Post-EPS Scatterometer Performance Simulation

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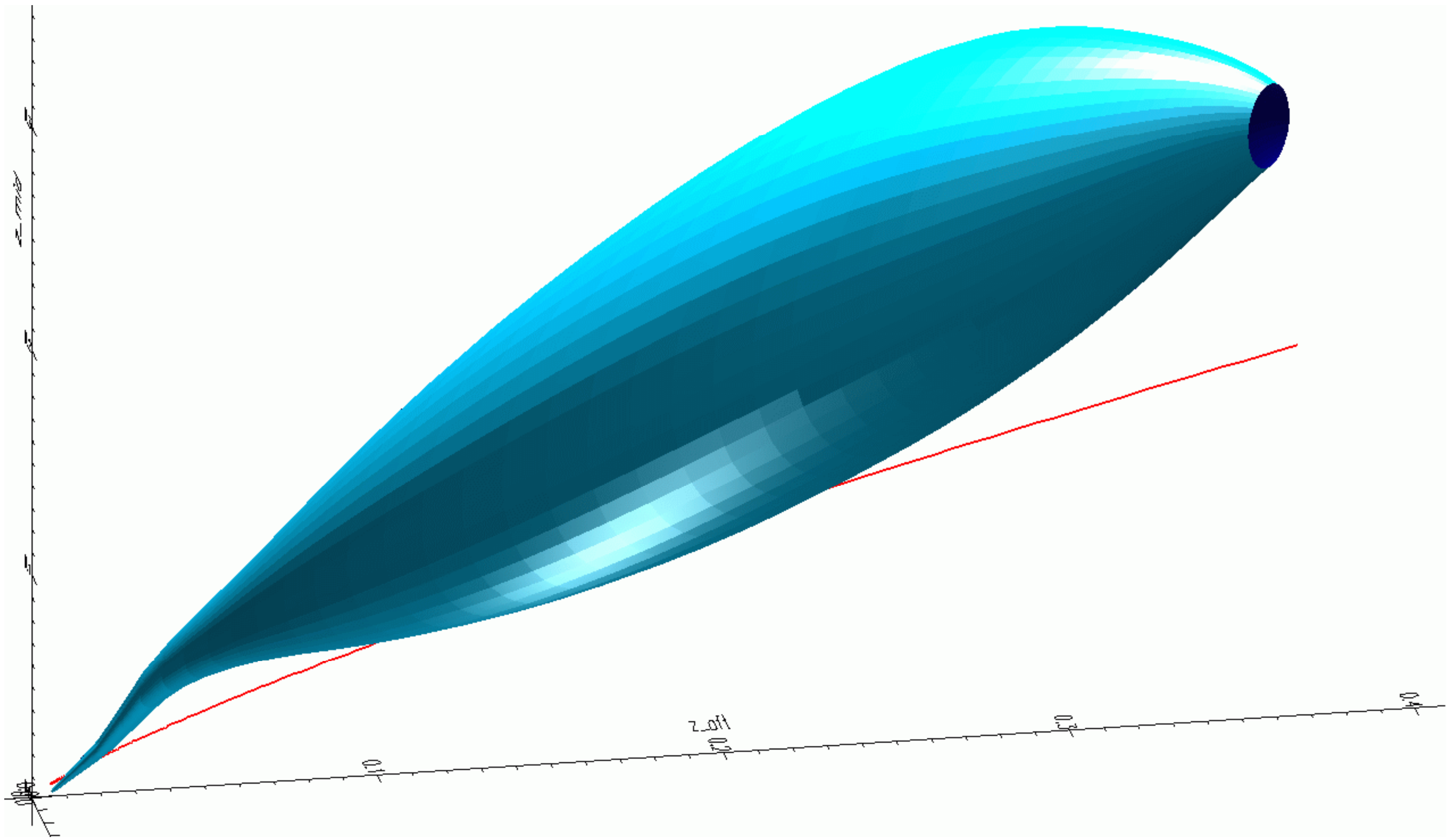
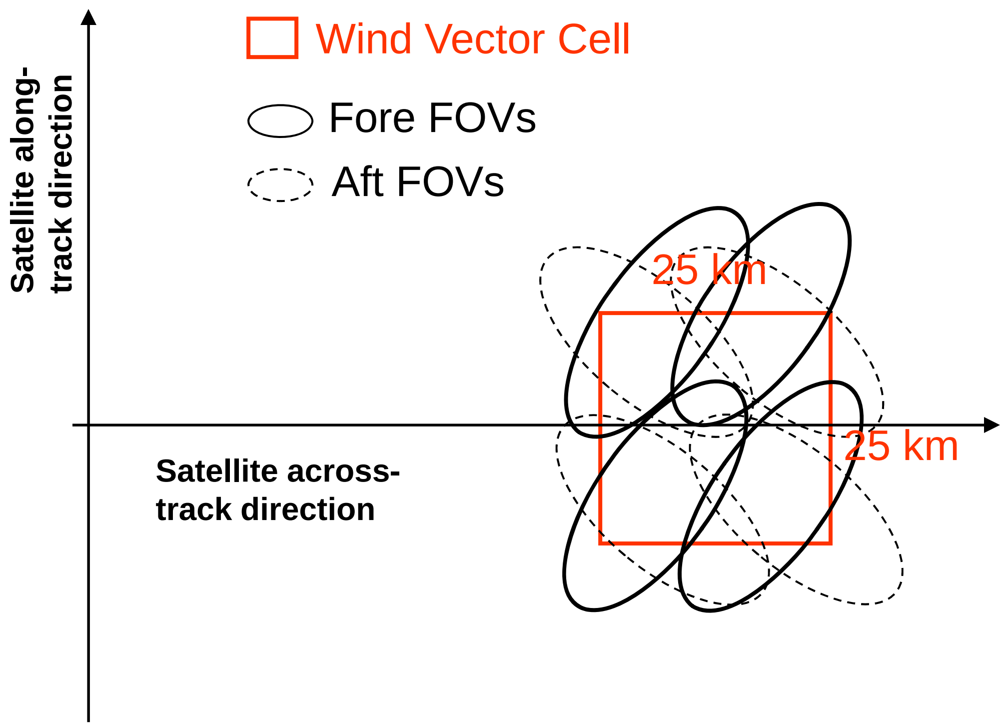
ESA Study

Wind retrieval and noise model

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



Geophysical noise



Post EPS scatterometer (SCA)

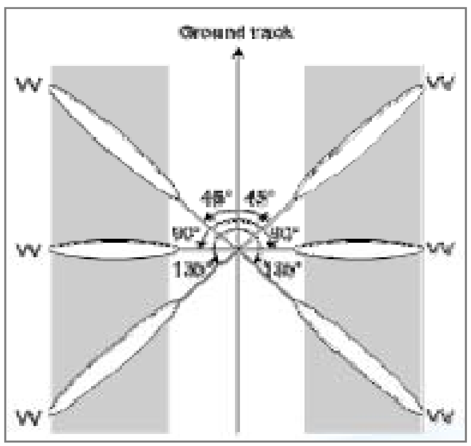
[baseline requirements and options]

MetOp orbit → Sun Sync with 820 km altitude

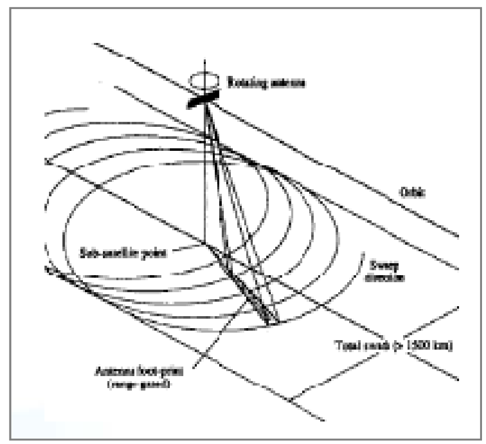
- Spatial resolution (25 km)
- Dynamic range (4-25 m/s)
- Radiometric resolution (~3-10% at 4 m/s)
- Swath coverage (95% in 48 hours for incidences between 20 and 60°)

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

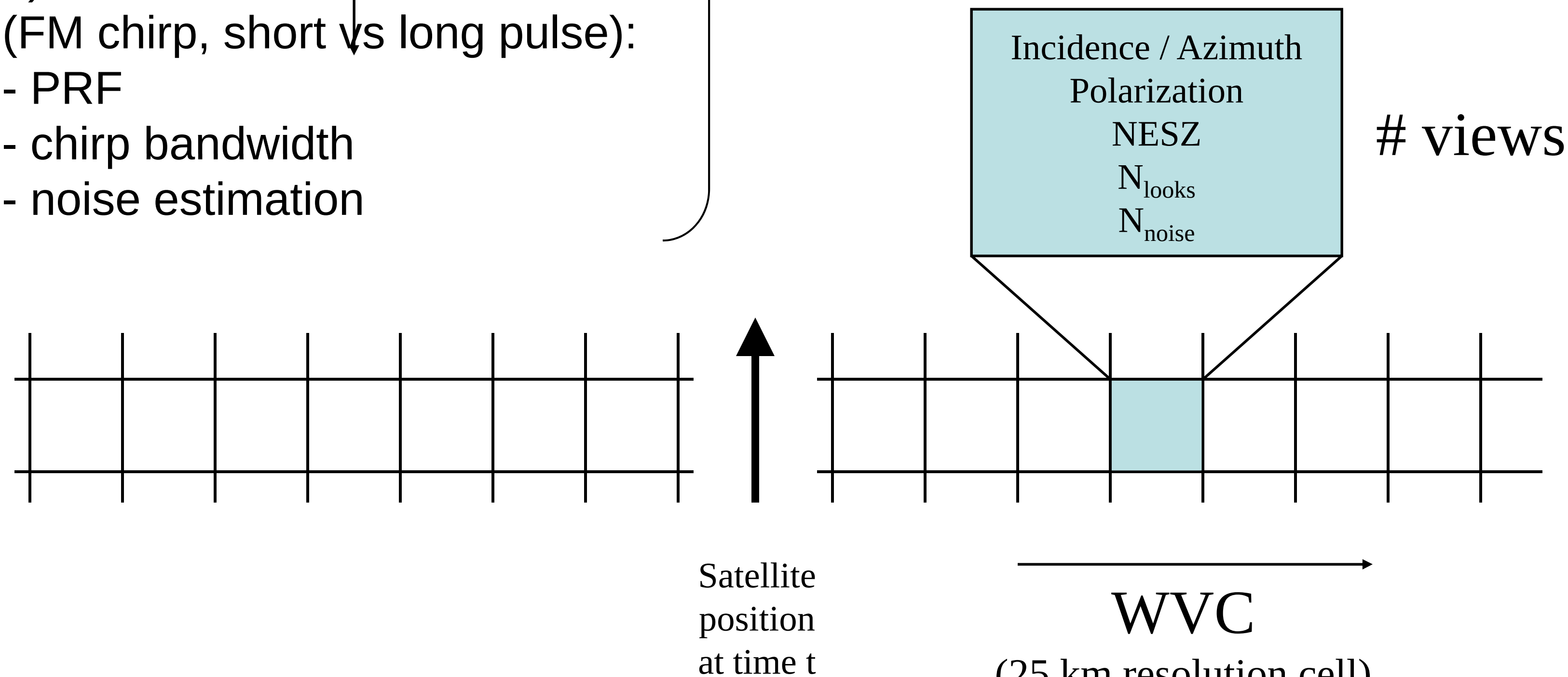
Specify complete SCA arrangement:

