WP3000 – Scatterometry

WP3100: Review of the current and past scatterometer systems and foreseen limitations for Wavemill

✓ Review of scatterometer systems (ERS, NSCAT, ASCAT, QuikScat, ...)
✓ Foreseen limitations for Wavemill as a classical scatterometer (relying only on the amplitude, RCS). Use of the NSCAT heritage (Ku-band and low incidence angles) and Monte Carlo simulations of the inversion process to characterize the performances.

WP3200: Inversion of the Wavemill measurements to retrieve the wind vector and error analysis

✓ Definition of a Ku-DOP model function for the Doppler shift parameter (from C-band empirical model and theoretical approach, Chapron, 2005; Mouche et al, 2008)
✓ A methodology to use the Doppler shift information (Mouche et al., 2012) in the inversion scheme
- definition of the cost function
- definition of the inversion scheme (bayesian approach)

✓ Error analysis

WP3300: Report and recommendations

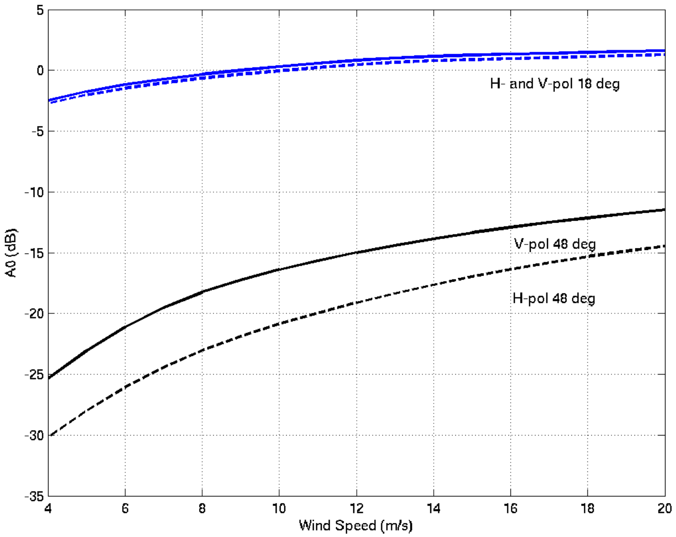
✓ Contribution of the wind/current to the Doppler shift: a consistent approach
✓ What wind/current sources to be used

WP3100 Foreseen limitations if using as a scatterometer (amplitude of the signal = NRCS)

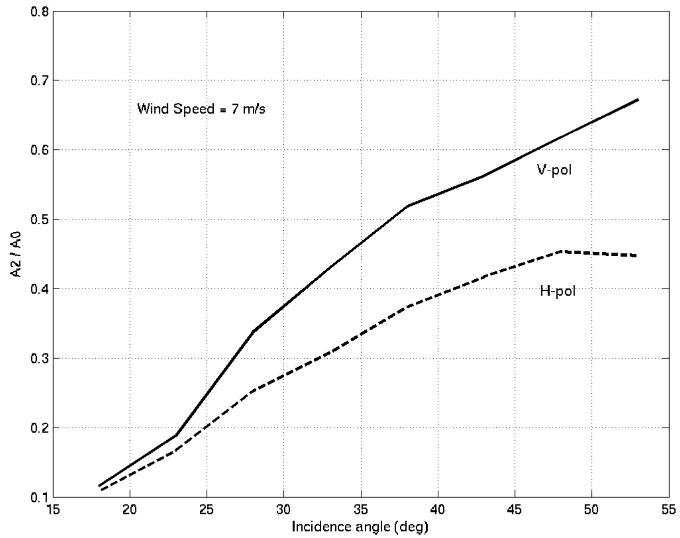
➢ The low incidence angle range (17 to 24 degrees): it implies reduced sensitivity to wind vector

Results obtained from the Ku-band NSCAT GMF (incidence ranging from 18 to 59 degrees), hereafter named KMOD

$$NRCS = \sigma_{0P} = A_{0P}(1 + A_{1P}\cos\Phi + A_{2P}\cos 2\Phi)$$



4dB at 18deg, 16dB at 48deg over 4 < V < 20 m/s



A2/ A0 < 20% for the Wavemill geometry

➢ Across-track variability of the squint angle: non-orthogonality of the two-antennas looking azimuths: upwind / crosswind modulation measurements impacted in a way to be analyzed

WP3100 Foreseen limitations: the precipitation radar on TRMM

Radar cross section at low incidence angles and Ku-band

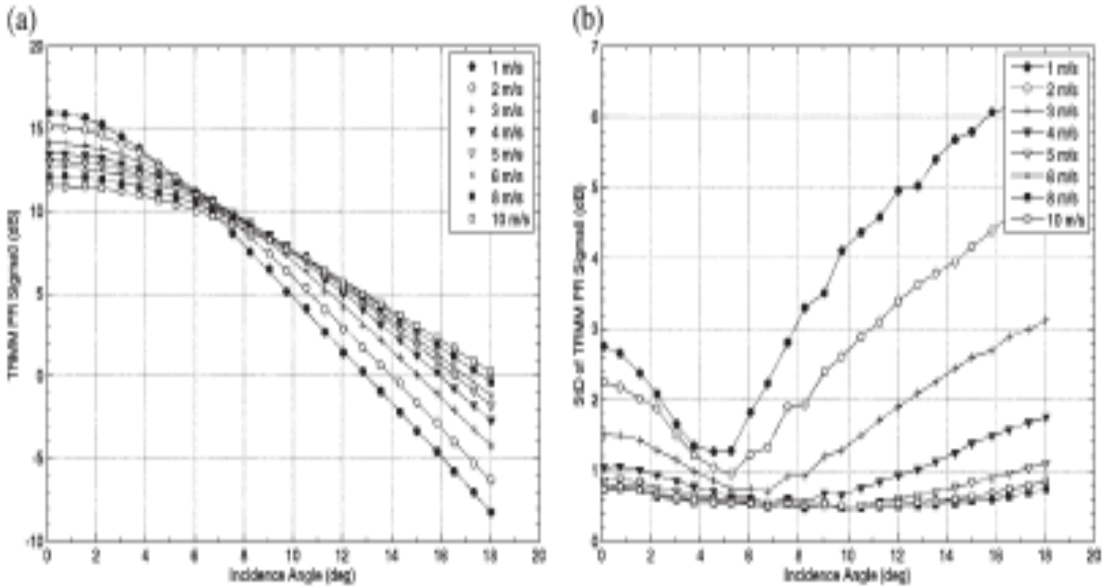


Fig. 1. (a) Mean values and (b) standard deviations of binned PR σ_0 as a function of incidence angle for different wind speeds (SWH between 0.5 and 6.5 m).

