On dual co-polarized SAR measurements of the Ocean surface

Alexander Myasoedov, RSHU, Russia
Vladimir Kudryavtsev, RSHU/NIERSC, Russia
Bertrand Chapron, IFREMER/RSHU, France
Fabrice Collard, CLS, France
Johnny Johannessen, NERSC, Norway
Main Goal

To promote an **effective** and **simple** methodology using SAR polarized information to **interpret** and **quantitatively assess** role of different **scattering mechanisms** in surface manifestation of

- Oceanic currents
- Slicks
- Wind field features
Original VV and HH images

Quad-polarized RADARSAT-2 image over Mediterranean Coast (Begur/Spain)

Area: 40 km × 50 km
Res: 5m (in A)x10m (in R)

32.7° < θ < 35.7°

17:40, 18th Dec 2010

(a) VV

(b) HH

slicks

Wind field feature

Current signatures
Model: Scattering decomposition
Chapron et al., 1997; Quilfen et al., 1999; Kudryavtsev et al., 2003

To interpret the observed SAR features HH and VV NRCS are represented as a sum of polarized scattering associated with 2-scale Bragg and nonpolarized from breaking waves

\[ \sigma_{0}^{PP} = \sigma_{0}^{BB} + \sigma_{WB}^{PP} \]

- PR = HH/VV deviates from PR_Bragg
- This justifies that radar returns from breaking waves (WB) play an important role
- PR => 1, role of wave breaking is dominant
- PR => PR_Bragg, role of wave breaking is weak

wave breaking contribution to NRCS
at \( \theta = 30^\circ \)
\~ 30% for VV
\~ 60% for HH
(e.g. see air-born C-band Du-Pol obs. by Mouche et al. 2006)
It is well known that PR serves as an indicator of Bragg scattering.

In our case study, mean PR is

- 1.5 dB ... - 2 dB
(0.7 linear units)

at coastal area PR = - 2.5 dB
(0.55 linear units) close to 2-scale Bragg model predictions

PR => 1 in “bright” current signatures

OUTCOME:

PR = HH/VV significantly deviates from PR Bragg for analyzed images

This justifies that radar returns from breaking waves (WB) play an important role.
Features:

- **In slicks:**
  Bragg waves are killed,
  PR => 1

- **Wave-current interact.:**
  (i) WB enhanced
  PR => 1
  (ii) WB suppressed
  PR => PR_{Bragg}

- **Down-wind condition**
  WB do not scatter
  PR => PR_{Bragg}
Polarization Difference VV-HH

PD is mostly controlled by short wind waves around the Bragg wavenumber

In C-band these waves have “quick-response” to surface wind
(~10m relaxation scale)

\[
\Delta \sigma_0 = \sigma_{0B}^{vv} - \sigma_{0B}^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh} + \sigma_{wb}^{vv} - \sigma_{wb}^{hh}
\]

PD-image should reflect
- wind field variability
- presence of slicks

(air-born C-band Du-Pol obs. by Mouche et al. 2006)
**Polarization Difference**

\[ PD = \sigma_{vv}^B - \sigma_{hh}^B \]

**Features:**

- Slicks are dark PD formed by Bragg which are damped

- No Current signatures

- Local wind field features can be either caused by wind speed variations or/and by wind vector rotation to radar L-D

Wind field feature

Slicks

NO Current signatures

Wind Arome model

Radar LD
Non-polarized contribution from breaking waves (NP WB)

\[ PD = \sigma_{0B}^{vv} - \sigma_{0B}^{hh} \]

**PD** directly relates to short Bragg waves which are sensitive to wind field variability & oil slicks

"new" characteristic - NP

\[ \sigma_{wb} = \sigma_{0}^{vv} - \Delta \sigma_{0}^{vv} / (1 - p_B) \]

\[ p_B = \sigma_{0B}^{hh} / \sigma_{0B}^{vv} \]

**NP** – reflects **wave current interaction** through variations in wave breaking
Non-polarized contribution

Features:
- Slicks are not visible
- Current signatures are well visible
- Wind field feature is well expressed
Ocean surface features manifestations interpretation

**a** NO slicks visible

**b** NO current visible

**c** VV

**d** PR

**e** PD

**f** NP

**g** Wb

**h** Wb contribution [linear units]
Summary

Simple and an effective approach
Transformation of VV and HH into new images:

- Polarization Difference (PD) VV-HH
- Non-Polarized (NP Wb) contribution to NRCS

- wind field variability
- presence of slicks
- wave current interaction
- wind field variability

Detection and discrimination of various ocean phenomena, e.g.:
- surface ocean current features and discrimination from wind field variability
- Detection of oil slicks and discrimination from look-alikes (calm area and current features)
- Detection of large-scale variability in wind vector field.
Some References


Kudryavtsev et al.
On dual co-polarized SAR measurements of the Ocean surface.
IEEE GRSL. Accepted 26 Sep. 2012 (in press).
Scattering Decomposition:

\[ \sigma_{0}^{pp} = \sigma_{0B}^{pp} + \sigma_{wb} \]

where

\[ \sigma_{0B}^{pp} \] is 2-scale Bragg scattering

\[ \sigma_{wb} \] is non-polarized (NP) impact of breaking waves

Polarization Ratio (PR):

\[ P = \frac{\sigma_{0}^{hh}}{\sigma_{0}^{vv}} = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}} \]