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



Radiometric resolution (NESZ and Kp)

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

$$NESZ = \frac{\sigma^0}{SNR} = \frac{k_B (T_0 + T_{eq})}{\frac{\lambda^2}{(4\pi)^3}\left(\frac{P_t G_{TX} G_{RX}}{R^4 \cdot L_{prop}}\right)} \frac{B_{look}}{A_{look}} \qquad A_{look} = \Delta_{range}\Delta_{azimuth}$$

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: $K_p^2 = \frac{\mathrm{var}\{\sigma^0\}}{\langle \sigma^0 \rangle^2} = \frac{1}{N_{looks}}\left(1 + \frac{1}{SNR}\right)^2 + \frac{1}{N_{noise}}\left(\frac{1}{SNR}\right)^2$

SCA end-to-end simulator

Input wind vector

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

Pseudo L1B file → GMF ← Geophysical noise

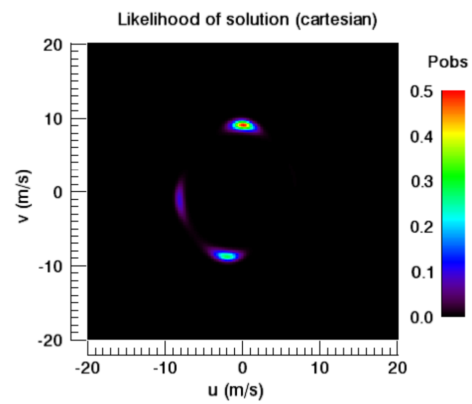
Backscatter vector observation

Wind inversion

Output wind vector
(minimum MLE solution)

$$MLE(w,\phi) = \frac{1}{\langle MLE \rangle} \sum_{i=1,\ldots,N} \frac{\left|\sigma_i^0 - \sigma_{GMF,i}^0(w,\phi)\right|^2}{K_p^2 \left(\sigma_i^0\right)^2}$$

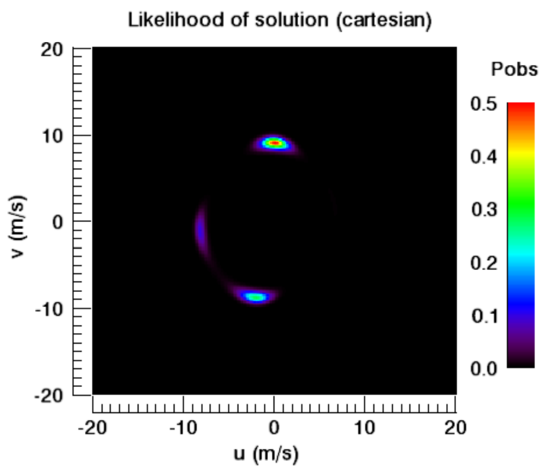
Observational likelihood



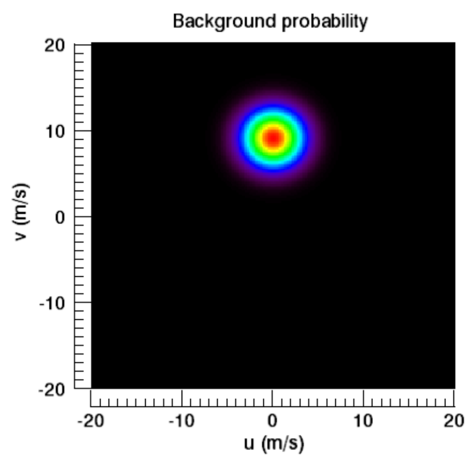
$P_{obs}(\mathbf{V}_{out}|\mathbf{V}_{in})$

Wind retrieval performance

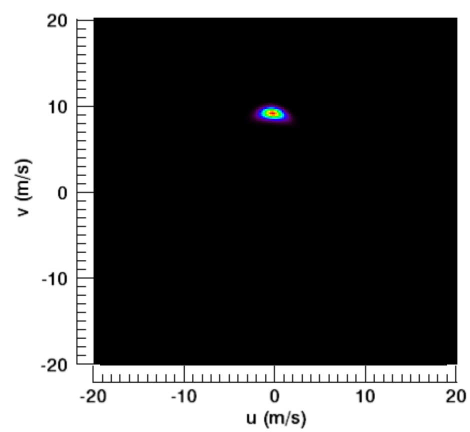
$P_{obs}(\mathbf{V}_{out}|\mathbf{V}_{in})$



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



$P_{obs}(\mathbf{V}_{out}|\mathbf{V}_{in})*P_{NWP}$



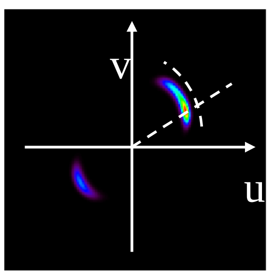


Figure of Merit

1) Wind Vector RMS error

2) Ambiguity susceptibility

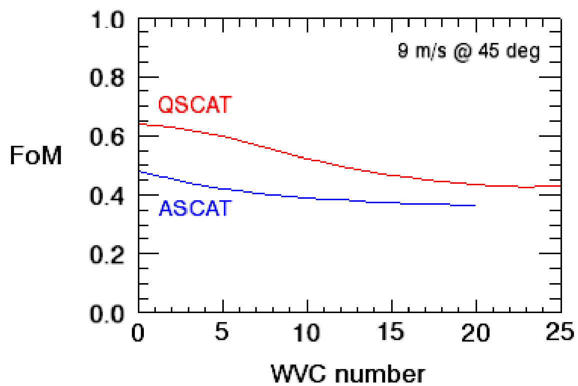
3) Wind biases (skewness)

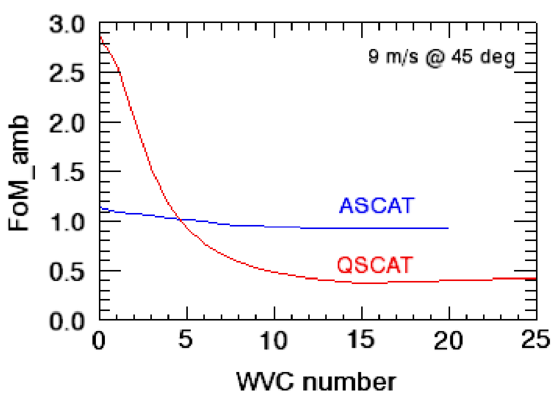
For example:

