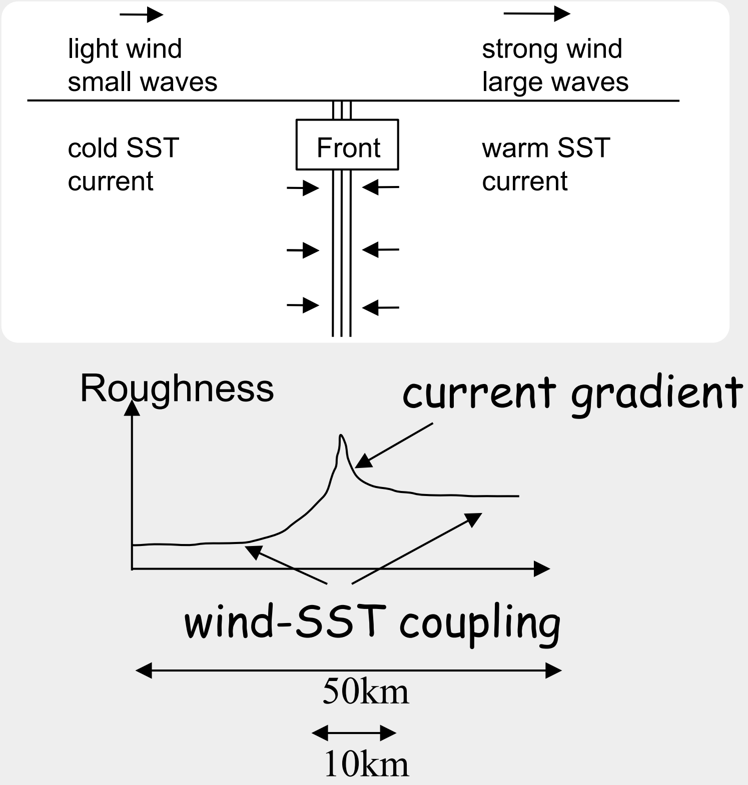
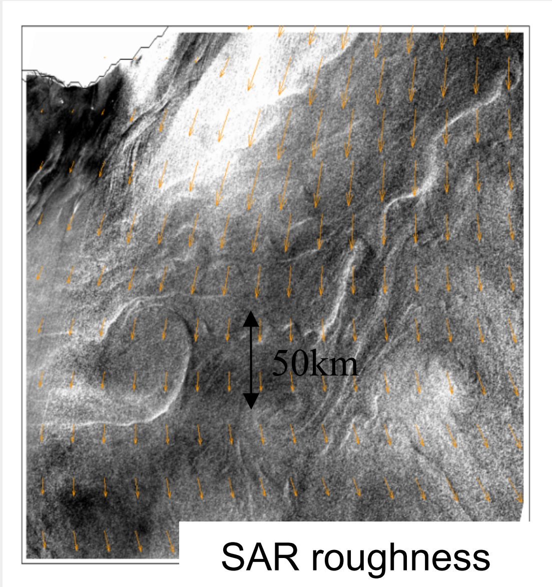
WP2300 – Wavemill Secondary Products
Ocean Atmosphere Interactions

SST fronts and roughness gradients collocated

1)scales 10-50 km SST/wind coupling : SST = wind = mss

2)scales 2-10 km wave/current coupling : dSST = du = mss

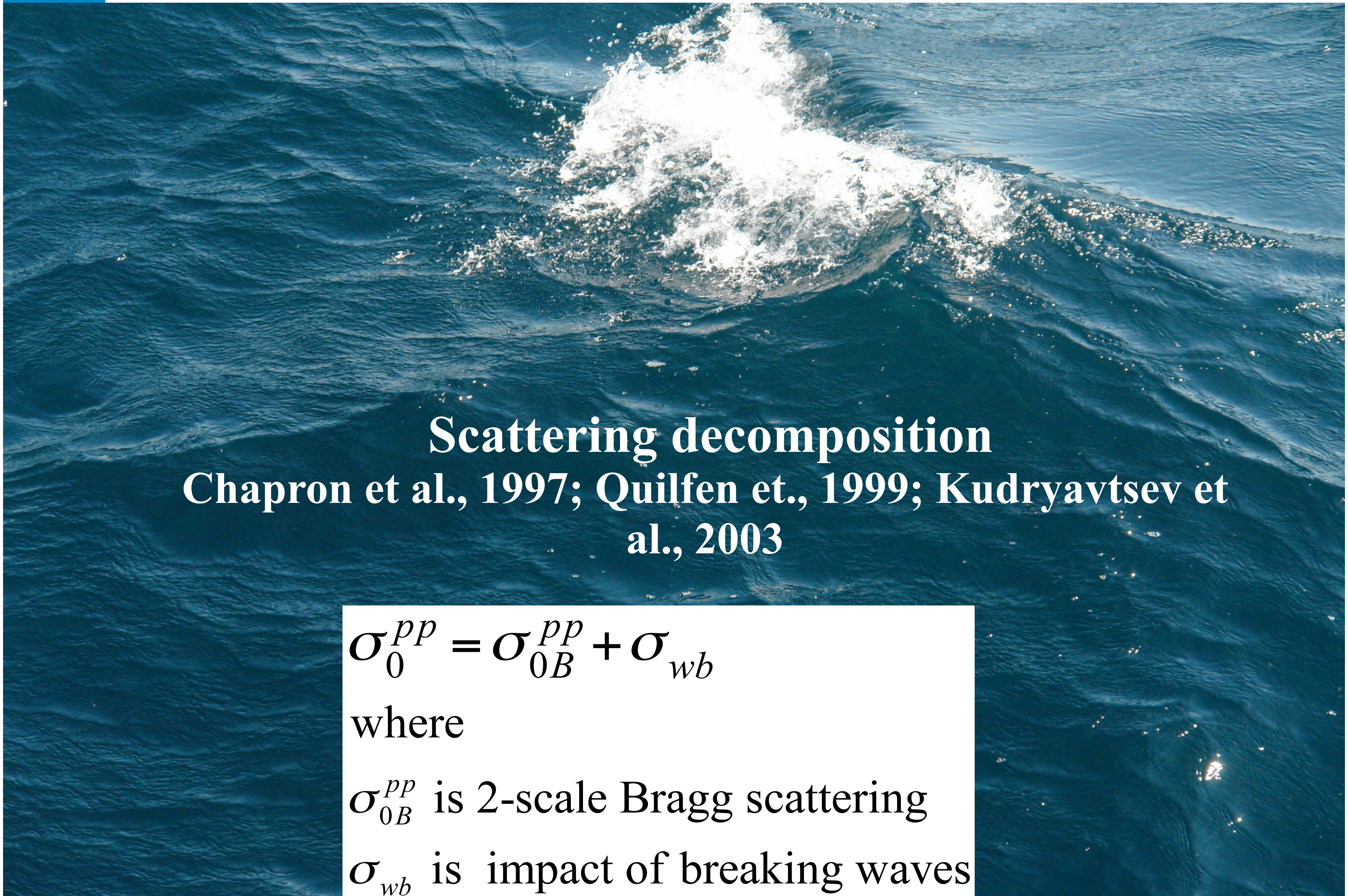




SAR roughness

Essentially related to the surface slope (mean square slope MSS) of short waves (roughly 1-10 cm)

Those waves are related to local wind and **current** (and surfactants)



Scattering decomposition

Chapron et al., 1997; Quilfen et., 1999; Kudryavtsev et al., 2003

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

where

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

σ_{wb} is impact of breaking waves

Main simple idea:

VV and HH polarized images to be combined to separate different surface properties:

-Polarizing short wind waves ~ 5 cm

-Non-polarized contribution (steep scatters and wave breaking)

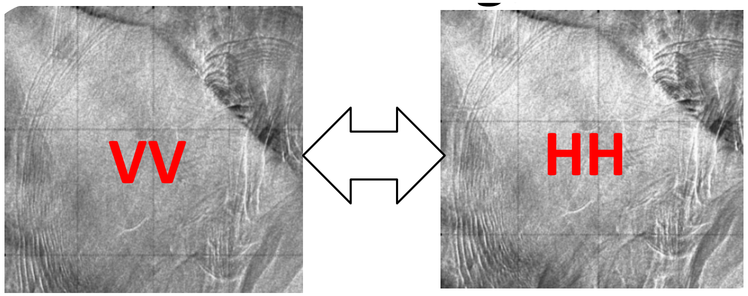
Polarization Difference, PD, short Bragg waves :

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

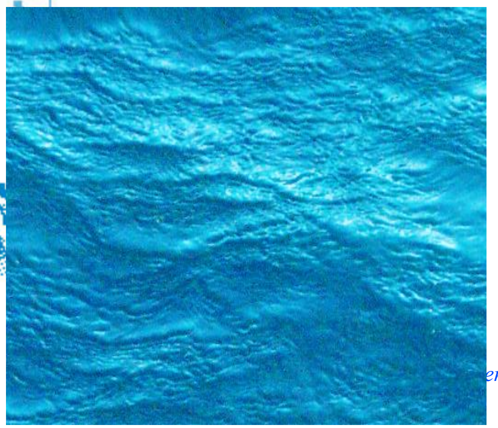
NP contribution from breaking waves :

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

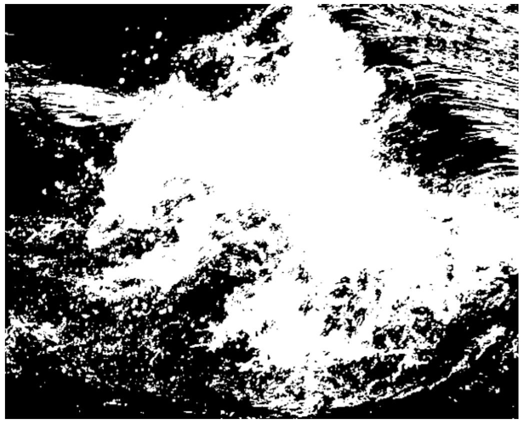
where $p_B = \sigma_{0B}^{hh} / \sigma_{0B}^{vv}$ is PR for Bragg scattering

