On dual co-polarized SAR measurements of the Ocean surface

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SATELLITE OCEANOGRAPHY LABORATORY

POLinSAR 2013 Workshop

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

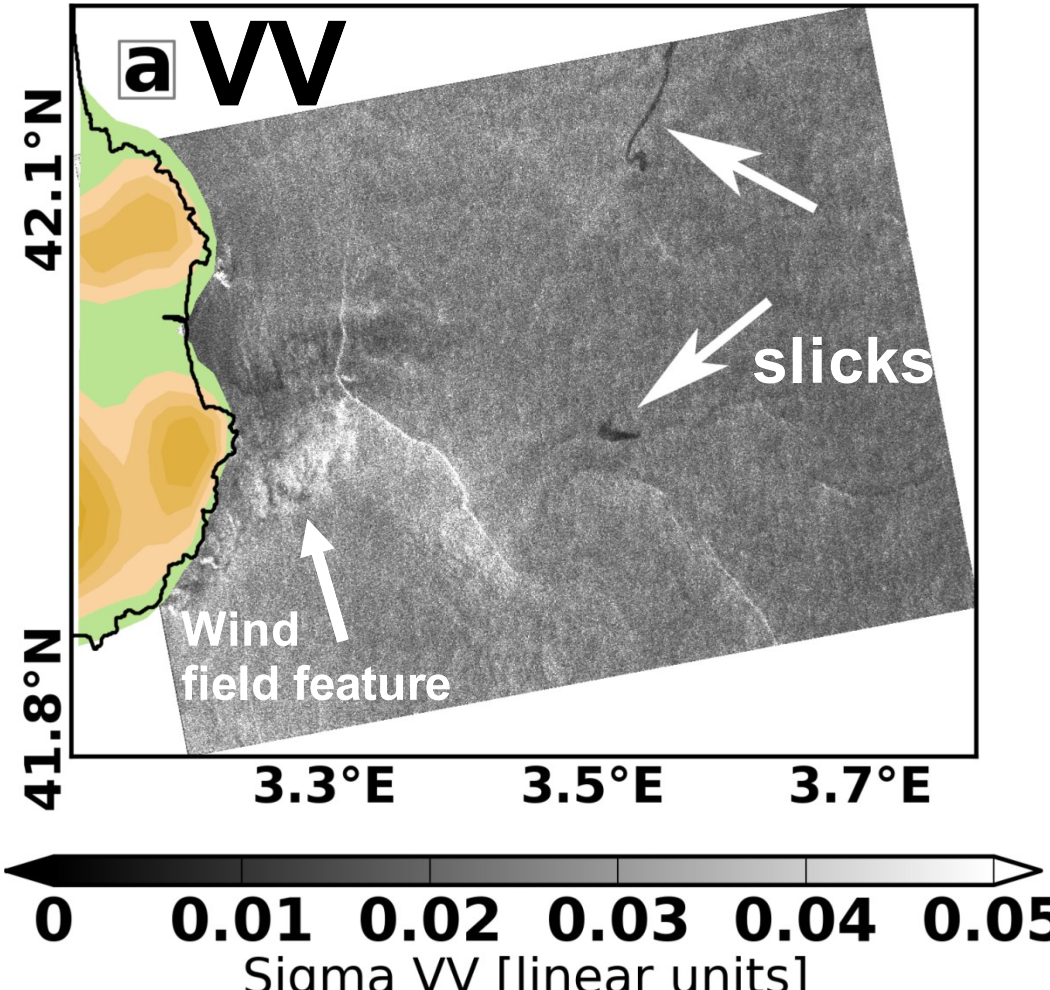
Quad-polarized RADARSAT-2 image over Mediterranean Coast (Begur/Spain)

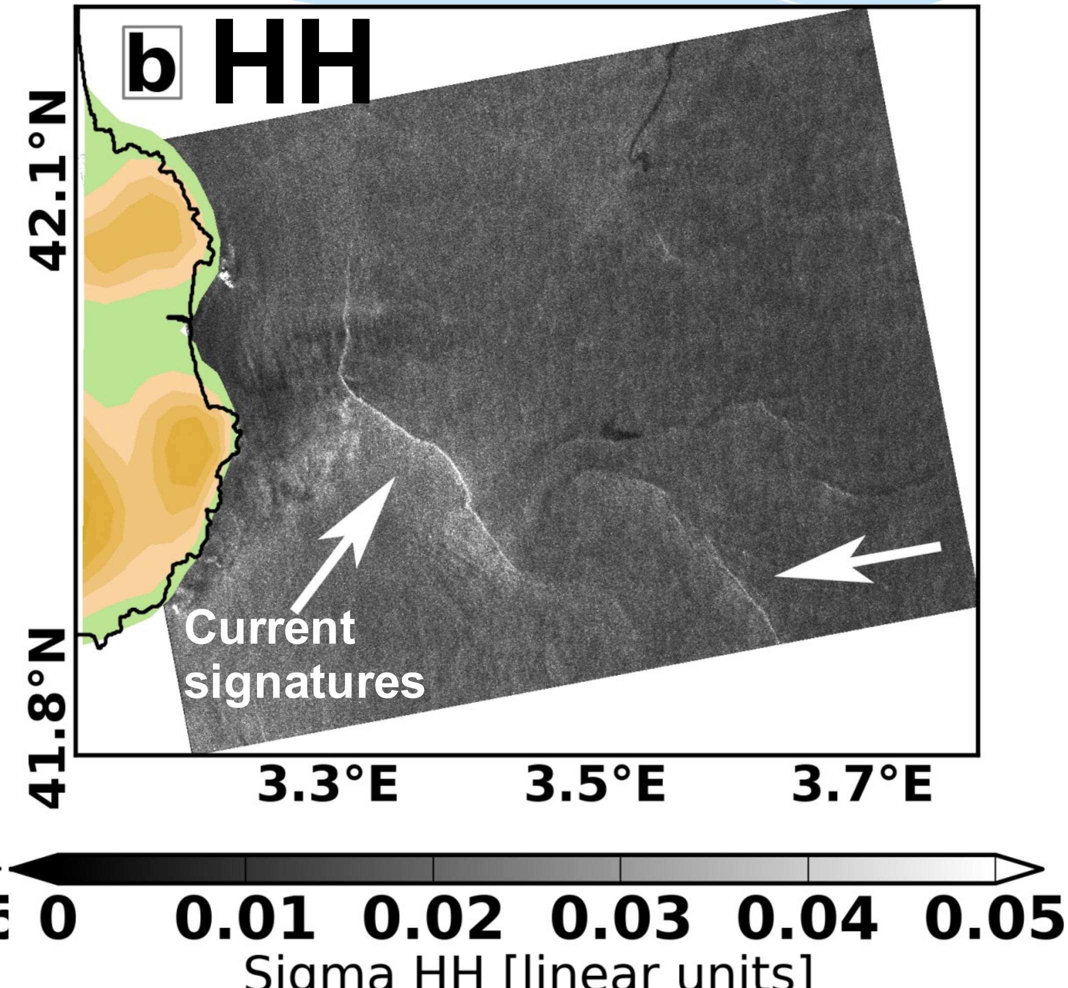
17:40, 18th Dec 2010

Area: 40 km × 50 km

Res: 5m (in A)x10m (in R)

32.7deg < θ < 35.7 deg





Model: Scattering decomposition

Chapron et al., 1997; Quilfen et., 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

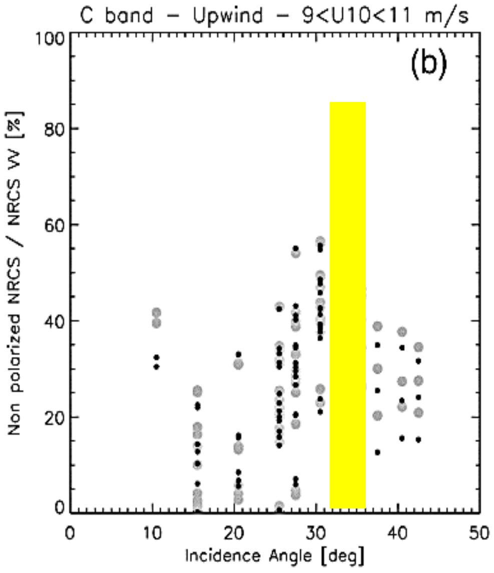
Scattering Model

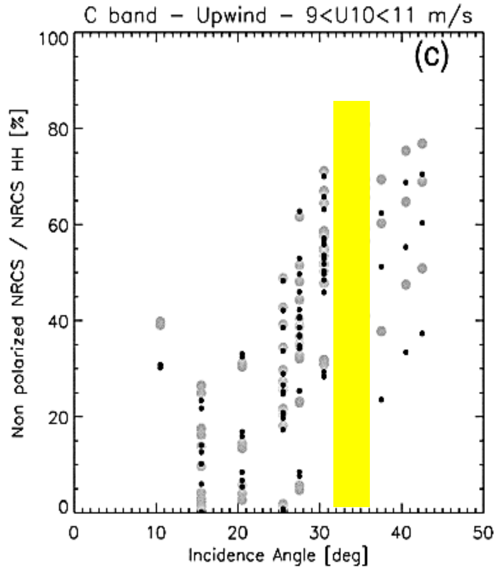
2-scale Bragg scattering | impact of breaking waves

