Post-EPS Scatterometer Performance Simulation

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ESA Study

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Wind retrieval and noise model

- Kp noise
- Geophysical noise due to ocean variability
- Approximate retrieval functions
Geophysical noise

- Different kinds of FOVs are combined (views)
- Each WVC view represents a different areal mean
- The ocean surface is variable
- A geophysical error occurs due to ocean surface variability and WVC non-uniform sampling
- Mainly affects low winds

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Post EPS scatterometer (SCA)  
[baseline requirements and options]

- Spatial resolution (25 km)
- Dynamic range (4-25 m/s)
- Radiometric resolution (~3-10% at 4 m/s)
- Swath coverage (95% in 48 hours for incidences between 20° and 60°)  
  15% improvement with respect to ASCAT on MetOp

I - Fixed beam (ASCAT type)  
II - Rotating beam (RFSCAT type)

Discarded: Ku-band (rain), pencil beam (skill), extended nadir coverage for ASCAT type

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Specify complete SCA arrangement:

1) **Antenna configuration**  
   (C-band, single vs dual pol):  
   - total power  
   - dimensions  
   - radiation pattern

2) **Radar waveform**  
   (FM chirp, short vs long pulse):  
   - PRF  
   - chirp bandwidth  
   - noise estimation

- Orbital model
- Pseudo Level 1B file

- Satellite position at time t
- WVC (25 km resolution cell)

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Radiometric resolution (NESZ and Kp)

1) NESZ (Noise Equivalent Sigma Zero) for a single look:

\[
NESZ = \frac{\sigma^0}{SNR} = \frac{k_B(T_0 + T_{eq})}{\lambda^2 \left(\frac{P_i G_{TX} G_{RX}}{R^4 \cdot L_{prop}}\right) \frac{B_{look}}{A_{look}}}
\]

\[
A_{look} = \Delta_{range} \Delta_{azimuth}
\]

2) Number of looks per node: \[N_{looks} = \frac{\Delta x \Delta y}{A_{look}}\] (reduce speckle)

3) Number of noise samples: \[N_{noise} = f_s T_{noise}\] (noise estimation)

Radiometric resolution:

\[
K_p^2 = \frac{\text{var}\{\sigma^0\}}{\langle \sigma^0 \rangle^2} = \frac{1}{N_{looks}} \left(1 + \frac{1}{SNR}\right)^2 + \frac{1}{N_{noise}} \left(\frac{1}{SNR}\right)^2
\]

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SCA end-to-end simulator

Input wind vector

Pseudo L1B file → GMF → Geophysical noise

Backscatter vector observation

Wind inversion

Output wind vector (minimum MLE solution)

\[ MLE(w, \phi) = \frac{1}{\langle MLE \rangle} \sum_{i=1,...,N} \frac{|\sigma_i^0 - \sigma_{GMF,i}^0(w, \phi)|^2}{K_\rho(\sigma_i^0)^2} \]

P_{obs}(V_{out}|V_{in})

Pencil beam, Kp = 20%
9 m/s @ 90 deg
Outer swath

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Wind retrieval performance

$P_{\text{obs}}(V_{\text{out}}|V_{\text{in}})$

NWP prior (5 m$^2$/s$^2$)

$P_{\text{obs}}(V_{\text{out}}|V_{\text{in}}) * P_{\text{NWP}}$

1) Wind Vector RMS error
2) Ambiguity susceptibility
3) Wind biases (skewness)

For example:

$$RMS_{obs} (\vec{v}_{true}) = \left( \int |\vec{v} - \vec{v}_{true}|^2 p_{obs} (\vec{v} | \vec{v}_{true}) p_{bg} (\vec{v}) d^2v \right)^{1/2}$$

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Wind retrieval performance QSCAT/ASCAT

Vector RMS error

QSCAT
ASCAT

FoM

WVC number

FoM_{amb}

AMBIGUITY

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Climatology FoMs

Wind retrieval performance is dependent on input wind and across track distance

Use a climatology average over wind speeds (3-16 m/s)

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SCA assessment

Wind Vector RMS error across swath
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Conclusion

RFSCAT performs well compared to ASCAT configuration, but …

To consider: geophysical noise, HH polarization, resolution

To optimize: antenna pattern…

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Thank you!

scat@knmi.nl
www.knmi.nl/scatterometer

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Backup Slides

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Wind retrieval and noise model

✓ Kp noise
✓ Geophysical noise due to ocean variability
✓ Approximate retrieval functions
GMF issues

- Measured triplets are centered well on cone within Kp for all speeds
- Geophysical noise at low winds incorporated
- Reasonable symmetry at medium-high winds
- Around 4 m/s most triplets inside the cone
- At very low winds, opposite effect
ERS-2

- Warm steady-flow air discerned from polar gusty air.
- Wind variability causes triplet inconsistency
- Noise at edge of the swath; ASCAT moved outward
Geophysical noise

- Different kinds of FOVs are combined (views)
- Each WVC view represents a different areal mean
- The ocean surface is variable
- A geophysical error occurs due to ocean surface variability and WVC non-uniform sampling

Portabella & Stoffelen, 2006
Accuray on 50-km WVC scale

- Triple collocation analysis of buoy, scatterometer & NWP

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<th>Vector RMS error [m/s]</th>
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Scatterometer winds provide excellent forcing
Remaining errors include representativeness
ASCAT contains small scales down to 25 km