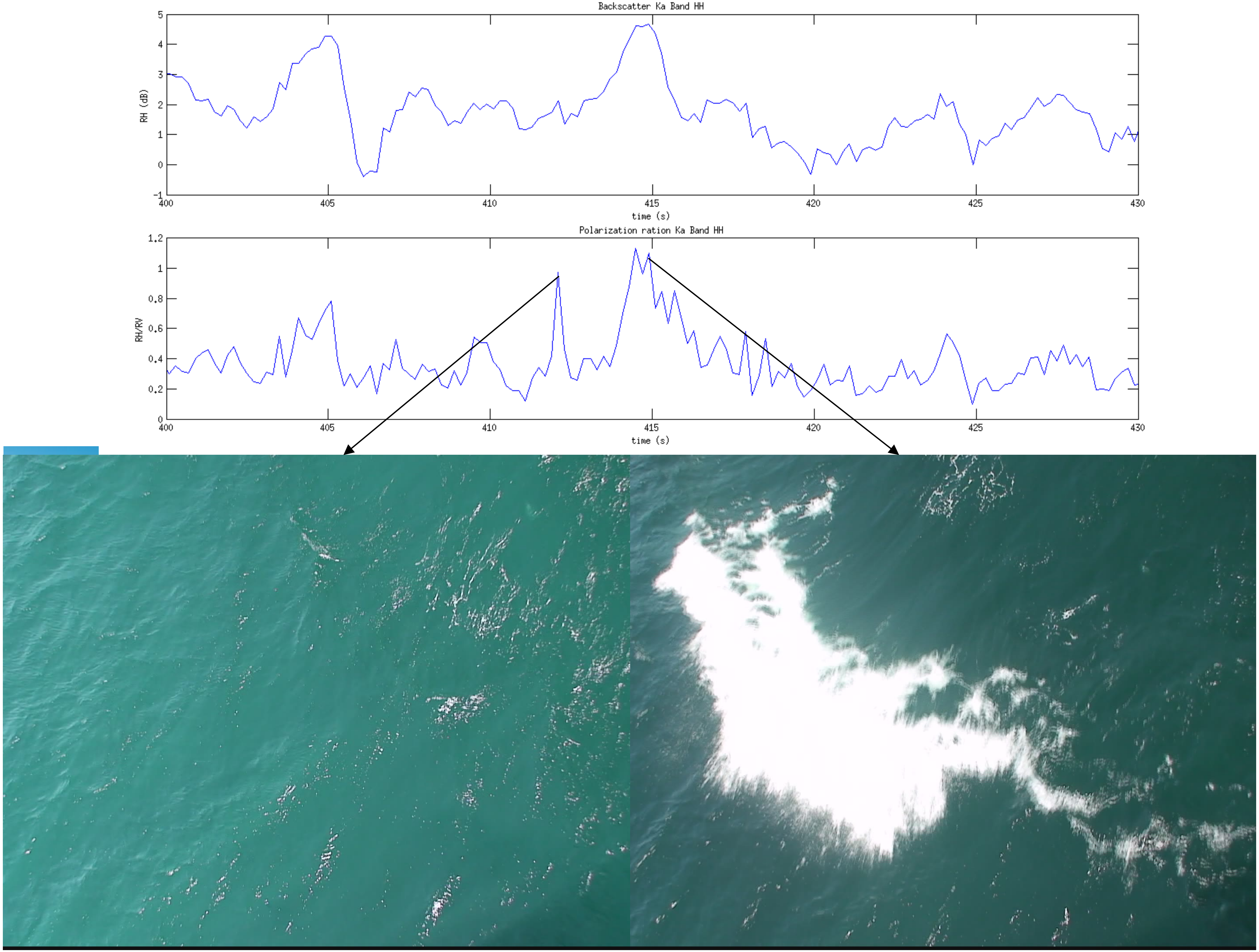


Polarized scattering
Short wind waves



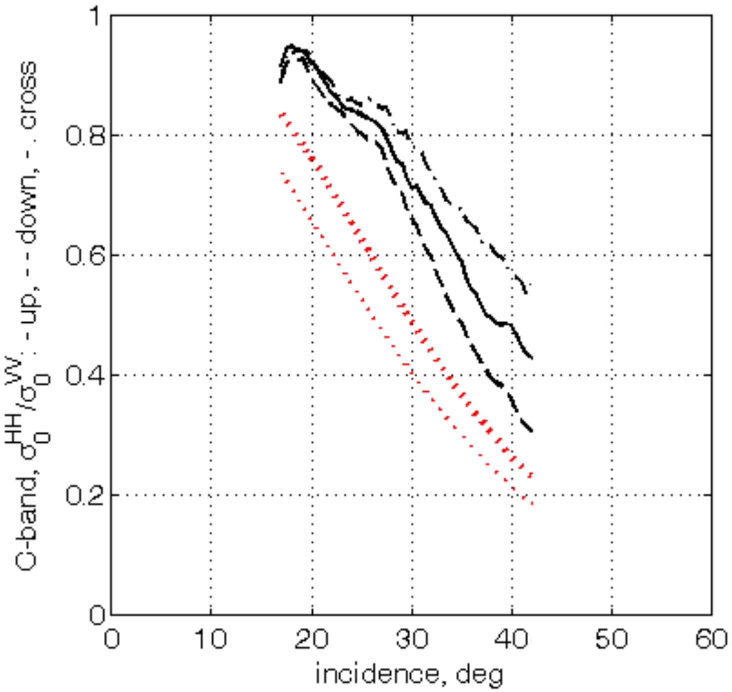
Non-polarized scattering
Wave breaking

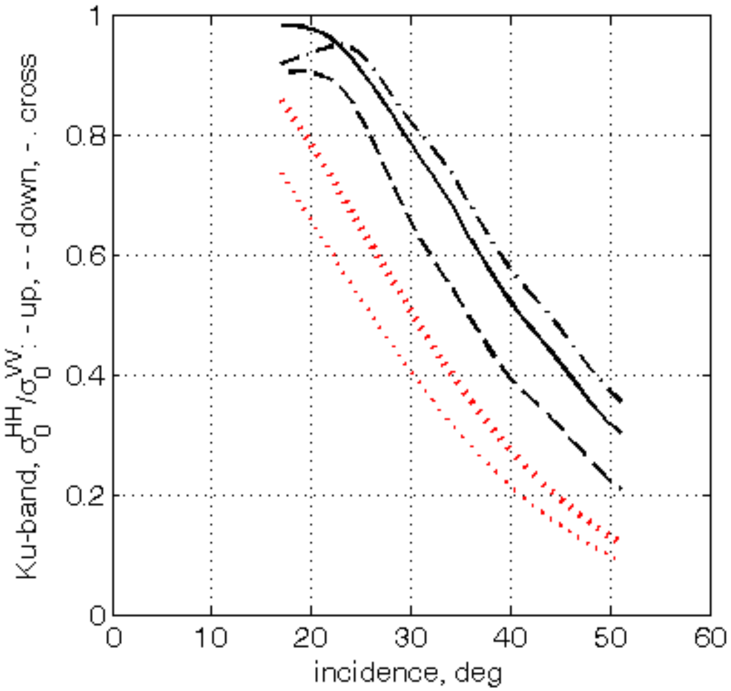



Backscatter Ka Band HH
RH (dB)
time (s)
Polarization ration Ka Band HH
RH/RV
time (s)

Polarization Ratio

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



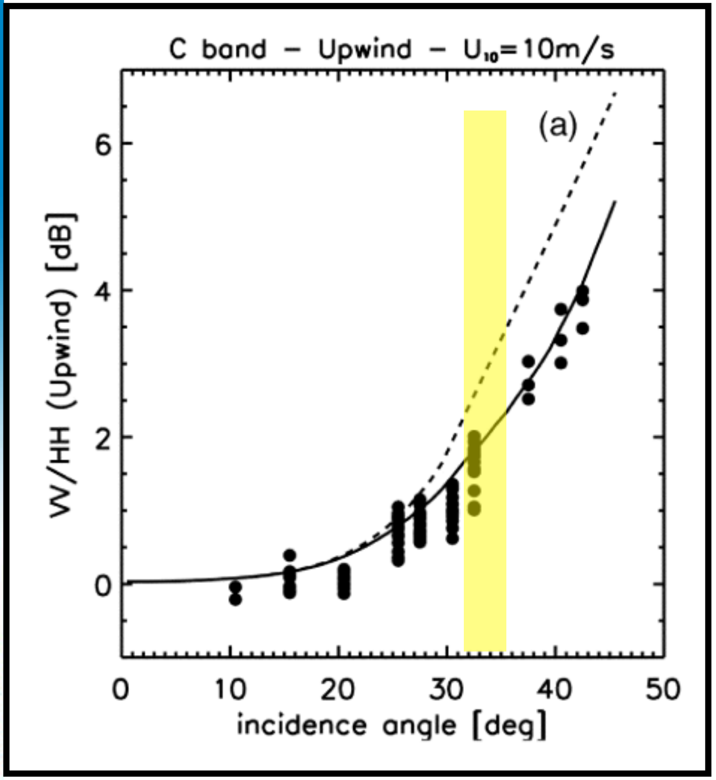


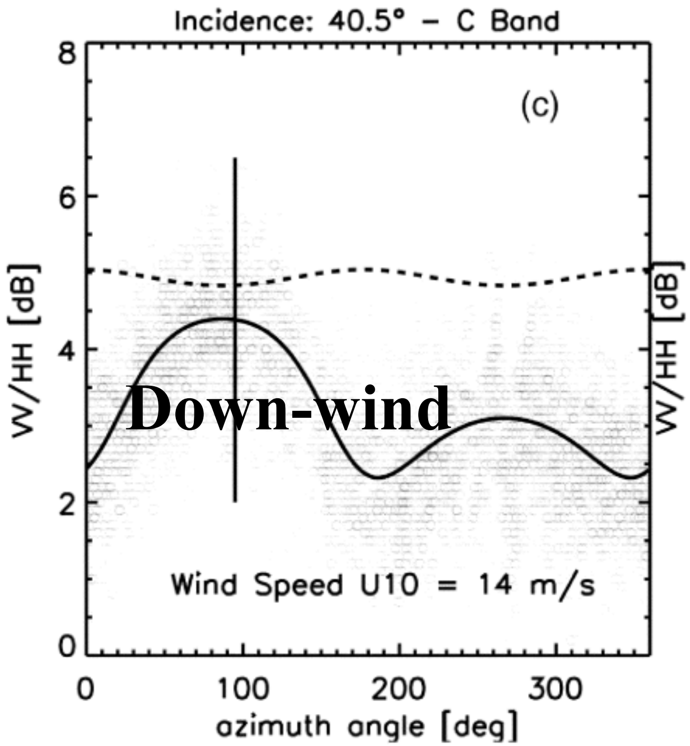
- C-band, Mouche et al., 2006 Ku-band, Quilfen et al., 1999

- PR = HH/VV significantly deviates from PR_Bragg.
- This justifies that radar returns from breaking waves (WB) play important role.

Polarization Ratio

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





- 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

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) :

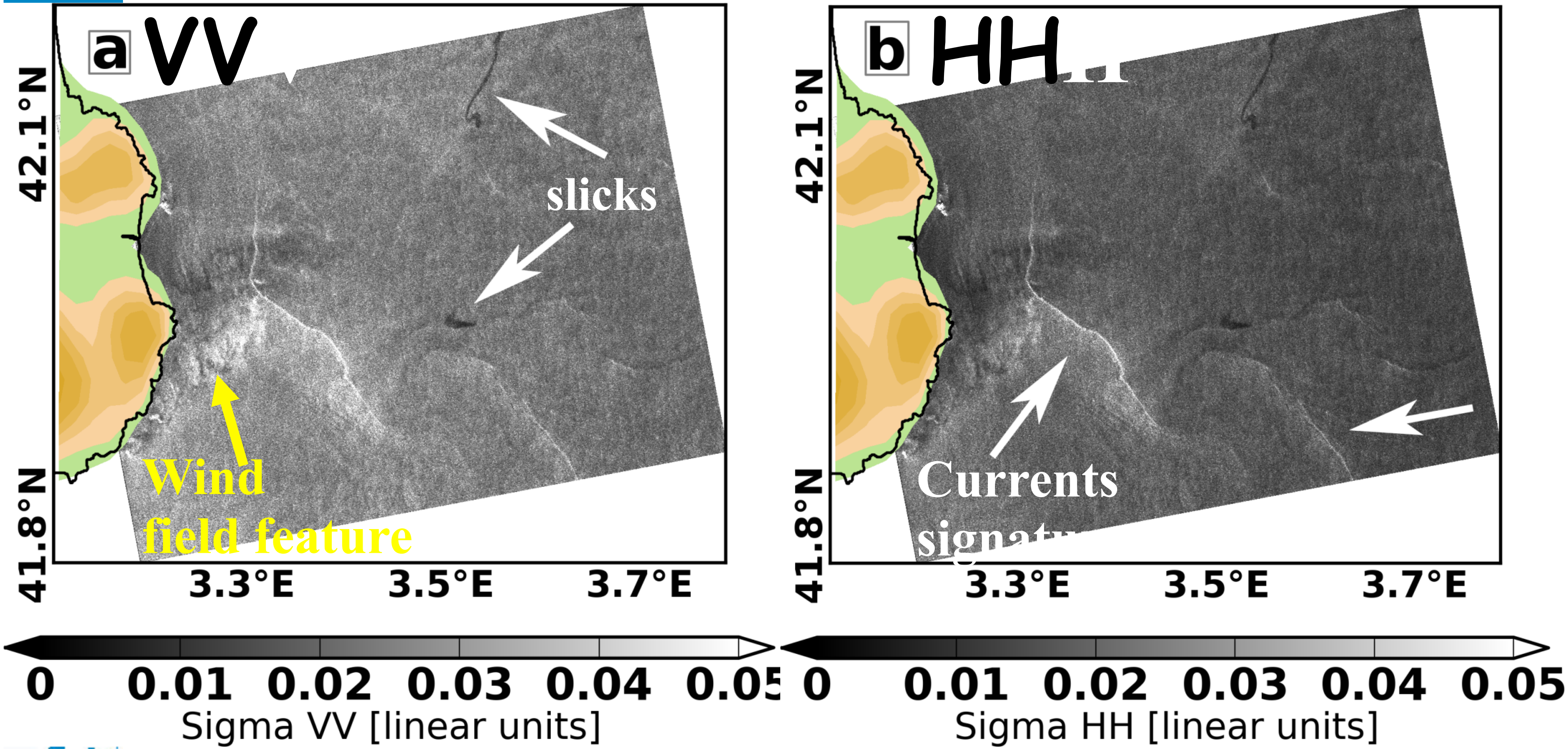
$$\Delta\sigma_0 \equiv \sigma_0^{vv} - \sigma_0^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}$$

