/11, 03.40 UTC, Wind 6-7 m/s, East</td>
<td>2 (k</td>
<td></td>
<td>V) inc. angle~21°</td>
</tr>
<tr>
<td>22/08/11, 14.35 UTC, Wind 6-8 m/s, North</td>
<td>4 (k⊥V) inc. angle~23°</td>
<td>7 (kV<del>155°) 6.2 (kV</del>155°)</td>
<td>4.4, 10.4 (kV<del>115°) 8.2 (kV</del>25°)</td>
</tr>
</tbody>
</table>

Wind velocity, m/s

Radar Contrast

- X-scatter, 2009, OLE
- X-scatter, 2011, OLE
- TS-X, 2009, OLE
- TS-X, 2011, OLE
- Envisat ASAR, OLE, BlackSea'08
- Composite Model, 35 deg
- Composite Model, 22 deg.
Composite model of radar cross section
(low-to-moderate inc. angles)

\[ \sigma_0 = \sigma_{0\text{Bragg}} + \sigma_{0\text{Specular}} \]

\[ \sigma_{0\text{Bragg}} = 16\pi k_{\text{radar}}^4 G(\theta) F(k_{\text{Bragg}} = 2k_{\text{radar}} \sin \theta, \varphi) \]

\[ \sigma_{0\text{specular}} = \frac{\pi R^2}{s_u s_c \cos^4 \theta} \exp\left(-\frac{\tan^2 \theta}{2s_{sp}^2}\right) \]

\( S_{u,c,sp} \) – mean square slopes of wind waves
(with \( k < 1/4 k_{\text{bragg}} \))

\[ K_{\text{radar}} = \frac{\sigma_{0\text{Bragg}} + \sigma_{0\text{Specular}}}{\sigma_{0\text{BraggSlick}} + \sigma_{0\text{SpecularSlick}}} \]
Models of wind wave damping and SAR contrast in slicks

\[ \frac{dN(k, x, t)}{dt} = \Pi_a + \beta(u_*, k)N - \gamma(E, \sigma, k)N + I_{nl}(N) \]

\[ N(k, x, t) = \rho F(k, x, t) \omega(k)/|k| \]

\( F \) – the wavenumber spectrum of wind waves

\( \beta \) - wind wave growth rate, \( \gamma \) - wave damping coefficient, \( \sigma \) - surface tension, \( E \) - film elasticity, \( u_* \) - friction velocity

A local balance model for the spectrum of wind waves (Pelinovsky, Donelan & Pierson, Ermakov et al.)

\[ I_{nl} = -\delta N^m \quad m=2 \]

Contrast \( K(k) = F_{nsl}(k)/F_{sl}(k) \) in the wavenumber spectrum of wind waves

\[ K(k) = \left[ \frac{\beta(u_{*nsl}, k) - \gamma(0, \sigma, k)}{\beta(u_{*sl}, k) - \gamma(E, \sigma, k)} \right]^n \]

\( \beta > \gamma \quad n=1; \quad \beta < \gamma \quad n=-1 \)

A non local model (Kudrjavtsev et al.)

\[ I_{nl} = -\delta N^m + I_{nl}^{sw}(k) \]

\[ I_{nl}^{sw}(k) = \frac{\omega}{k^5} c_b \int \int_{k'<k_{mb}} \beta(k', \varphi)k'^4 \cdot N(k')/\omega(k') \cdot dk'd\varphi \]
OLE films (E= 25 mN/m) strongly (>10 times) depresses the Bragg component, and weakly affects the specular component.

\[ \sigma_{0\text{BraggSlick}} \ll \sigma_{0\text{BraggNonslick}} \]

\[ \sigma_{0\text{specularSlick}} \approx \sigma_{0\text{specularNonslick}} \]

Wind wave damping = Radar Bragg Contrast vs. wavenumber of wind waves. \( K^* \) - max wavenumber for specular model.
On possibilities of film characterization

\[ K_{\text{radar}} = \frac{\sigma_{0,\text{Bragg}} + \sigma_{0,\text{Specular}}}{\sigma_{0,\text{BraggSlick}} + \sigma_{0,\text{SpecularSlick}}} \]

1. Low inc. angles (<20°): Specular>>Bragg
Contrast is almost insensitive to film elasticity
(at moderate wind >5 m/s)

2. Inc. angles ~ 25°: Specular≈Bragg
Contrast weakly depends on film elasticity

3. Inc. angles >25-30°: Specular<Bragg
- Bragg(Slick)<<Specular(Slick): contrast weakly depends on film elasticity
- BraggSlick>>SpecularSlick: contrast \( K = K(E) \), and \( E \) varied in some limited range can be estimated

\[ K_{\text{radar}} = \frac{\sigma_{0,\text{SpecularNonslick}}}{\sigma_{0,\text{SpecularSlick}}} \approx 1 \]

\[ K_{\text{radar}} = \frac{\sigma_{0,\text{Bragg}} + \sigma_{0,\text{Specular}}}{\sigma_{0,\text{SpecularSlick}}} \geq 2 \]

\[ K_{\text{radar}} = \frac{\sigma_{0,\text{Bragg}}}{\max\{\sigma_{0,\text{BraggSlick}}, \sigma_{0,\text{SpecularSlick}}\}} >> 1 \]
Summary

• SAR contrasts (inc. angles ~22-36 deg.) are smaller than scat-contrasts (inc. angles ~60 deg.)
• SAR contrasts for films with strongly different elasticity values (OLE, $E \approx 22 \text{ mN/m}$ and DA, $E \approx 70 \text{ mN/m}$) are close to each other.
• Rough estimates using a composite radar model (Bragg + Specular) at low-to-moderate angles are consistent with experimental SAR contrasts

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• SAR (at low-to-moderate inc. angles) can be used to detect slicks, but probably is not very effective for film characterization, since the contrasts weakly depend on film elasticity
• More experiments & data analysis are needed, however.
TerraSAR-X. 03.06.2012, inc. angle 22-25°, wind 8 m/s, VO-slick
Thank you
TerraSAR slick experiment of July 14, 2009

Wind vel 7:10 local time 2.5 – 3 m/s, 290-300 deg (NW) Inc angle 31.9 deg.
Model of wave damping in slicks

Hydrodynamic contrasts in the spectrum of wind waves. Local (thin curves) and non local (solid curves) models. Film elasticities 25, 12, 4 mN/m.

Radar contrasts in slicks – composite model. Film elasticity 25 mN/m.
Radar contrasts for OLA artificial slicks
a) wind 5m/s, $\theta=35^0$, b) wind 7 m/s, $\theta=31^0$.
«o»– SAR L-C-X-band (Gade et.al., 1998),
«x» - L-S-C-X-Ku-band scatterometer simultaneous with SAR (Gade et.al., 1998)