Improved w.r.t. SeaWinds

No noise floor

$k^{-1.9}$
Mesoscales

- 12.5-km box details appear spectrally correct
- It verifies well with buoys
- It corresponds well with cloud features

www.knmi.nl/scatterometer
High Winds
C-band Model Function

- C-band HH sensitive to high winds
- No EUM priority due to lack of high winds

Courtesy
D. Esteban
JPL, NASA
ASCAT L1 backscatter averaging

- Wind Vector Cell
- Hamming filter
- Averaging window

ASCAT Level 2 product:
- 50 km resolution
- up to 60 km off the coast to avoid land effects

ASCAT Coastal product:
- 30-40 km resolution
- up to 25 km off the coast
- $\sigma^o$ more noisy

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ASCAT L1 backscatter averaging

Wind Vector Cell

Hamming filter averaging window

ASCAT Level 2 product:
- 50 km resolution
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- 30-40 km resolution
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- \( \sigma \) more noisy

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Prototype at 25 km
Box AWDP@12.5

- Box averaging maintains more tail variance
- No apparent noise floor
- Buoy verification confirms this; see later presentation
- Still u bump, but at lower wavelength (?)
- $k^{-1.8}$, pretty close to -1.67 for 3D turbulence

NWP SAF

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Nastrom and Gage 1987
- 28 minutes clearly optimal
- No gain in tropics at 50 minutes
Antenna assembly

C-band, VV polarization (extension to dual HH polarization an option)

Swath FoV \(\rightarrow\) 3dB width
Spatial resolution \(\rightarrow\) 3dB length

[20% better than ASCAT on MetOp (from 20 to 16 km)]

Beam shaping in elevation

Dynamic range

\[
SNR = \frac{\lambda^2}{(4\pi)^3} \left( \frac{G_{TX} G_{RX}}{R^4 \cdot L_{prop}} \right) \left( \frac{T_0 + T_{eq}}{k_B B_{look}} \right) \sigma^0 A_{look}
\]

[SNR is determined by Pt and chirp bandwidth]

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Radar PRF

Limited by swath extent: two different strategies

A) Long pulse ($T_{TX} >> t_{SWATH}$)

PRF = $1/(T_{HOR}+T_{TX}+T_{N}) = 29.4$ Hz (30%DC)

B) Short pulse ($T_{TX} << t_{SWATH}$)

PRF = $1/(T_{FAR}+T_{TX}) = 230$ Hz (7%DC)

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2) Radar waveform

LFM chirp for range resolution

Chirp $\sim \exp[i(\mu/2)t^2]$

Deramping $\sim \exp[-i(\mu/2)t^2] \exp[i f_D t + i(\mu/2)(t-t_r)^2] = \exp[i(f_D + i\mu t_r)t]$

Echo bandwidth $B_{\text{echo}} \approx \mu (t_{\text{FAR}} - t_{\text{NEAR}}) + \Delta f_D$

Detection bandwidth $B_{\text{detection}} \approx 1/T_{RX} = B_{\text{look}}$

Resolved look area:

$$A_{\text{look}} = 16 \text{ km} \times \frac{B_{\text{look}}}{2(\mu/c)\sin(\text{inc})}$$

Inversely proportional to chirp rate, but so is SNR!

In dB:

$$dB_{\text{echo}}/dx \approx 2(\mu/c)\sin(\text{inc})$$

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Radiometric resolution

Received signal = backscatter + speckle + emission

\[ K_p^2 = \frac{\text{var}\{\sigma^0\}}{\langle \sigma^0 \rangle^2} = \frac{1}{N_{\text{looks}}} \left( 1 + \frac{1}{SNR} \right)^2 + \frac{1}{N_{\text{noise}}} \left( \frac{1}{SNR} \right)^2 \]

1) Accumulate independent looks to reduce speckle

\[ N_{\text{looks}} = N_{az} N_{el} \]

\[ N_{az} = \left( \frac{\text{PRF}}{v_{\text{ground}}} \right) L_{WVC} \]  
Maximum PRF  
(compatible with unambiguous range)

\[ N_{el} = \left[ 2(\mu/c)\sin(\text{inc})/B_{\text{look}} \right] L_{WVC} \]  
Maximum \( \mu \)  
(compatible with SNR >-1.5dB)

\[ \text{SNR} \propto P_t \sigma^0/\mu \sin(\text{inc}) \]  
Minimum Pt  
(compatible with Kp requirements)

2) Noise (emission) estimation and subtraction

\[ N_{\text{noise}} = N_{az}B_{\text{echo}} T_N \]

Where \( B_{\text{echo}} = f_s/2 \) sets the sampling frequency

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Trade-offs to optimize Kp via chirp rate and total power (antenna pattern)

Min SNR check

Max Kp check

Non-compliance leads to increments in peak power
(and/or antenna pattern accommodation?)

Non-compliance leads to increments in chirp rate

Compliant SCA configurations enter the wind performance study

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Complete SCA configuration

1) Antenna assembly
- total power & pattern

2) Radar waveform
- PRF, chirp rate & noise

Orbital model

Pseudo Level 1B file

NESZ (Noise Equivalent Sigma Zero):

\[
NESZ = \frac{\sigma^0}{SNR} = \frac{k_g(T_0 + T_{eq})}{\lambda^2} \left( \frac{PG_{tx} \cdot G_{rx}}{R^4 \cdot L_{prop}} \right) \frac{B_{look}}{A_{look}}
\]

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Azimuth Incidence # Looks 1/NESZ Polarization

WVC Node

Views

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