Quad-polarization SAR imaging of ocean currents

I. Kozlov [a,b], V. Kudryavtsev [a], B. Chapron [a,c], F. Collard [d], J. Johannessen [e]

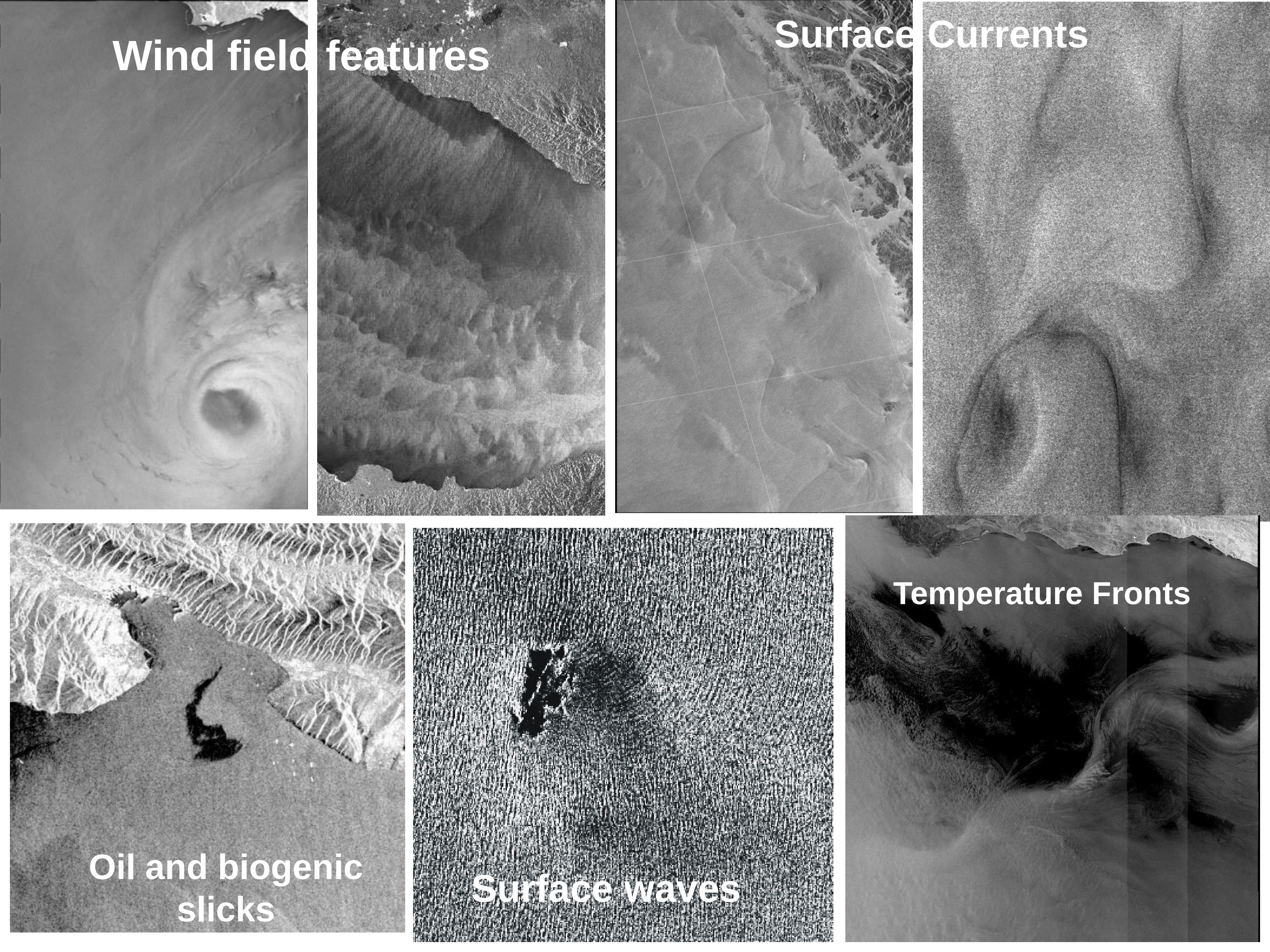
a) Satellite Oceanography Lab (SOLab) RSHU, St. Petersburg, Russia
b) Klaipeda University, Klaipeda, Lithuania
c) IFREMER, Brest, France
d) OceanDataLab, Brest, France
e) Nansen Centre, Bergen, Norway

Intro

* Synthetic Aperture Radars (SAR) are powerful tool to monitor marine and atmospheric environment.

* Main advantages of SAR observations are
- Independency on cloud conditions and Illumination,
- Ability to provide observations with high spatial resolution (>5 m) on the global scales

* SAR have already demonstrated their capabilities to observe various oceanic phenomena


Wind field features
Surface Currents
Temperature Fronts
Oil and biogenic slicks
Surface waves

Intro

* Synthetic Aperture Radars (SAR) are powerful tool to monitor marine and atmospheric environment.

* Main advantages of SAR observations are
- Independency on cloud conditions and Illumination,
- Ability to provide observations with high spatial resolution (>5 m) on the global scales

* SAR have already demonstrated their capabilities to observe various oceanic phenomena.

* In spite of the great informational capabilities, physics of SAR imaging of ocean phenomena is still poorly understood.

* Polarization sensitivity of SAR signals allows to separate between roughness changes associated with wave breaking and resonant (Bragg) scattering.

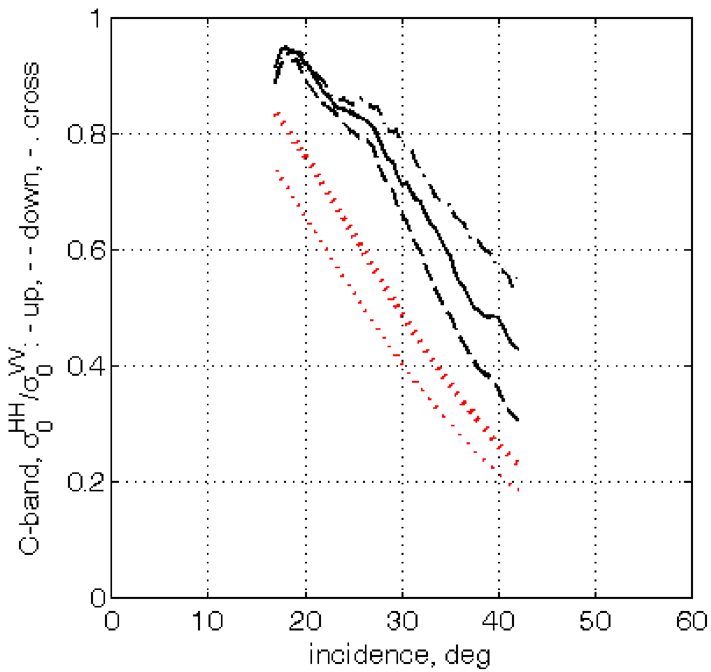
Main goal:

- To demonstrate and promote an effective and simple methodology to exploit Quad-Polarized SAR data (VV, HH and cross-pol VH or HV)
- - to interpret and quantitatively assess role of different scattering mechanisms in surface manifestation of oceanic currents
- - to discriminate SAR signature of upper ocean dynamics from varying wind field features.
-

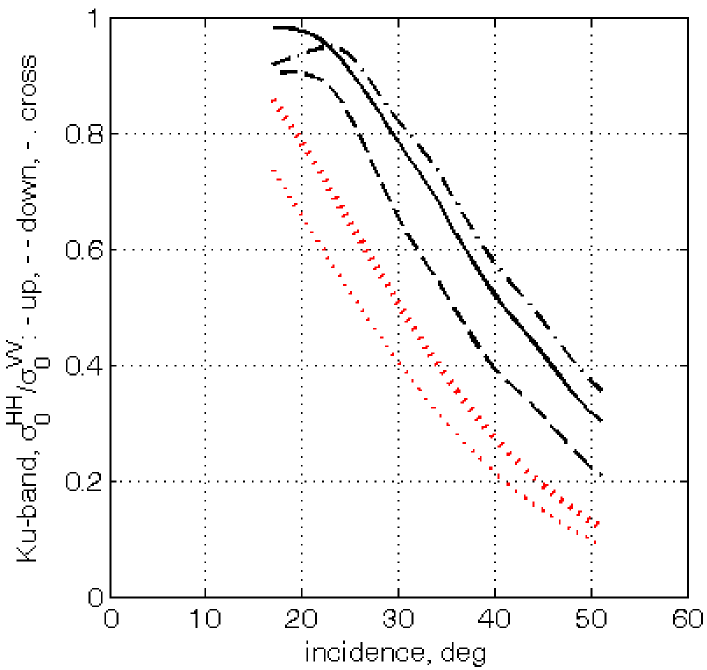
Based on an approach for analysis of Dual Co-pol SAR (Kudryavtsev et al., IEEE GRSL, 2013) and further extended to Quad-pol SAR data (Kudryavtsev et al., JGR, 2014 (submitted).