NP contribution of breaking waves :

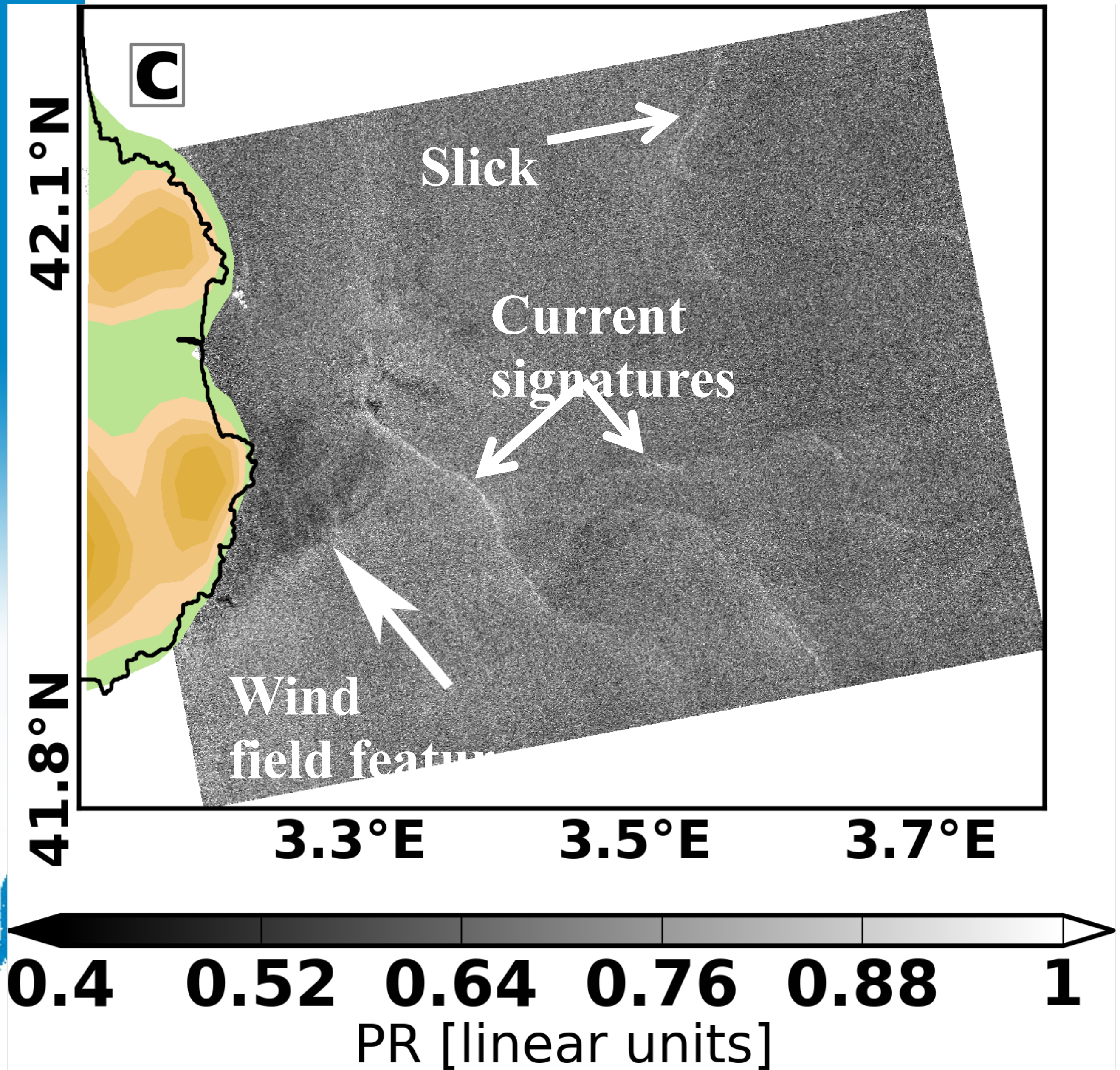
$$\sigma_{wb} = \sigma_0^{vv} - \Delta\sigma_0 / (1 - p_B)$$

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

Original VV and HH RS-2 SAR images



Polarization Ratio HH/VV

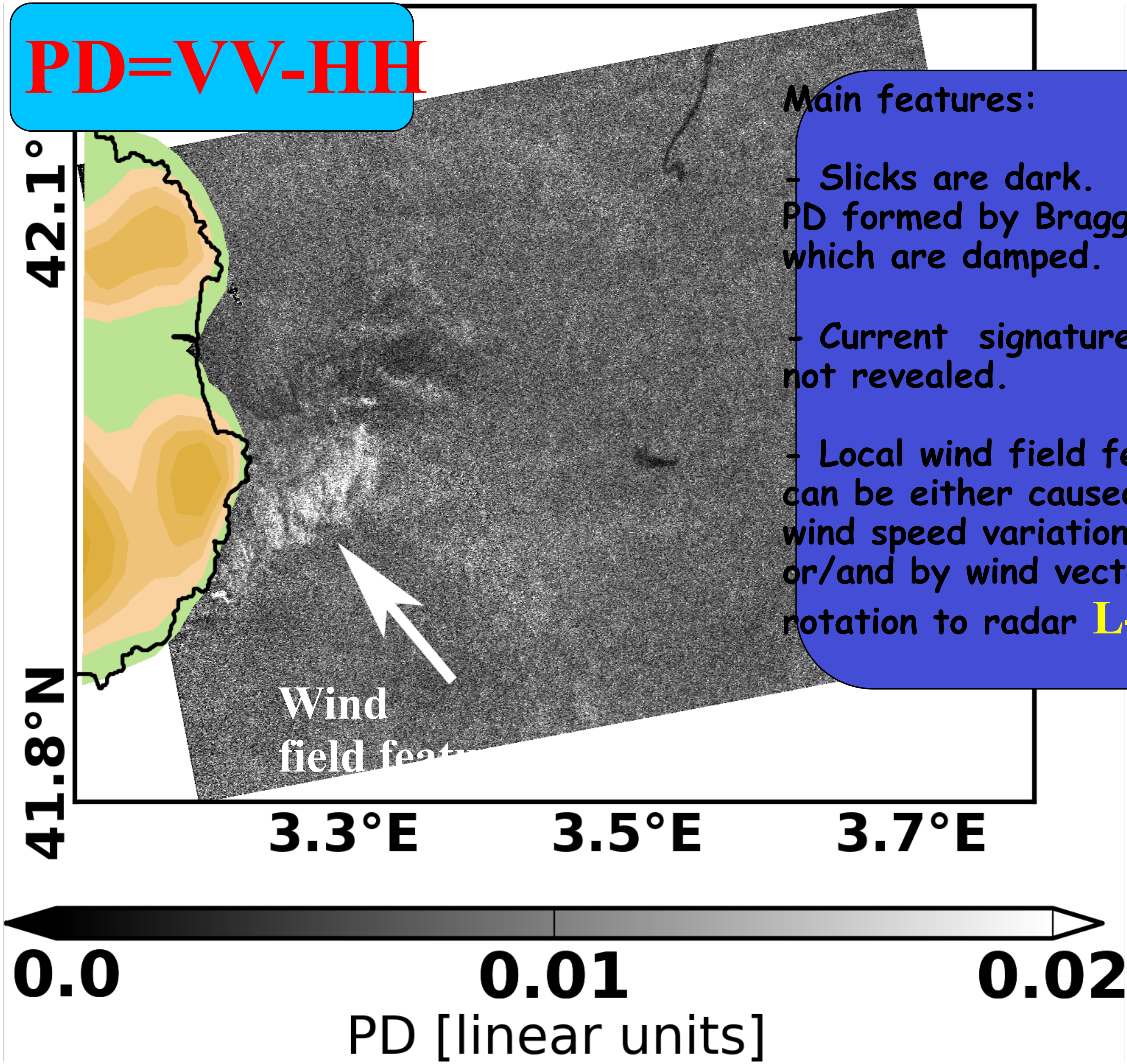


The mean PR is
 - 1.5 dB … - 2 dB
except coastal
area, PR= - 2.5 dB
that close to 2-scale
Bragg
model predictions.

PR attains PR=1 in
"bright" current
signatures.

OUTCOME: Impact of
non-polarized
scattering associated
with wave breaking is
important

PD=VV-HH



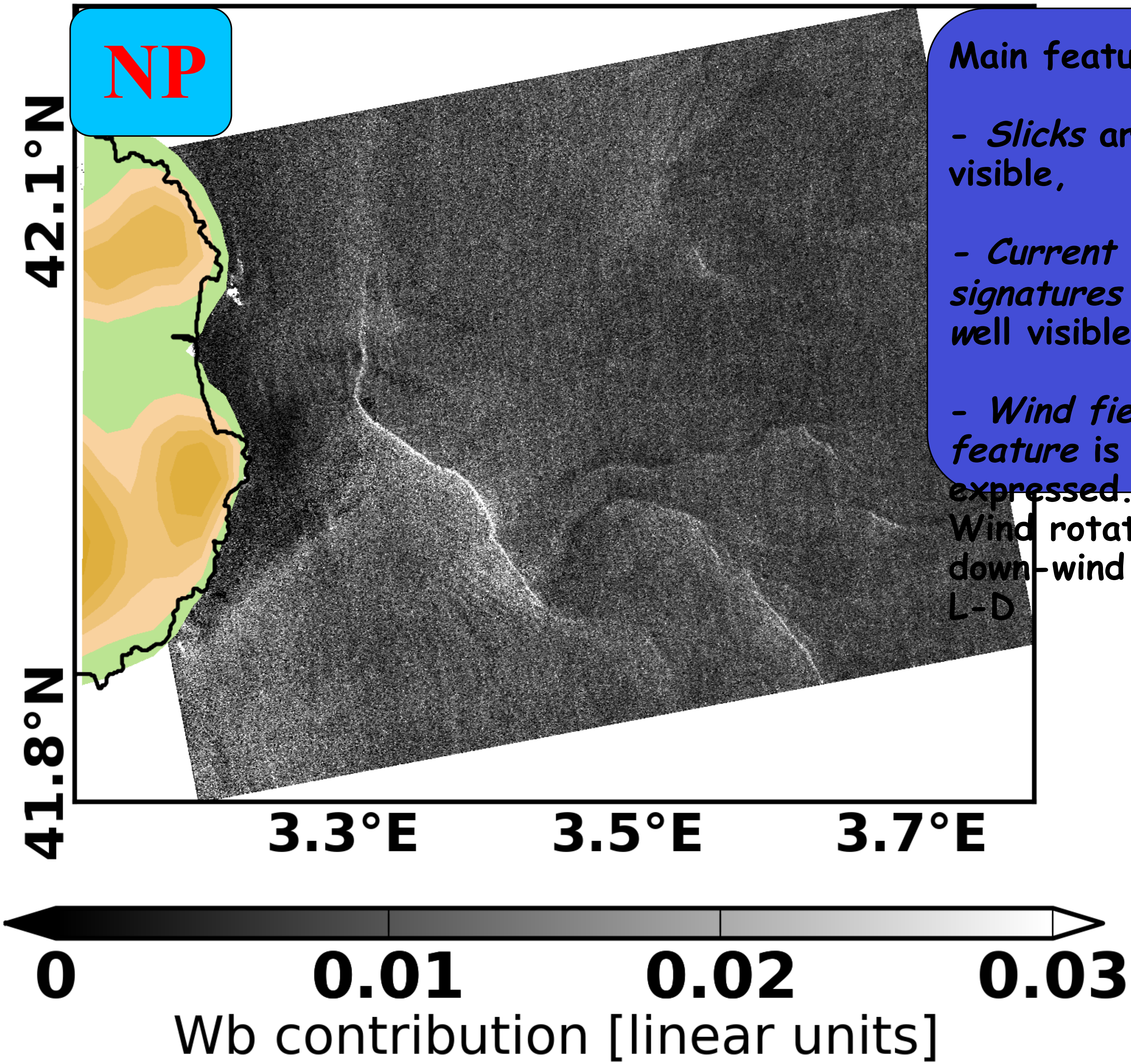
Main features:

- Slicks are dark. PD formed by Bragg which are damped.