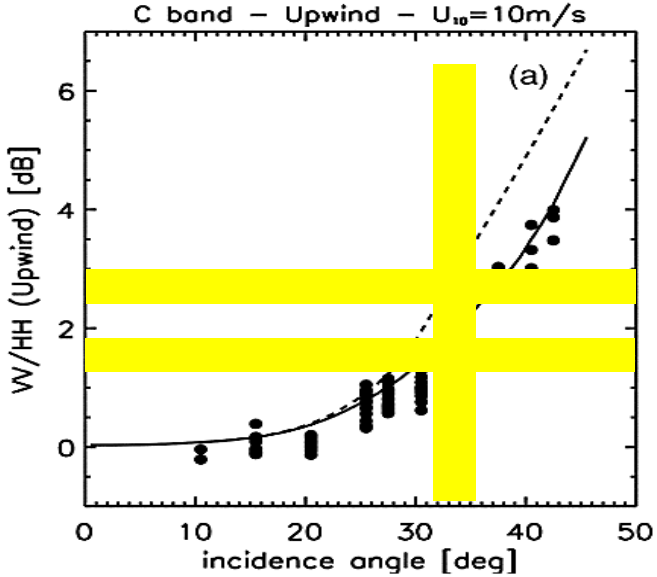
$$\sigma_0^{pp} = \sigma_{0B}^{pp} + \sigma_{wb}$$

Polarization Ratio

$$PR = \frac{\sigma_0^{hh}}{\sigma_0^{vv}} = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}}$$





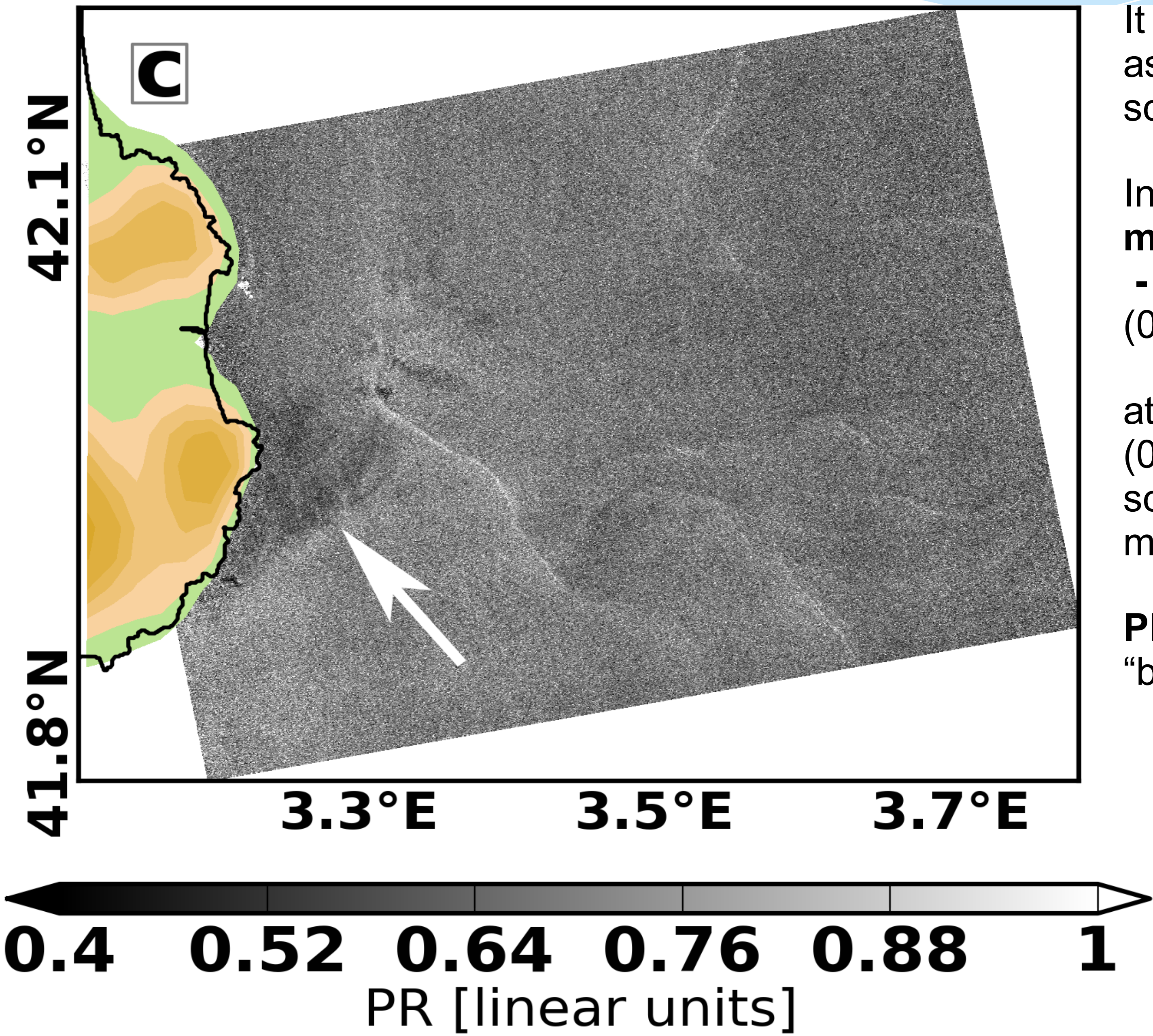


wave breaking contribution to NRCS at θ=30°
~ 30% for VV
~ 60% for HH
(e.g. see air-born C-band Du-Pol obs. by Mouche et al. 2006)

- 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

Polarization Ratio

$$\frac{\sigma_0^{hh}}{\sigma_0^{vv}} = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}}$$



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)

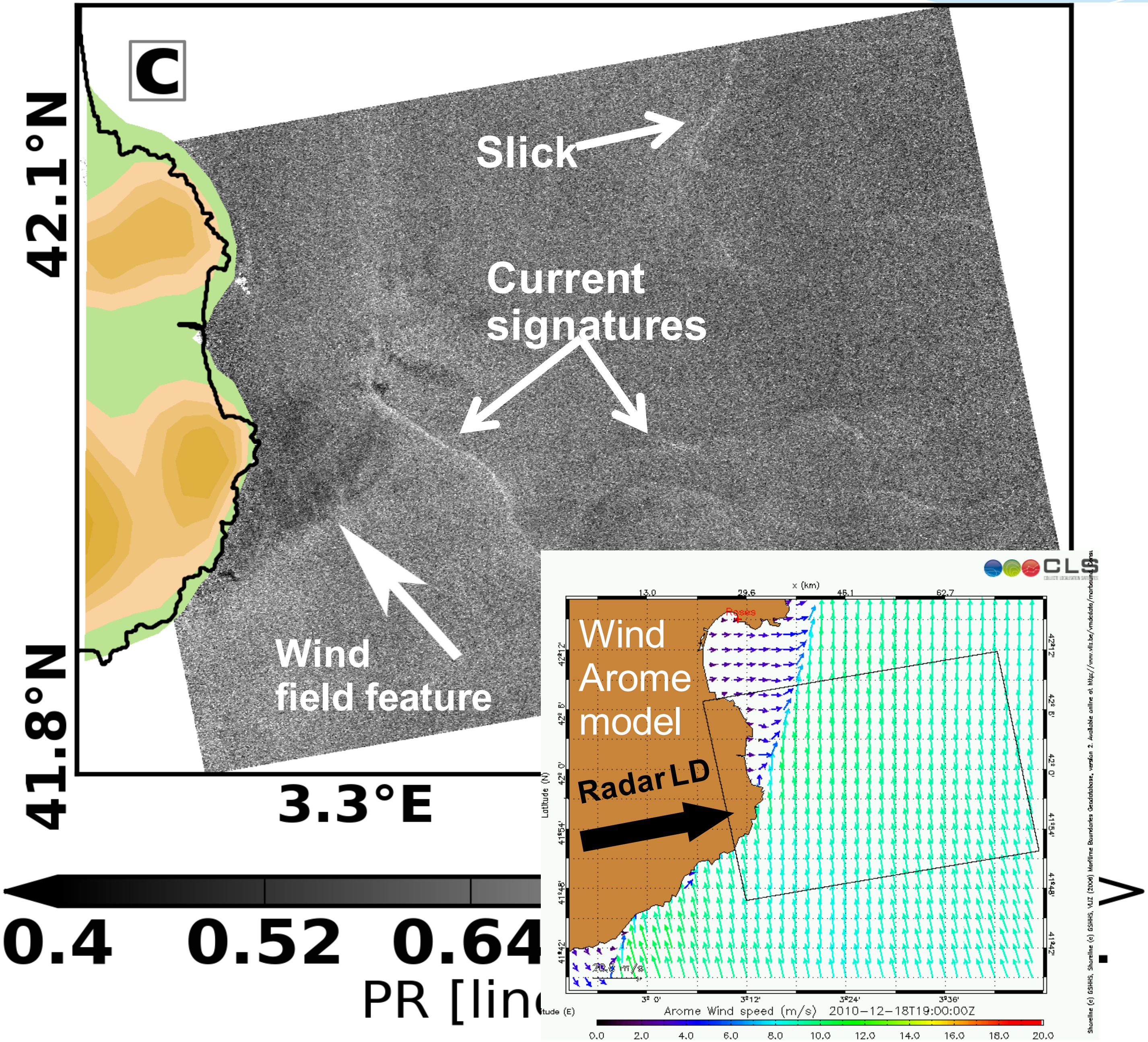
at coastal area **PR = - 2.5 dB** (0.55 linear units) close to 2-scale Bragg model predictions