Polarization Ratio as indicator of governing scattering mechanisms

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



C-band, Mouche et al., 2006

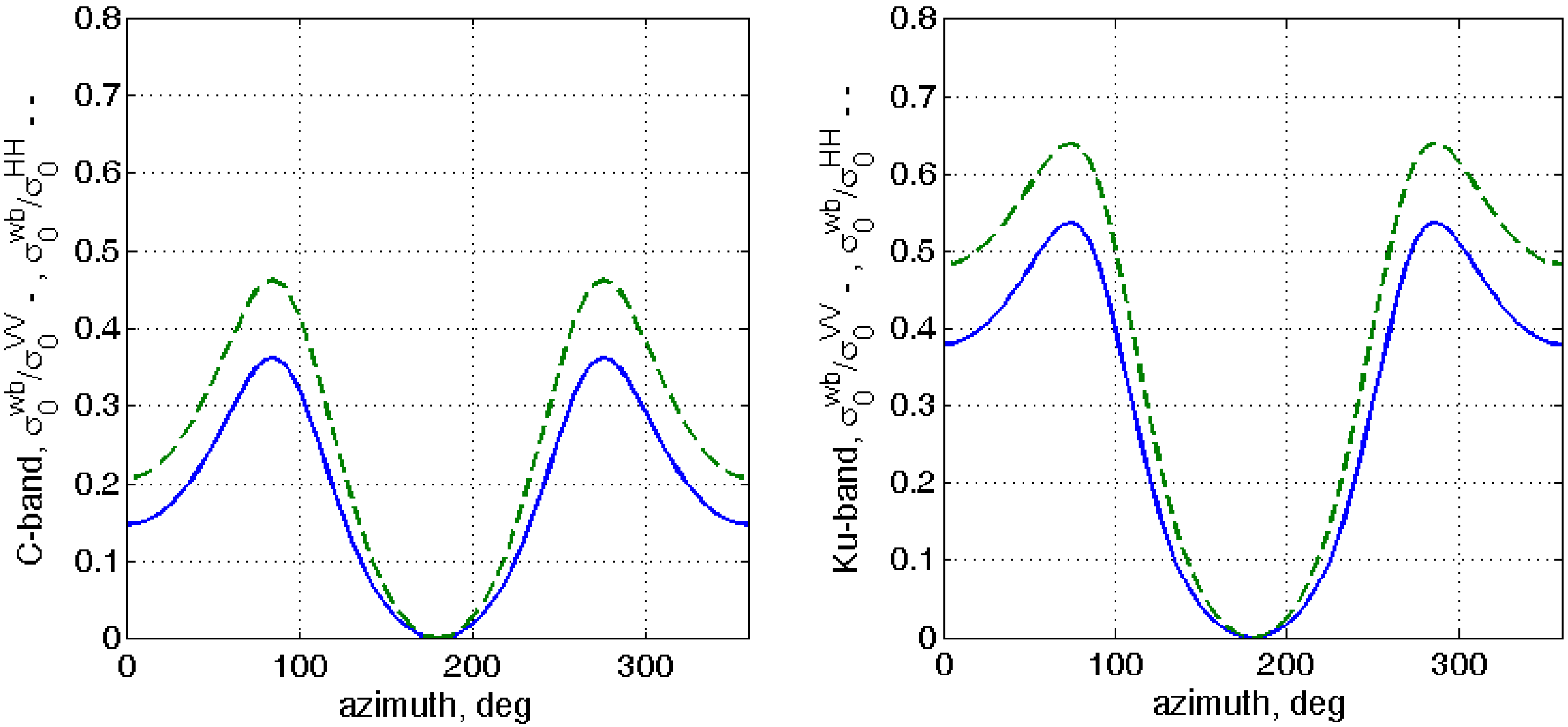


Ku-band, Quilfen et al.,1999

- PR significantly deviates from Bragg predictions.
- Thus radar returns strongly affected by breaking waves

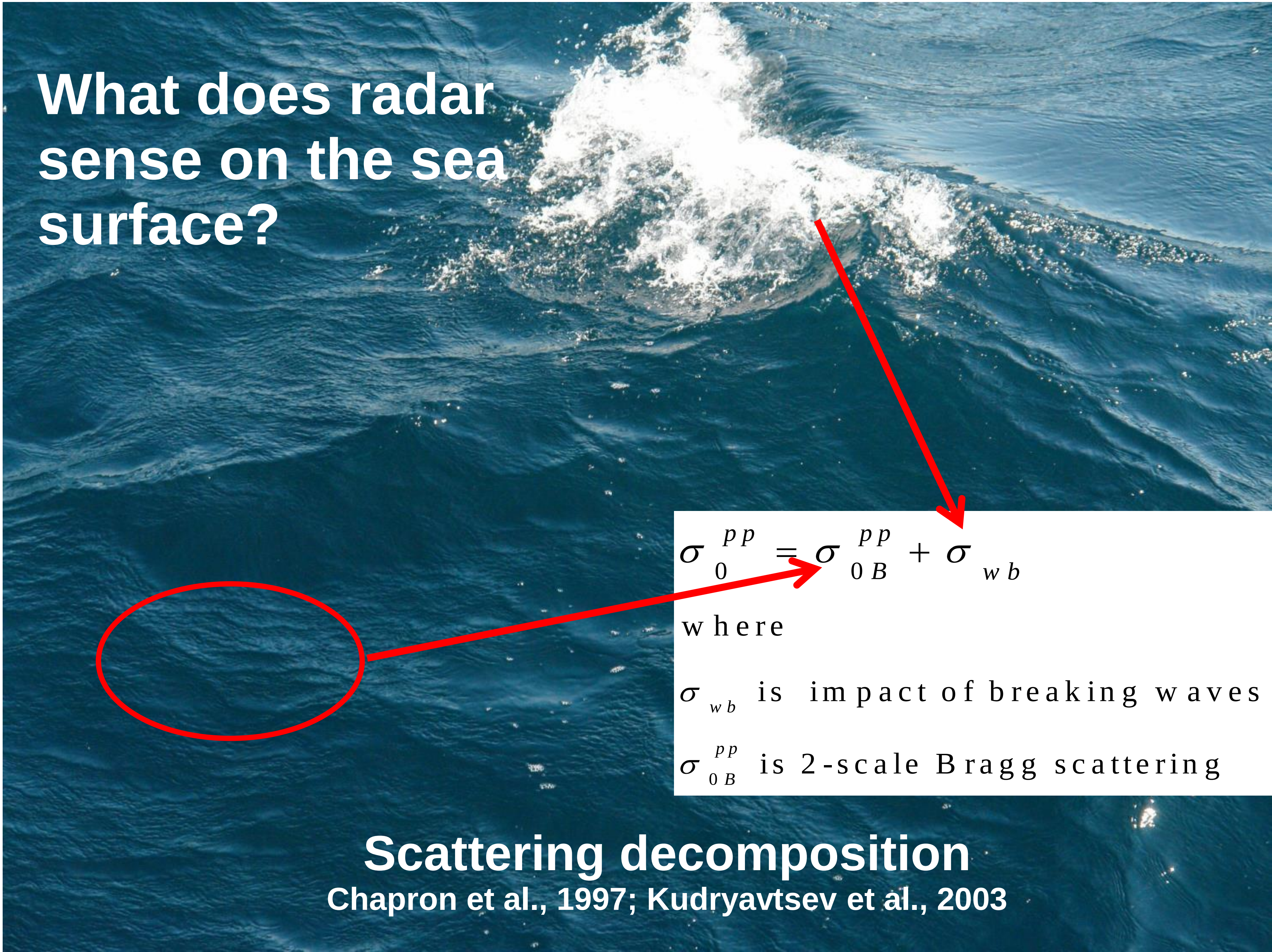
Relative Contribution of wave breaking

$$\sigma_{wb} / \sigma_0^{pp}$$



C-band U10 = 10 m/s, incidence angle 30 deg Ku-band

What does radar sense on the sea surface?



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

where

σ_{wb} is impact of breaking waves

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

Scattering decomposition

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

Scattering decomposition: short Bragg and breaking waves contributions

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

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

The main idea:

VV and HH polarized image are transformed in 2 other new images describing very different surface properties:

- **Short wind waves (~ 6 cm)**
- **Wave breaking**

Polarization Difference, PD, short Bragg waves:

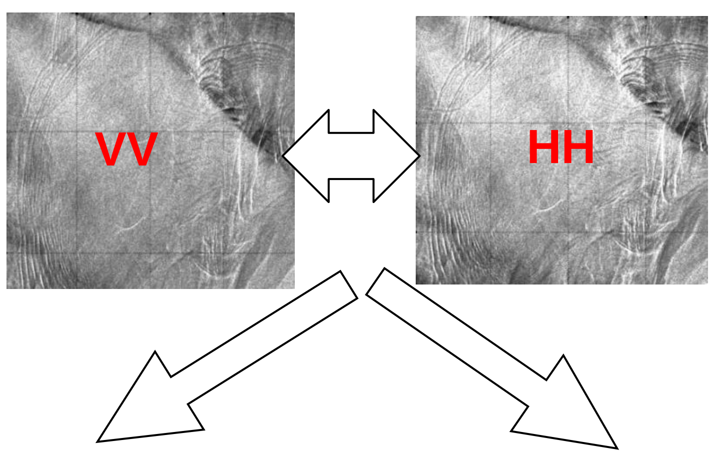
$$\Delta\sigma_0 \equiv \sigma_0^{vv} - \sigma_0^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}$$

NP contribution from breaking waves:

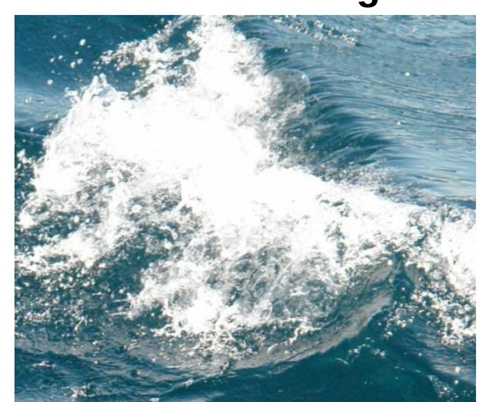
$$\sigma_{wb} = \sigma_0^{vv} - \Delta\sigma_0 \big/ (1 - p_B)$$

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

Polarized scattering
Short wind waves



Non-polarized scattering
Wave breaking

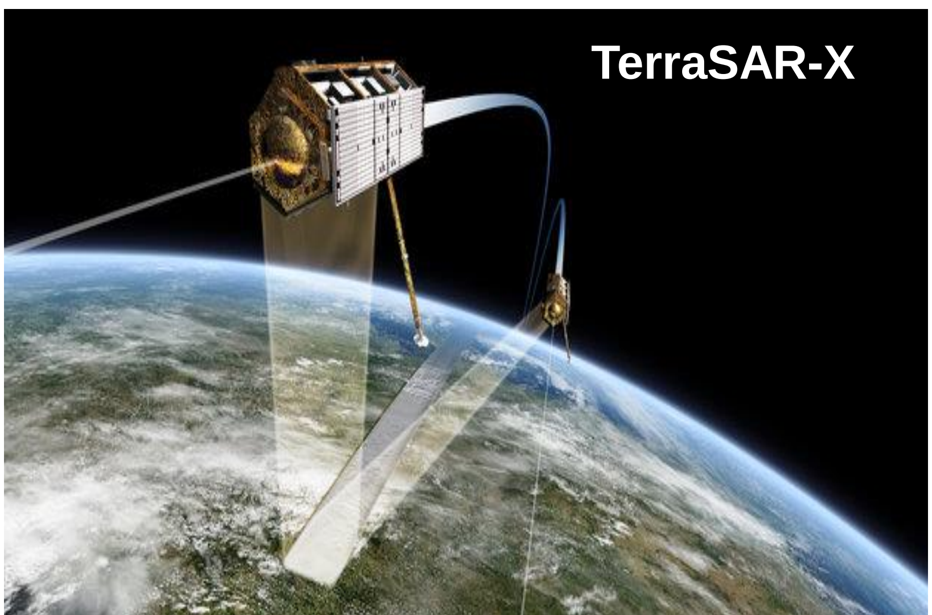


- **PD-image** is linked to resonant scattering mechanism, and since Bragg waves are fast-response waves, this image should carry information about **wind field variability and surface slicks**.