- Current signatures are not revealed.

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

NP



Main features:

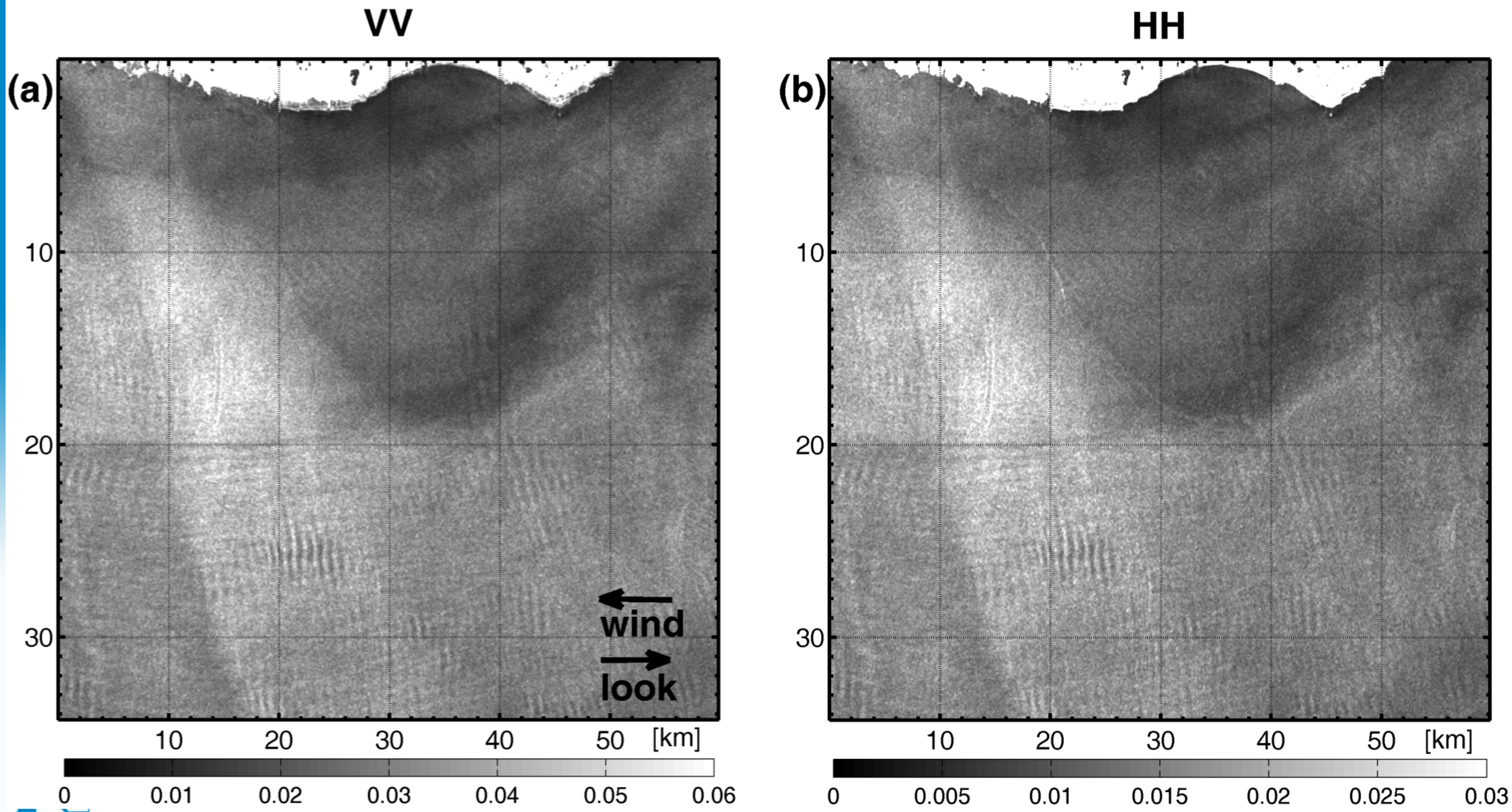
- *Slicks* are not visible,

- *Current signatures* are well visible.

- *Wind field feature* is well expressed.

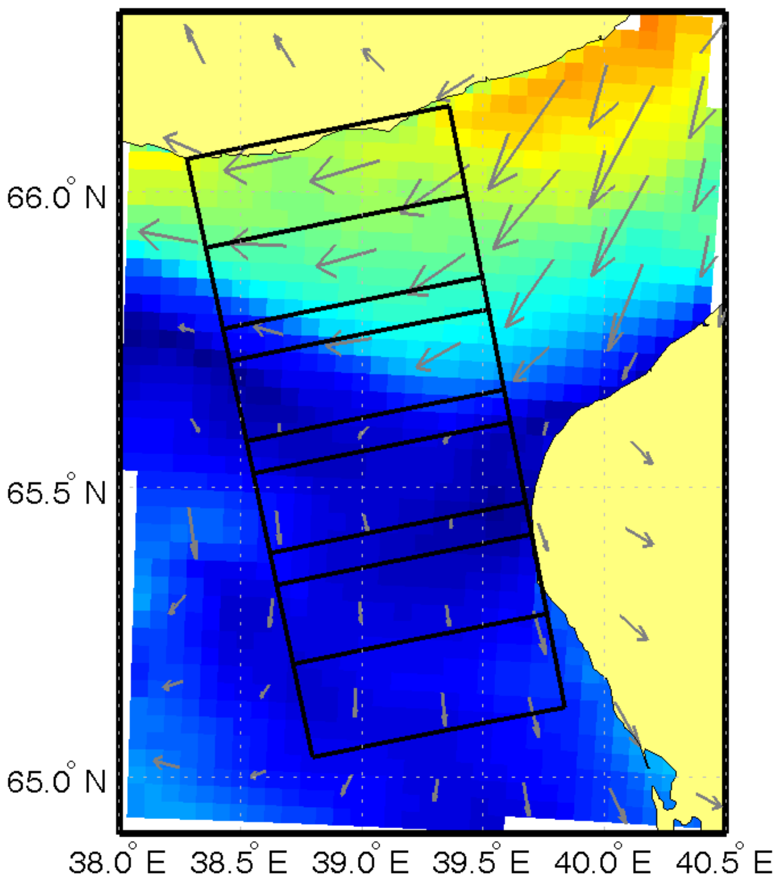
Wind rotates to down-wind SAR L-D

Original SAR images: August 1, 2012



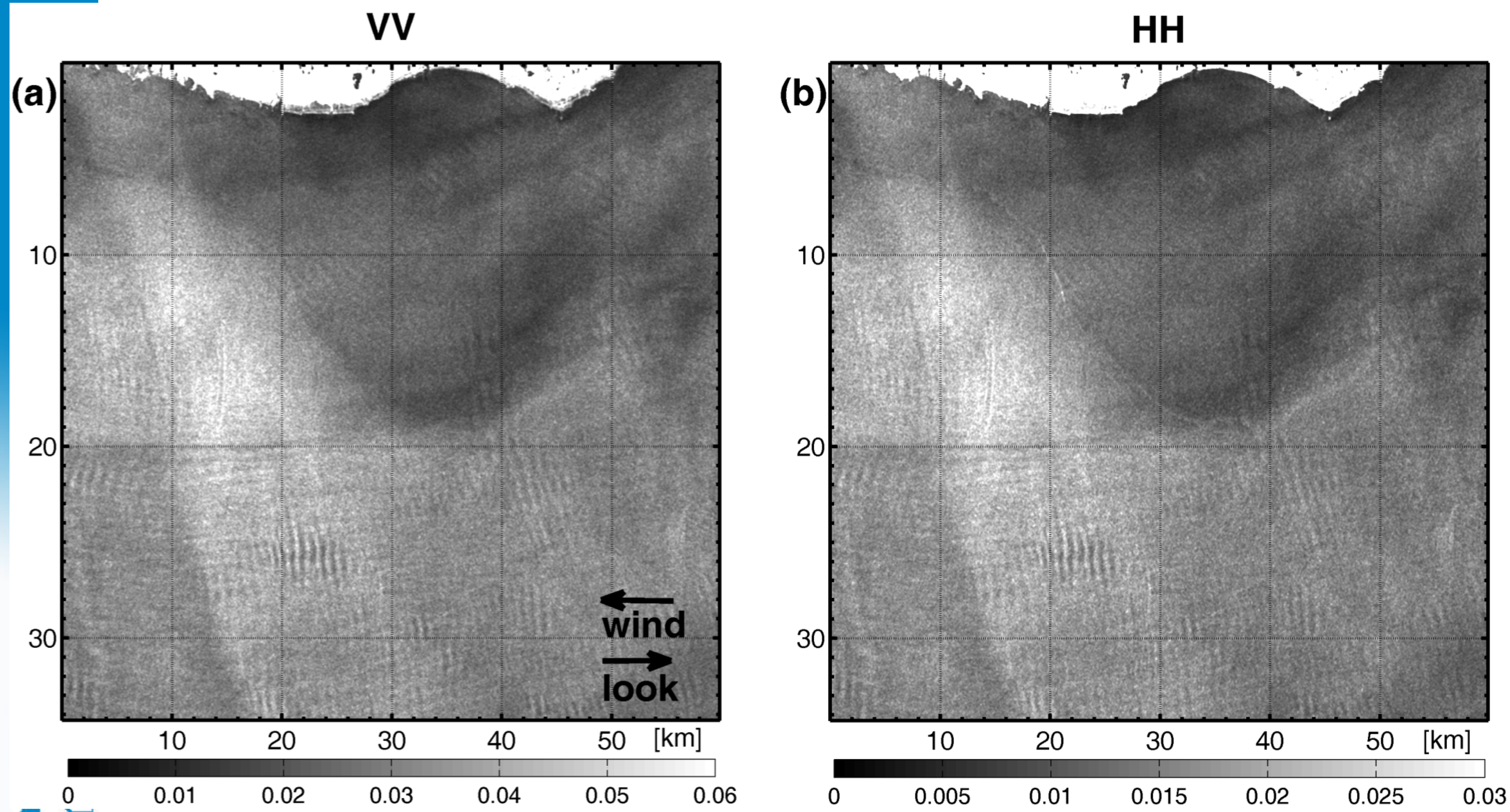
RADARSAT-2 SAR (a) VV- and (b) HH NRCS (in linear units) over the northeastern White Sea
acquired on 1 August 2012 (14:58 UTC) depicting manifestations of the SST front. Black solid
line shows a position of transect A-B across the front. © MDA © CSA