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

Polarization Ratio

$$\frac{\sigma_0^{hh}}{\sigma_0^{vv}} = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}}$$



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)

$$\sigma_0^{pp} = \sigma_{0B}^{pp} + \sigma_{wb}$$

$$\sigma_0^{vv} = \sigma_{0B}^{vv} + \cancel{\sigma_{wb}}$$

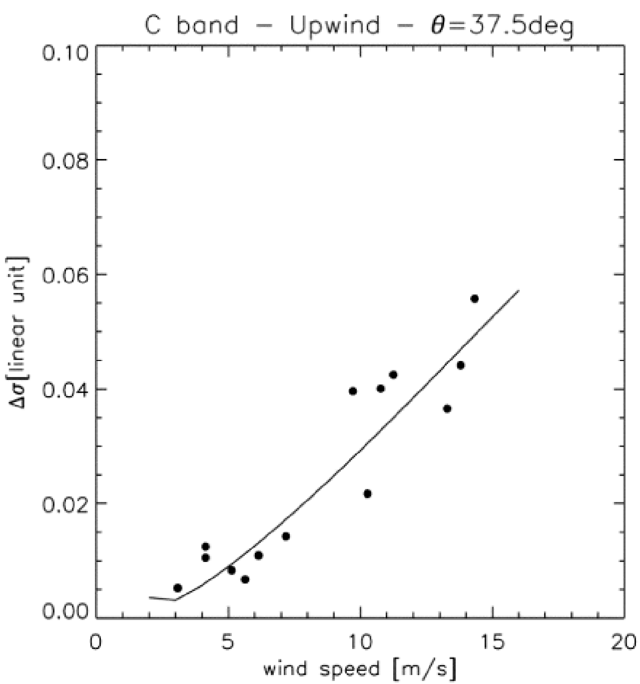
$$\Delta\sigma_0 = \sigma_0^{vv} - \sigma_0^{hh} = \left.\begin{array}{l} \sigma_0^{vv} = \sigma_{0B}^{vv} + \cancel{\sigma_{wb}} \\ - \\ \sigma_0^{hh} = \sigma_{0B}^{hh} + \cancel{\sigma_{wb}} \end{array}\right\} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}$$

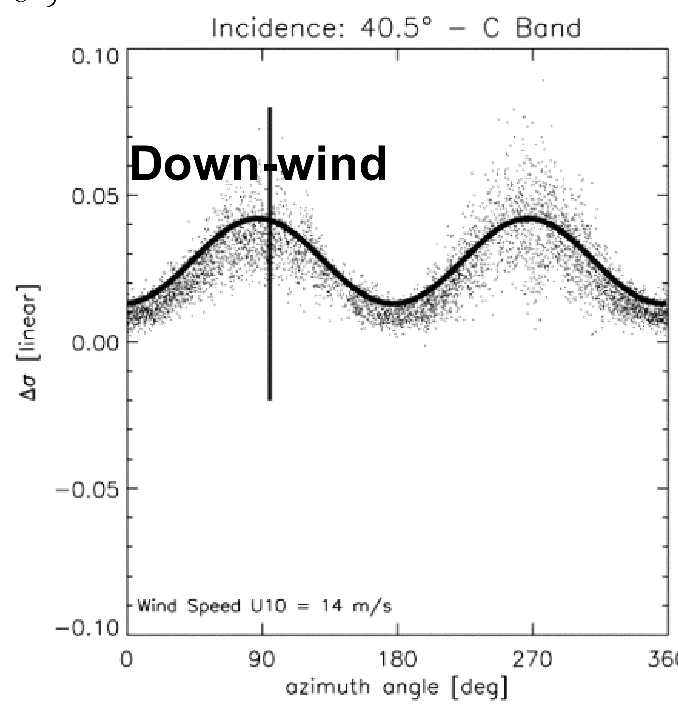
$$\sigma_0^{hh} = \sigma_{0B}^{hh} + \cancel{\sigma_{wb}}$$

PD-image should reflect

-wind field variability

-presence of slicks

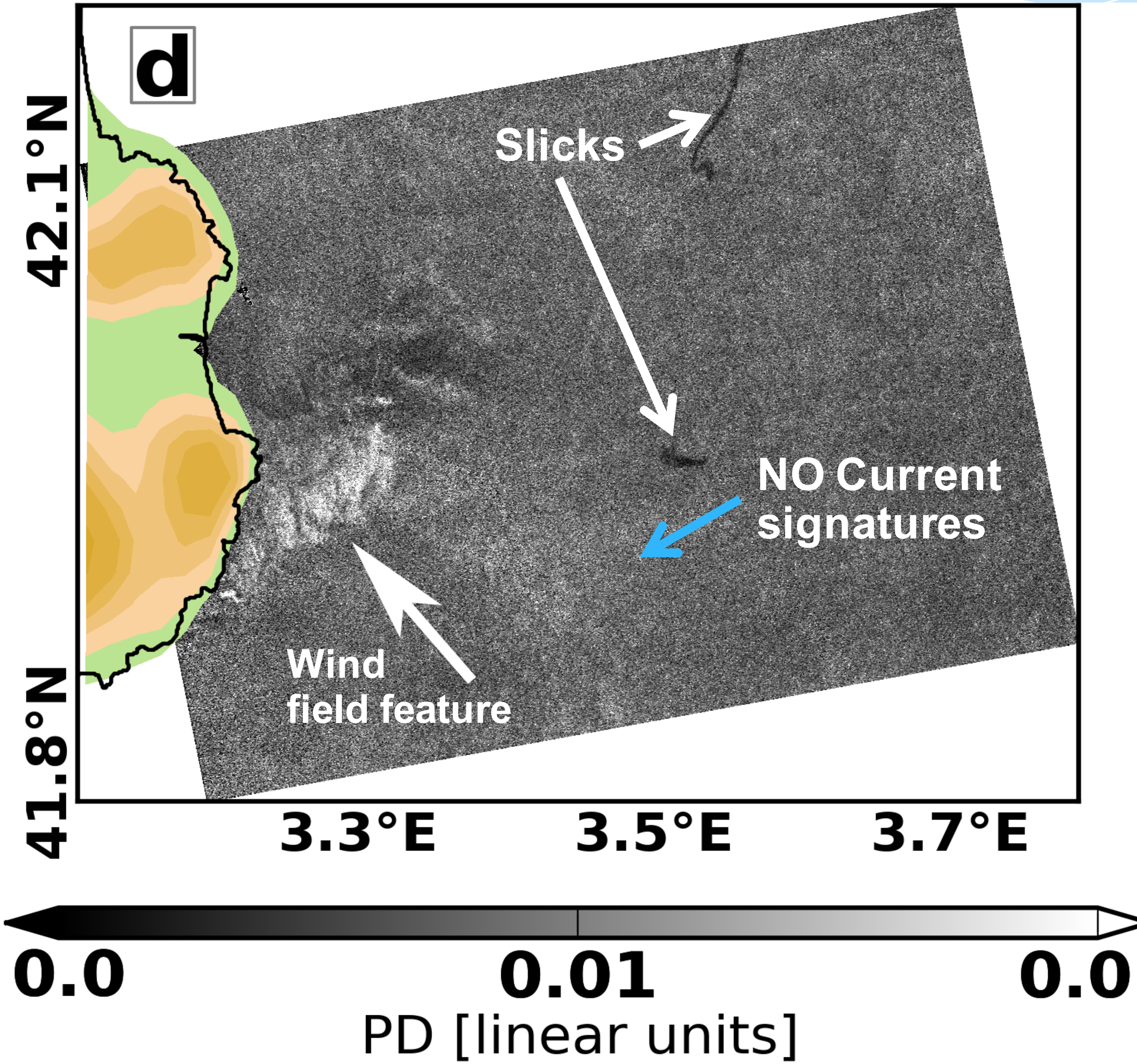




(air-born C-band Du-Pol obs. by Mouche et al. 2006)