WP3100 Foreseen limitations: wind errors as a result of low azimuthal modulation at low incidence

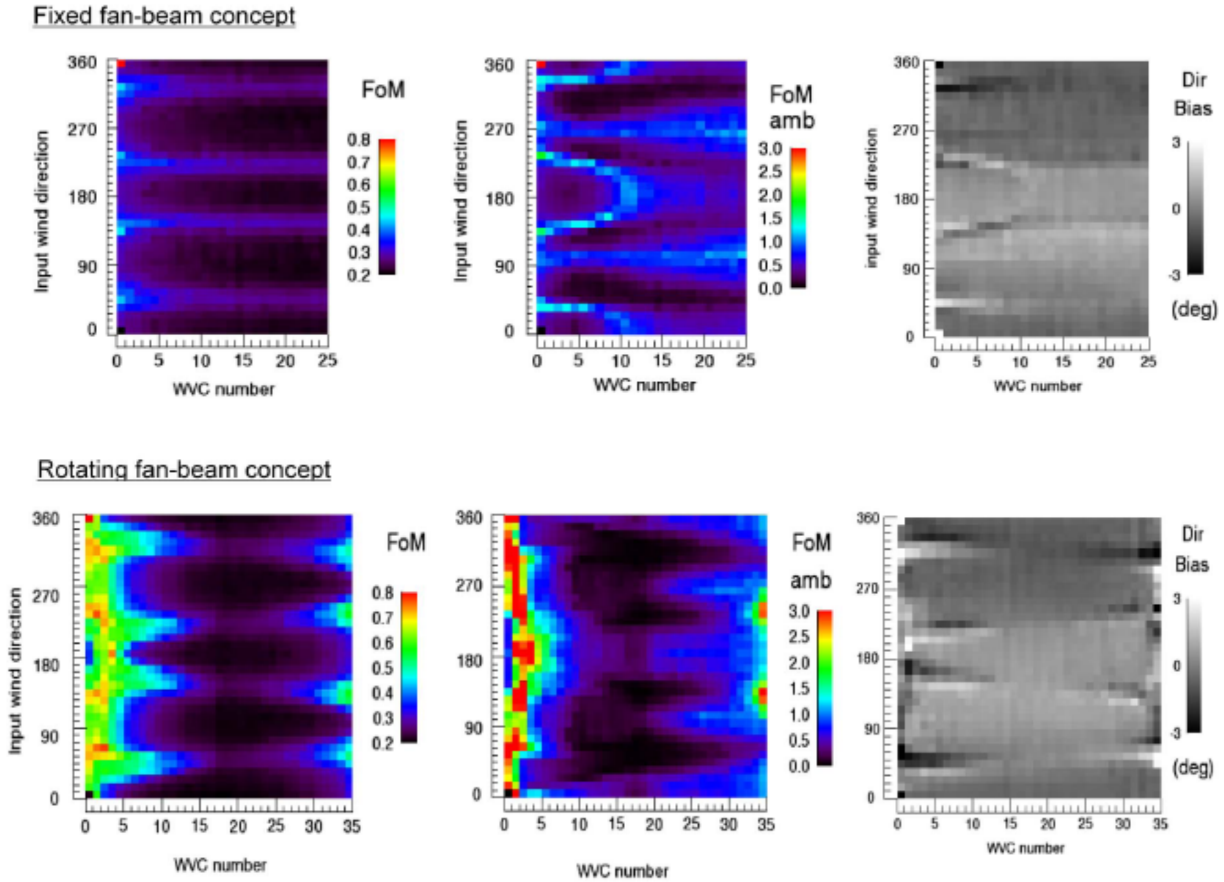


Fig. 13. (Top row) Fixed fan-beam and (bottom) rotating fan-beam (2 r/min) FoMs as a function of across-track location and wind direction (wind speed is 9 m/s). Wind direction is measured clockwise from the axis of abscissas in across-track direction pointing toward east. The WVC numbers increase with stand-off distance from the subsatellite track.

From Lin C.C. and al., IEEE, 2012

WP3200: Inversion of the Wavemill data to retrieve the wind vector and error analysis

- Objective: to make use of this unique opportunity to combine NRCS and Doppler with a two-antennas system

Heritage of SAR studies (Chapron et al., 2005; Mouche et al., 2008, 2012)

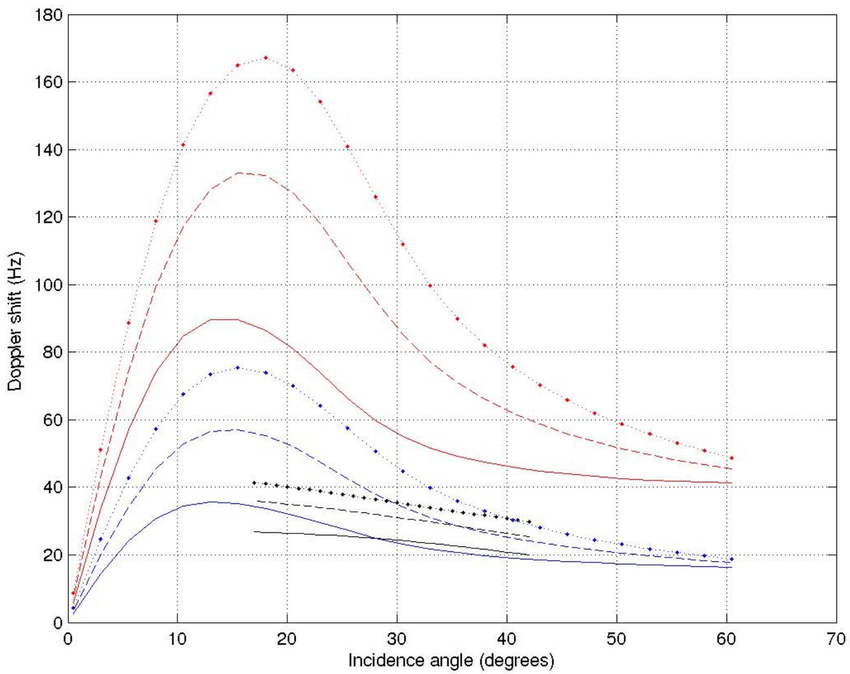
A bayesian (statistical approach) inversion scheme is used, minimization of the cost function:

$$J(\vec{u}) = \underbrace{\left(\frac{\sigma_0 - CMOD(\vec{u})}{\Delta\sigma_0}\right)^2}_{a} + \underbrace{\left(\frac{df - CDOP(\vec{u})}{\Delta df}\right)^2}_{b} + \underbrace{\left(\frac{\vec{u} - \vec{u}_B}{\Delta\vec{u}}\right)^2}_{c}$$