- **NP-image** is linked to “scalar” radar returns associated with breaking waves. Since wave breaking are sensitive to surface current, NP-image should carry information about **sub- and meso-scale ocean current features**.

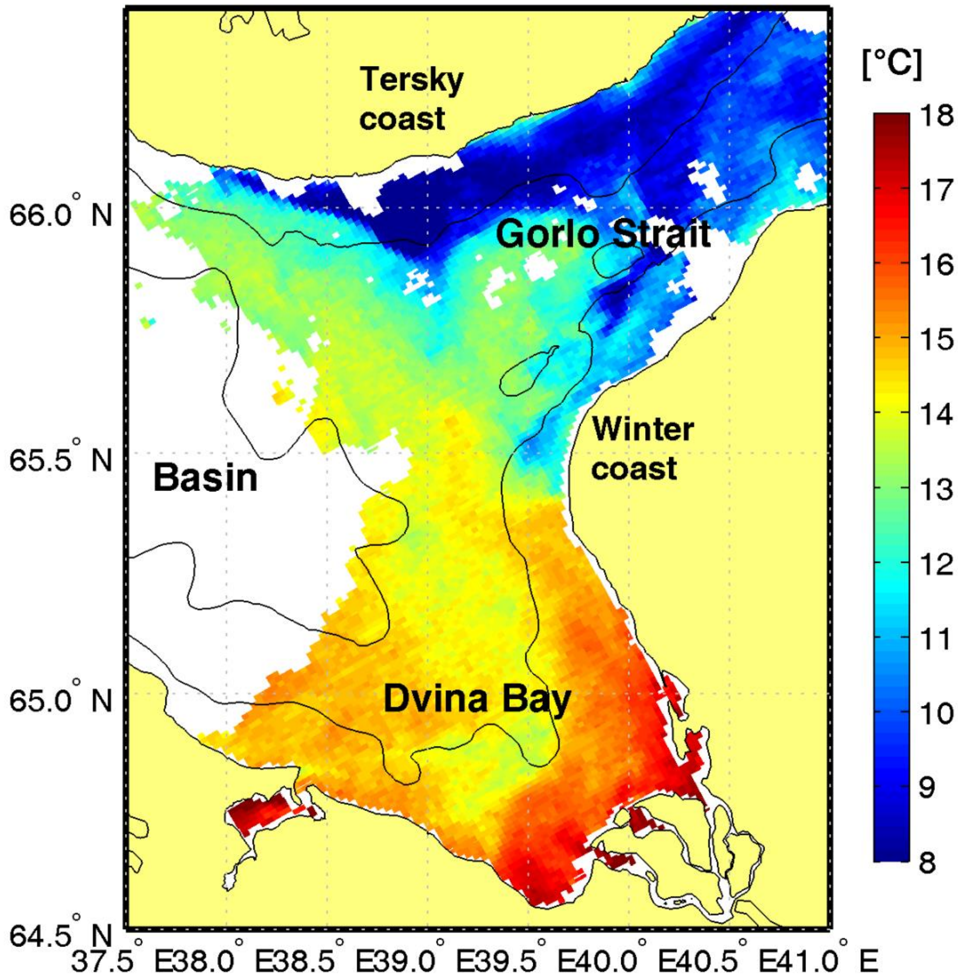
- Different sensitivity of short waves and wave breaking to wind, current, and surface contaminations opens new opportunity to investigate various ocean phenomena

Operating SAR are multi-polarized instruments: VV, HH, VH, HV



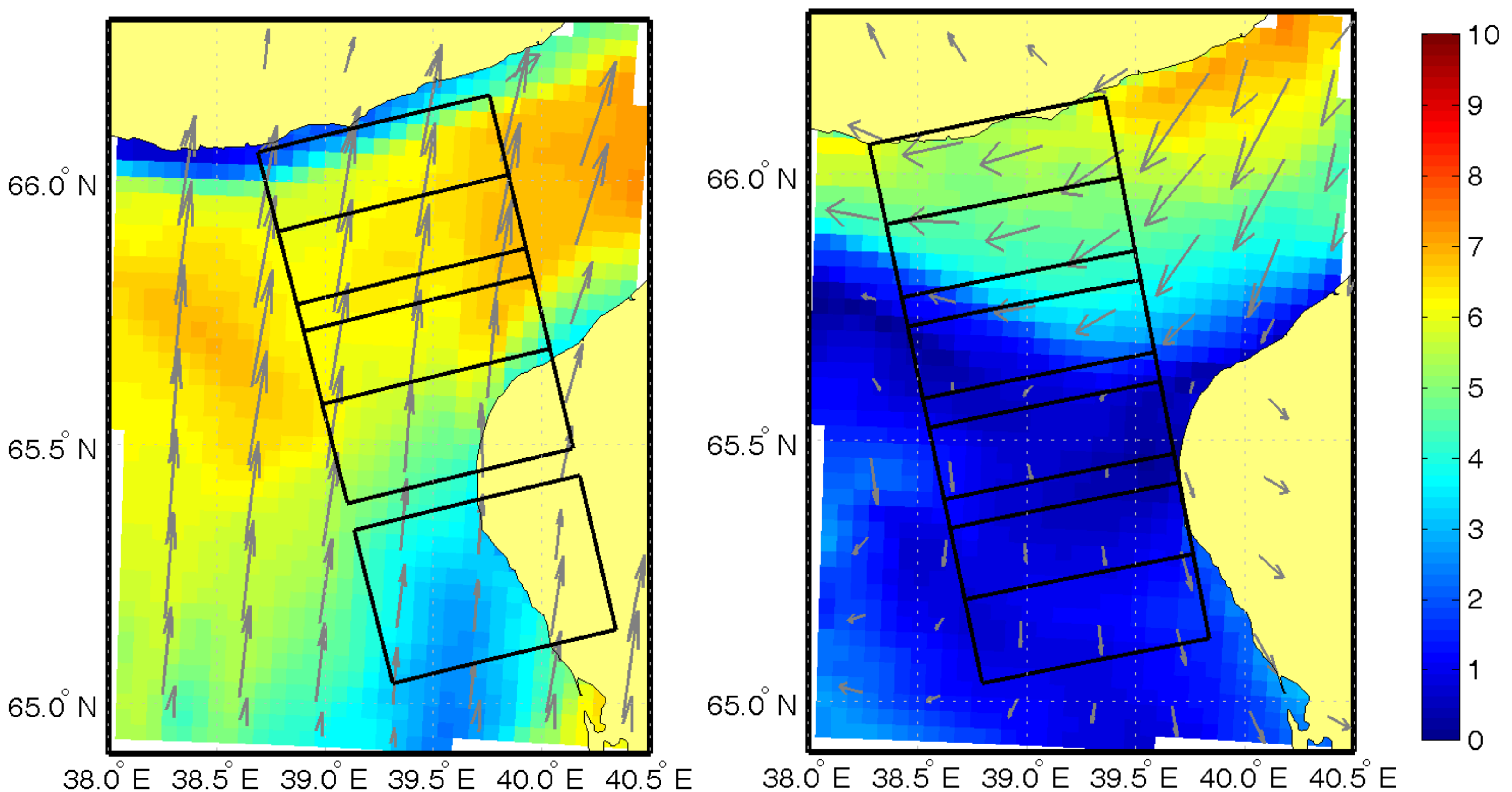
Data set and study area

- 9 Radarsat-2 SLC Quad Pol (HH+VV+VH+HV), C-band, 5 m pixel resolution over the White Sea
- Incidence angles: 32° and 40°



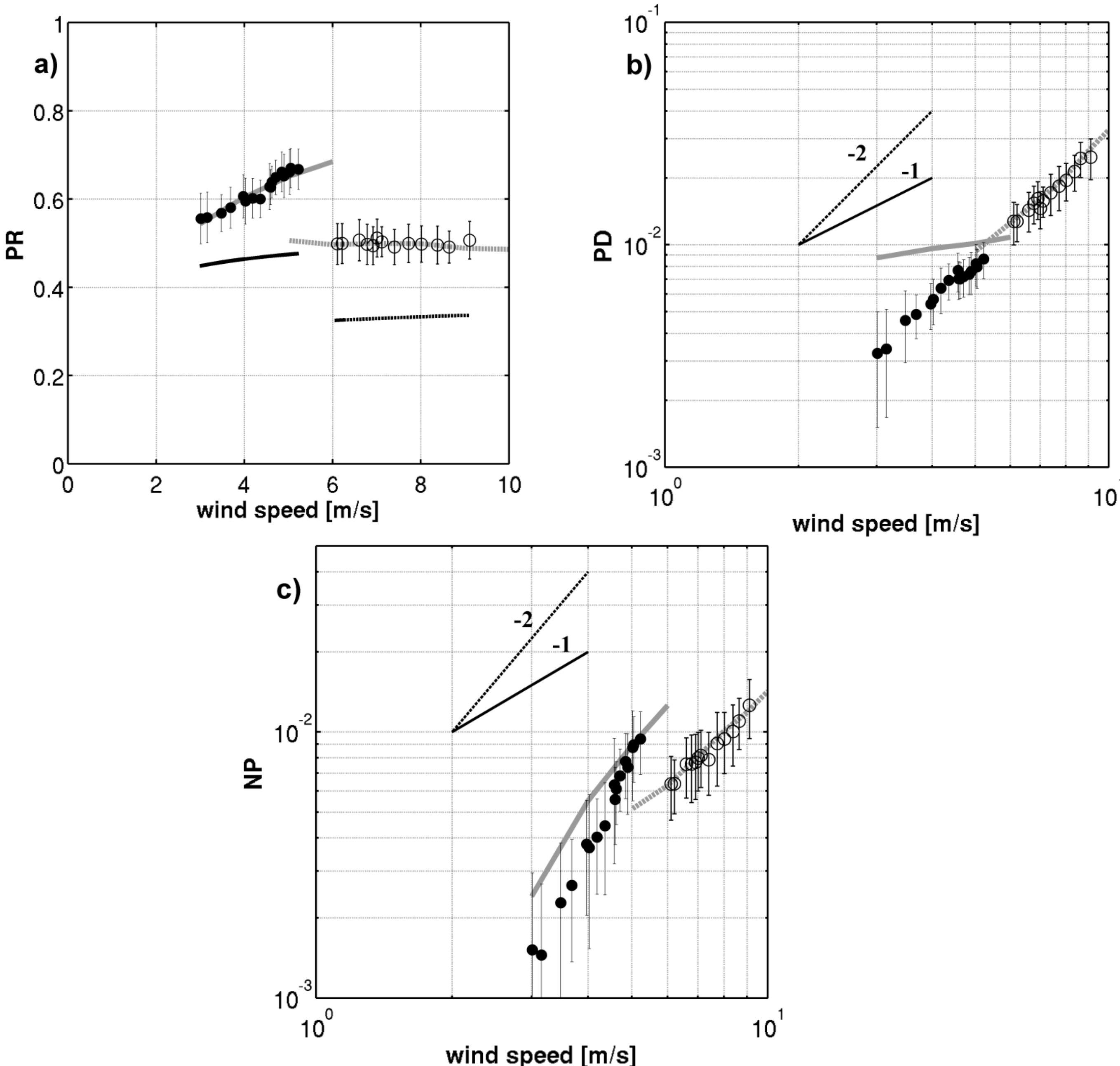
Background wind conditions

MM5 model winds (S. Mostamandi, RSHU)