Polarization Difference

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

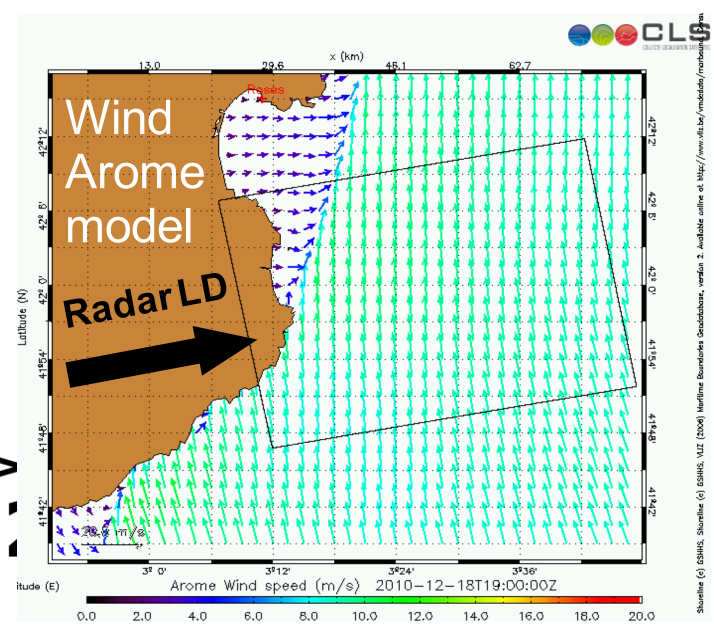


Features:

- **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



Non-polarized contribution from breaking waves (NP WB)

$$\sigma_0^{vv} ; \sigma_0^{hh}$$

"new" characteristic - NP

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

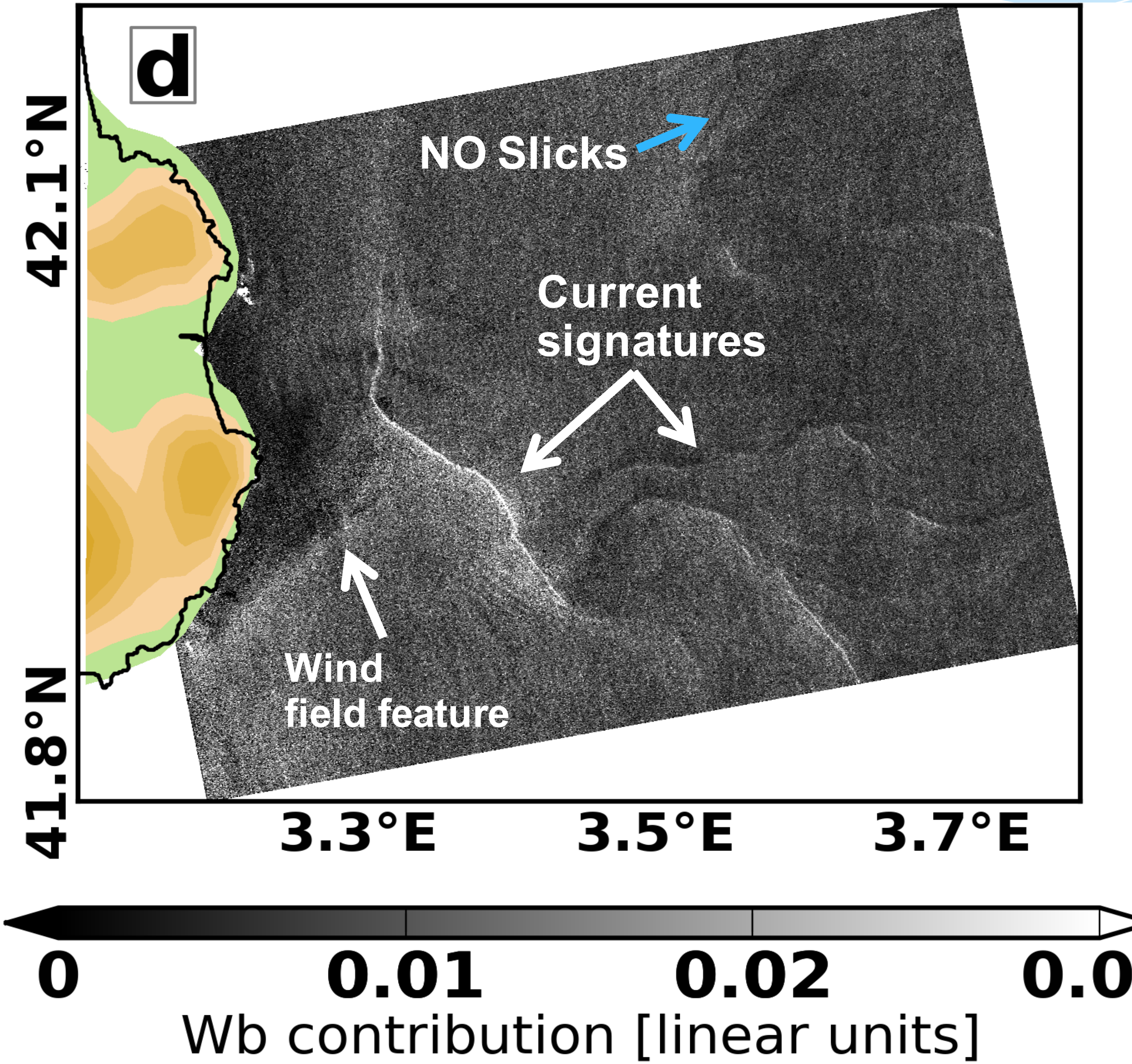
$$\sigma_{wb} = \sigma_0^{vv} - \Delta\sigma_0 / (1 - p_B)$$

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

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

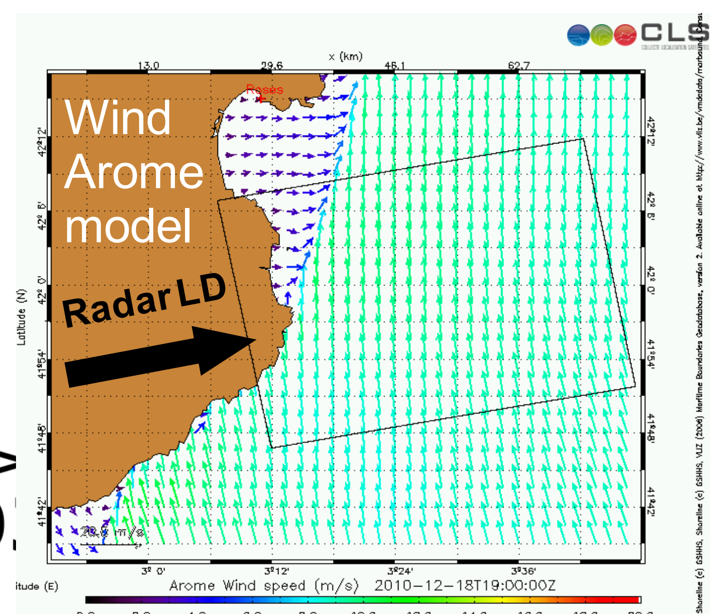
NP – reflects **wave current interaction** through variations in wave breaking