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

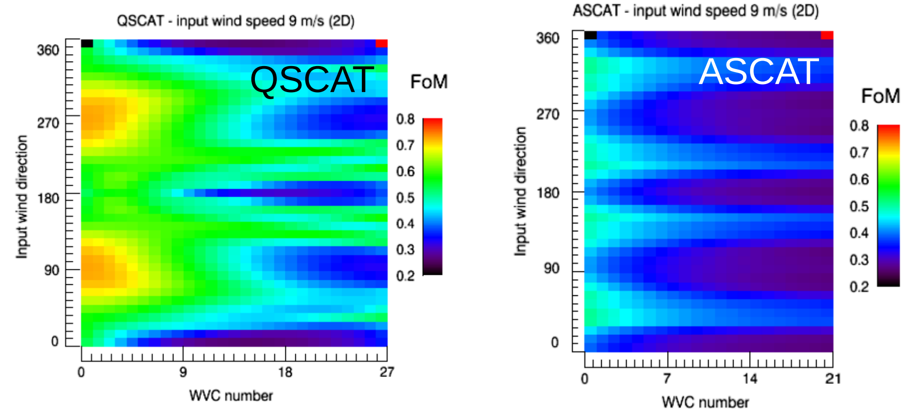
Wind retrieval performance QSCAT/ASCAT

Vector RMS error

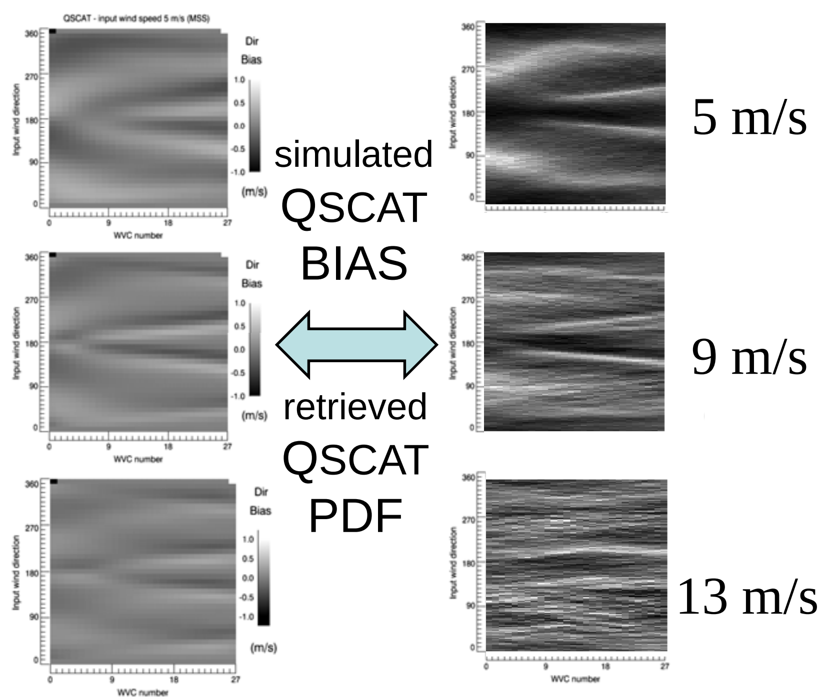




AMBIGUITY



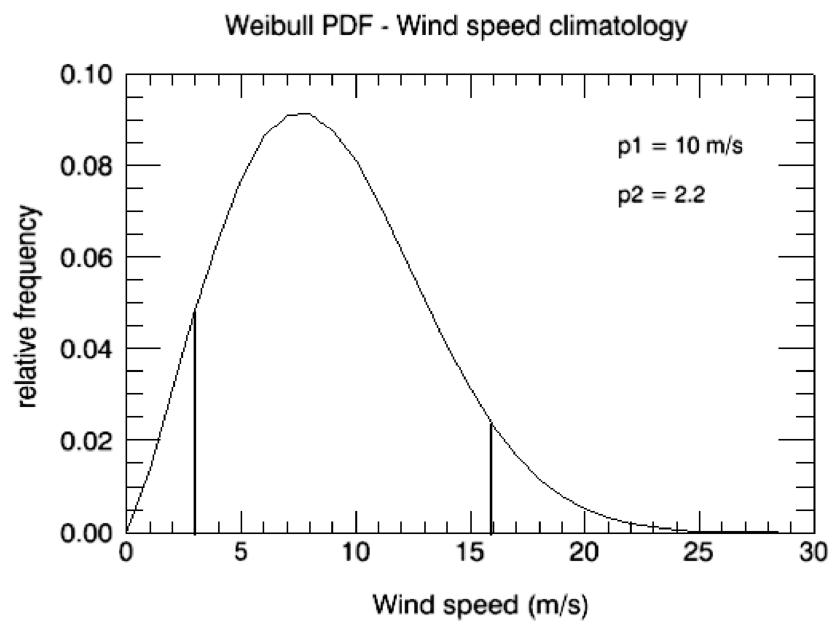
Vector RMS error at 9 m/s



IOVWST

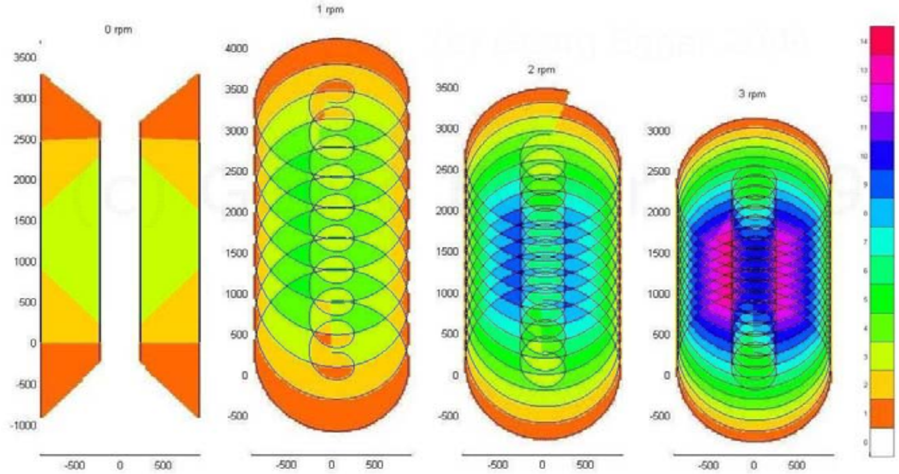
Climatology FoMs

Wind retrieval performance is dependent on <u>input wind</u> and <u>across track distance</u>



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

SCA assessment

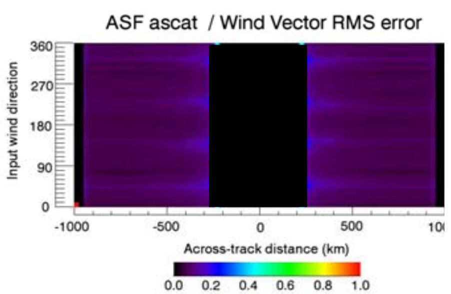


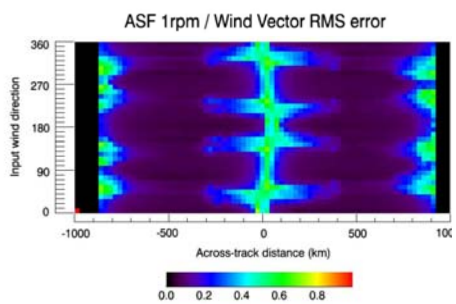
ASCAT type

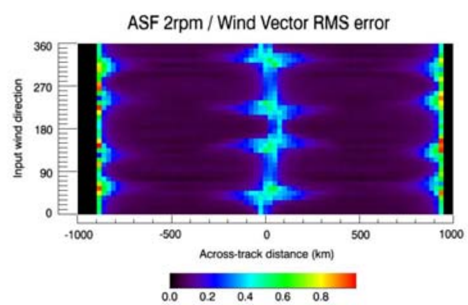
RFSCAT (1rpm)

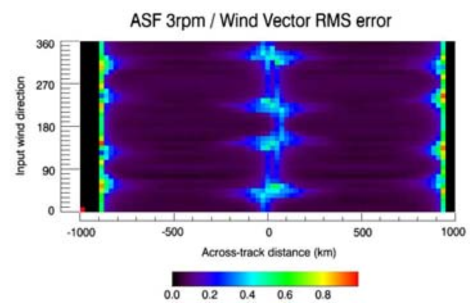
RFSCAT (2rpm)

RFSCAT (3rpm)





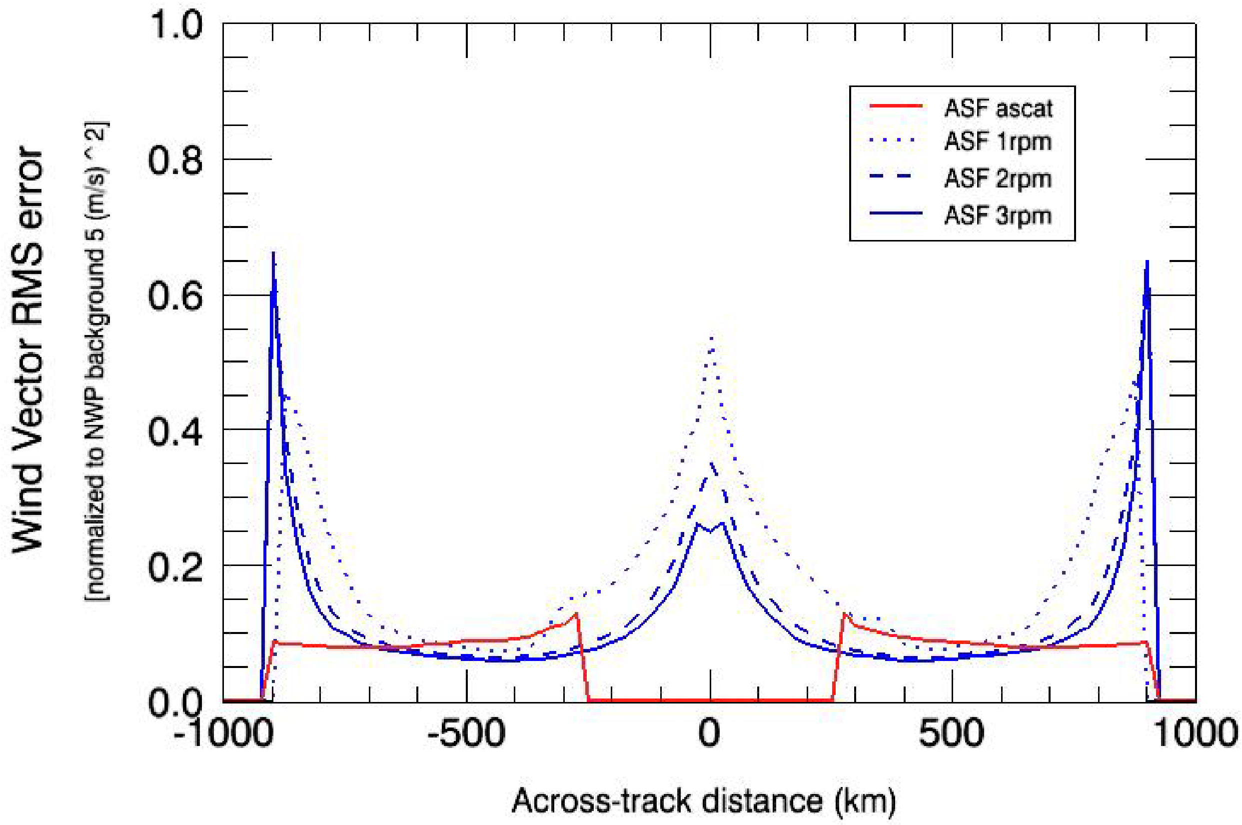




Wind Vector RMS error across swath

Conclusion

RFSCAT performs well compared to ASCAT configuration, but …



To consider: geophysical noise, HH polarization, resolution

To optimize: antenna pattern…

Thank you !