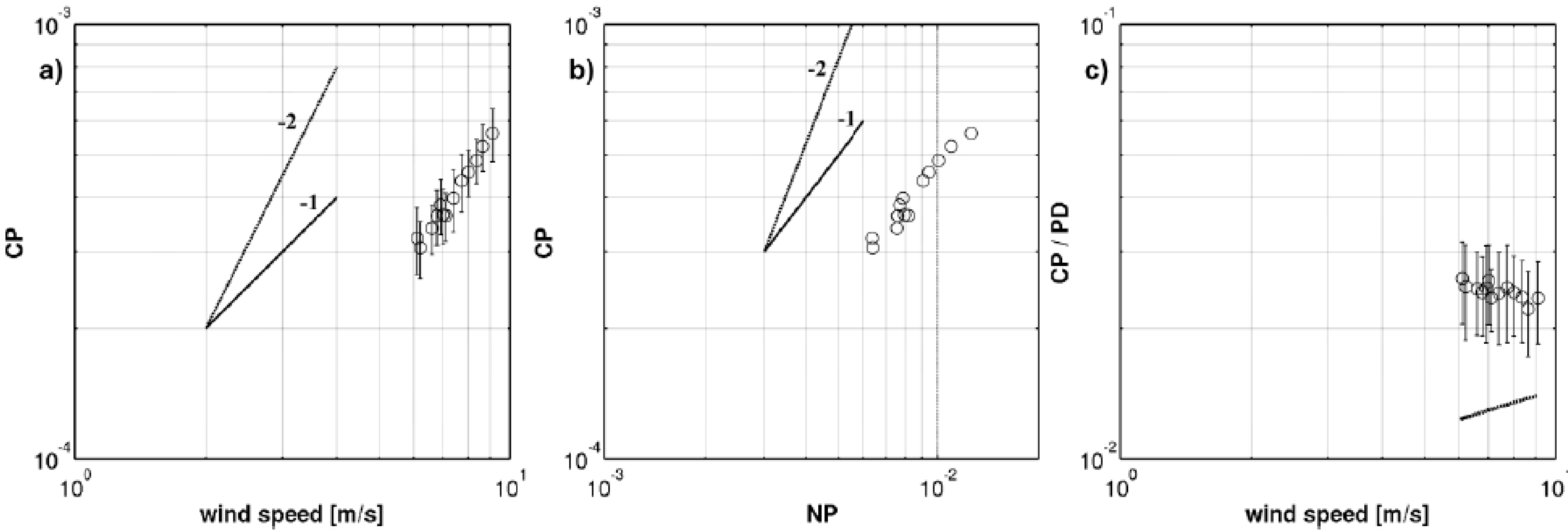


29 July 2012 **1 August 2012**

Background properties of NRCS

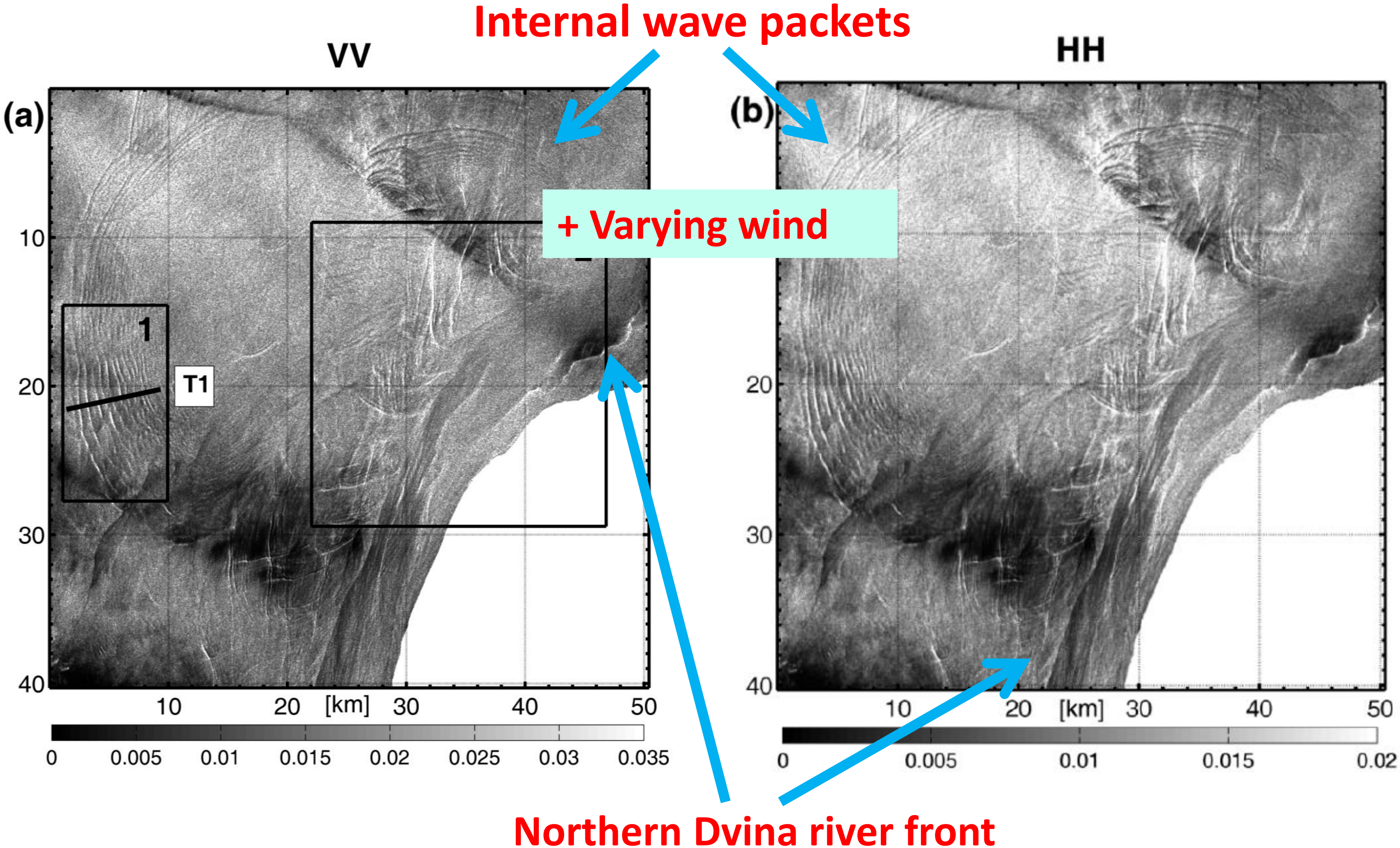


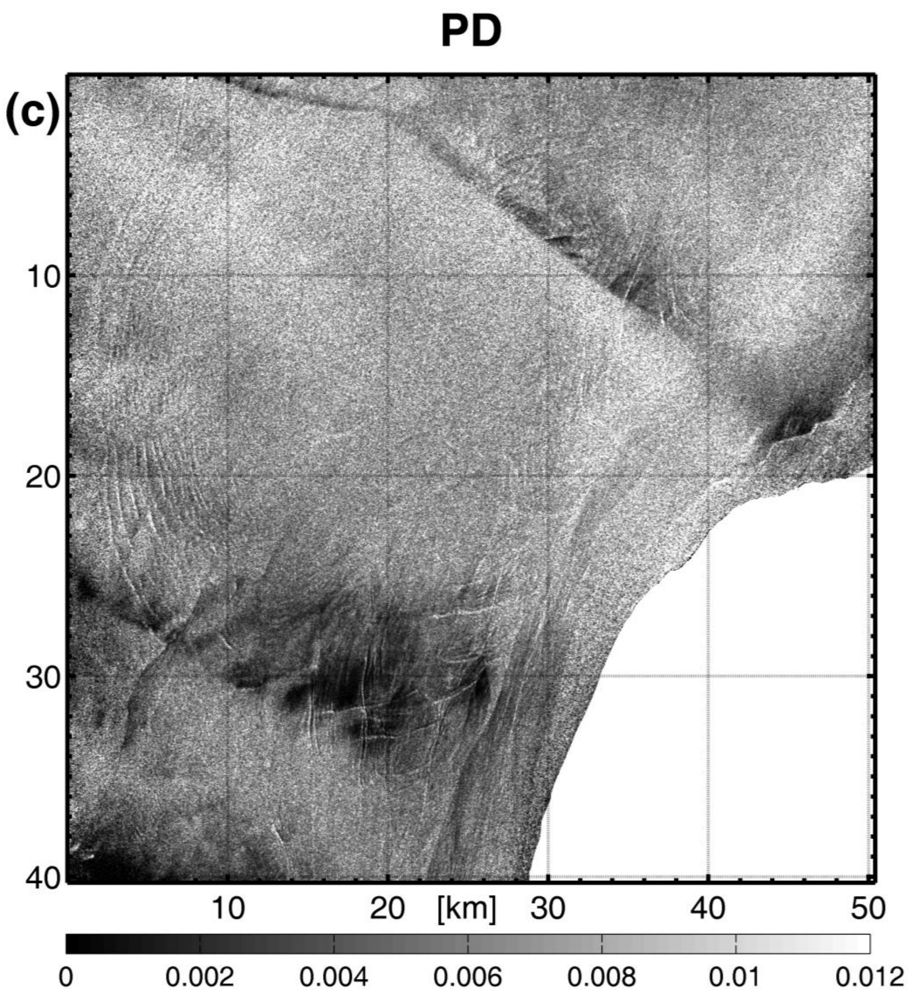
Background properties of NRCS – Cross-Pol (VH)