Non-polarized contribution

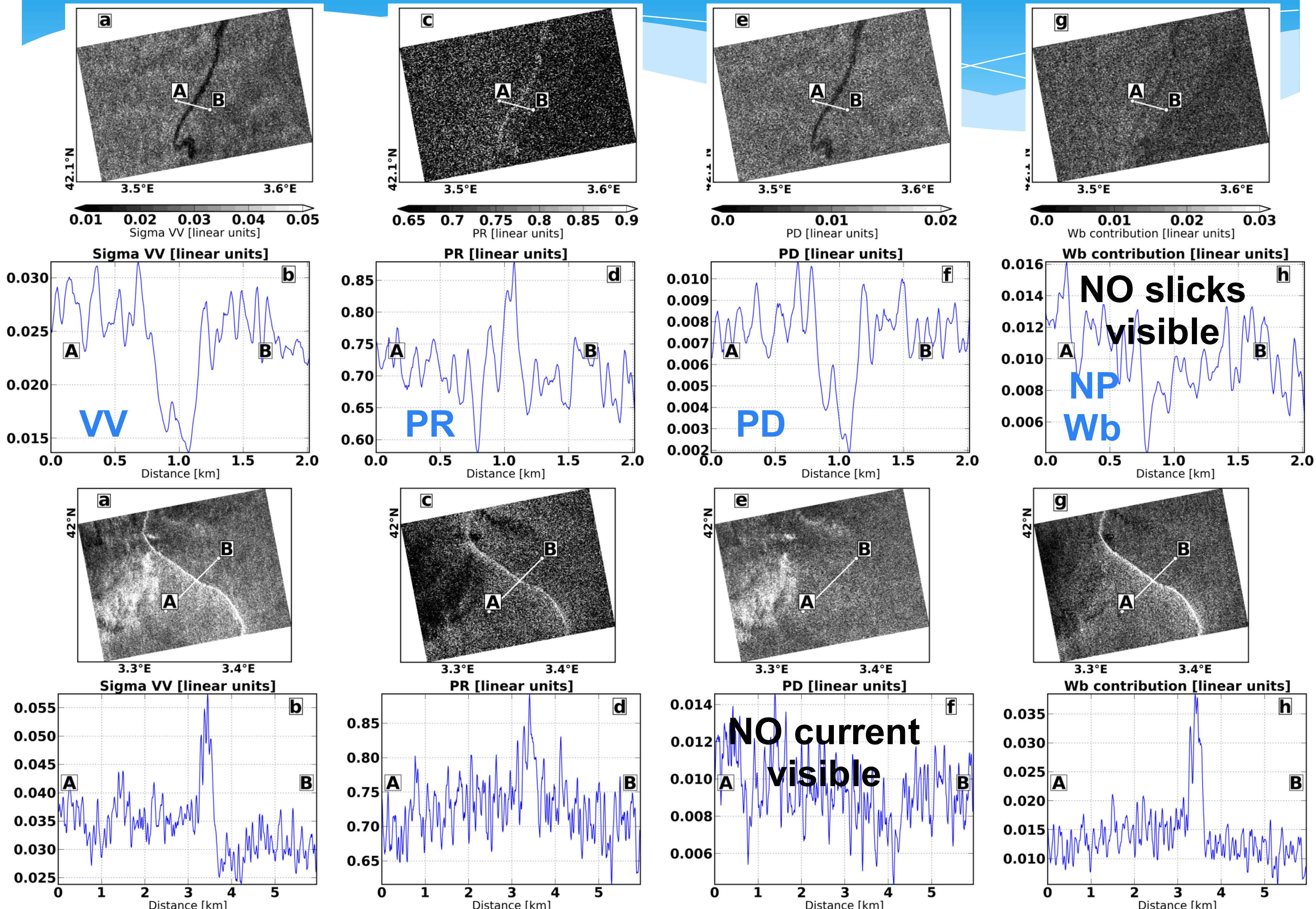


Features:

- **Slicks** are **not visible**
- **Current** signatures are **well visible**
- **Wind field** feature is **well expressed**



Ocean surface features manifestations interpretation



Summary

Simple and an effective approach

Transformation of VV and HH into new images:

Polarization Difference (PD) VV-HH

-wind field variability
-presence of slicks

Non-Polarized (NP Wb) contribution to NRCS

-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

[1] V. N. Kudryavtsev, D. Hauser, G. Caudal, and B. Chapron, "**A semiempirical model of the normalized radar cross-section of the sea surface 1. Background model**," Journal of Geophysical Research, vol. 108, no. C3, p. 24, Jan. 2003.
[2] V. N. Kudryavtsev, D. Akimov, J. A. Johannessen, and B. Chapron, "**On radar imaging of current features: 1. Model and comparison with observations**," Journal of Geophysical Research, vol. 110, no. C07016, pp. 1–27, Jul. 2005.
[3] A. A. Mouche, D. Hauser, and V. Kudryavtsev, "**Radar scattering of the ocean surface and sea-roughness properties: A combined analysis from dual-polarizations airborne radar observations and models in C band**," Journal of Geophysical Research, vol. 111, no. C9, p. C09004, 2006.

[4] V. Kudryavtsev, A. Myasoedov, B. Chapron, J. A. Johannessen, and F. Collard, "**Imaging mesoscale upper ocean dynamics using synthetic aperture radar and optical data**," Journal of Geophysical Research, vol. 117, no. C4, p. C04029, Apr. 2012.
[5] V. Kudryavtsev, A. Myasoedov, B. Chapron, J. A. Johannessen, and F. Collard, "**Joint sun-glitter and radar imagery of surface slicks**," Remote Sensing of Environment, vol. 120, pp. 123–132, May 2012.

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

σ_{0B}^{pp} is 2-scale Bragg scattering

σ_{wb} is non-polarized (NP) imapct 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):

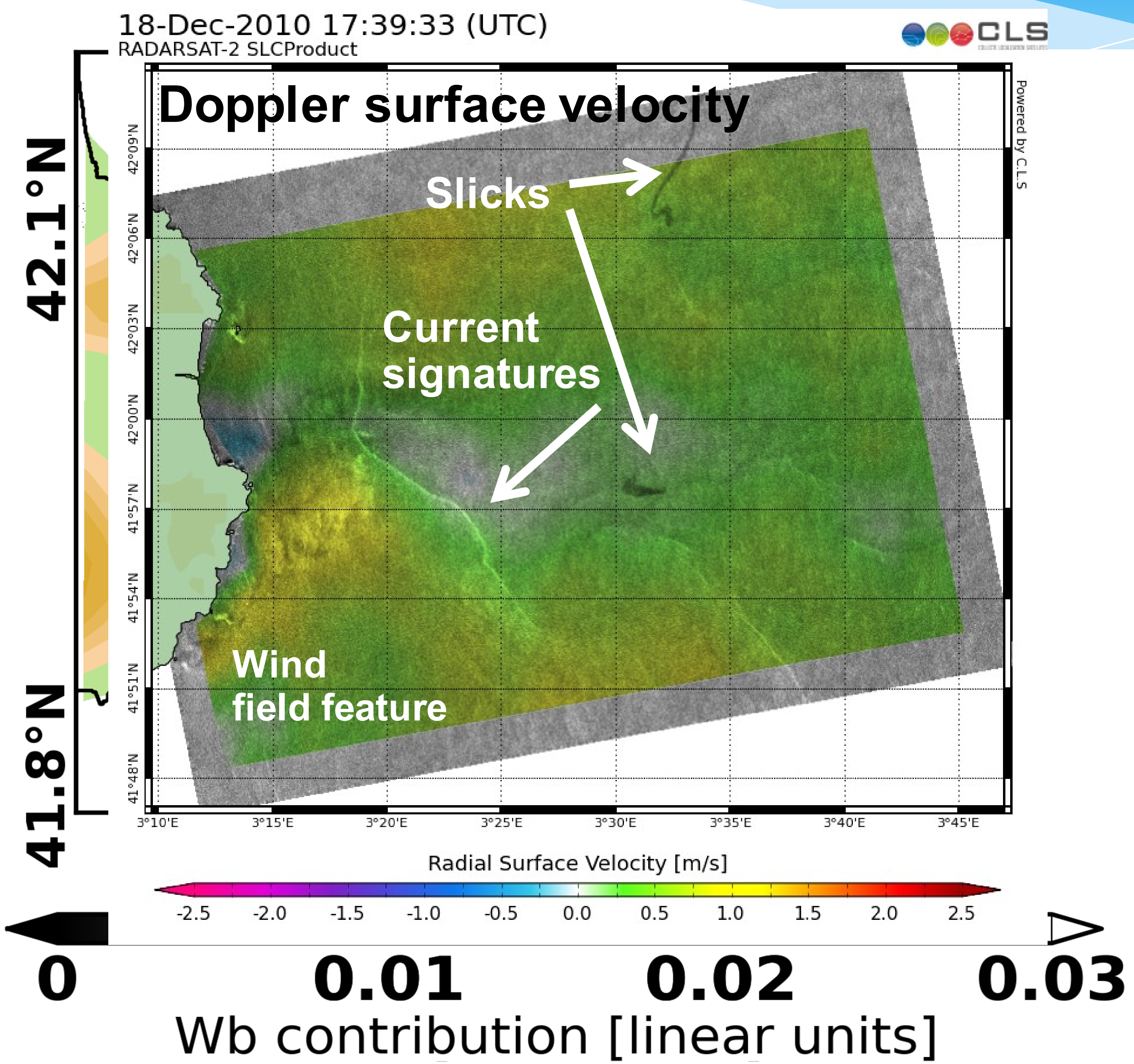
$$\Delta\sigma_0 \equiv \sigma_0^{vv} - \sigma_0^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}$$