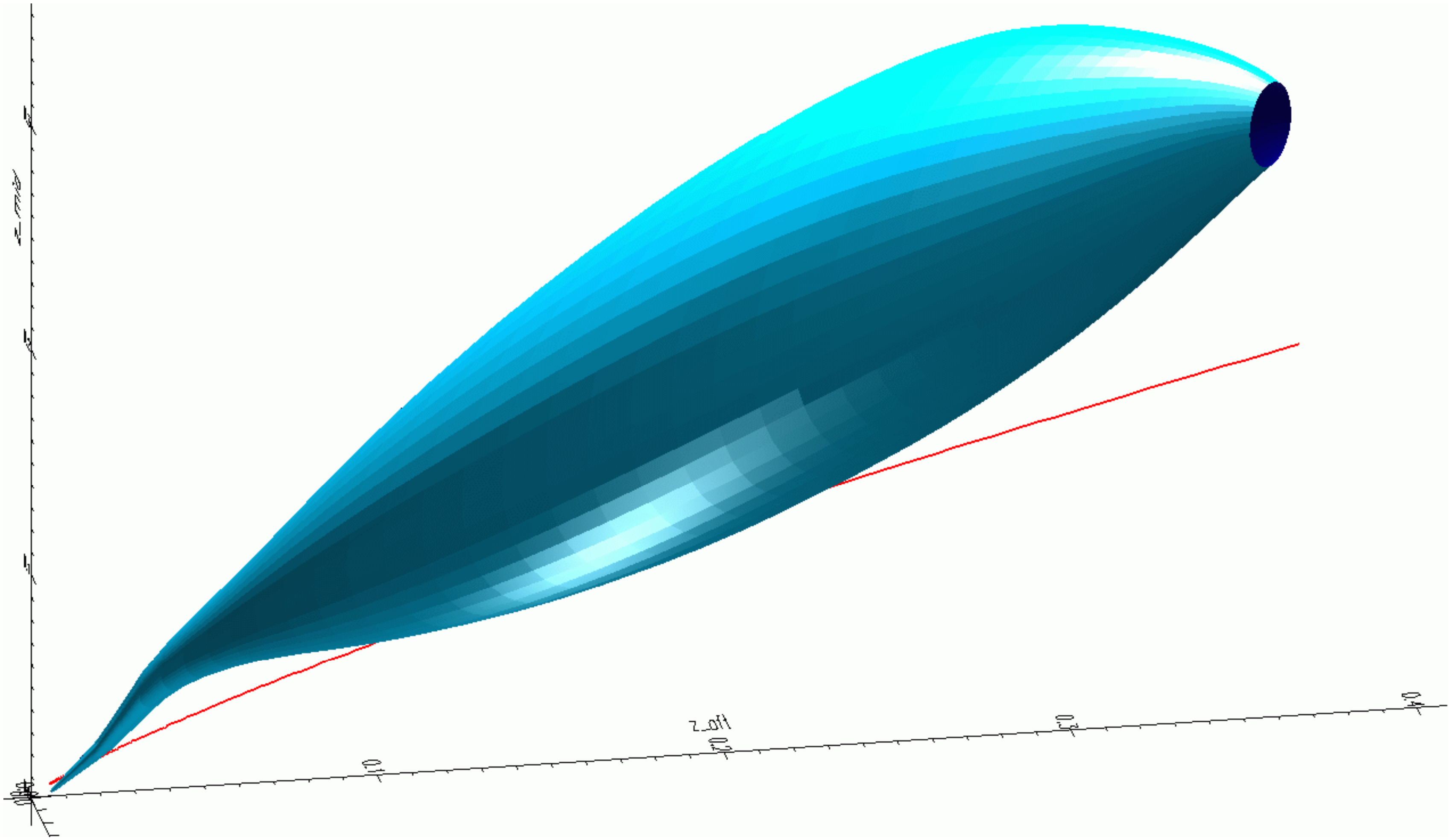
scat@knmi.nl

www.knmi.nl/scatterometer

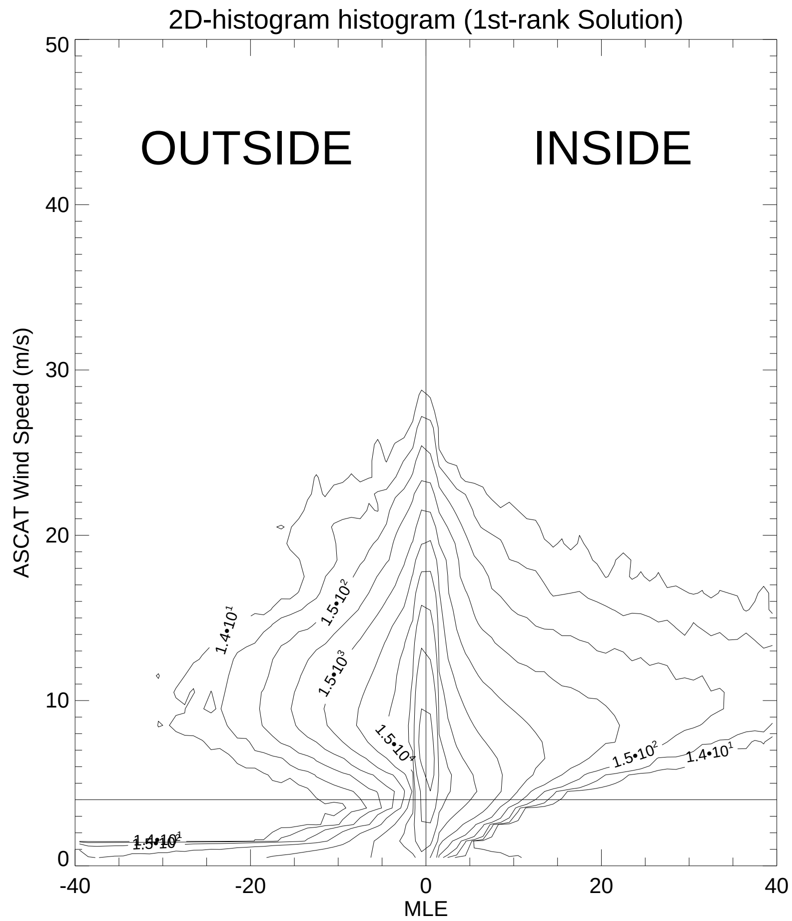
Backup Slides

Wind retrieval and noise model

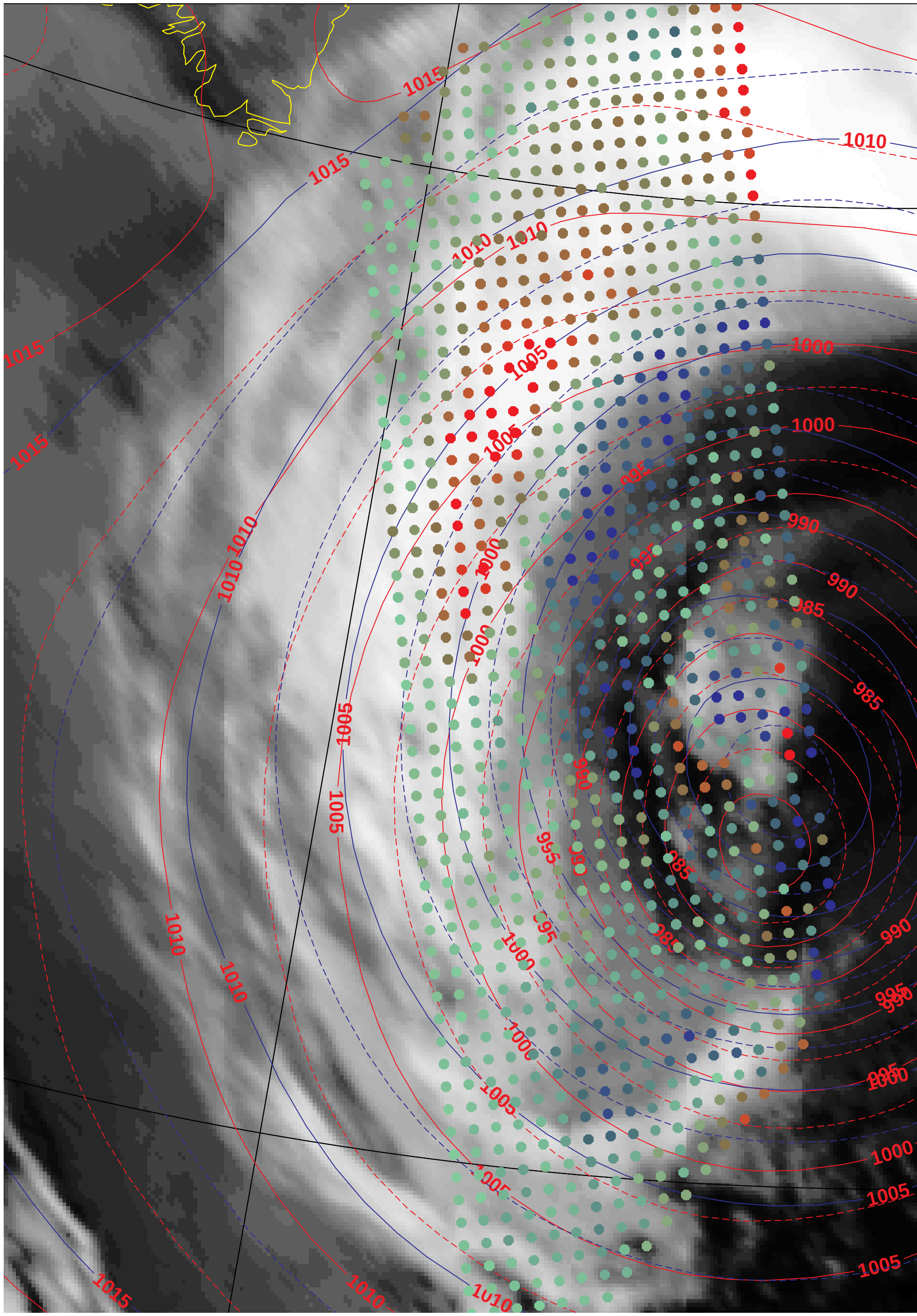
- ✓ Kp noise
- ✓ Geophysical noise due to ocean variability
- ✓ Approximate retrieval functions



GMF issues



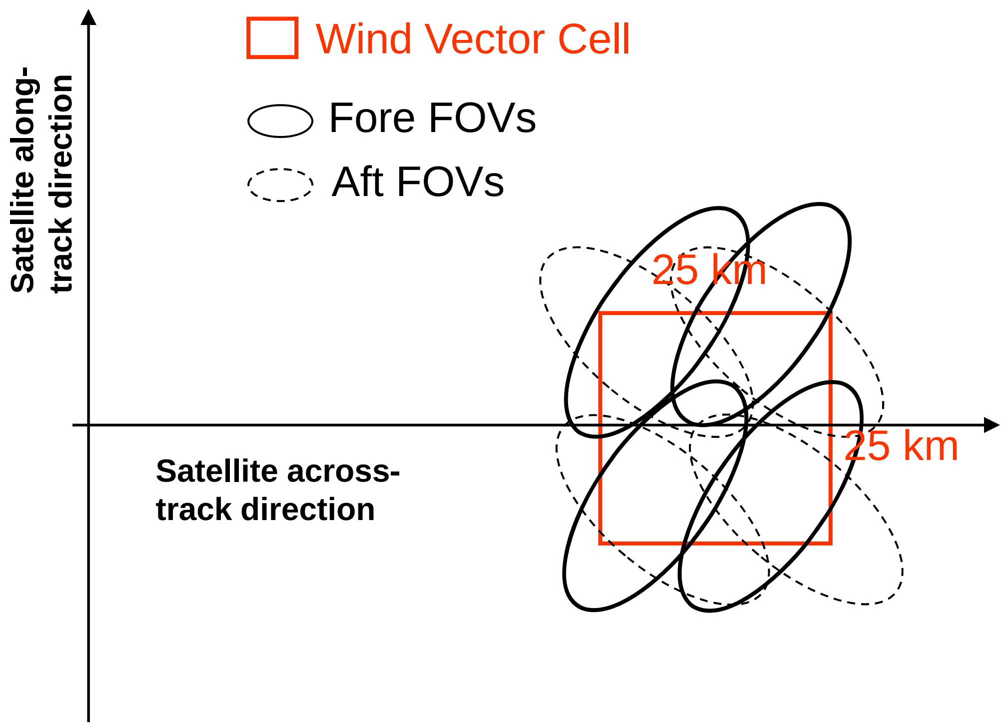
- Measured triplets are centered well on cone within Kp for all speeds
- Geophysical noise at low winds incorporated
- Reasonable symmetry at medium-high winds
- Around 4 m/s most triplets inside the cone
- At very low winds, opposite effect