Wind and SST conditions



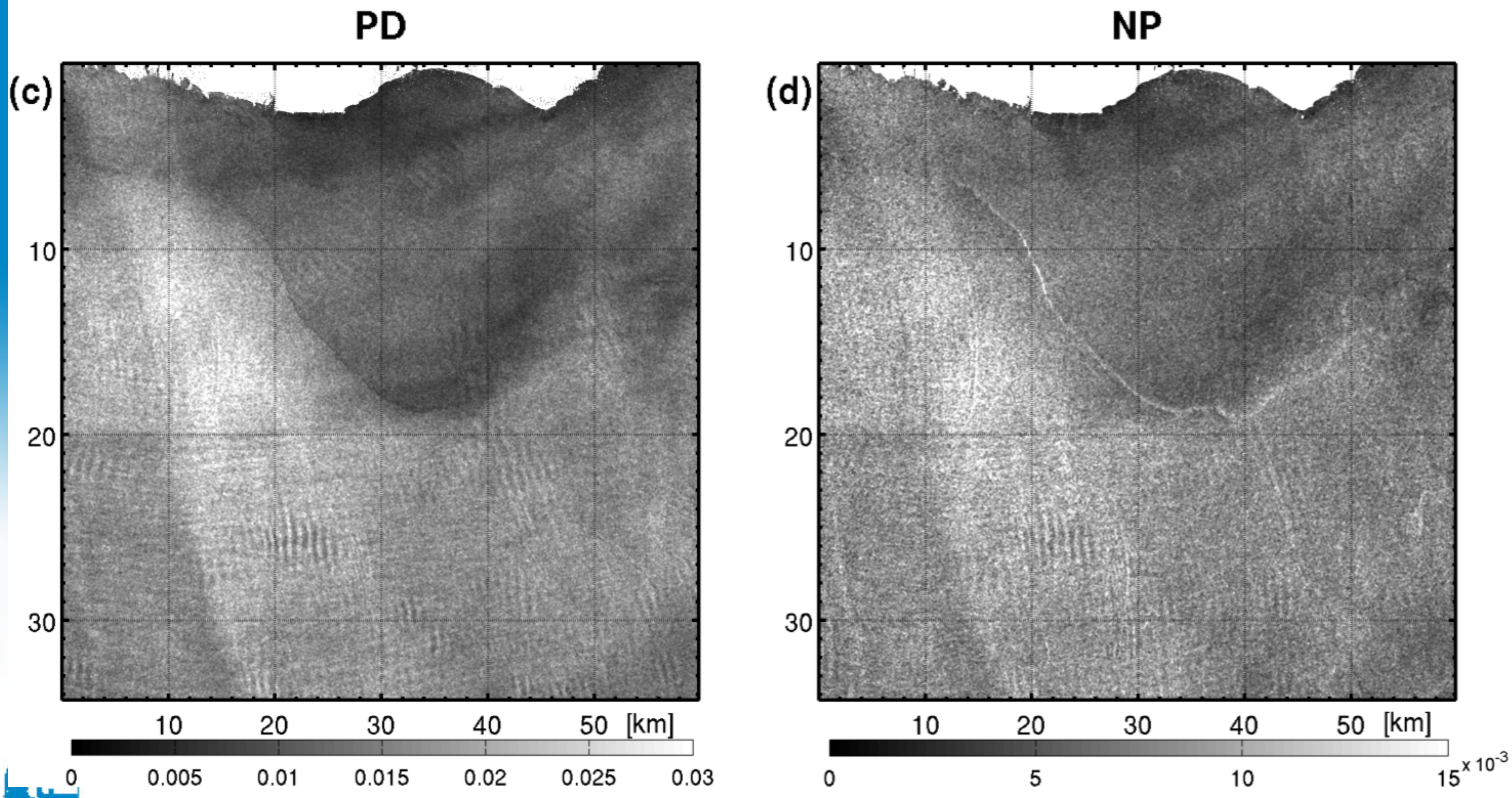
1 August 2012

Original SAR images: August 1, 2012



RADARSAT-2 SAR (a) VV- and (b) HH NRCS (in linear units) over the northeastern White Sea acquired on 1 August 2012 (14:58 UTC) depicting manifestations of the SST front. Black

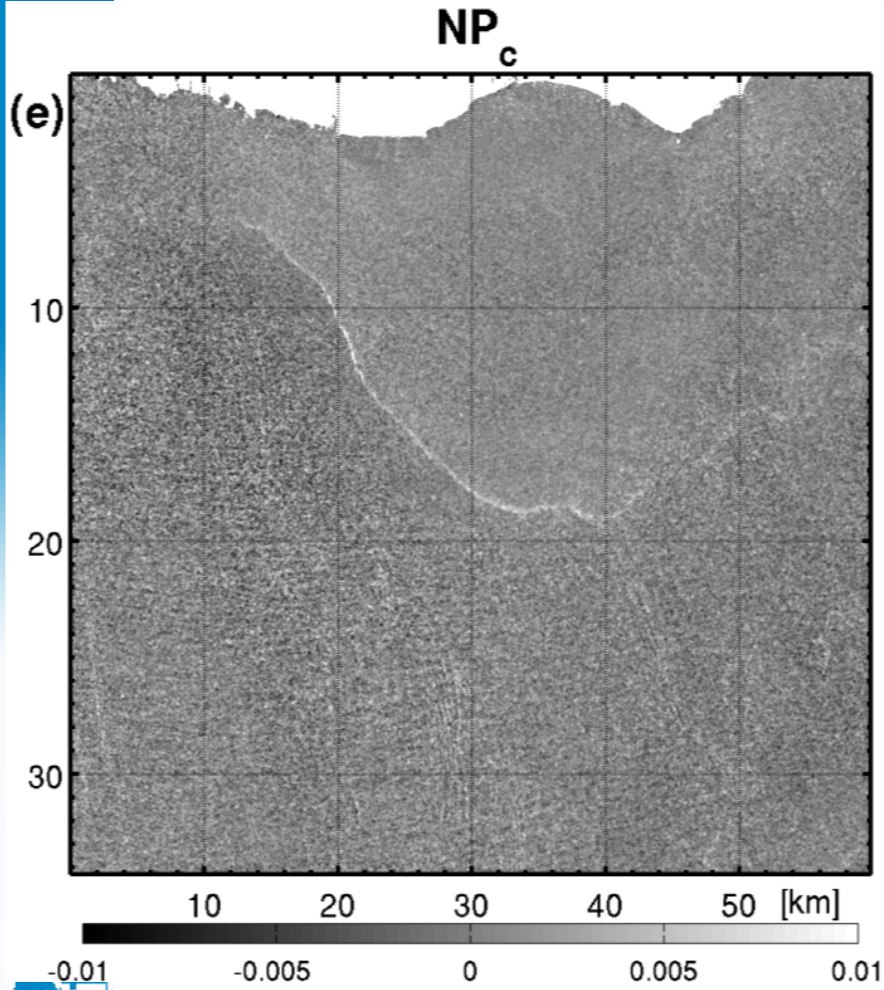
Manifestation of SST front: Bragg waves and wave breaking

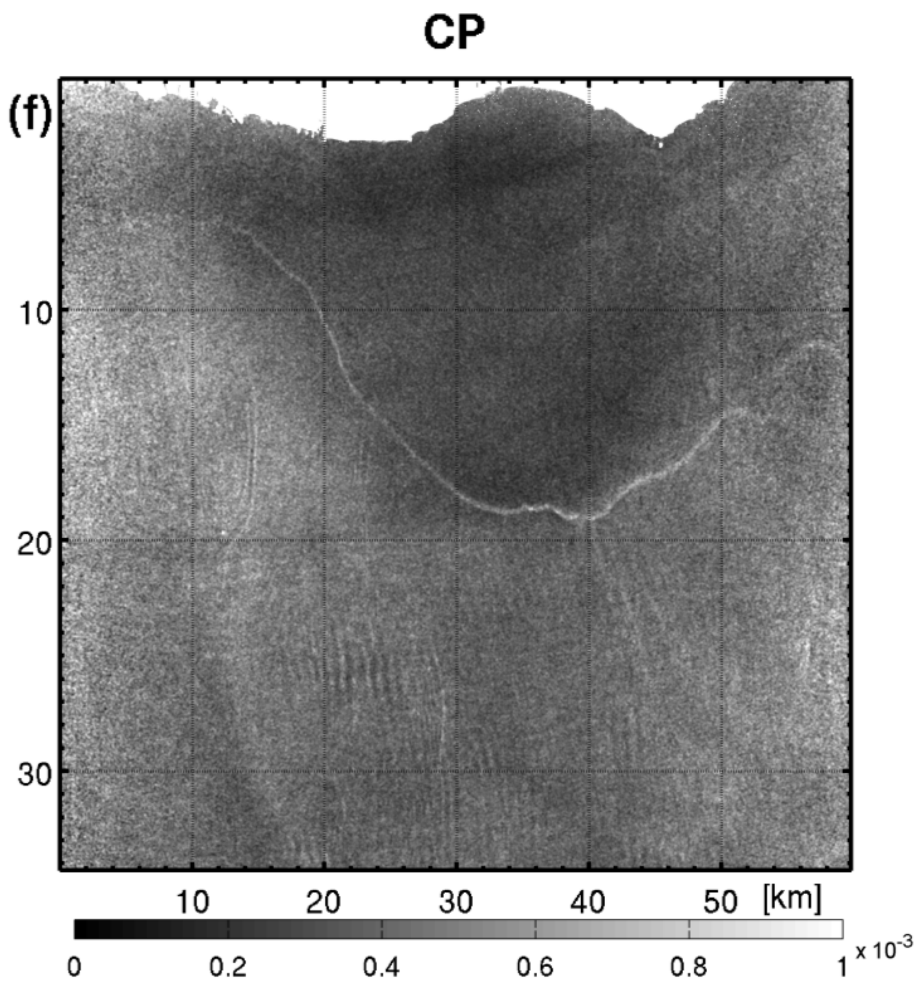


PD: Bragg waves trace wind field transformation over cold side of the front
NP: Wave breaking trace both (i) wind field transformation over cold SST waters, and convergent zone which edges the front.