29 July 2012 - Internal waves and current

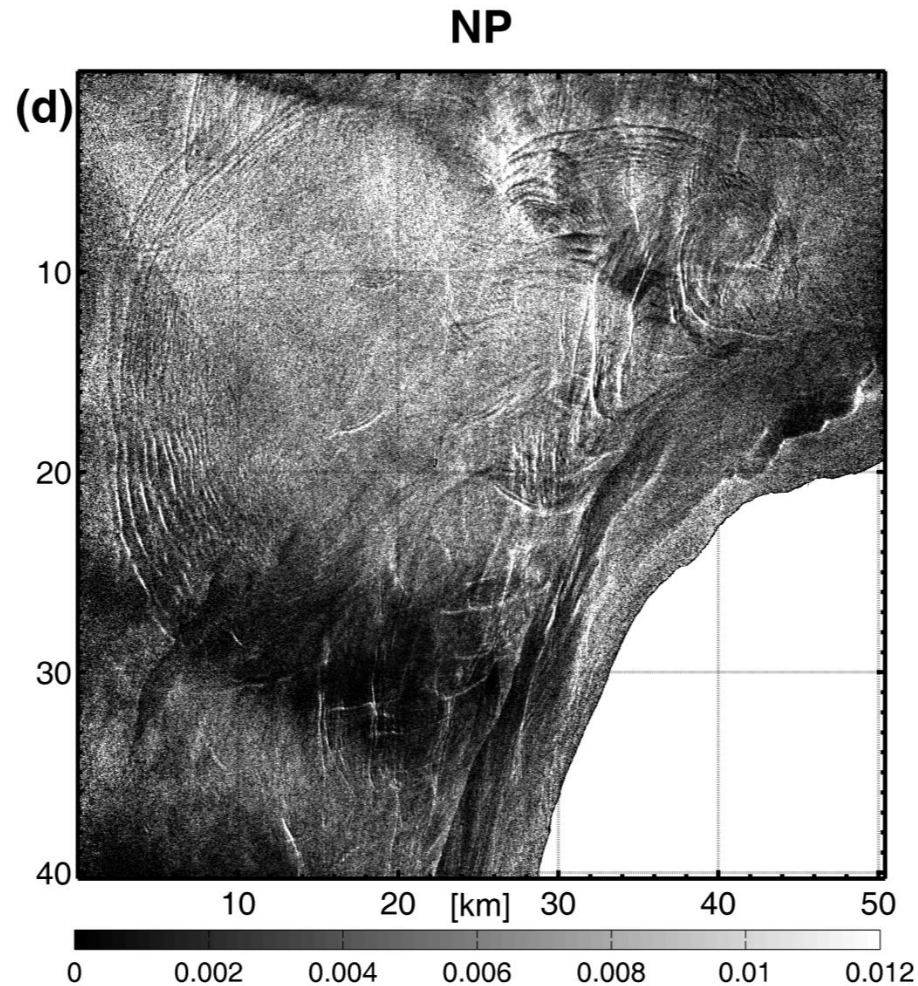
Cross-wind, wind 3-5 m/s, incidence angle=32°





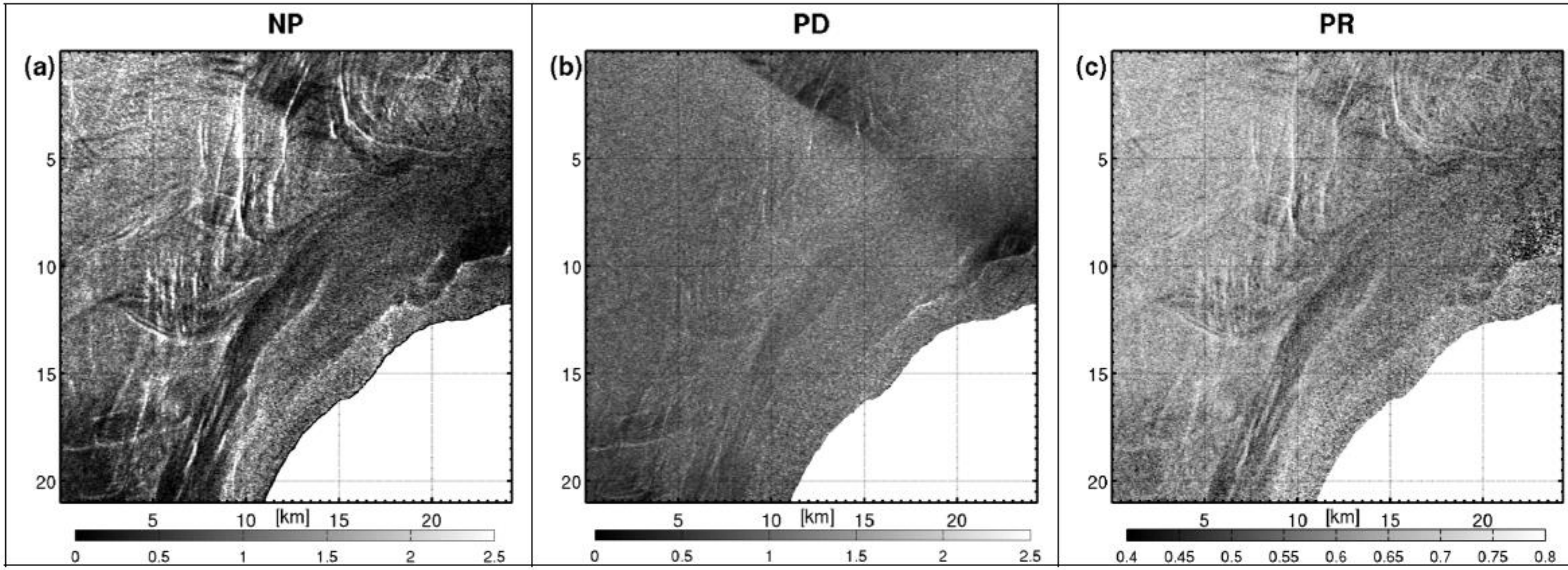
PD = VV – HH (Bragg)

Wind field variation



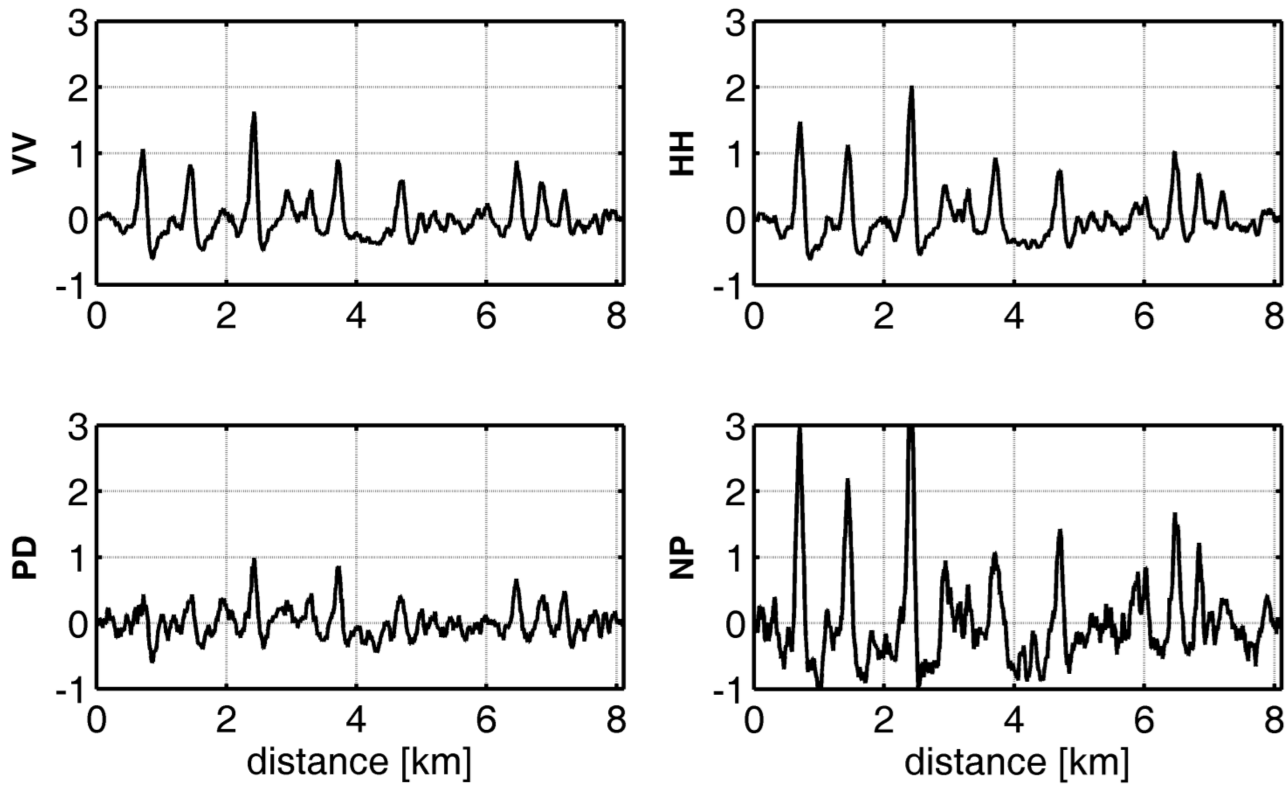
NP (wave breaking)

Combined effect of wind and currents on wave breaking



Modulation of wave breaking by surface currents dominates SAR images contrasts compared to the modulation of short-scale Bragg waves