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

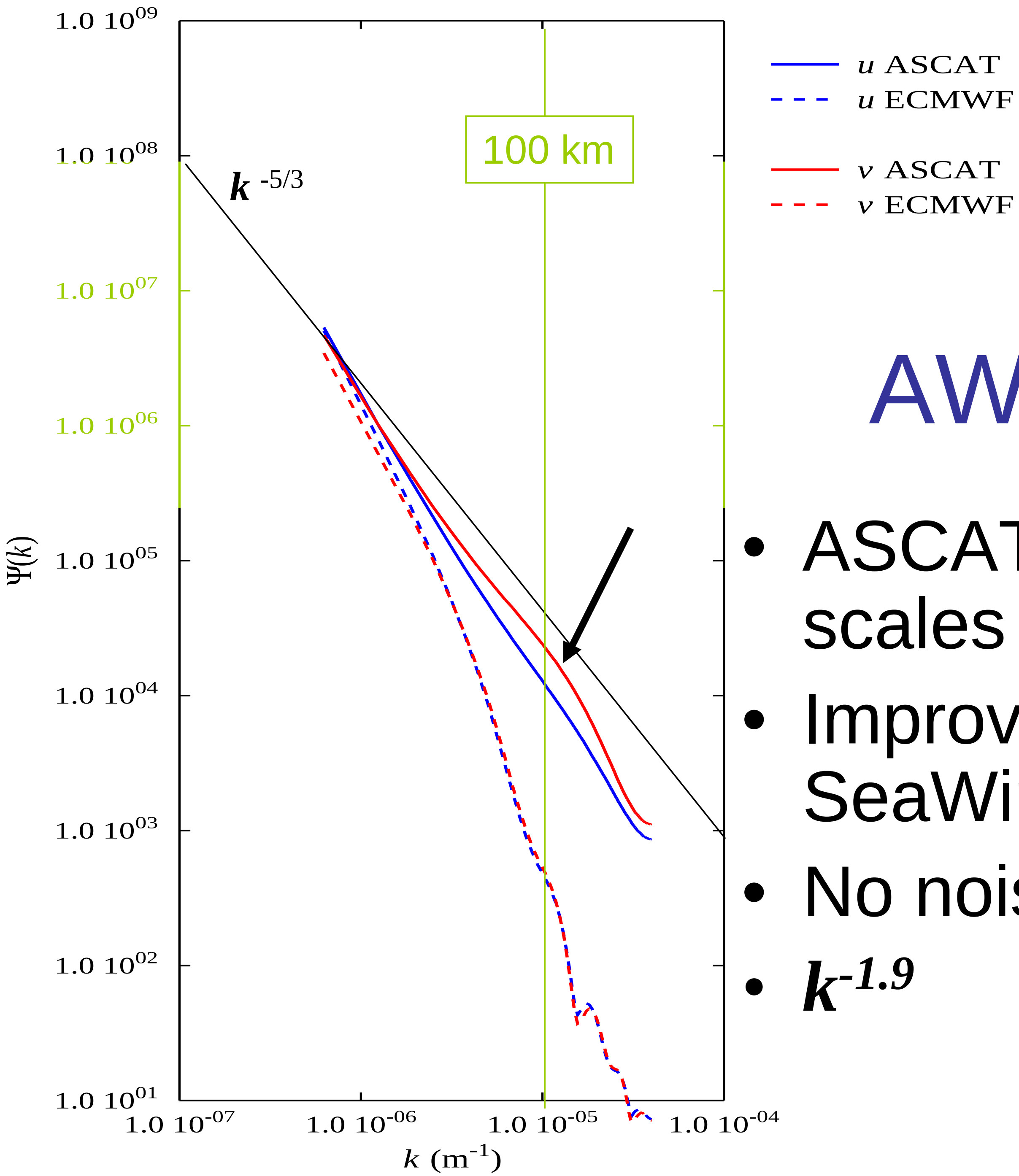
Accuray on 50-km WVC scale

- Triple collocation analysis of buoy, scatterometer & NWP

Vector RMS error [m/s]	Tropical TAO/PIRATA	Extratropical NDBC/MEDS/UKMO
Buoy	1.5	1.5
Scatterometer	1.2	1.6
ECMWF model	2.0	2.1

Scatterometer winds provide excellent forcing

Remaining errors include representativeness



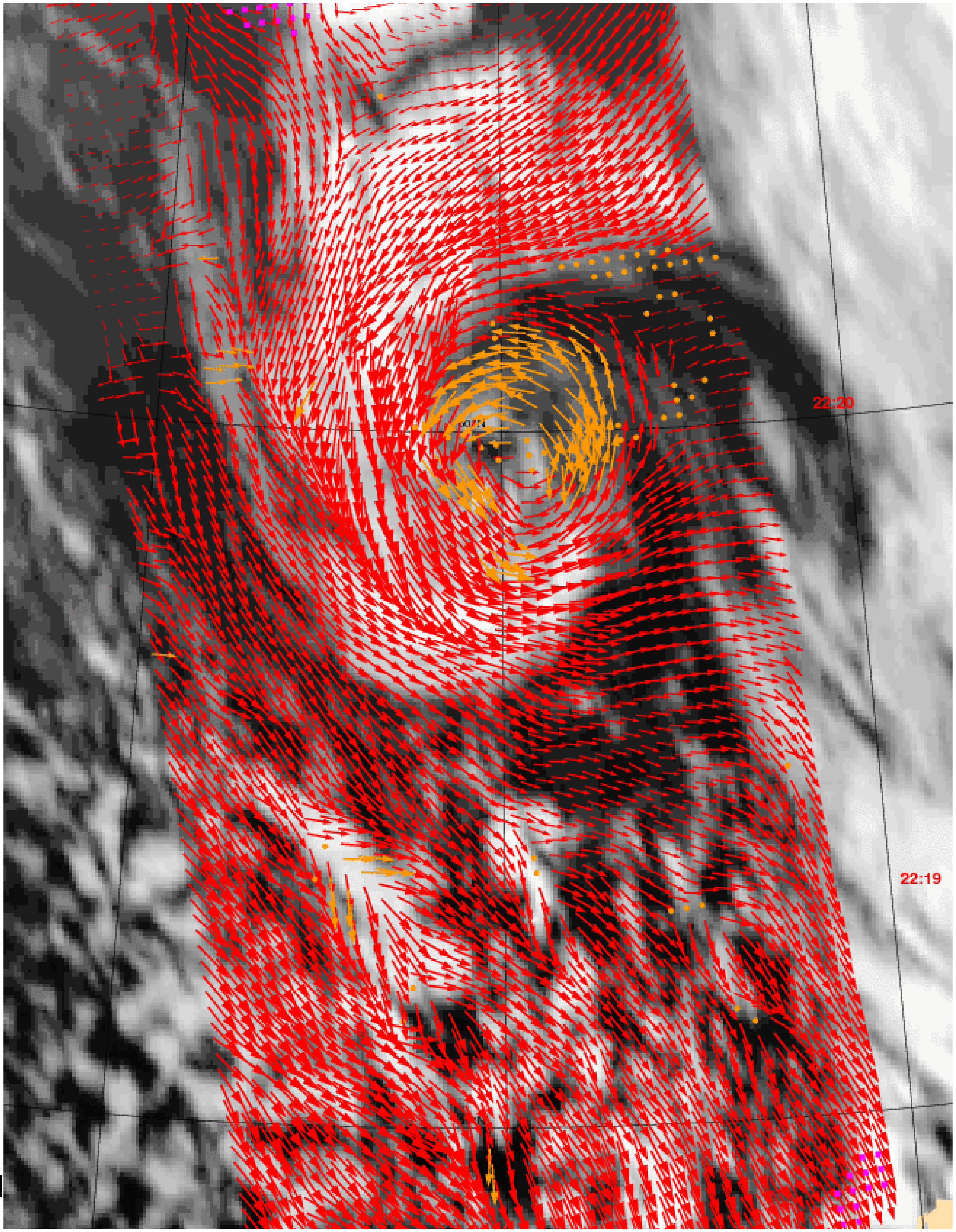
AWDP@12.5

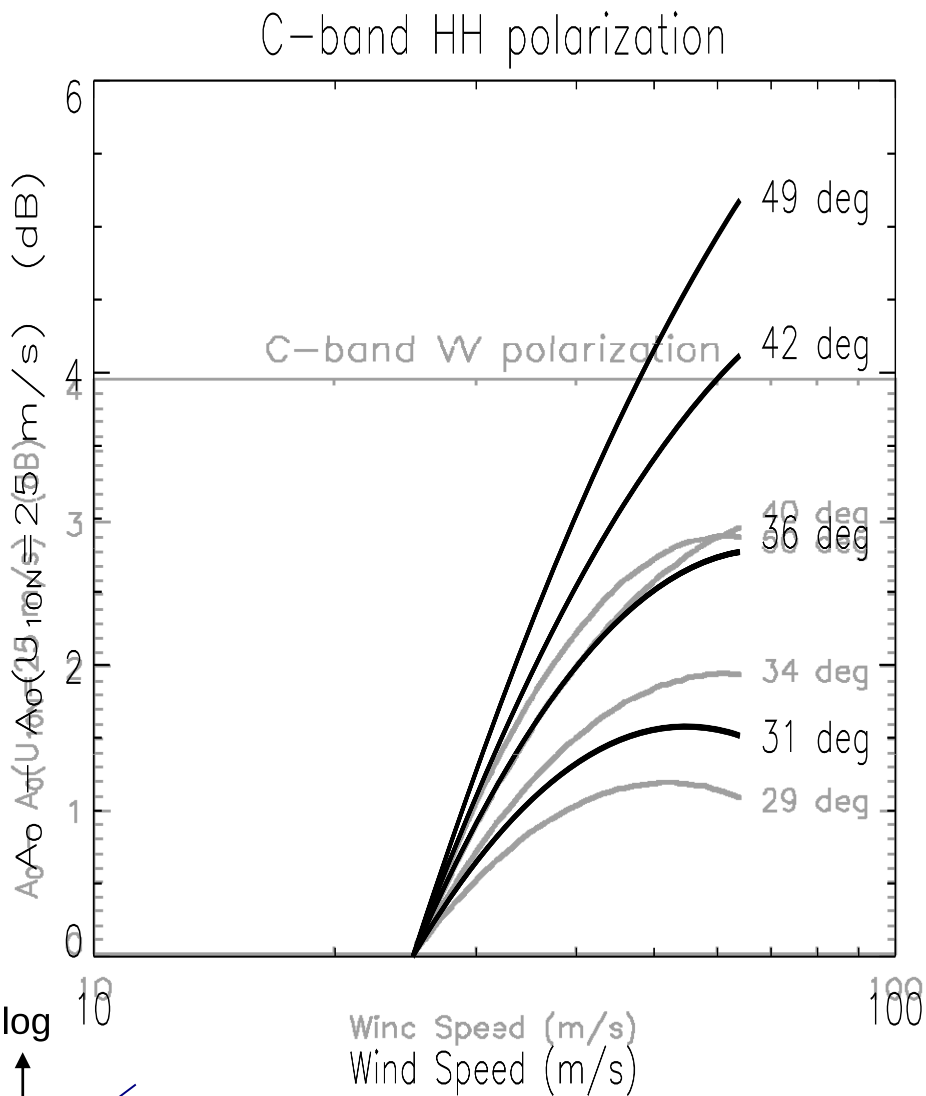
- ASCAT contains small scales down to 25 km
- Improved w.r.t. SeaWinds
- No noise floor
- $k^{-1.9}$