Impact of current on wave breaking

Cross-Polarized image

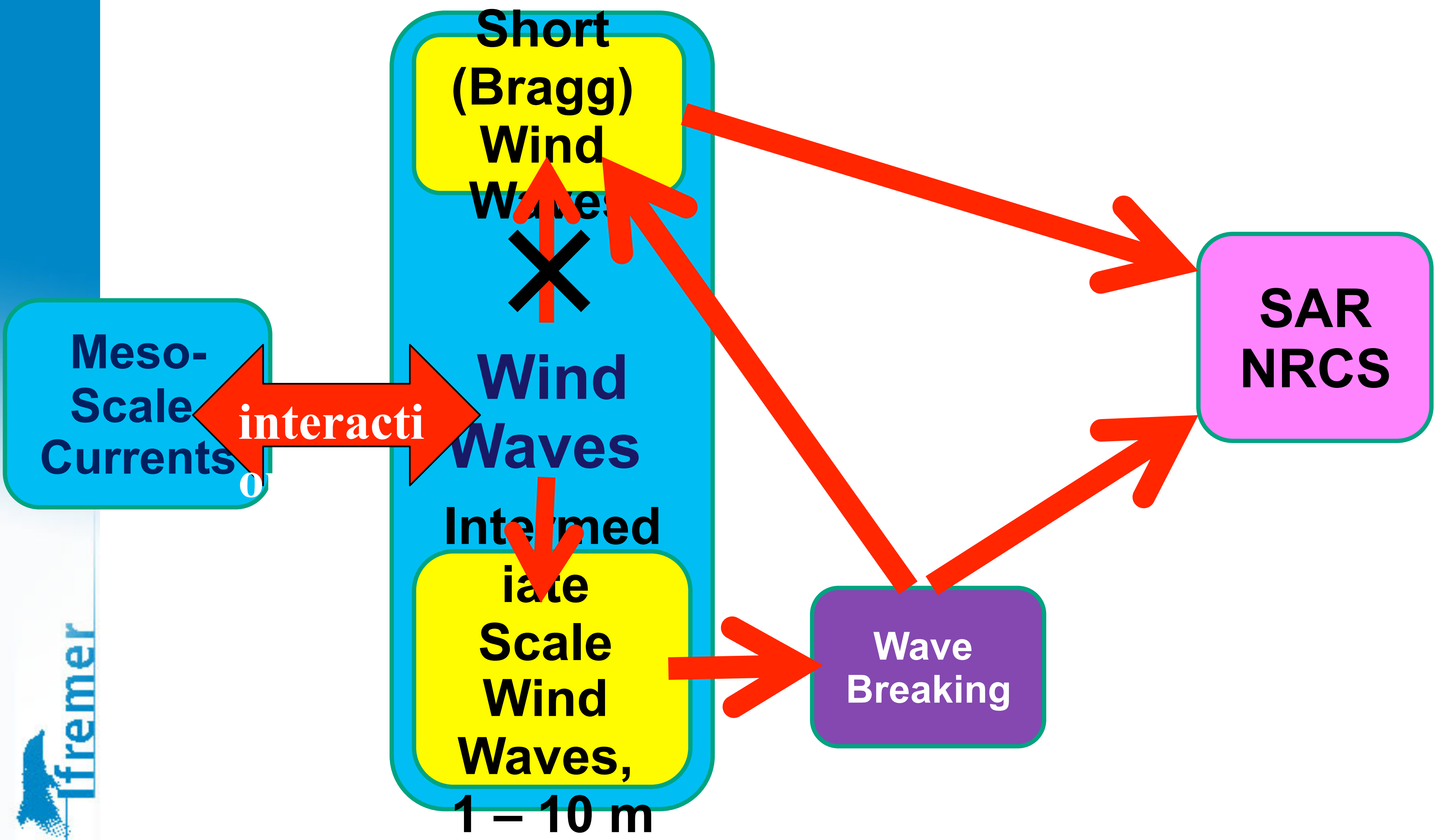




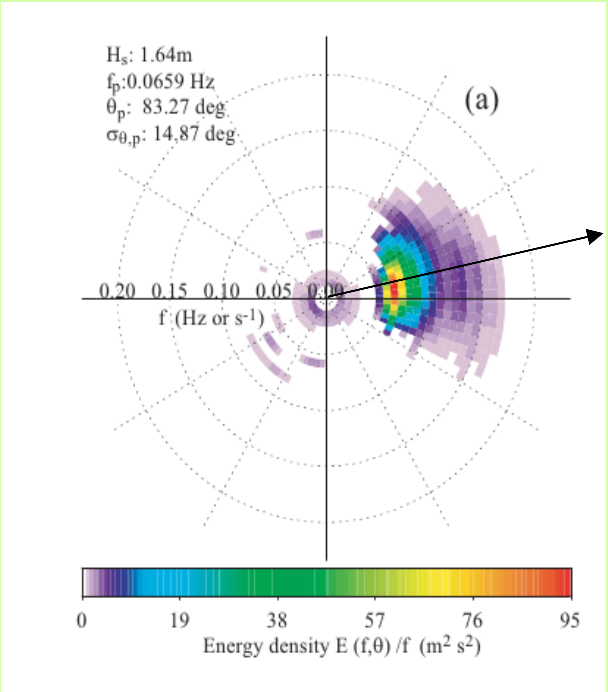
NP_c = NP – NPwind;

NPwind = a + b*PD

Physics of SAR imaging



Background wave spectr



Evolution of wave spectrum in the current

$$\frac{\partial N(\mathbf{k})}{\partial t} + (c_{gi} + u_i)\frac{\partial N}{\partial x_i} = -k_j \frac{\partial u_j}{\partial x_i}\frac{\partial N}{\partial k_i} + Q$$

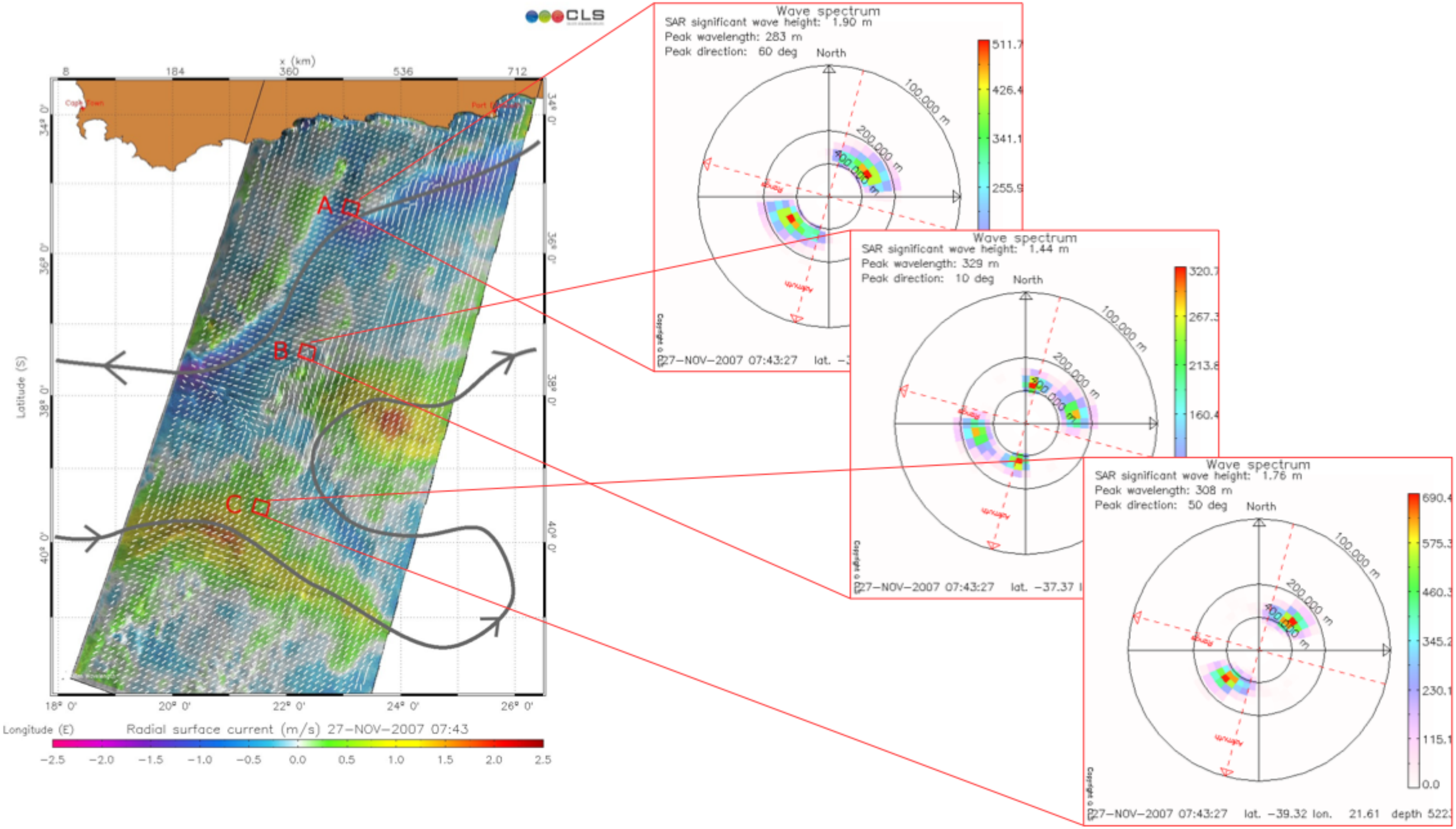
Propagation Current Sources, Sinks (wind, breaking,...)

Waves short enough to neglect propagation
Without current, equilibrium wind/breaking

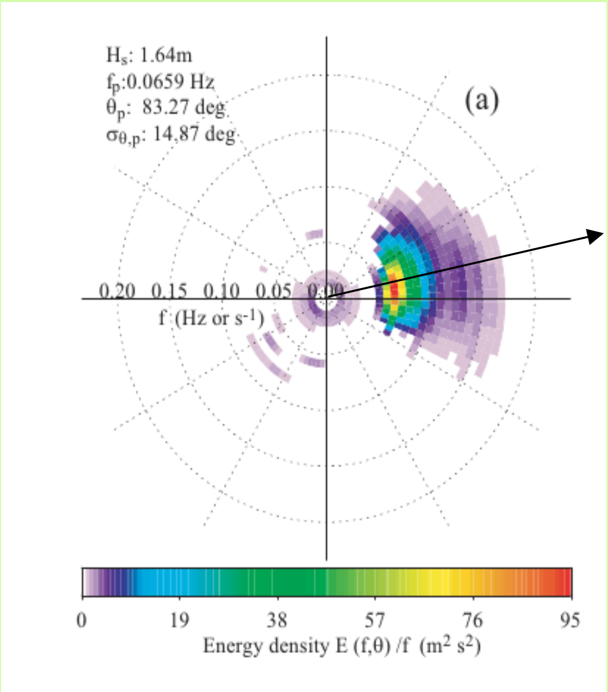
Spectrum anomaly

$$\tilde{N}(\mathbf{x}, k, \phi) = \tau_c \left[\begin{array}{cc} \cos\phi & \sin\phi \end{array}\right] \left[\begin{array}{cc} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{array}\right] \left[\begin{array}{cc} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{array}\right] \left[\begin{array}{c} \frac{\partial N_0}{\partial \ln k} \\ \frac{\partial N_0}{\partial \phi} \end{array}\right]$$

Corresponding slope (mss) anomaly


CLS
x (km)
8
184
360
536
712
Cape Town
Latitude (S)
34° 0'
36° 0'
38° 0'
40° 0'
18° 0'
20° 0'
22° 0'
24° 0'
26° 0'
Longitude (E)
A
B
C
Radial surface current (m/s) 27–NOV–2007 07:43
−2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5
Wave spectrum
SAR significant wave height: 1.90 m
Peak wavelength: 283 m
Peak direction: 60 deg
North
100.000 m
200.000 m
400.000 m
511.7
426.4
341.1
255.9
27–NOV–2007 07:43:27 lat.
Wave spectrum
SAR significant wave height: 1.44 m
Peak wavelength: 329 m
Peak direction: 10 deg
North
100.000 m
200.000 m
400.000 m
320.7
267.3
213.8
160.4
27–NOV–2007 07:43:27 lat. −37.37
Wave spectrum
SAR significant wave height: 1.76 m
Peak wavelength: 308 m
Peak direction: 50 deg
North
100.000 m
200.000 m
400.000 m
690.4
575.3
460.3
345.2
230.1
115.1
0.0
27–NOV–2007 07:43:27 lat. −39.32 lon. 21.61 depth 522

Wave spectrum



$$\tilde{N}(\mathbf{x},k,\phi) = \tau_c \begin{bmatrix} \cos\phi & \sin\phi \end{bmatrix} \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \frac{\partial N_0}{\partial \ln k} \\ \frac{\partial N_0}{\partial \phi} \end{bmatrix}$$

$$\widetilde{mss_x}(\mathbf{x}) = \int_k \int_\phi \omega^{-1} k \tilde{N} \; k^2 \cos^2\phi \; \mathrm{d}k\mathrm{d}\phi$$

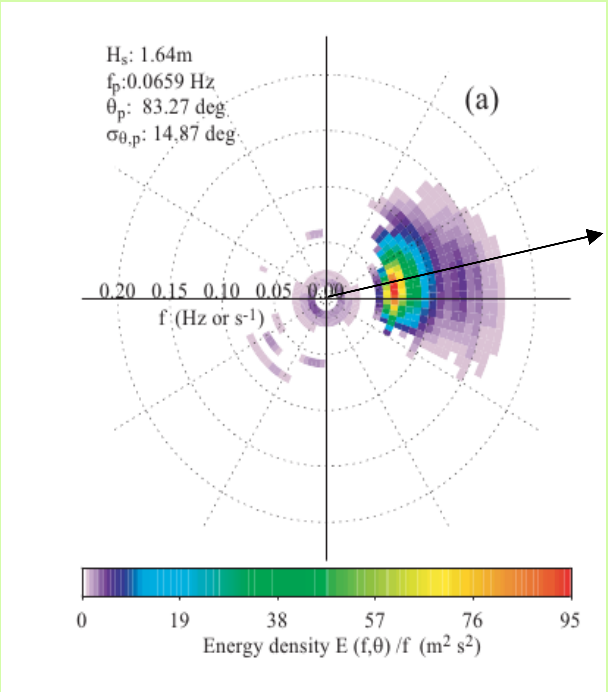
•For a spectrum symmetrical about the wind direction
•For wind in the x-direction

-> 2 types of currents will give no mss anomaly

$$\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix}$$

-> Only 2 over 4 types of current deformations will sign on the roughness image.