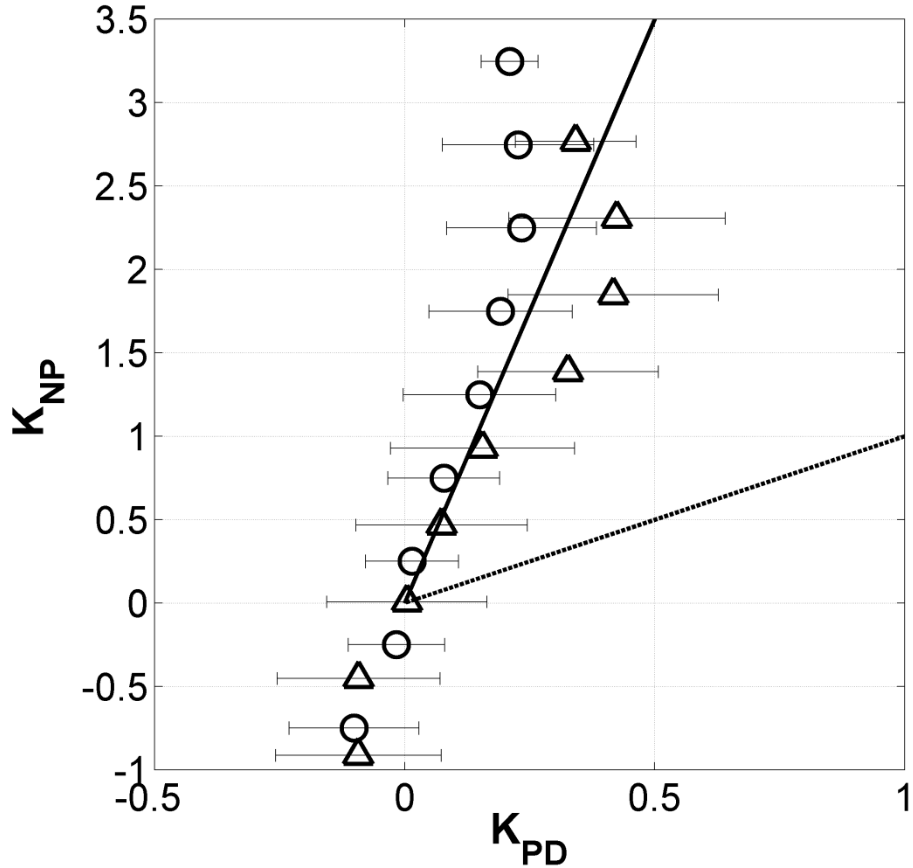
Transect over the IW packet



The contrast of the quantity y is defined as $K_y = (y - \overline{y}) / \overline{y}$, where $\overline{y}$ is its mean value.

The largest contrasts amplitudes are observed for NP, and the smallest for PD.

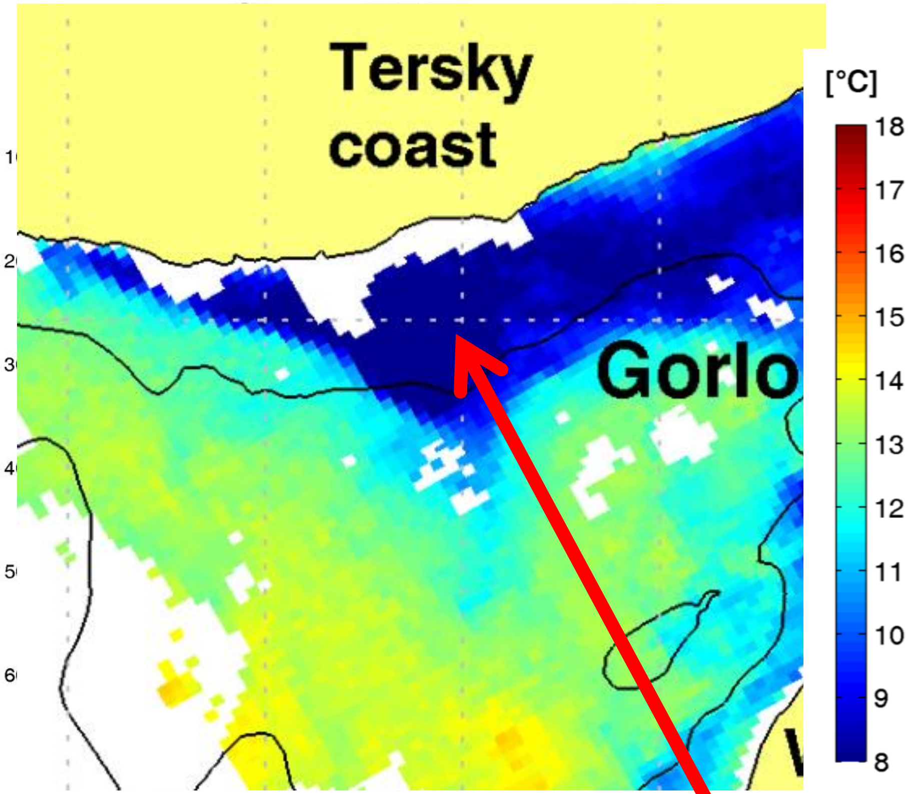
scatter plot of K_{NP} - and K_{PD} -contrasts.

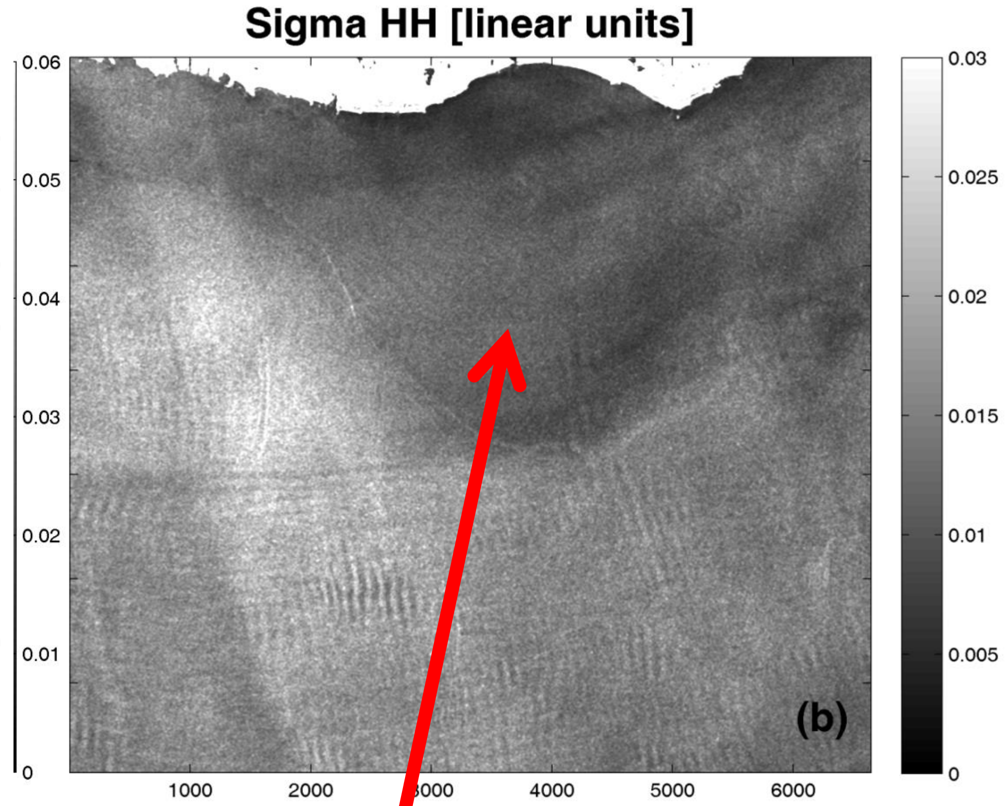


The combine data set gives $K_{NP} = 7 \times K_{PD}$, confirming that NP contrasts are largely amplified compared to PD contrasts.