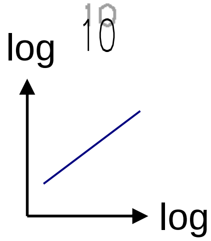
Mesoscales

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

www.knmi.nl/scatterometer







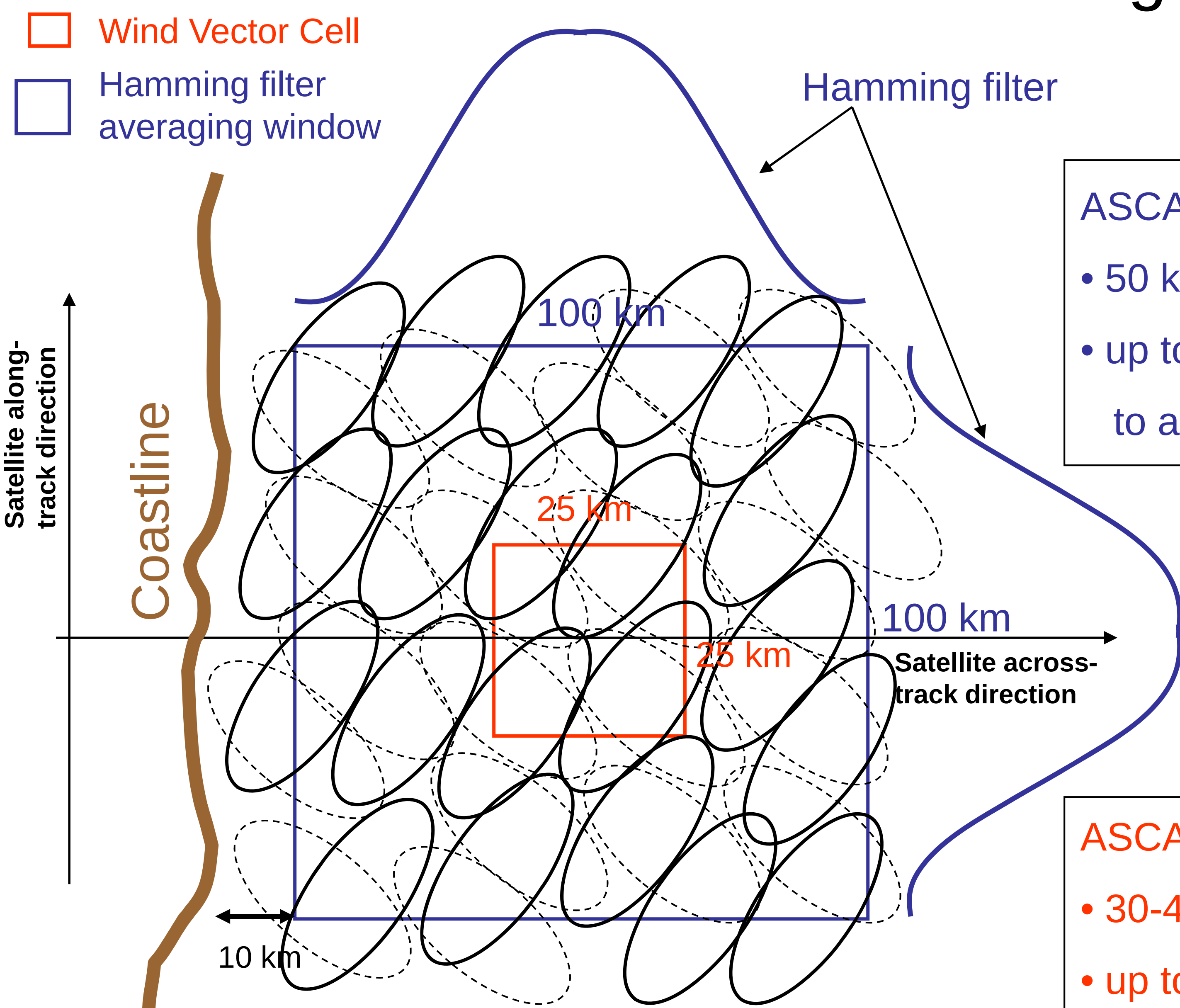
High Winds **C**-band Model Function

•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



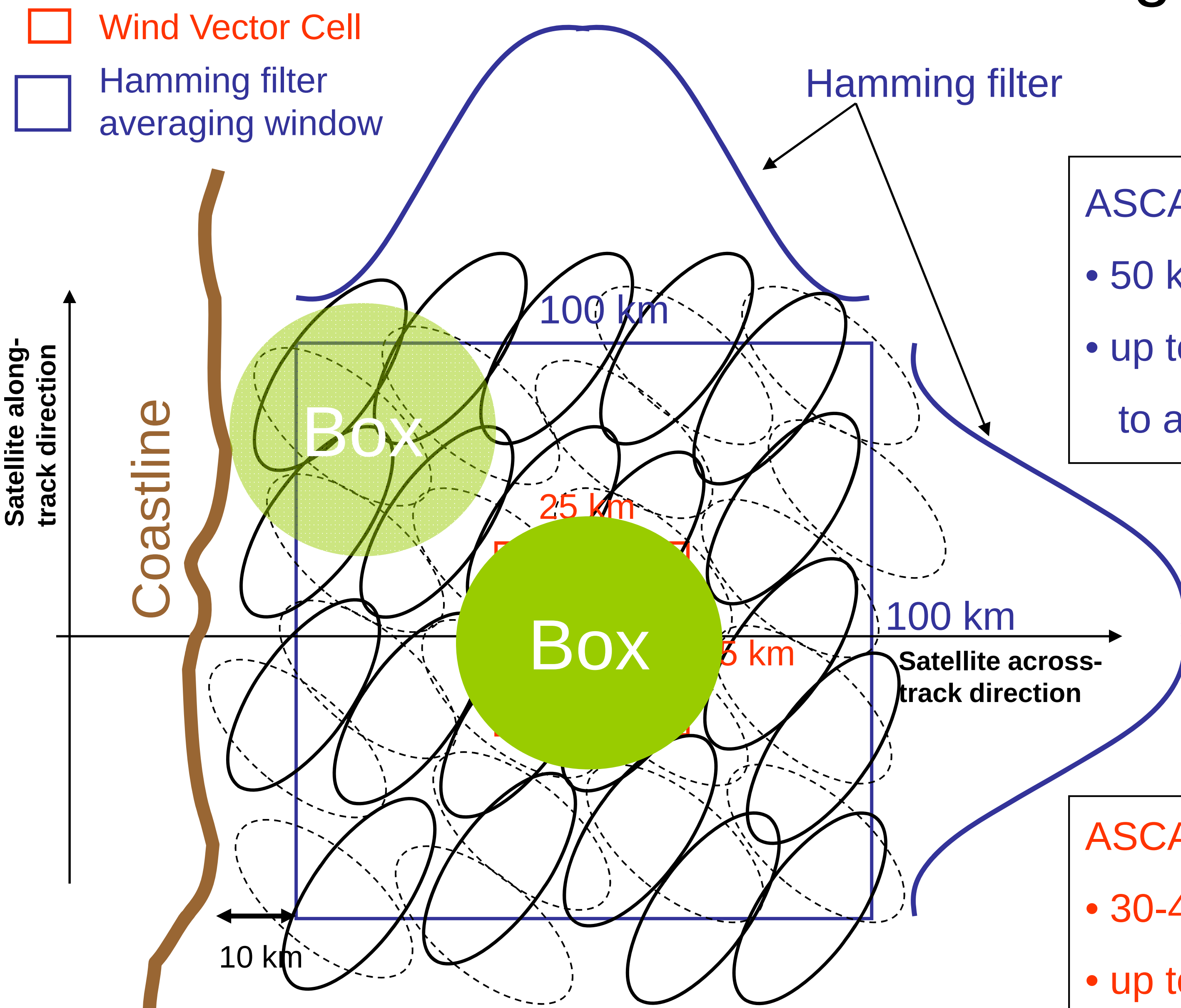
ASCAT Level 2 product:

- 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
- **$\sigma°$ more noisy**

ASCAT L1 backscatter averaging



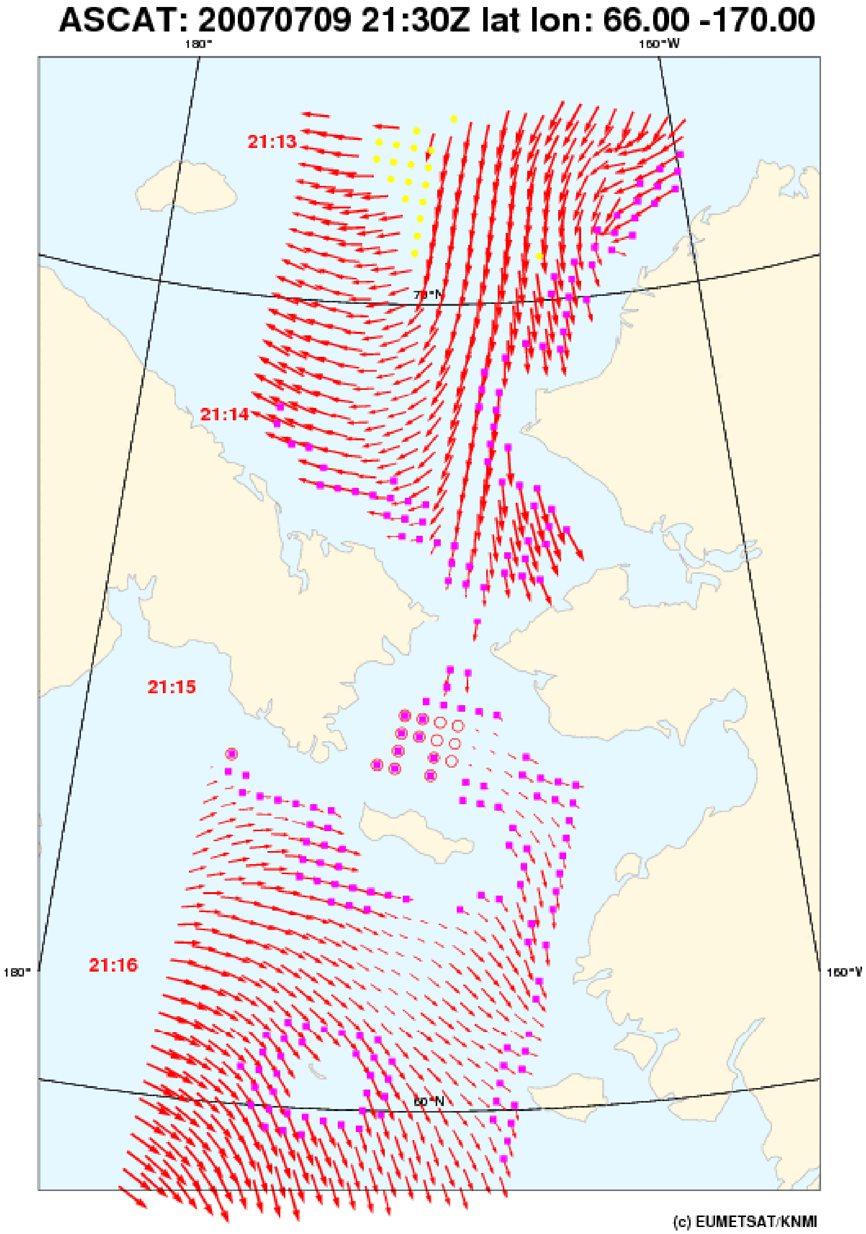
ASCAT Level 2 product:

- 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
- **σ° more noisy**

Prototype at 25 km



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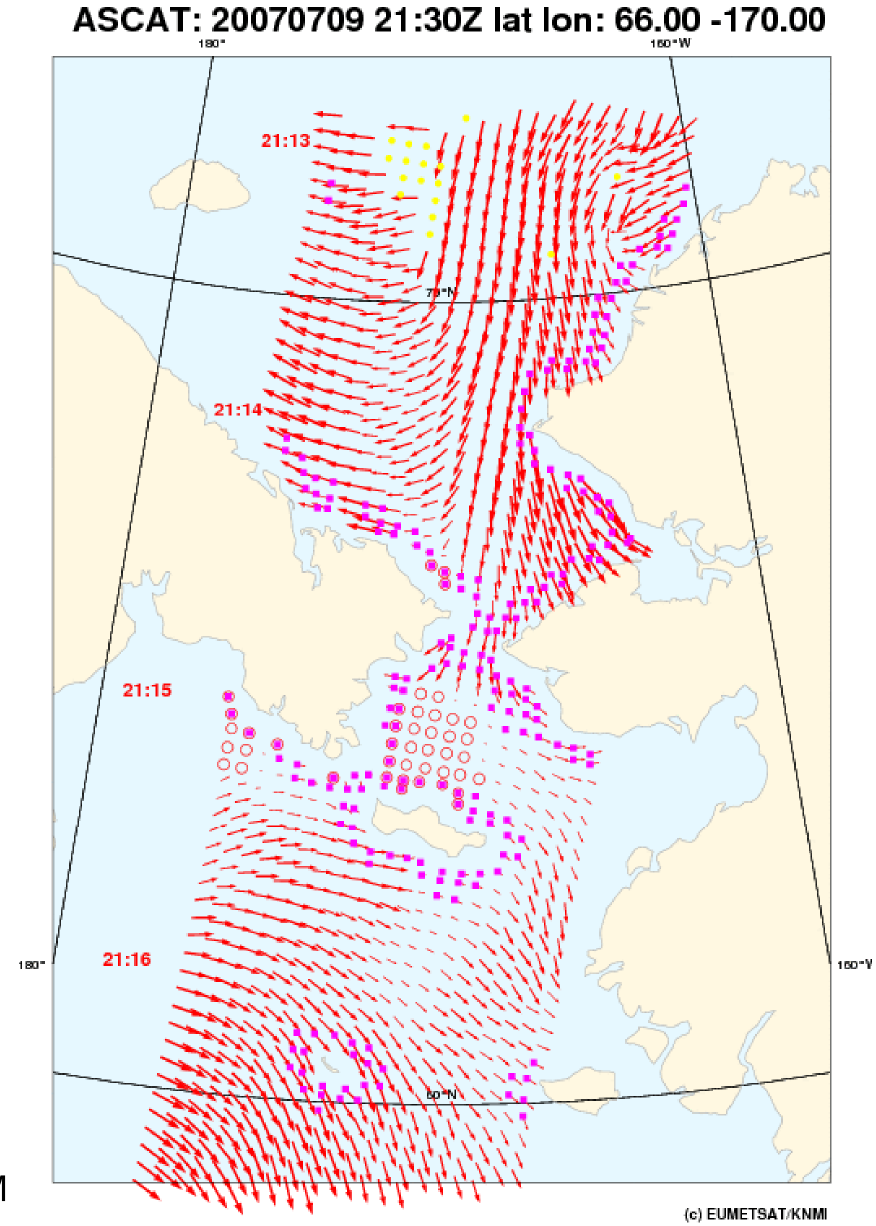
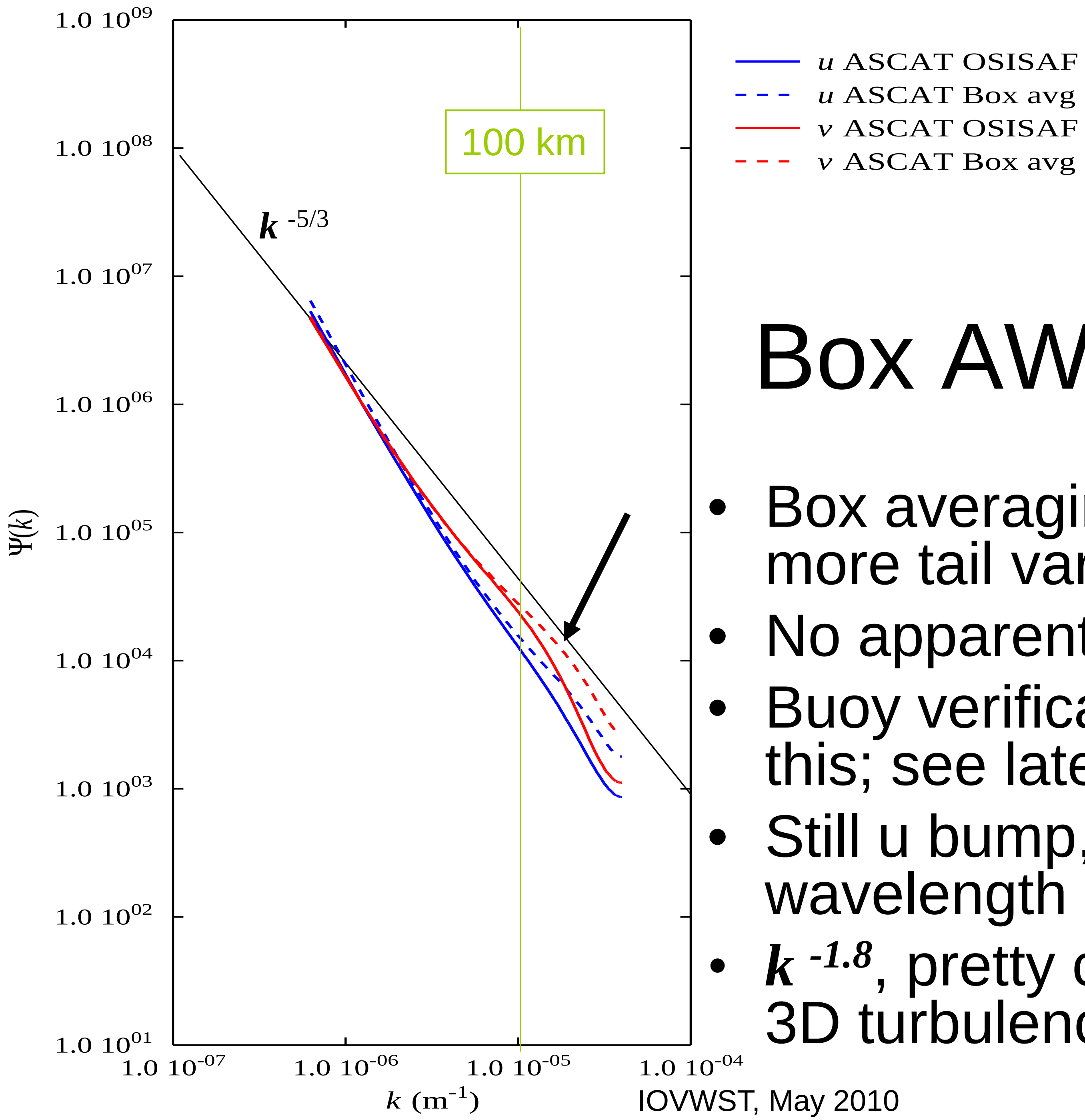