NRCS term — Doppler term — a priori term

Envisat wind inversion (Mouche et al., 2012)

For Wavemill we need to define a KDOP function



RCA Ku-band (red), C-band (blue) and CDOP (black)

Large differences between the physical model RCA and the empirical CDOP

An heuristic approach to define a suitable KDOP model

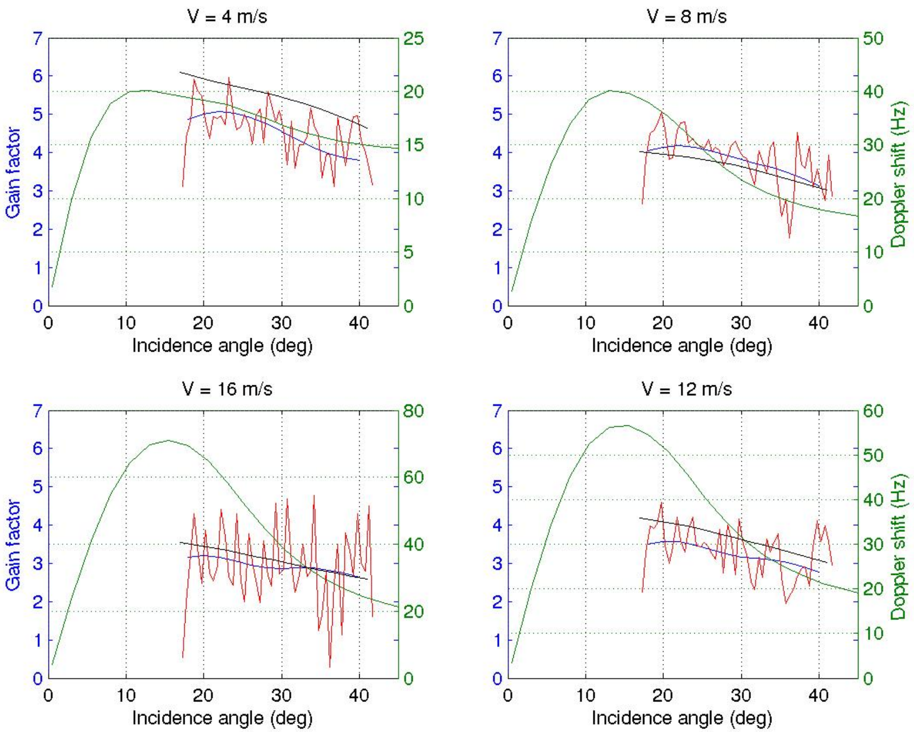
WP3200: Heuristic analysis to define a suitable KDOP model

$U_D = -f_D / k_e \sin\theta$ - relationship between the velocity of a target and the induced Doppler shift

$U_D = 0.022G\left[1. - 0.52\tanh\frac{U_{10}}{25}\right]U_{10}$ - empirical relation between the wind-induced velocity and the wind speed derived from physically-based reasoning

With $G = (1/\sigma_0)(\partial\sigma_0/\partial\theta)$ defined as a gain factor resulting from facets tilting by longer waves: contributes to more than 60% to the velocity at Wavemill incidence angles

Combining the above relations, it gives $f_D = C k_e \sin\theta G f(U_{10})$

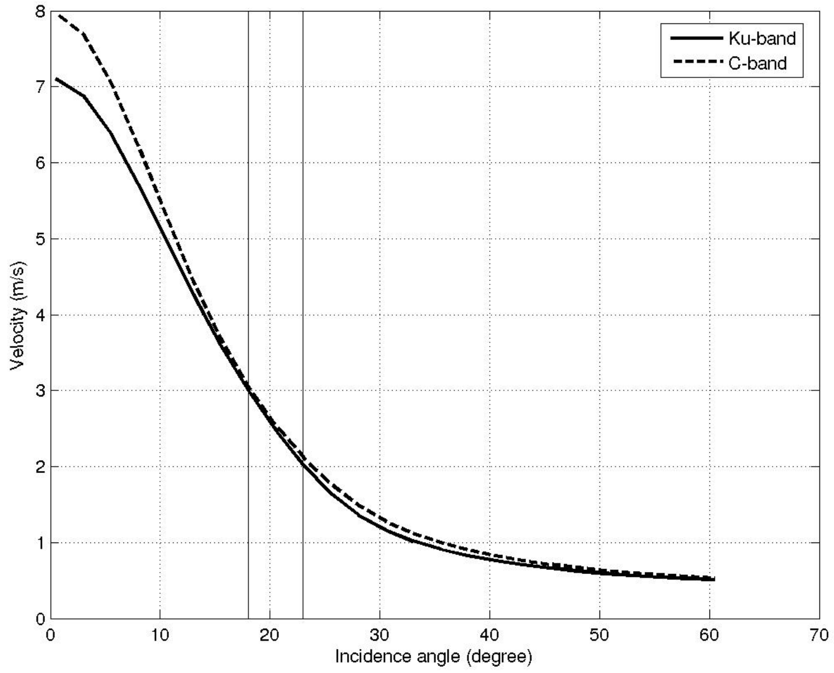


We obtain good agreement between the gain factor behavior and the CDOP model. It gives confidence in the CDOP model to derive a KDOP as follows

WP3200: Heuristic analysis to define a suitable KDOP model

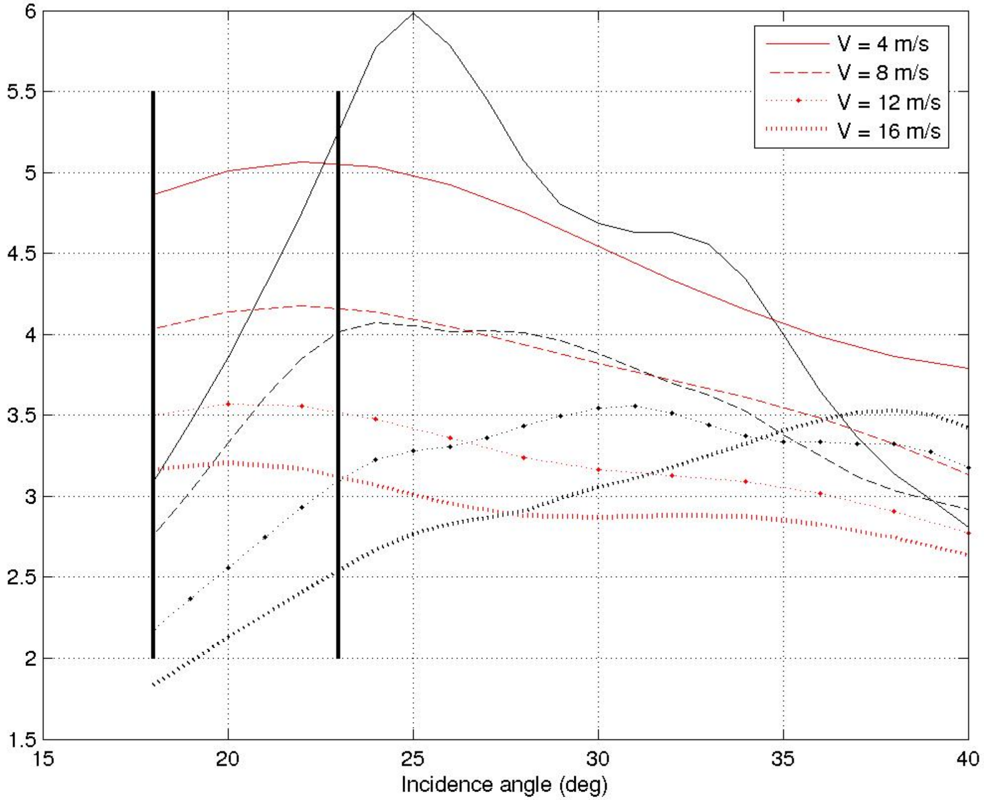
As shown from the RCA model, surface velocities are close at C- and Ku-band at Wavemill incidence angles.