1 August 2012 - Coastal current

Up-wind, wind 5-8 m/s, incidence angle=40°

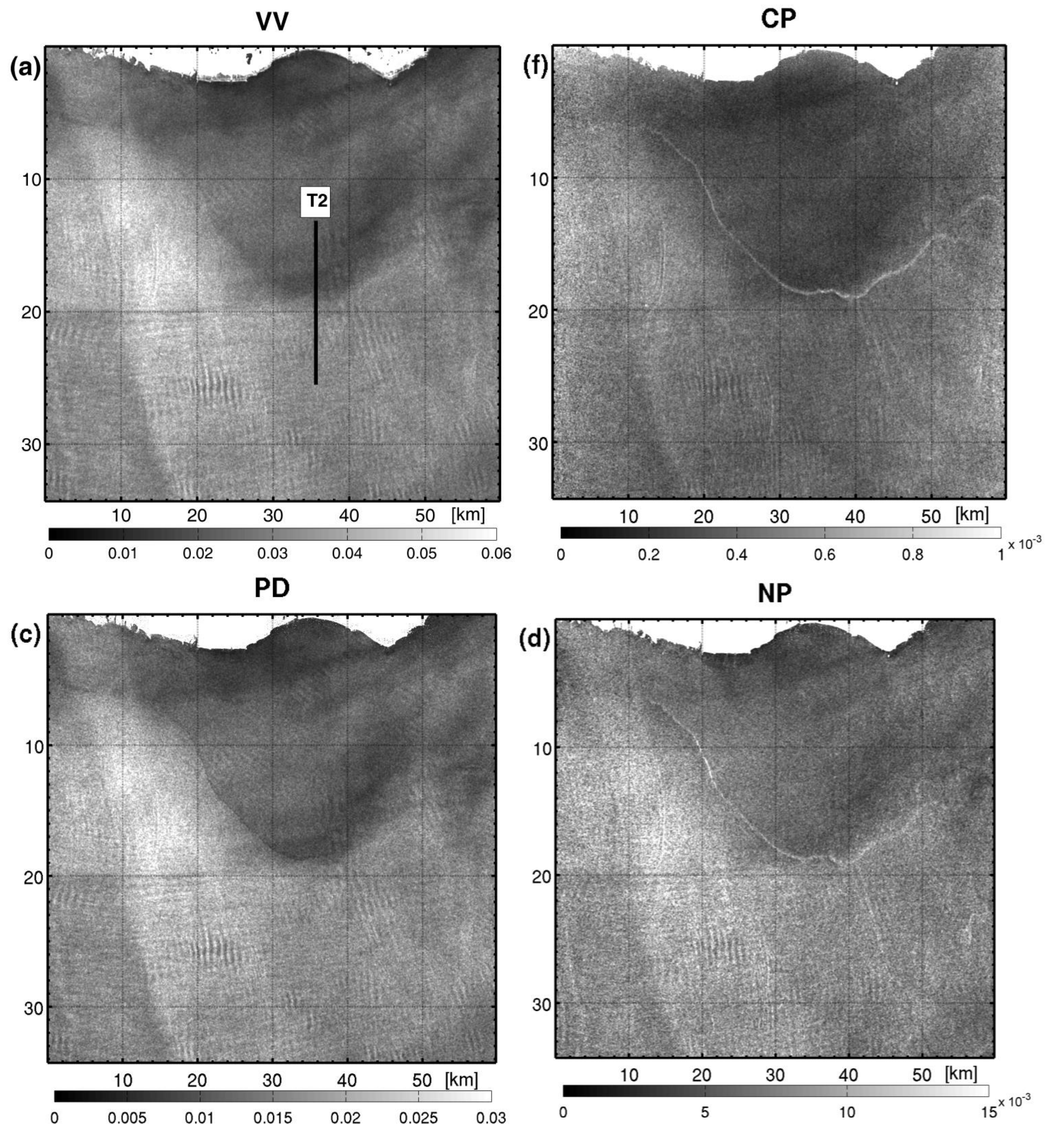




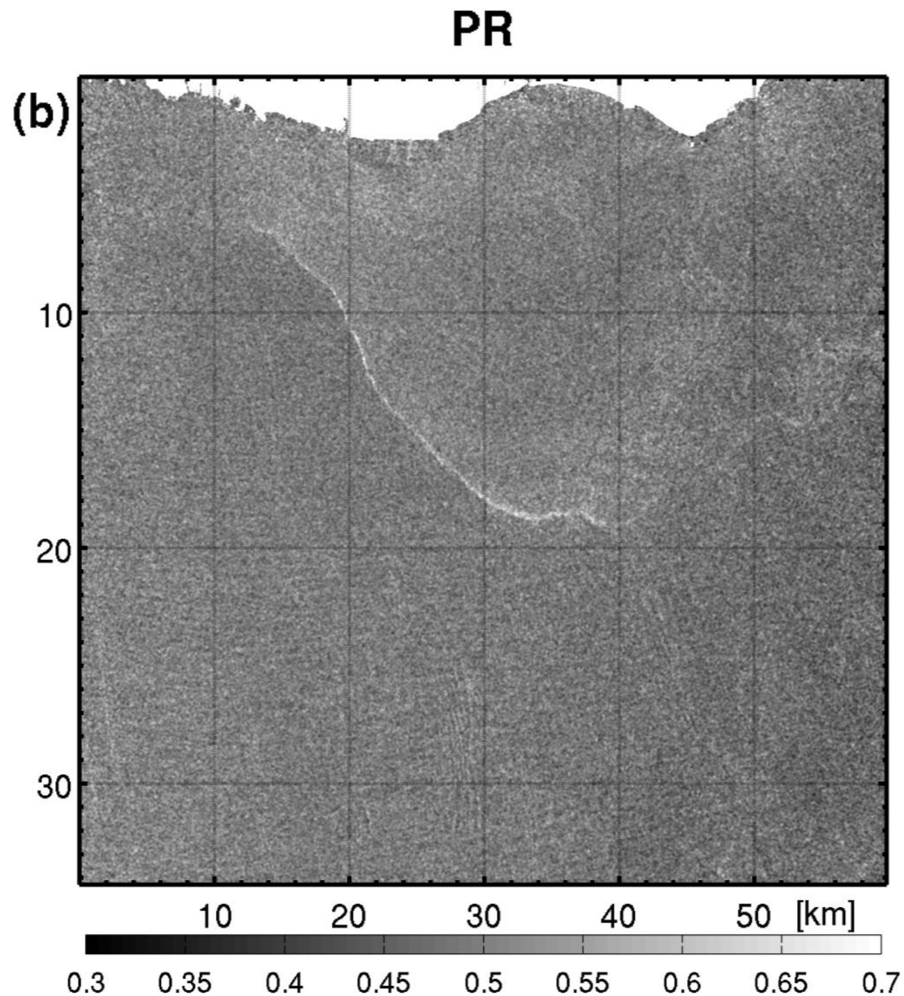
VV **HH**

Dark area near the coast
is cold SST region

Suppression of wind stress over cold area and atmospheric gravity waves (AGW) are well visible in VV, CP(VH), PD and NP images

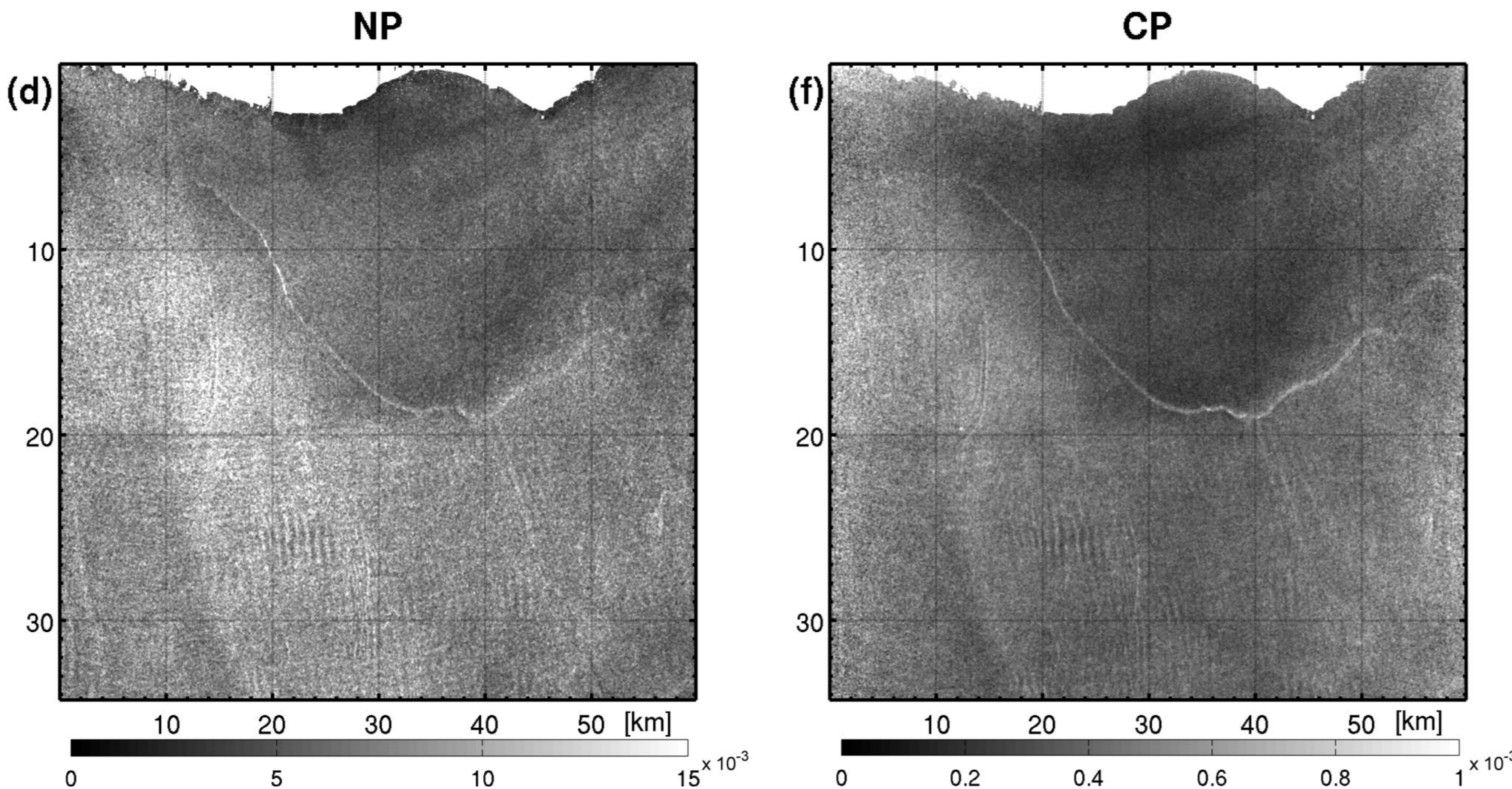


- AGW and SST impact on wind are not seen in PR due to its weak wind dependence
- The bright line in PR shows the edge of SST front
- This is a local enhancement of NP radar returns (wave breaking)
- Enhancement of wave breaking traces convergence of surface current near the SST front (Kudryavtsev et al., 2012).