Polarization Difference (PD):

\[ \Delta \sigma_{0} \equiv \sigma_{0}^{vv} - \sigma_{0}^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh} \]

NP contribution of breaking waves:

\[ \sigma_{wb} = \sigma_{0}^{vv} - \Delta \sigma_{0} \left/ \left(1 - p_{B}\right) \right. \]

where \[ p_{B} = \frac{\sigma_{0B}^{hh}}{\sigma_{0B}^{vv}} \] is PR for Bragg scattering
Ocean surface features manifestations

Features:

- Slicks are dark PD formed by Bragg which are damped
- No Current signatures
- Local wind field features can be either caused by wind speed variations or/and by wind vector rotation to radar L and D

In slicks:
- Bragg waves are killed, PR => 1
- Wave-current interact:
  (i) WB enhanced PR => 1
  (ii) WB suppressed PR => PR_Bragg
- Downwind condition WB do not scatter PR => PR_Bragg

- Slicks are not visible
- Current signatures are well visible
- Wind field feature is well expressed in wind speed variations
- Doppler surface velocity

Features:

- Doppler surface velocity [m/s]

Radial Surface Velocity [m/s]

-2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5

0.01 0.02 0.03

Wb contribution [linear units]

Features:

- Current signatures are well visible
- Wind field feature expressed
- Local wind field speed variations (i) WB enhanced PR => PR
- (ii) WB suppressed PR => PR_Bragg
- Wind field feature
- Local wind field speed variations
- Doppler surface velocity

Features:

- Doppler surface velocity

Radial Surface Velocity [m/s]

-2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5

0.01 0.02 0.03

Wb contribution [linear units]
Wind Field Features
Some C-band PR properties from Mouche et al. 2006.

In our case study, mean PR is:
- 1.5 dB ... 2 dB (0.7 linear units)

at coastal area
PR = -2.5 dB
(0.55 linear units)
close to 2-scale Bragg model

PR => 1 in “bright” current signatures

- PR = HH/VV significantly deviates from PR_Bragg for analyzed images, This justifies that radar returns from breaking waves (WB) play important role.
- When PR->1, role of wave breaking is dominant.
- and when role of wave breaking is weak, PR -> PR_Bragg
Polarization Difference VV-HH

PD is mostly controlled by short wind waves around the Bragg wavenumber. In C-band these waves have “quick-response” to surface wind (~10m relaxation scale). PD-image should reflect wind field variability and presence of slicks.

\[ \Delta \sigma_0 \equiv \sigma_{0v}^v - \sigma_{0h}^h = \sigma_{0Bv}^v - \sigma_{0Bh}^h \]
Non-polarized contribution from breaking waves (NP)

Bragg PR is a function of $\theta$ only and since PD reflects wind field variability the NP image should mainly reflect variations in wave breaking field associated with wave current interaction.

$$\sigma_{wb} = \sigma_{0}^{vv} - \Delta \sigma_{0} \left(1 - p_{B}\right),$$

where $p_{B} = \sigma_{0B}^{hh} / \sigma_{0B}^{vv}$ is PR for Bragg scattering.
Approach:
Surface is split into “regular” surface \((1-q)\) and zones of wave breaking \((q)\)

Total NRCS

2-scale Bragg

Quasi-specular reflection

Scattering from breaking waves

\[
\sigma_0^p = \sigma_{0R}^p (1 - q) + \sigma_{wb}^p q
\]

\[
\sigma_{br}^p (\theta) = \int_{1} \sigma_{0br}^p (\theta - \eta_i) P(\eta_i) d\eta_i
\]

\[
\sigma_{sp}^p (\theta) = \pi R^2 \sec^4 \theta \cdot P(\eta_i, \eta_i) \bigg|_{\eta_j = \tan \theta, \theta_i = 0}
\]

\[
\sigma_{wb} \propto \frac{\sec^4 \theta}{s_{wb}^2} \exp \left( - \frac{tg^2 \theta}{s_{wb}^2} \right) + \frac{\varepsilon_{wb}}{s_{wb}^2}
\]
Wave - Current Interaction:

\[ M \equiv B(k) / B(k) \propto \omega^{-1}(c / u_*)^2 m_{k} u_{i,j} \]

Integral Parameters governed by:

\[ M \propto \omega^{-1}(c / u_*)^2 m_{k} \nabla \cdot u \]

\[ s^2 \propto \int M k^2 B(k) dk \propto \nabla \cdot u \]

\[ q \propto \int M k^{-2} \beta B(k) dk \propto \nabla \cdot u \]

Bragg Waves modulations affected by WB

\[ B(k_{br}) \propto q \propto \nabla \cdot u \]

NRCS: \( \sigma_0^{PP} = \sigma_{BR}^{PP} (1 - q) + \sigma_{SP} q \)