The relation $U_D = -f_D / k_e \sin\theta$ is then used to derive the Ku-band Doppler shift model multiplying CDOP by the Ku/C wavenumber ratio



Surface velocities predicted by the RCA model. Vertical bars give the Wavemill incidence angle range.

Comparison of gain factors at Ku- and C-band (derived from KMOD and CMOD5)



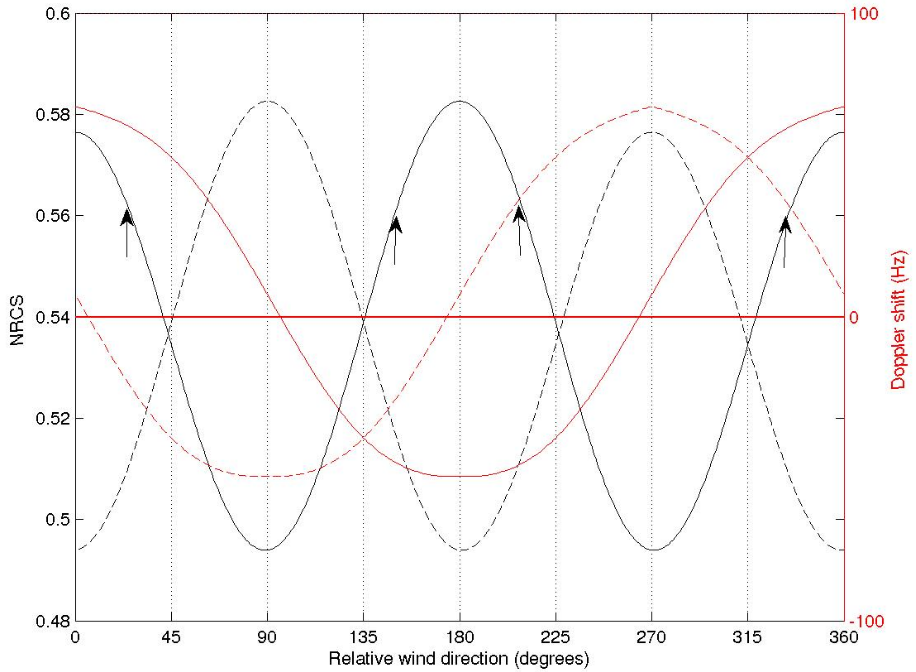
- ✓ Both gain factors are decreasing with increasing wind speed but large differences also appear near Wavemill incidence angles
- ✓ The obtained KDOP model certainly needs further attention.
- ✓ Ku-band Doppler shift measurements to be collected

WP3200: Inversion of the Wavemill data to retrieve the wind vector and error analysis

For the Wavemill wind inversion, the cost function to be minimized over the wind space can be defined as:

$$J(\vec{u}) = \underbrace{\left(\frac{\sigma_0 - KMOD(\vec{u})}{\Delta\sigma_0}\right)^2}_{a} + \underbrace{\left(\frac{df - KDOP(\vec{u})}{\Delta df}\right)^2}_{b} + \underbrace{\left(\frac{\vec{u} - \vec{u}_B}{\Delta\vec{u}}\right)^2}_{c}$$

NRCS (black) and Doppler shift (red) azimuthal dependency at fixed wind speed



- ✓ For a given pair of radar cross section values, 4 wind vectors fit with the KMOD model.
- ✓ The two Doppler shift measurements enable to pick up the right one unambiguously.
- ✓ In the Wavemill configuration, no ancillary information is needed to solve for the directional ambiguity

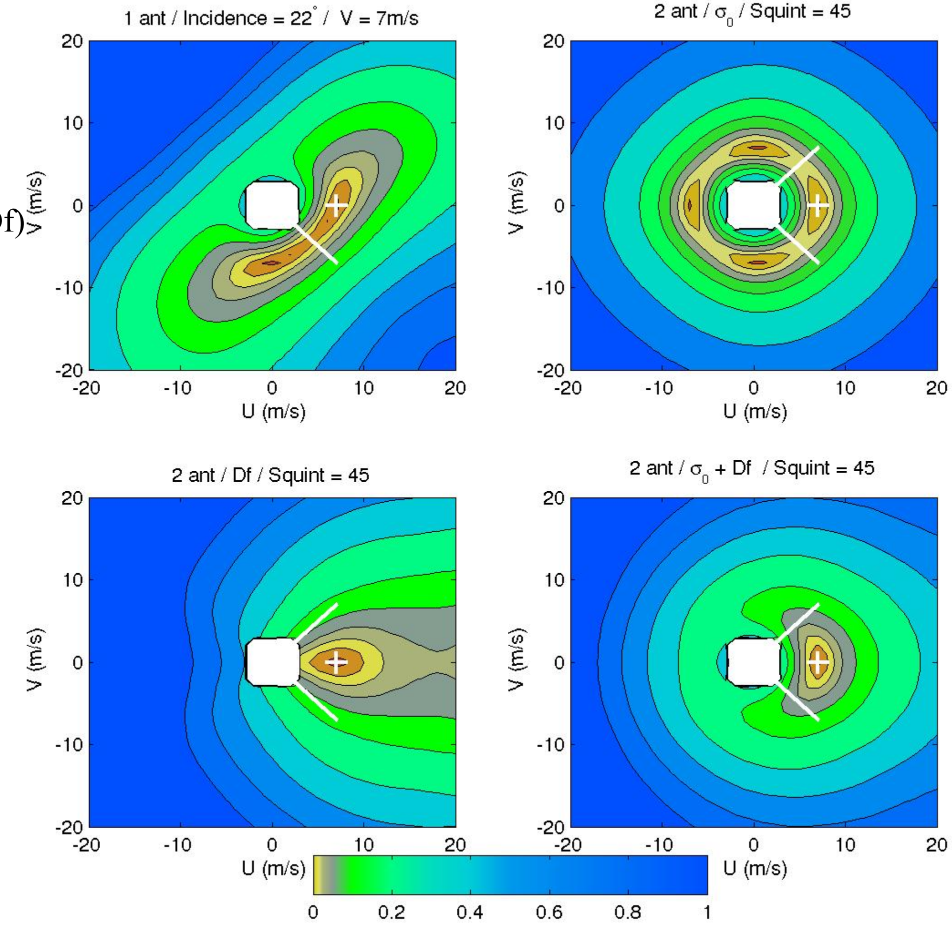
Mapping of the cost function for different configurations and a given wind vector