NP contribution of breaking waves:

$$\sigma_{wb} = \sigma_0^{vv} - \Delta\sigma_0 \Big/ (1 - p_B)$$

where $p_B = \sigma_{0B}^{hh} \Big/ \sigma_{0B}^{vv}$ is PR for Bragg scattering

Ocean surface features manifestations



Features:

- Slicks are well visible

- Current signatures are well visible

- Wind field features are well expressed

- Local wind field features can be either due to wind speed variations

- Or/and to wind direction rotation and divergence

- Slicks are dark

PD formed by Bragg which are PR~1

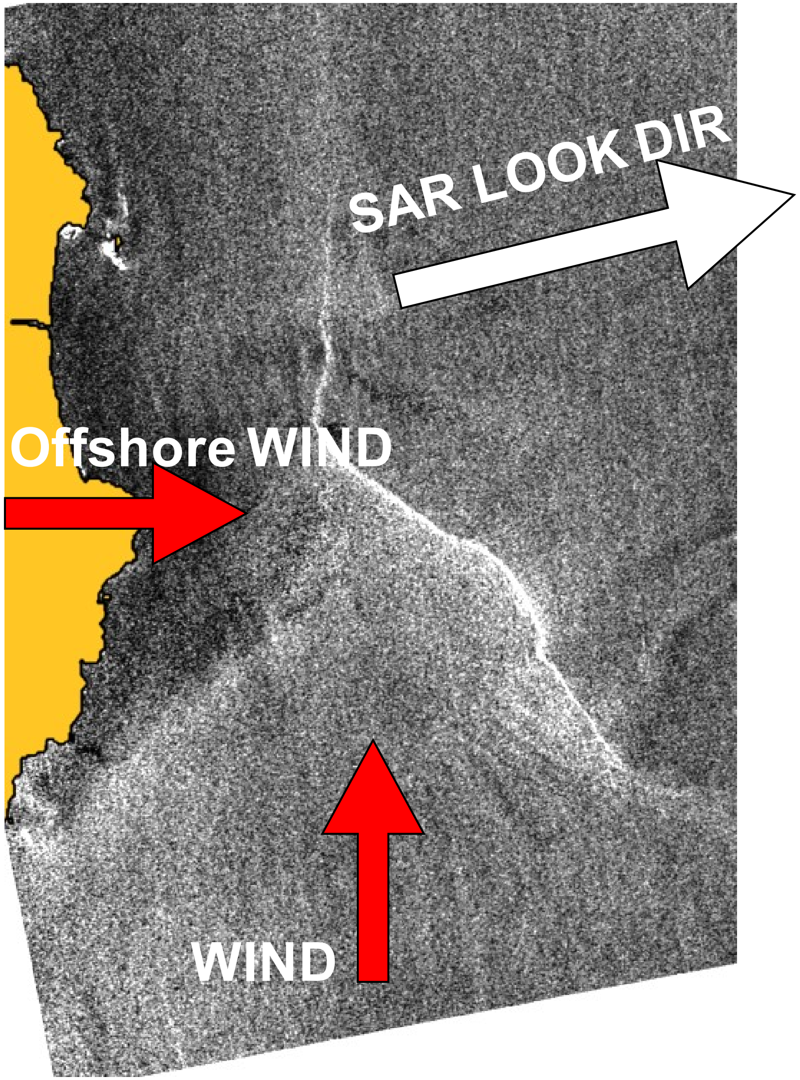
- *Wave-Current* interaction:

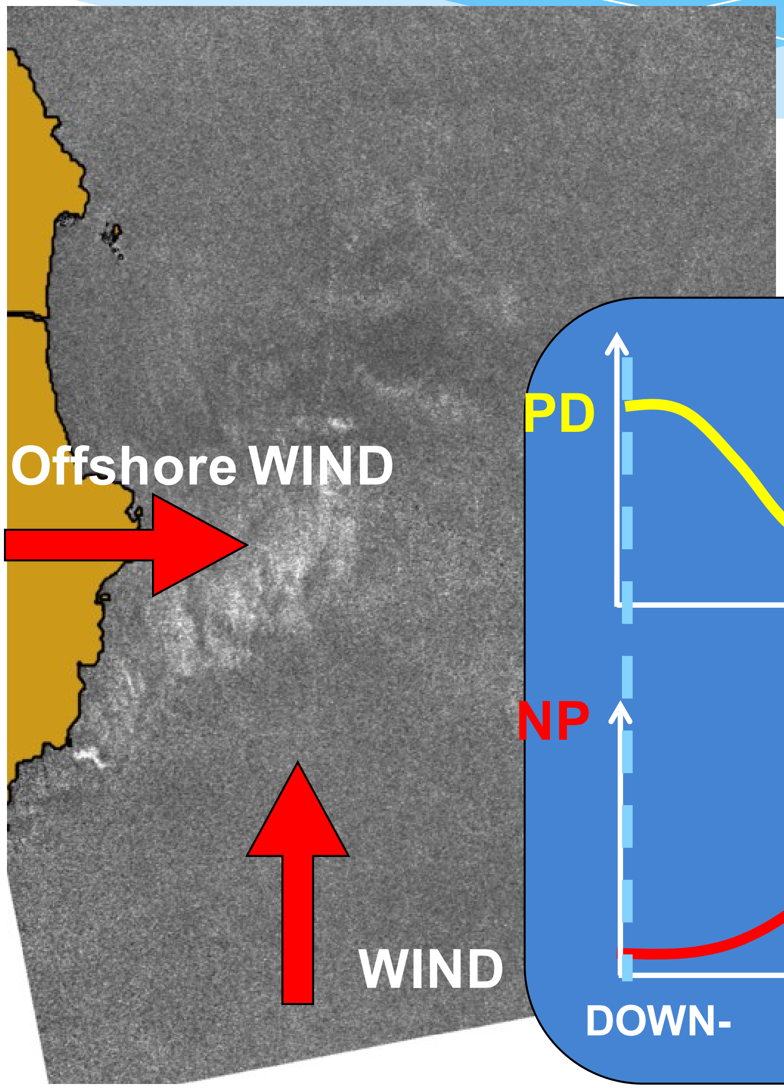
(i) WB enhanced PR > 1

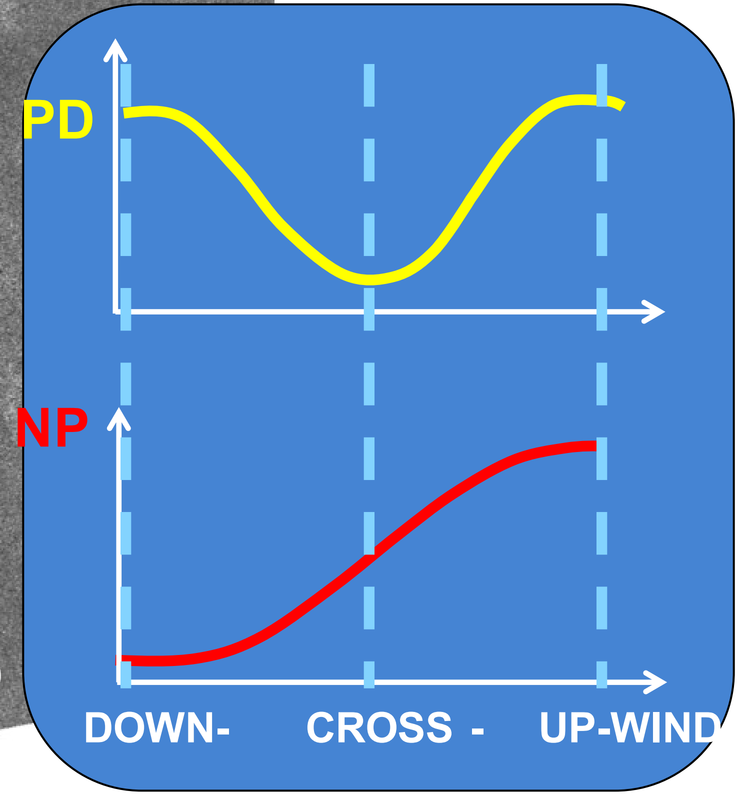
(ii) WB suppressed PR => PR_Bragg

WB dominated PR => PR_Bragg

Wind Field Features



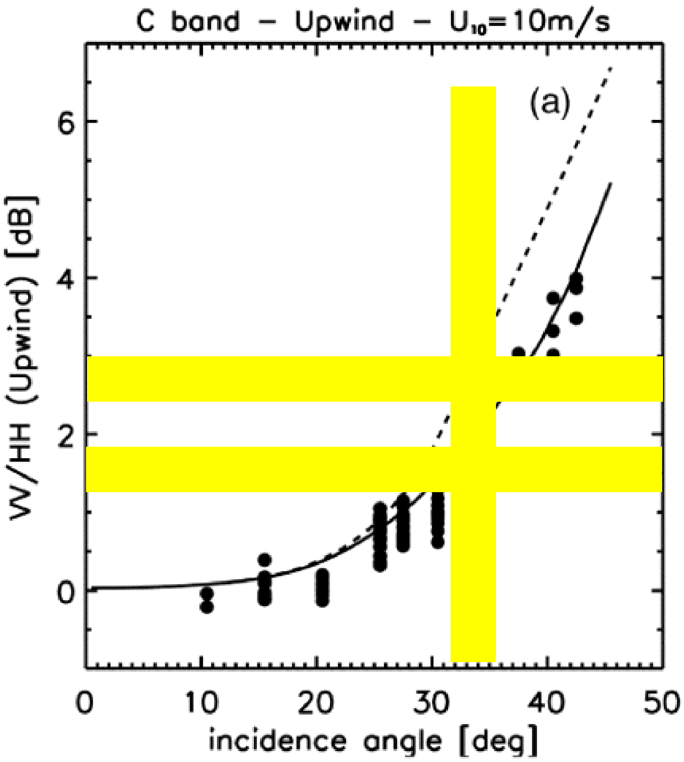




Polarization Ratio

$$PR = \frac{\sigma_0^{hh}}{\sigma_0^{vv}} = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}}$$

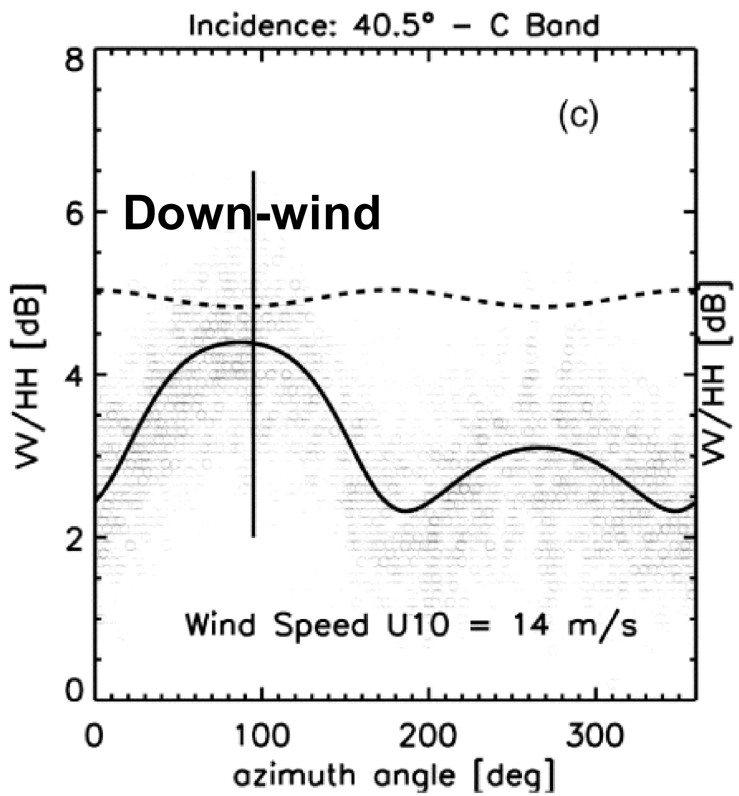
Some C-band PR properties from Mouche et al. 2006.



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

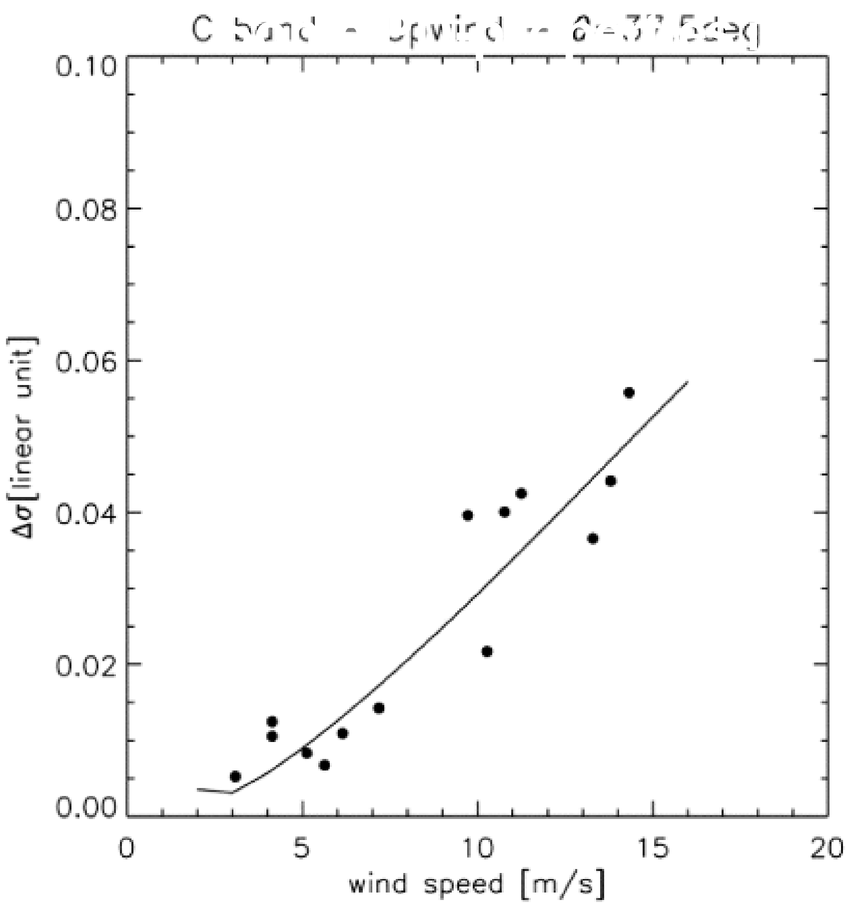


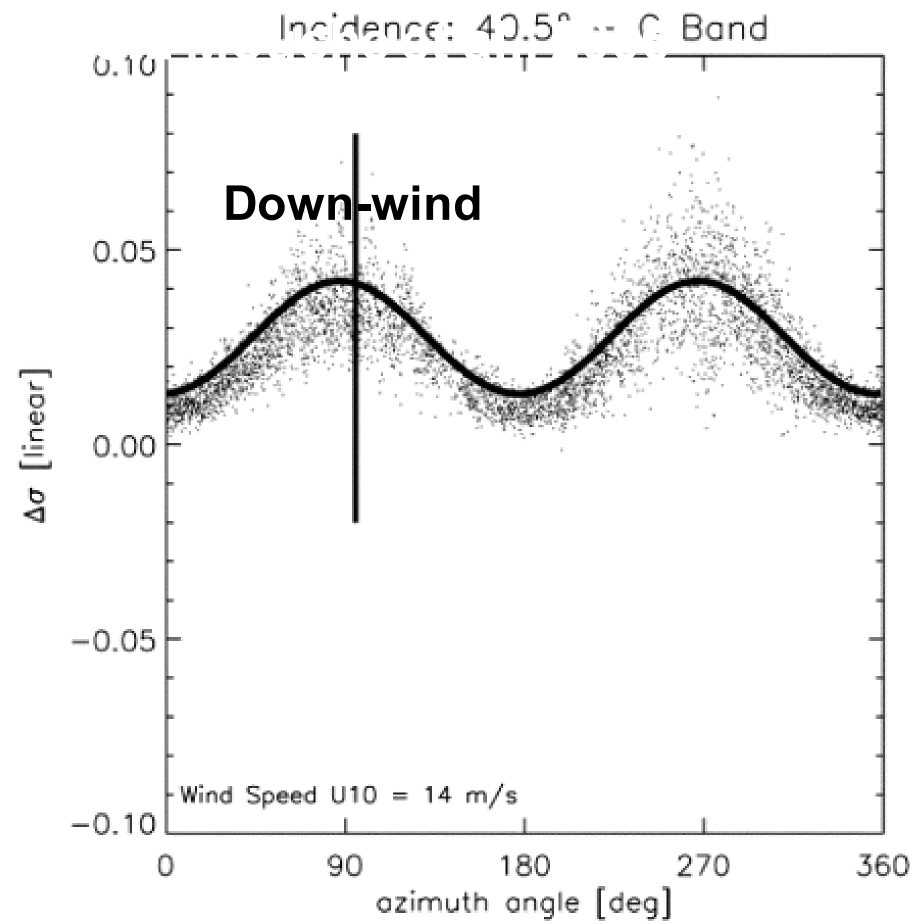
- PR = HH/VV significantly deviates from PR_Bragg for analyzed images, This justifies that radar returns from breaking waves (WB) play important role.
- When PR->1, role of wave breaking is dominant.
- and when role of wave breaking is weak, PR -> PR_Bragg