Wave spectrum



$$\tilde{N}(\mathbf{x},k,\phi) = \tau_c \begin{bmatrix} \cos\phi & \sin\phi \end{bmatrix} \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \frac{\partial N_0}{\partial \ln k} \\ \frac{\partial N_0}{\partial \phi} \end{bmatrix}$$

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- For a spectrum symmetrical about the wind direction
- For wind in the x-direction

-> 2 types of c $\begin{bmatrix} \frac{\partial u}{\partial x} & \cancel{\frac{\partial u}{\partial y}} \\ \cancel{\frac{\partial v}{\partial x}} & \frac{\partial v}{\partial y} \end{bmatrix}$ ll give no mss anomaly

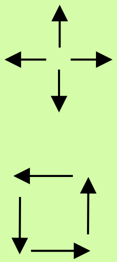
-> Only 2 over 4 types of current deformations will sign on the roughness image

Only 2 over 4 types of current deformations

will sign on the roughness image.

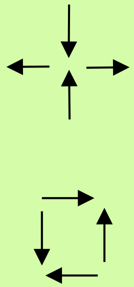
$$\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} D + S_t & -R + S_h \\ R + S_h & D - S_t \end{bmatrix}$$

t it:



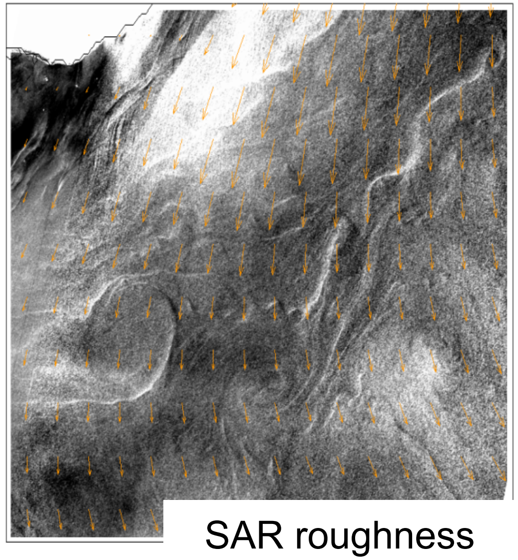
$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}, \quad S_t = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},$$

$$R = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad S_h = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}.$$



Which type of currents will sign?

- rotational currents
- divergent currents
- shear in the wind direction
- strain in the wind direction



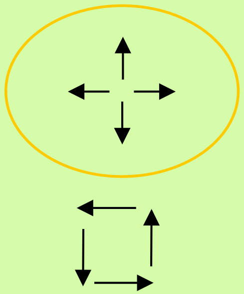
SAR roughness

Only 2 over 4 types of current deformations

will sign on the roughness image.

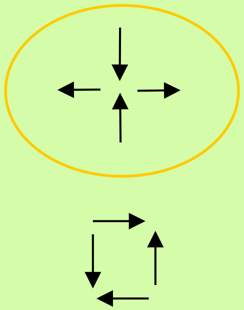
$$\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} D + S_t & -R + S_h \\ R + S_h & D - S_t \end{bmatrix}$$

t it:



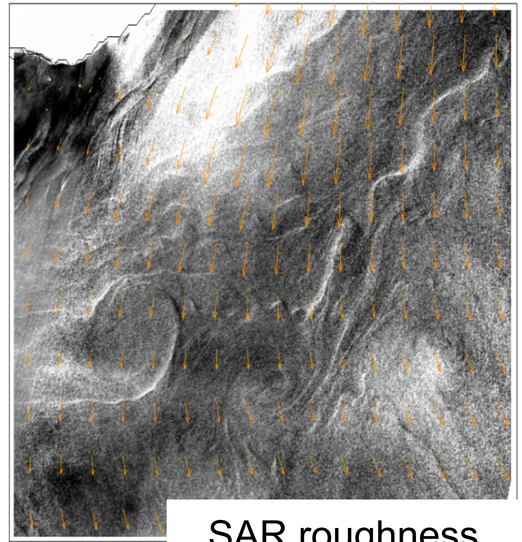
$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}, \quad S_t = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},$$

$$R = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad S_h = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}.$$



Which type of currents will sign?

- ~~rotational currents~~
- **divergent currents**
- ~~shear in the wind~~ direction
- **strain in the wind direction**



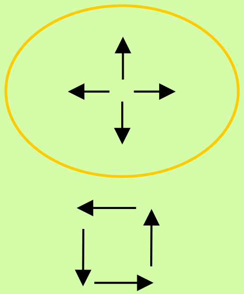
SAR roughness

Only 2 over 4 types of current deformations

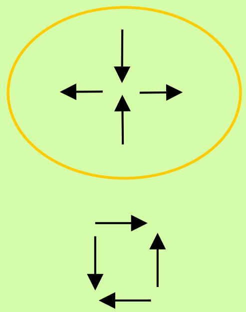
will sign on the roughness image.

$$\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} D + S_t & -R + S_h \\ R + S_h & D - S_t \end{bmatrix}$$

t it:

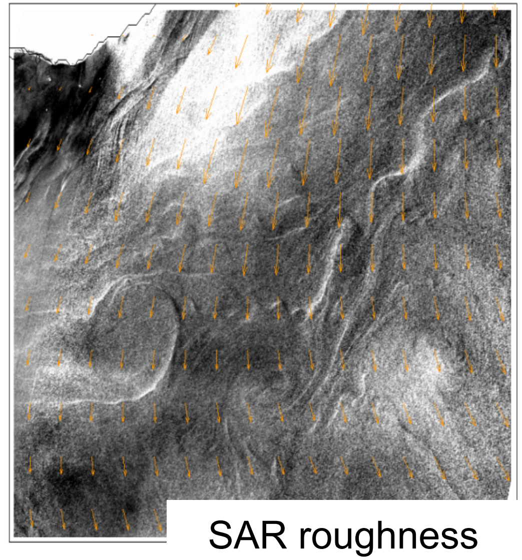


$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}, \quad S_t = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y},$$
$$R = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad S_h = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}.$$



Which type of currents will sign?

- ~~rotational currents~~
- **divergent currents**
- ~~shear in the wind~~ direction
- **strain in the wind direction**



SAR roughness

•Divergent currents appear independently of the wind direction

•Non divergent currents appear
with a 45°-sensitivity to the wind/current angle.

Physics of SAR imaging

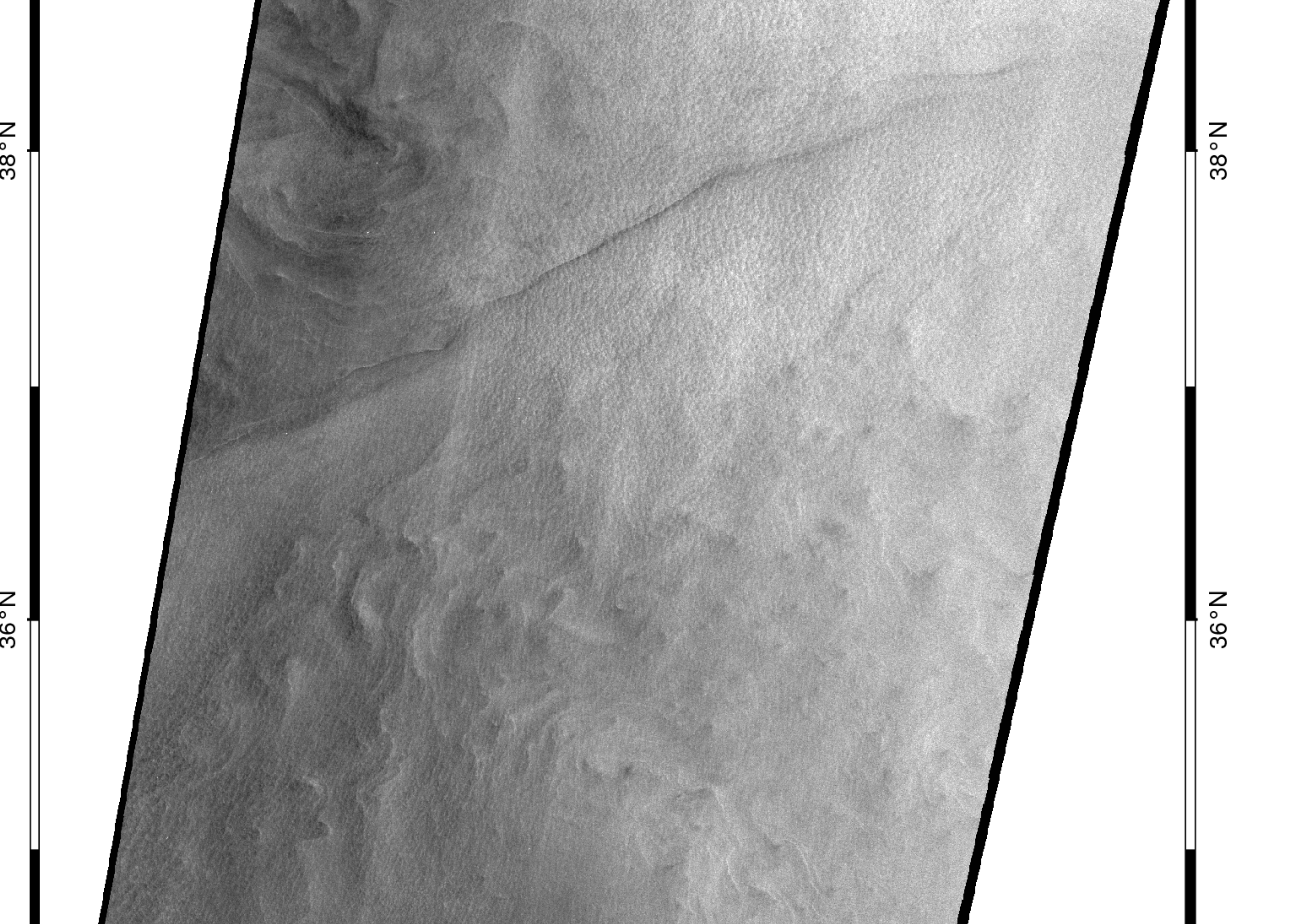
- Due to small relaxation scale, sub- and meso-scale current cannot affect Bragg wave directly;

- Wave-current interaction affects intermediate wave spectrum, with wavelength of order 1m and more;