One antenna (1NRCS + Df)
Envisat configuration

Two antennas (2 NRCS)

Two antennas (2 Df)

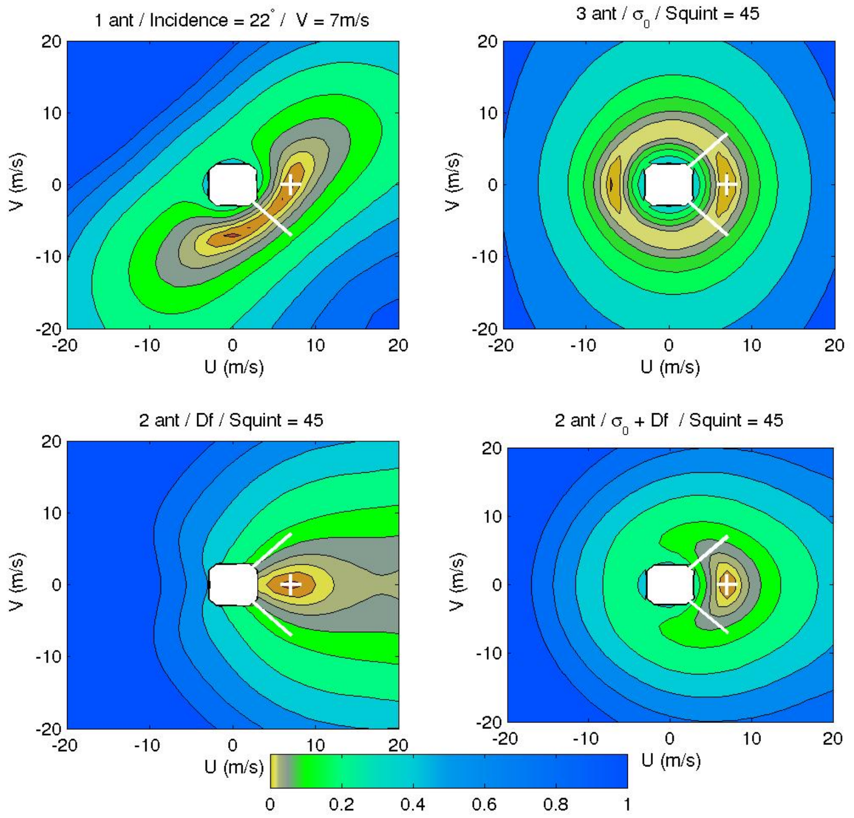
Two antennas (2NRCS + 2 Df)



Mapping of the cost function for different configurations and a given wind vector

One antenna (1NRCS + Df)
Envisat configuration

Three antennas (3 NRCS)
ASCAT configuration



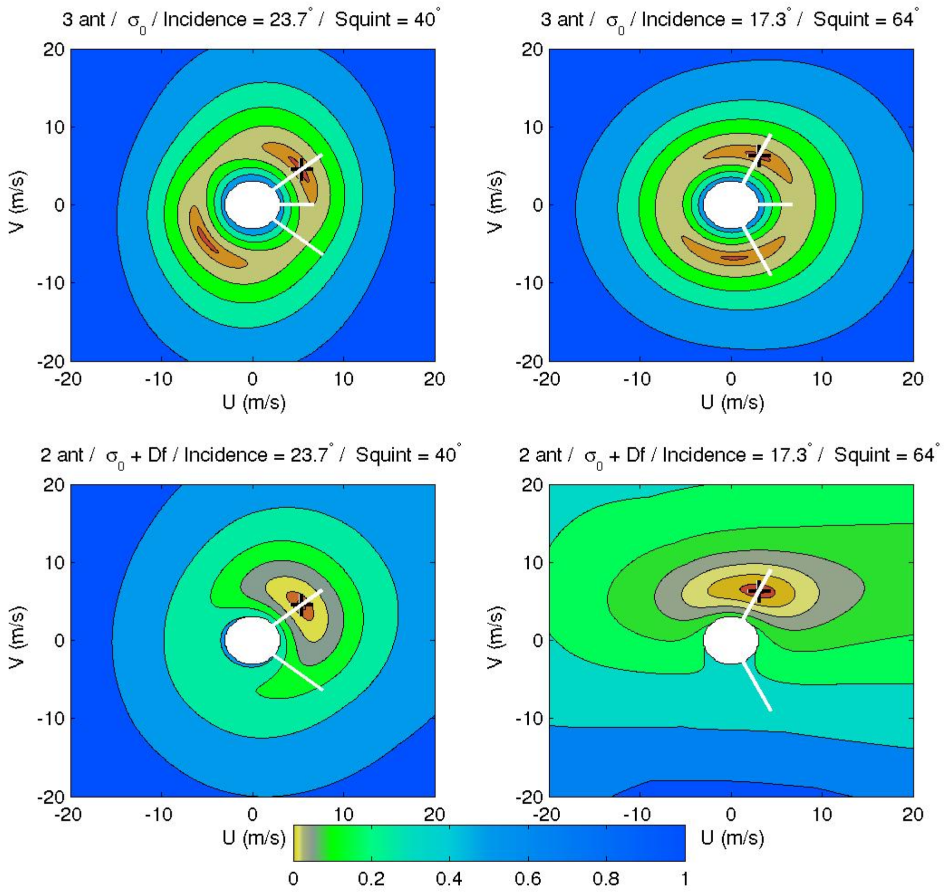
Two antennas (2 Df)

Two antennas (2NRCS + 2 Df)

Mapping of the cost function for different configurations: influence of squint angle

Three antennas (3 NRCS)
ASCAT configuration

Two antennas (2 NRCS + 2 Df)