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 reflectwind field variability and presence of slicks

$$\Delta\sigma_0 \equiv \sigma_0^{vv} - \sigma_0^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}$$



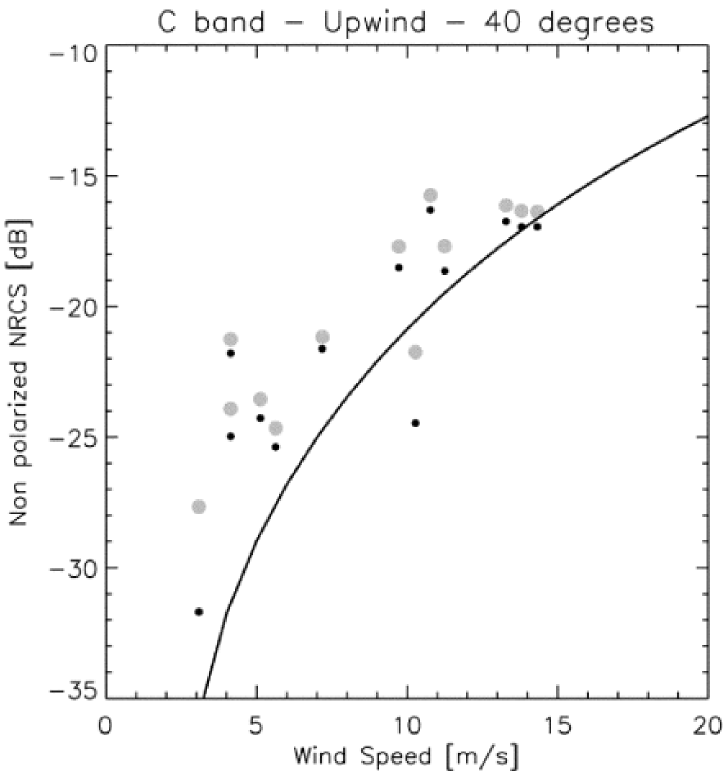


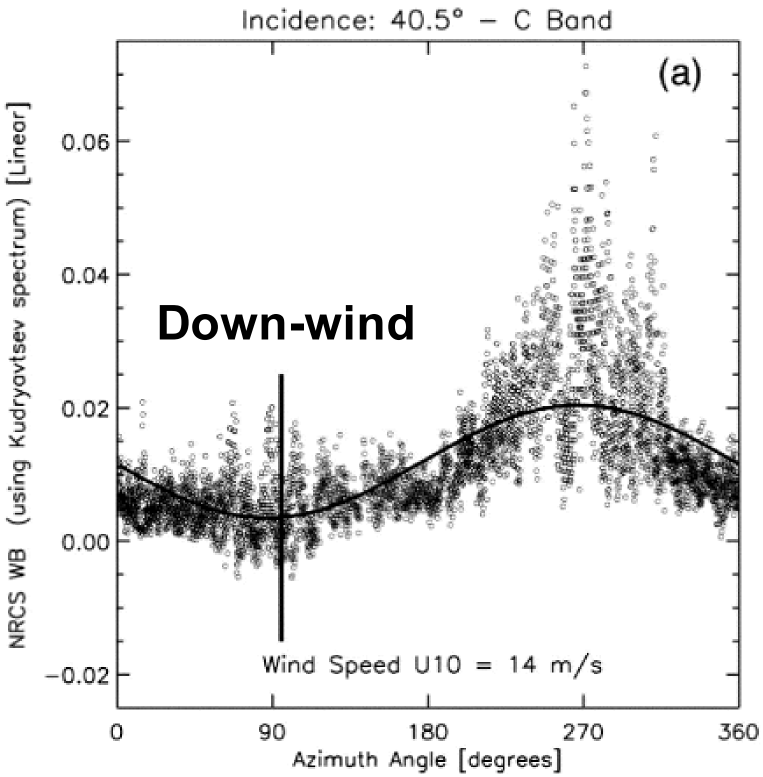
Non-polarized contribution from breaking waves (NP)

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

$$\sigma_{wb} = \sigma_0^{vv} - \Delta\sigma_0 / (1 - p_B),$$

$$\text{where } p_B = \sigma_{0B}^{hh} / \sigma_{0B}^{vv} \text{ is PR for Bragg scattering}$$

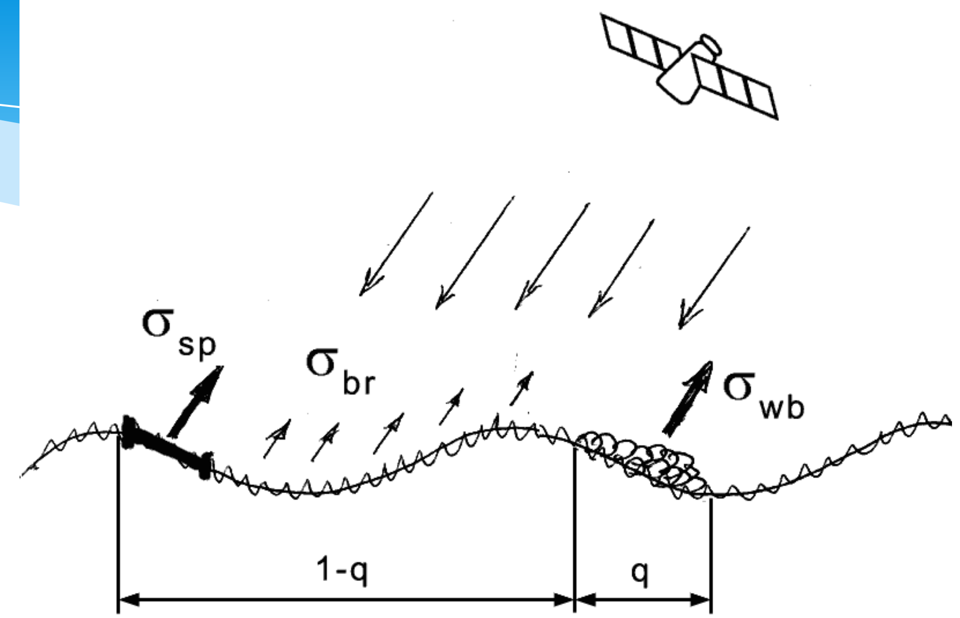




Electromagnetic Unit

Approach:

Surface is split into “regular” surface (1-q) and zones of wave breaking (q)



Total NRCS

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

2-scale Bragg

$$\sigma_{br}^p(\theta) = \int_\Gamma \sigma_{0br}^p(\theta - \eta_i) P(\eta_i)\, d\eta_i$$

Quasi-specular reflection

$$\sigma_{sp}^p(\theta) = \pi R^2 \sec^4\theta \cdot P(\eta_i, \eta_n)\Big|_{\substack{\eta_i = \tan\theta \\ \eta_n = 0}}$$

$$\left.\begin{array}{l}\text{2-scale Bragg} \\ \text{Quasi-specular reflection}\end{array}\right\} \sigma_{0R}^p$$

Scattering from breaking waves

$$\sigma_{0wb} \propto \frac{\sec^4\theta}{s_{wb}^2} \exp\left(-\frac{tg^2\theta}{s_{wb}^2}\right) + \frac{\varepsilon_{wb}}{s_{wb}^2}$$

Radar Imaging Model (RIM) Kudryavtsev et al., 2005; Johannessen et al., 2005

Wave-Current Interaction:

$$M \equiv B(\boldsymbol{k})/B(\boldsymbol{k}) \propto \omega^{-1}(c/u_*)^2 m_k^{i,j} u_{i,j}$$

Integral Parameters governs by:

$$M \propto \omega^{-1}(c/u_*)^2 m_k \nabla\cdot\boldsymbol{u}$$

$$s^2 \propto \int M k^2 B(\boldsymbol{k})\, d\boldsymbol{k} \propto \nabla\cdot\boldsymbol{u}$$

$$q \propto \int M k^{-2} \beta B(\boldsymbol{k})\, d\boldsymbol{k} \propto \nabla\cdot\boldsymbol{u}$$

Bragg Waves modulations affected by WB

$$B(\boldsymbol{k}_{br}) \propto q \propto \nabla\cdot\boldsymbol{u}$$

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