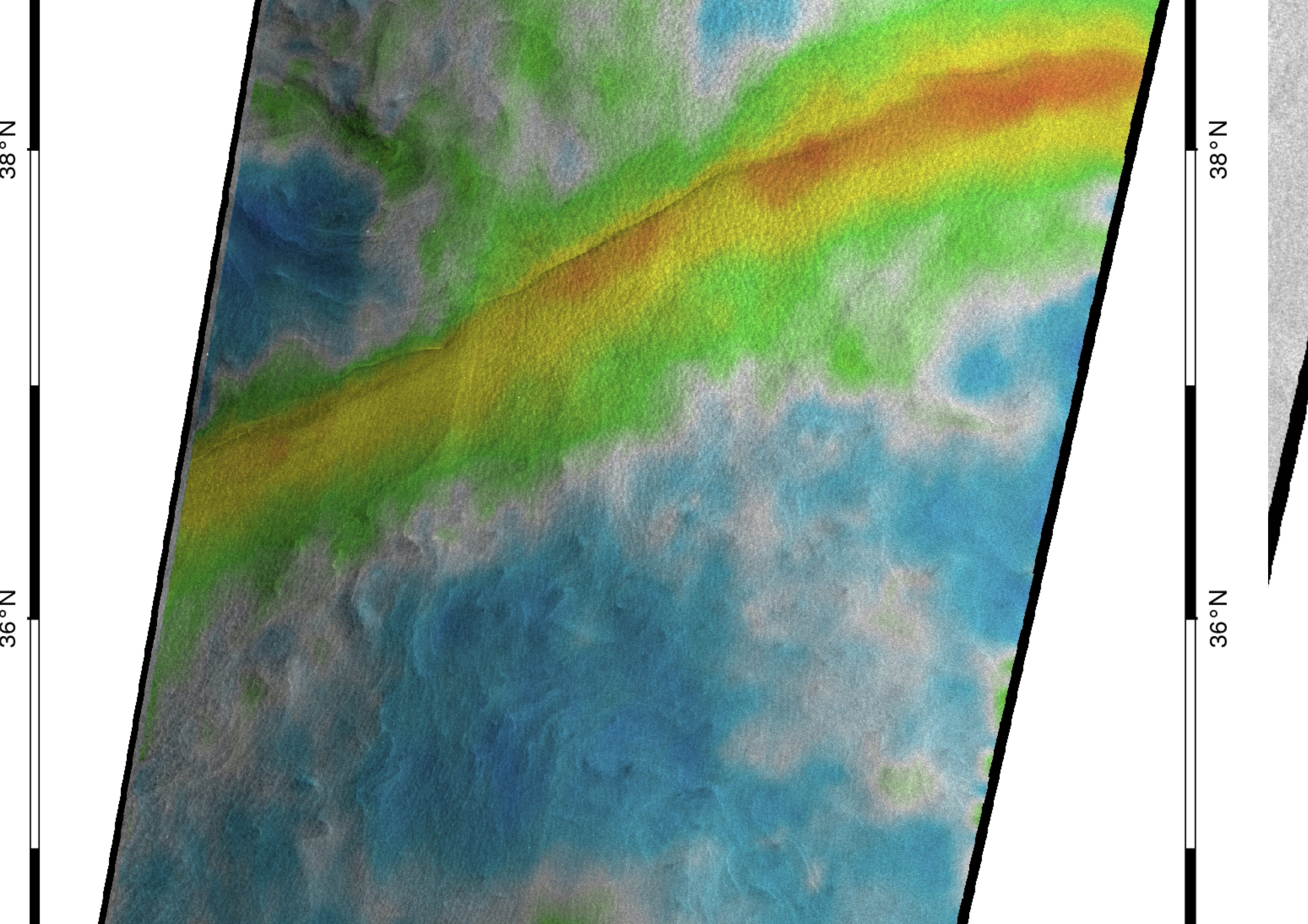
- Wave breaking are very sensitive to small spectrum variations;

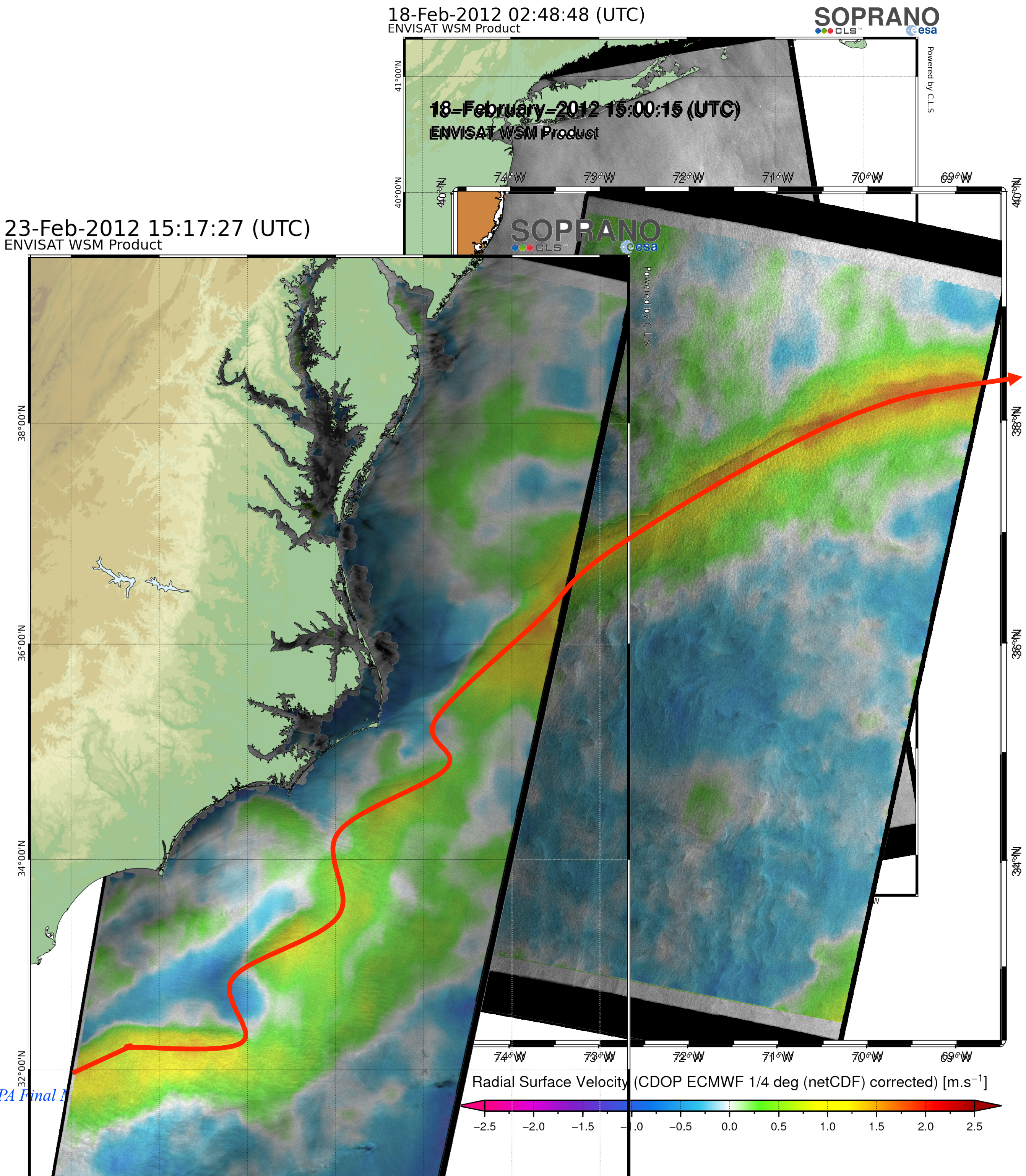
- Modulation of wave breaking provides Bragg waves modulations (via mechanical disturbances) and modulations of radar returns from breaking waves.

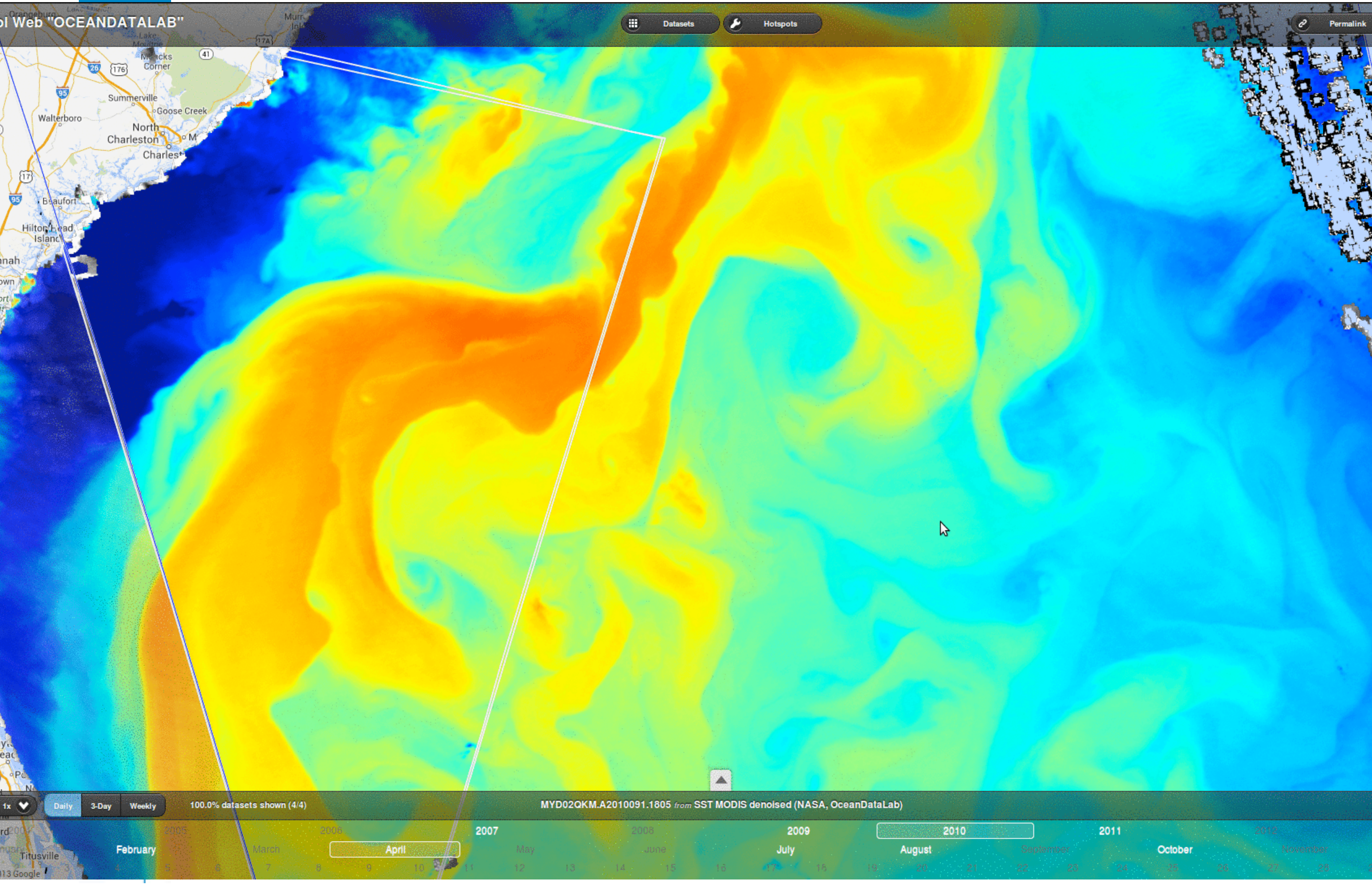
- Wave breaking mostly trace current divergence.



38°N
36°N
38°N
36°N


38°N
36°N
38°N
36°N


18-Feb-2012 02:48:48 (UTC)
ENVISAT WSM Product
SOPRANO
CLS
esa
Powered by C.L.S
18-February-2012 15:00:15 (UTC)
ENVISAT WSM Product
23-Feb-2012 15:17:27 (UTC)
ENVISAT WSM Product
41°00'N
40°00'N
38°00'N
36°00'N
34°00'N
32°00'N
74°W
73°W
72°W
71°W
70°W
69°W
Radial Surface Velocity (CDOP ECMWF 1/4 deg (netCDF) corrected) [m.s⁻¹]
−2.5
−2.0
−1.5
−0.5
0.0
0.5
1.0
1.5
2.0
2.5



Web "OCEANDATALAB"
Datasets
Hotspots
Permalink
Summerville
Walterboro
North Charleston
Goose Creek
Beaufort
Hilton Head Island
Daily
3-Day
Weekly
100.0% datasets shown (4/4)
MYD02QKM.A2010091.1805 from SST MODIS denoised (NASA, OceanDataLab)
2007
2009
2010
2011
February
April
July
August
October
Titusville