Three antennas (3 NRCS)
ASCAT configuration

Two antennas (2NRCS + 2 Df)

Across-track change in squint angles does not induce apparent artifacts but it needs to be tested for noisy measurements

→ Monte-Carlo simulations – ASCAT configuration used as a testbed for comparison

Error analysis from a Monte-Carlo approach for the different configurations

- Estimation of statistical properties of the errors in retrieved wind vectors: i.e mean bias and root mean square error (rmse)

- Needs realistic figures of noise for the NRCS and Doppler shift measurements: (5%, 5Hz) and (3%, 3Hz)

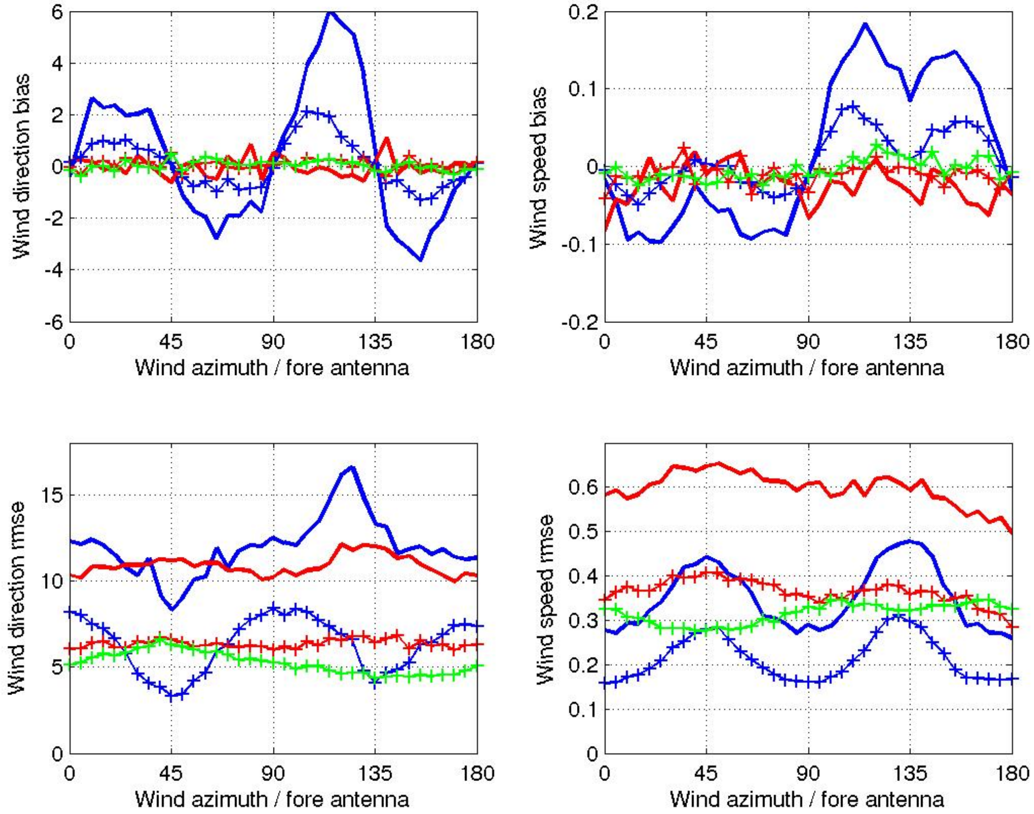
- For a given true wind vector, the true NRCS and Doppler shift are computed using the corresponding GMFs, and a set of 1000 random realizations of (NRCS, Df) is produced fitting a normal distribution whose standard deviation is given by the chosen noise figure.

- Each of the 1000 (NRCS, Df) pair is used in the bayesian wind inversion scheme for different cost function definitions (ASCAT-like, Wavemill-like)

- As the the true wind vector is known, no ancillary information is needed to solve for the directional ambiguity, if any as in an ASCAT-like configuration

- The NRCS and Doppler shift measurements are supposed to be solely wind-induced: a sensitivity analysis will further incorporate surface current effects

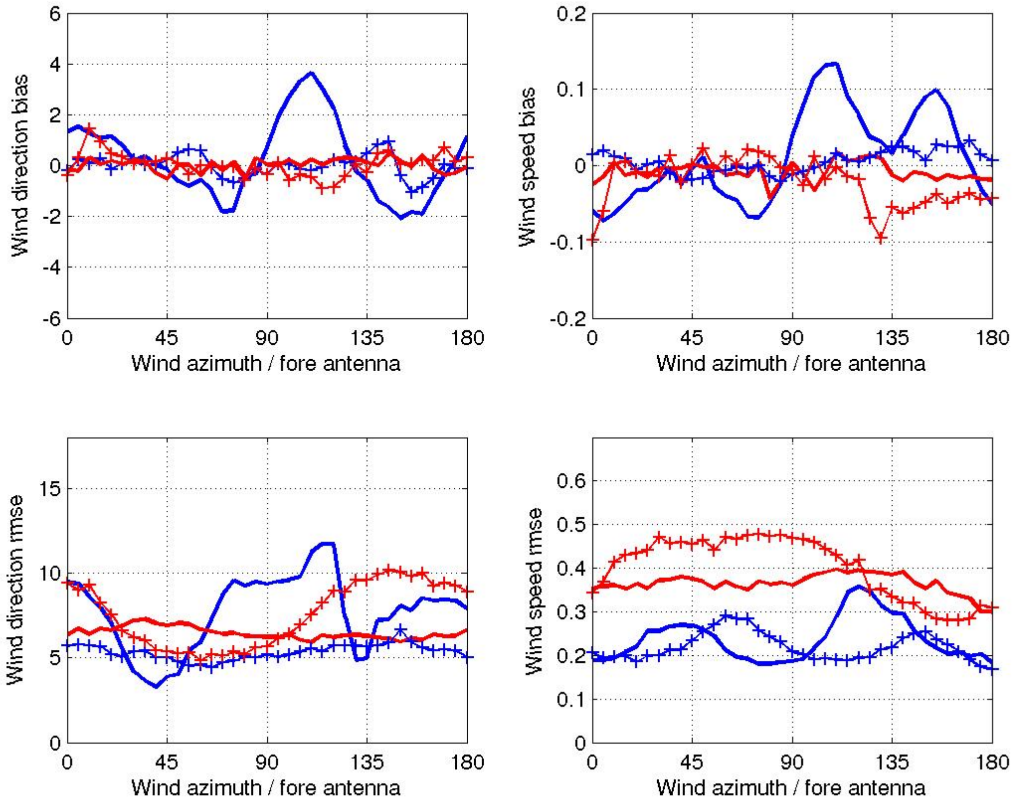
Error analysis from a Monte-Carlo approach



- ✓ Errrors depend on the wind azimuth/antenna system for ASCAT configuration (cf Lin et al.)
- ✓ No such cross-track dependency for Wavemill
- ✓ Usual accuracy requirements (2 m/s, 20°) are fulfilled whatever the configuration
- ✓ Wind direction rmse comparable, wind speed rmse slightly better for ASCAT

Wind speed (m/s, right panels) and direction (°, left panels) biases (top panels) and rmse (bottom panels) as a function of the wind azimuth (0 corresponds to upwind / the fore antenna) for a squint angle of 45° . The sensor configuration is for Wavemill 2-antenna (red lines) and 3-antenna (green lines), and ASCAT-like (blue lines) configurations and the noise figures are (5%, 5 Hz, solid lines) and (3%, 3 Hz, plus symbols) for the NRCS and Doppler shift, respectively. The wind speed has been set at 8 m/s.