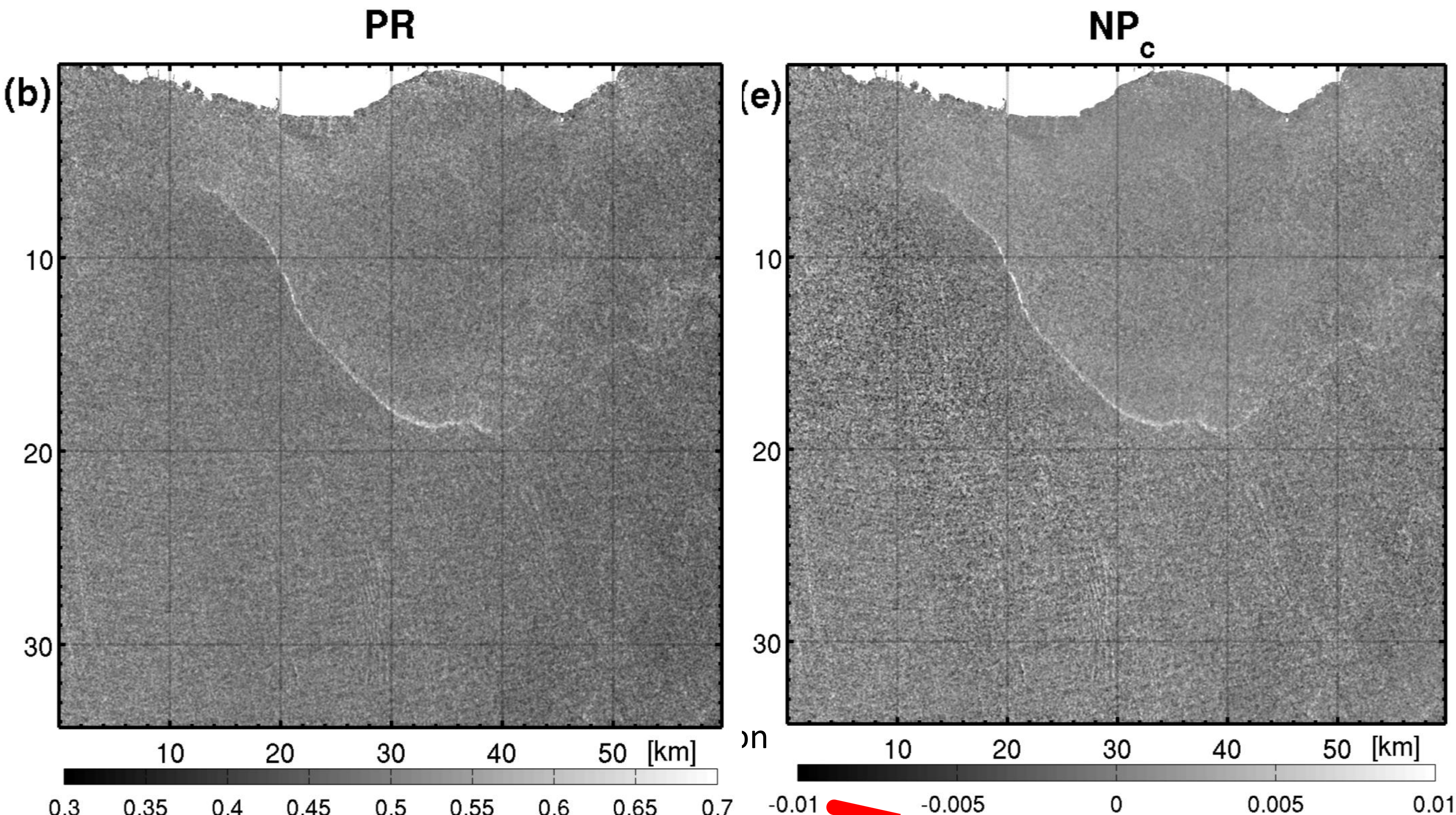


PR= HH/VV

Striking similarity is observed between NP and VH images, meaning that **wave breaking is also dominating cross-pol** radar returns.

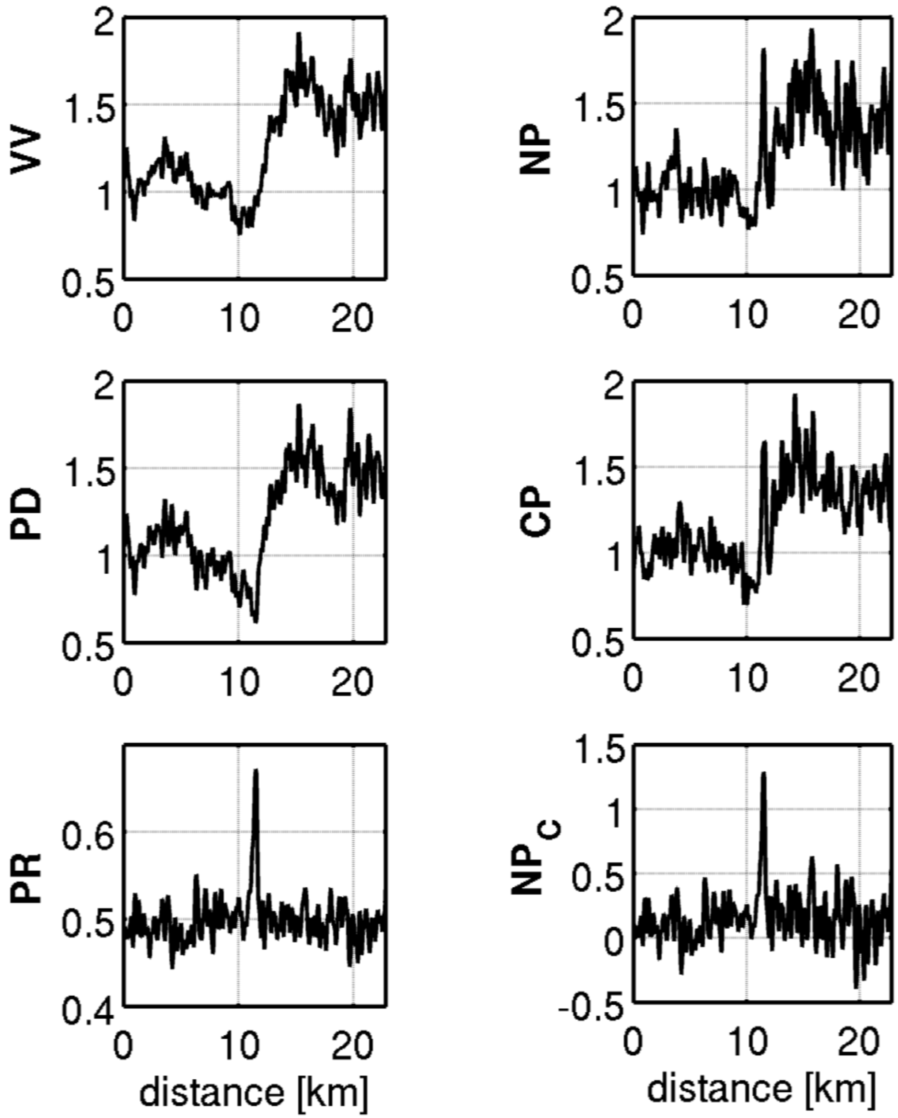


Separation between wind and currents



$$\sigma_{wb}^{C} = \sigma_{wb} - \left[\overline{\sigma_{wb}^{W}} + A(\Delta\sigma - \overline{\Delta\sigma}) \right]$$

Transect across the current front



- **VV, PD and NP data - drop over the cold SST front, as all these quantities depend on friction velocity at the surface.**
- **PR and NPc - peak associated with enhanced wave breaking in the surface current convergence zone.**
- **NP and CP – both effects.**
- **Contribution of wave breaking to NRCS,**

$$\sigma_{wb}/\sigma_{0B}^{vv} = (P - p_B)/(1-P)$$

$$\sigma_{wb}/\sigma_{0B}^{hh} = (P/p_B - 1)/(1-P)$$

- **Background conditions:**

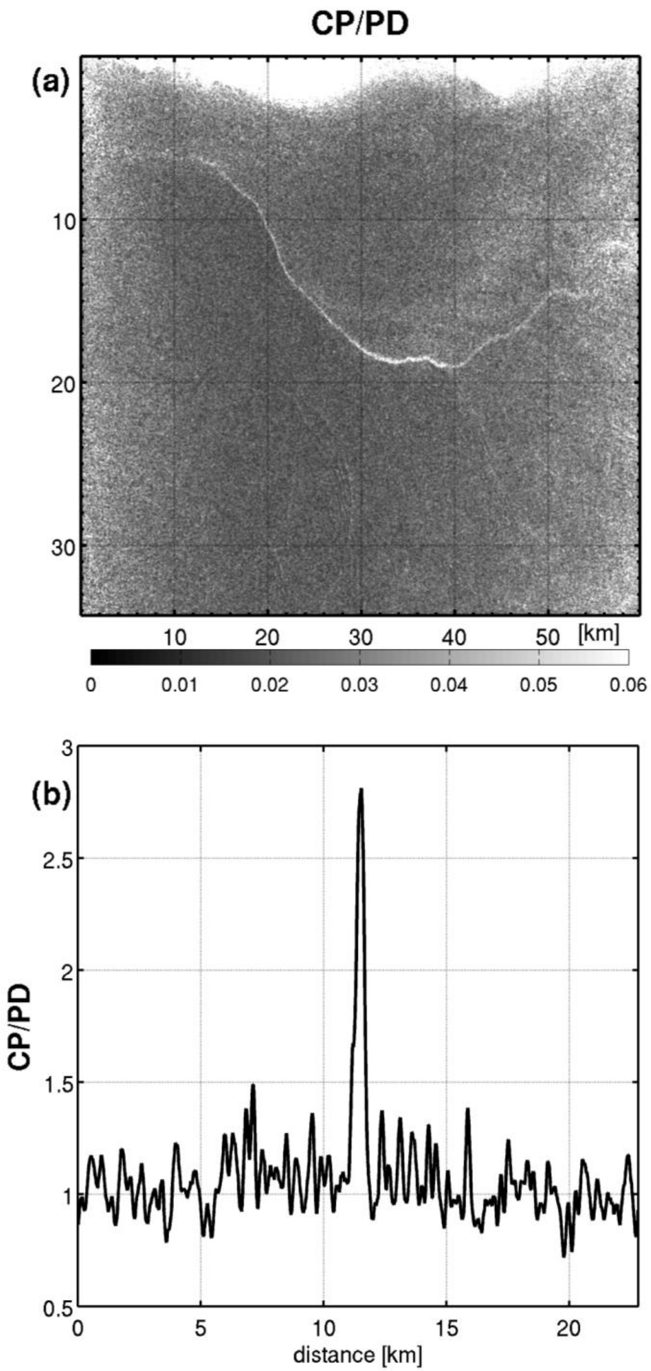
$$\sigma_{wb}/\sigma_{0B}^{vv} = 0.3 \text{ and } \sigma_{wb}/\sigma_{0B}^{hh} = 0.86$$

- **Inside the current feature**

$$\sigma_{wb}/\sigma_{0B}^{vv} = 0.86 \quad \text{and} \quad \sigma_{wb}/\sigma_{0B}^{hh} = 2.45$$

Impact of currents results in redistribution of radar returns between Bragg waves and breakers!

Wave breaking impact to CP [CP/PD]



CP/PD ratio is weakly dependent on wind, as both CP and PD similarly depend on wind.

The wind variability is almost entirely removed.

As PD is not sensitive to the surface current, bright linear feature in CP/PD confirms the impact of breaking and near breaking scatters on CP scattering, even at moderate winds.

The transect shows 2.5-fold increase over the surface current convergence zone, which equals to 4-fold increase of wave breaking contribution.

Conclusions

PD and NP images represent the information on very different radar scattering mechanisms, i.e.
PD - the polarized Bragg scattering by short fast-response wind waves,
NP - radar returns from breaking waves in a wide spectral range.

Modulation of wave breaking plays the dominant role in the formation of surface current signatures (IWs, surface currents) while impact of Bragg waves modulations is negligibly small.

NP and PD can be used to discriminate ocean current features from variable wind field features (incl. AGW)

Wave breaking is also strongly impacting CP signals.

Future observations, e.g. Sentinel-1 with one Co-Pol and one Cross-Pol, HH+HV or VV+VH, can build on such a potential to separate effects of currents and wind variability.

SATELLITE OCEANOGRAPHY LABORATORY

RSHU

Thank you!

ACKNOWLEDGMENT

Core support of this research was provided by Russian Federation Government via **Mega-Grant No. 11.G34.31.0078** to support scientific research under the supervision of leading scientist at Russian State Hydrometeorological University.

www.solab.rshu.ru