Error analysis from a Monte-Carlo approach: influence of varying squint angles



- ✓ Rmse slightly larger and azimuth-dependent at 64° of squint angle
- ✓ Conversely, non orthogonality helps to regularize the ASCAT errors
- ✓ Usual accuracy requirements (2 m/s, 20°) are fulfilled whatever the configuration

Wind speed (m/s, right panels) and direction (°, left panels) biases (top panels) and rmse (bottom panels) as a function of the wind azimuth (0 corresponds to upwind / the fore antenna) for a squint angle of 40° (solid lines) and 64° (plus symbols). The sensor configuration is for Wavemill 2-antenna (red lines) and ASCAT-like (blue lines) configurations. The noise figures are (3%, 3 Hz) for the NRCS and Doppler shift, respectively. The wind speed has been set at 8 m/s.

Sensitivity to surface currents

$U_D = \gamma U_{10\parallel} + U_{c\parallel}$ $\gamma \sim 0.2$

$f_c = -U_{c\parallel} k_e \sin\theta$

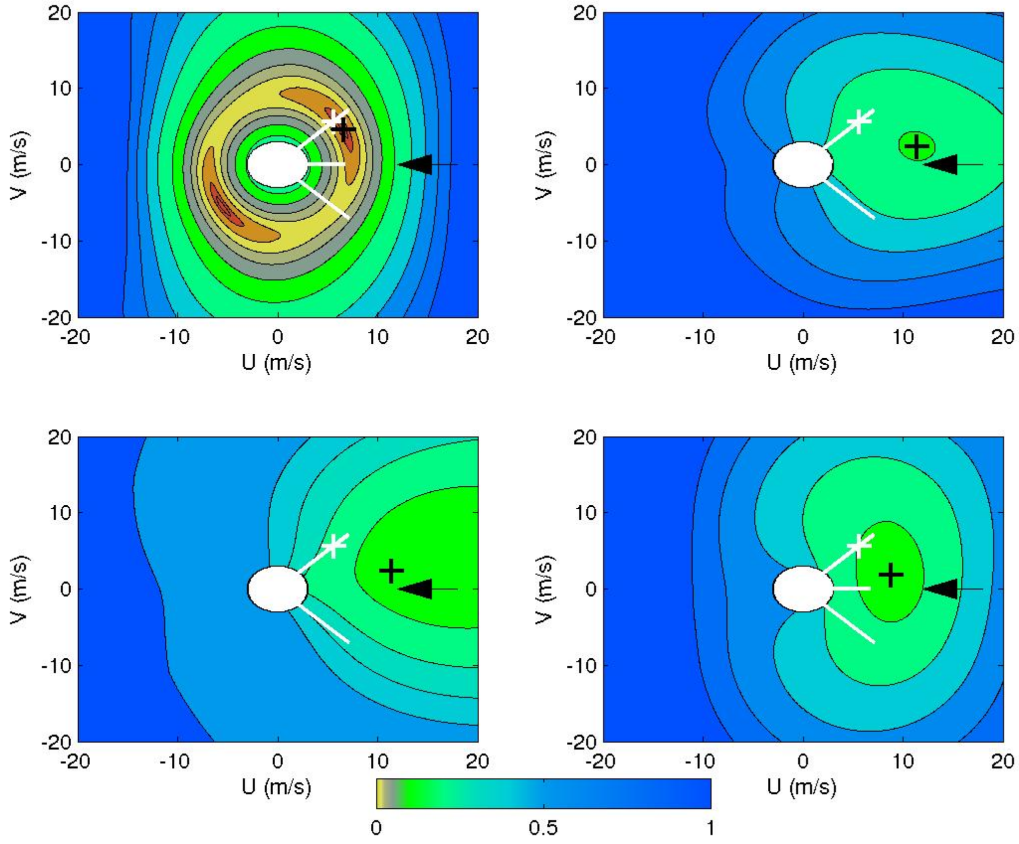
A Doppler corresponding to a surface current of 1m/s has been added to the wind-induced one

Three antennas (3 NRCS) ASCAT configuration

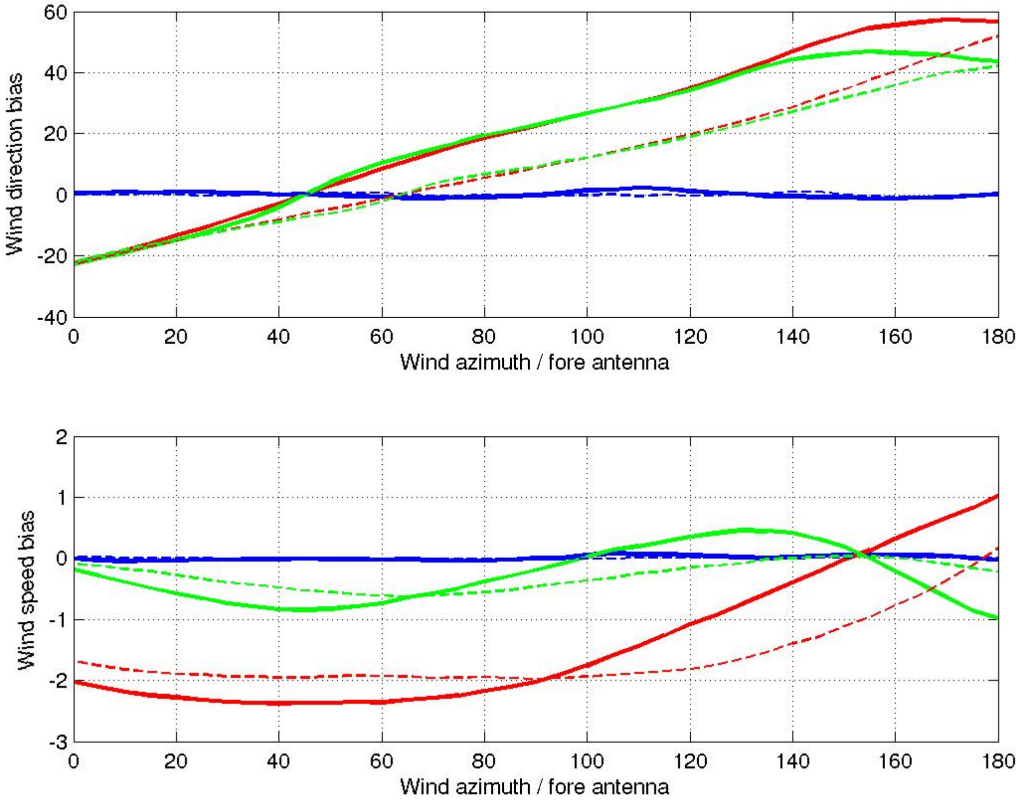
Two antennas (2NRCS + 2 Df)

Two antennas (2 Df)

Three antennas (3NRCS + 3 Df)



Error analysis from a Monte-Carlo approach: sensitivity to surface currents



- ✓ For a surface current of 0.5 m/s, large errors are induced in the retrieved wind vectors
- ✓ Wind speed errors are reduced in case where a third antenna is added in the Wavemill system
- ✓ These results confirm that it is not possible to ignore surface current contribution to Doppler shift when used for wind inversion
- ✓ At least and as a first step, data can be easily checked to verify if surface currents contribute

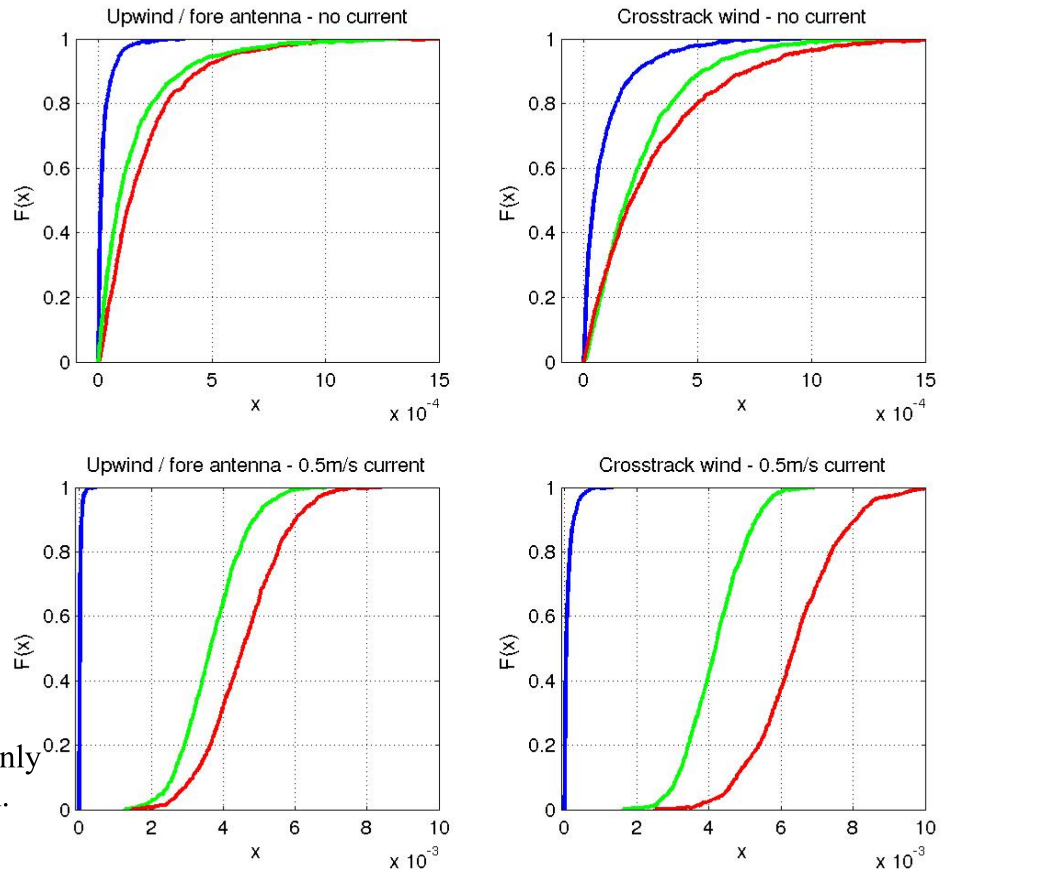
Wind speed (bottom) and direction (top) biases as a function of the wind azimuth (0 corresponds to upwind / the fore antenna) for a squint angle of 45º (solid lines) and 64º (dashed lines). The sensor configuration is for Wavemill 2-antenna (red lines), Wavemill 3-antenna (green lines), ASCAT-like (blue lines) configurations and the noise figure is (3%, 3 Hz). The wind speed has been set at 8 m/s and the surface current at 0.5 m/s cross-track.

Error analysis from a Monte-Carlo approach: a rule to identify data impacted by current

$$J(\vec{u}) = \sum_i \left(\frac{\sigma_0 - KMOD(\vec{u})}{\Delta\sigma_0}\right)^2 + \sum_j \left(\frac{df - KDOP(\vec{u})}{\Delta df}\right)^2$$

The cost function NRCS term residuals can be checked and compared in the two cases whether the Doppler shift is used or not in the wind inversion scheme.

$$x = \sum_i \left(\frac{\sigma_0 - KMOD(\vec{u})}{\Delta\sigma_0}\right)^2$$



- ✓ The surface current impacts the Doppler shift data in such a way that the retrieved wind vectors no longer fit with the KMOD model making the cost function residuals well above a threshold defined for a wind-only case.

- ✓ In such a case the wind vector can be estimated using only the NRCS data with help of an ancillary wind information.

Cumulative distribution function of x values obtained from the 1000 iterations of the Monte-Carlo process for an ASCAT-like processing (solely NRCS, blue curve), a 2-(red curve) and 3-antenna (green curve) Wavemill processing (NRCS+Doppler). An across-track surface current of 0.5 m/s has been added for the results presented in bottom panels.

WP3300: Recommendations

✓ A third antenna looking cross-track would be a reliable solution to mimic a standard ASCAT-like system using only radar cross-sections for the wind inversion, to obtain a reliable first guess for an iterative wind/current inversion scheme

✓ It is recommended that Wavemill operates at higher incidence angles than those used for this study (18 to 25 degrees). Getting closer to 30° would bring very significant benefit

✓ Dual-pol cross section and doppler measurements needed to better identify the surface current and wind contributions