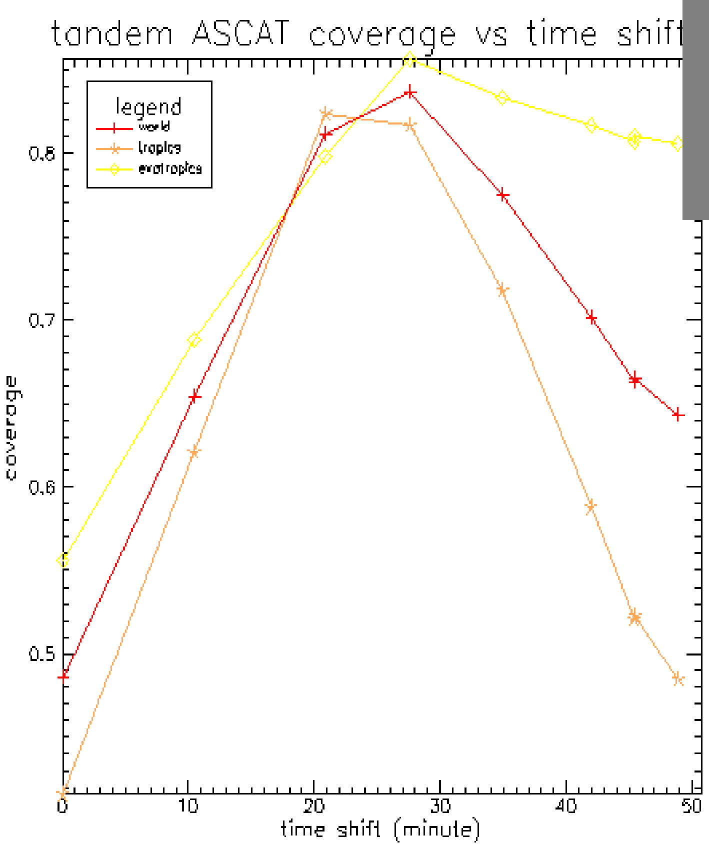
NWP SAF

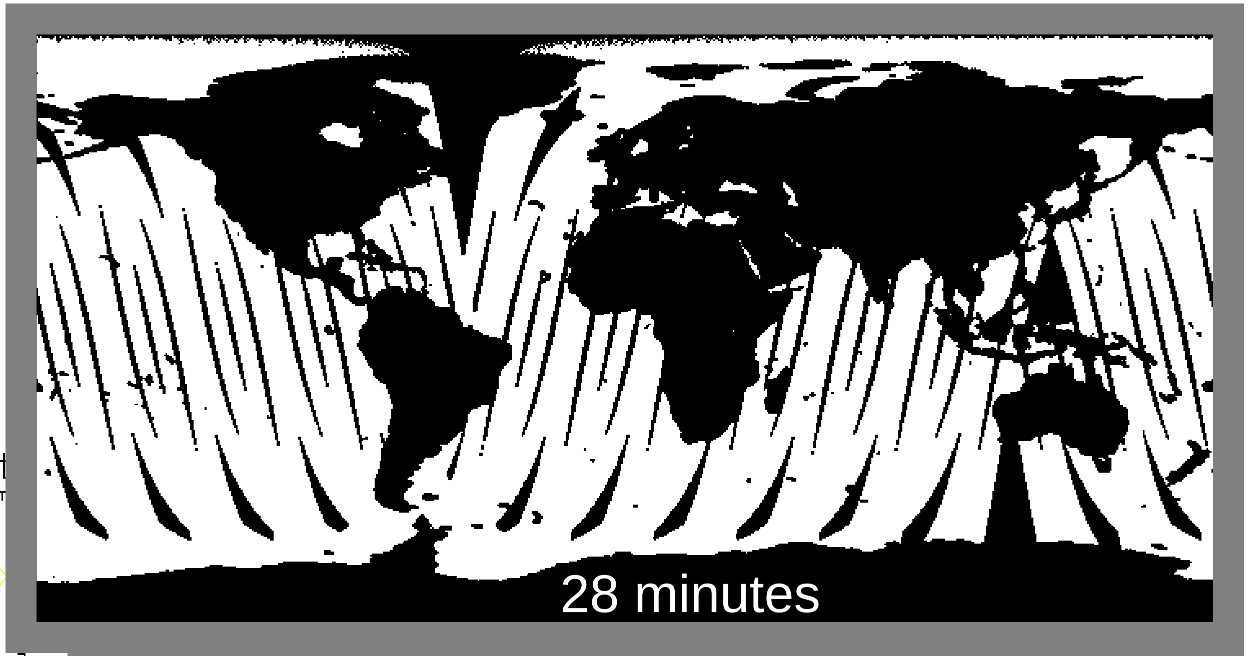
Box AWDP@12.5

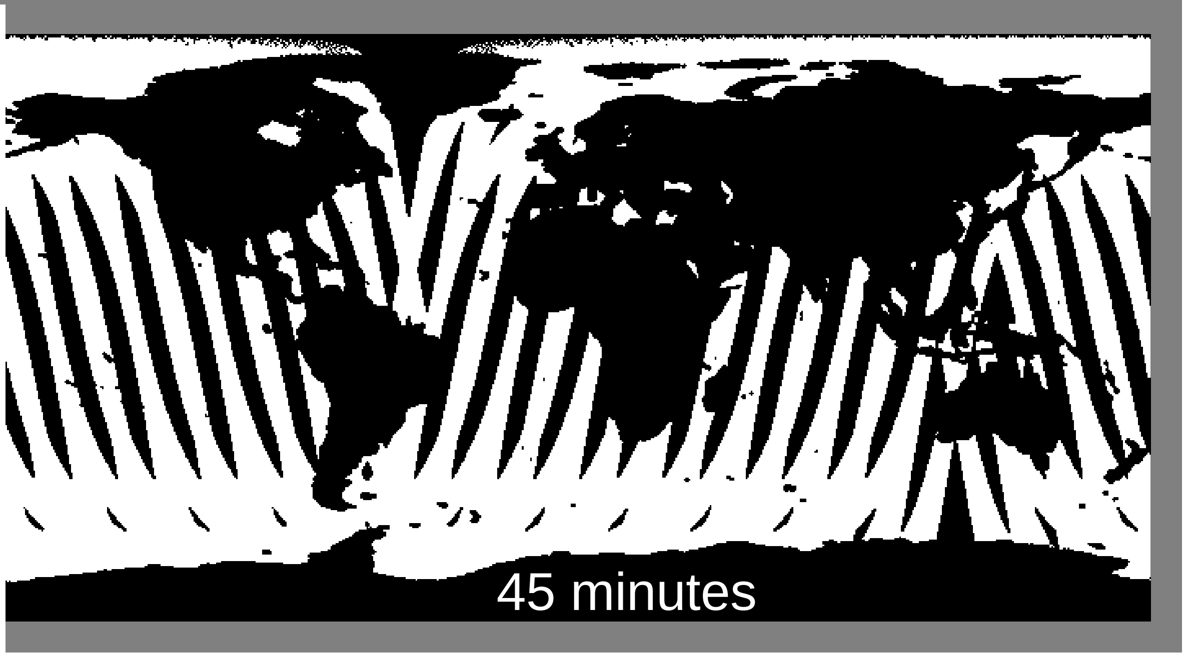
- Box averaging maintains more tail variance
- No apparent noise floor
- Buoy verification confirms this; see later presentation
- Still u bump, but at lower wavelength (?)
- $\boldsymbol{k}^{-1.8}$, pretty close to -1.67 for 3D turbulence Nastrom and Gage 1987

KNMI ASCAT on MetOp Phasing Study

- 28 minutes clearly optimal
- No gain in tropics at 50 minutes







Antenna assembly

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

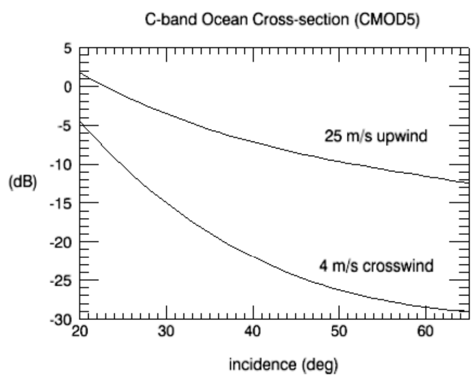
Swath FoV → 3dB width
Spatial resolution → 3dB length

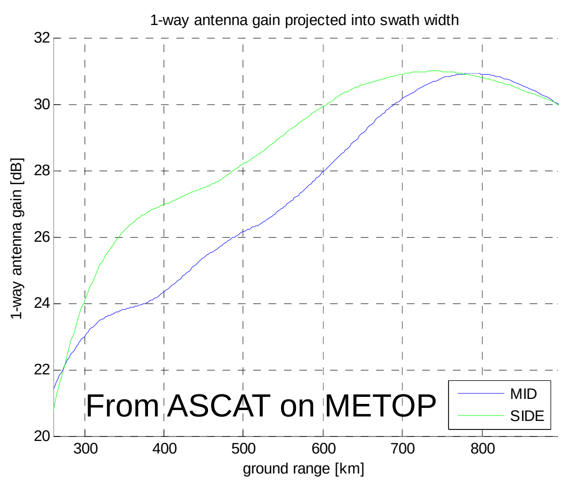
Antenna effective dimensions

⊕

Beam shaping in elevation

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





Dynamic range

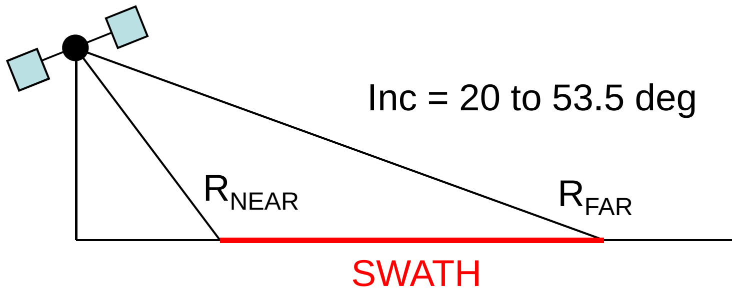
$$SNR = P_t \frac{\frac{\lambda^2}{(4\pi)^3}\left(\frac{G_{TX}G_{RX}}{R^4 \cdot L_{prop}}\right)}{k_B(T_0 + T_{eq})} \frac{\sigma^0 A_{look}}{B_{look}}$$

[SNR is determined by Pt and chirp bandwidth]

Slotted waveguide radiators:
to compensate for larger slant range across swath (~10 dB)

Radar PRF

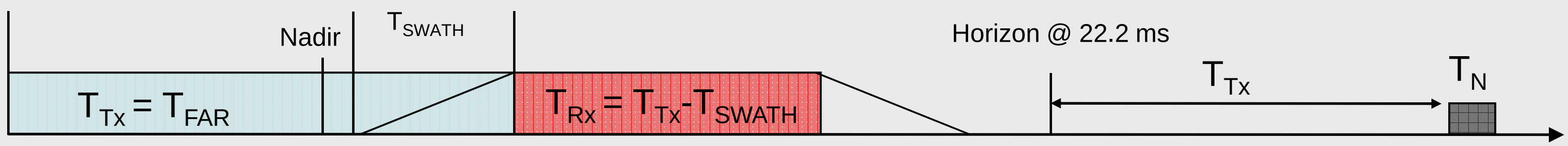
Limited by swath extent: two different strategies



T_{SWATH}	MID	SIDE
T_{NEAR}	5.7 ms	8.4 ms
T_{FAR}	6.0 ms	10.5 ms

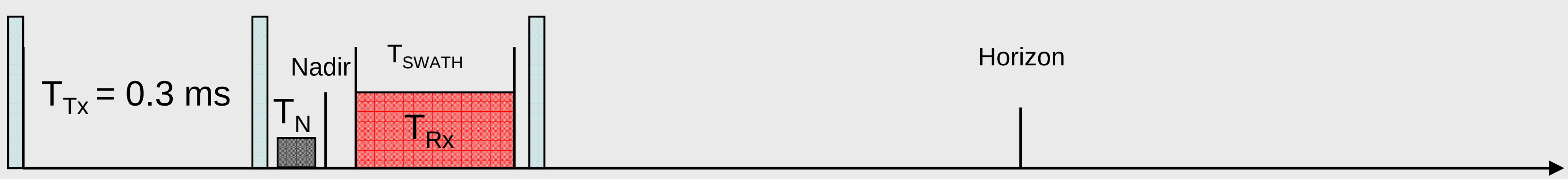
A) Long pulse ($T_{TX} >> t_{SWATH}$)

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



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

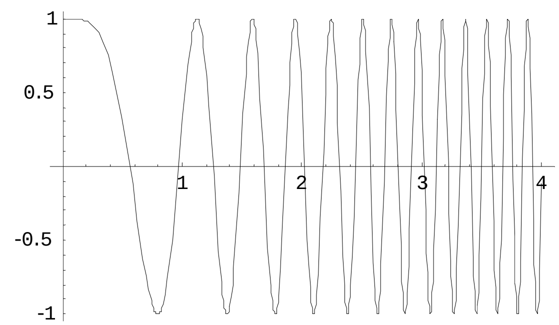
PRF = $1/(T_{FAR}+T_{Tx})$ = 230 Hz (7%DC)



2) Radar waveform

LFM chirp for range resolution

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



(μ = chirp rate $\approx B_{Tx}/T_{Tx}$)

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

FFT

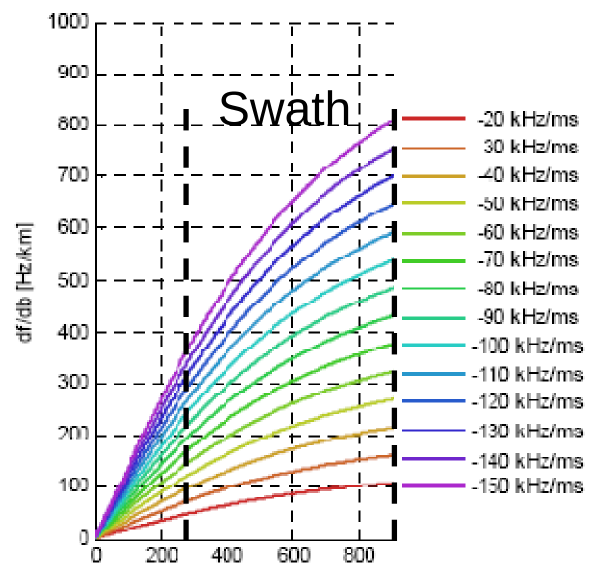
Echo bandwidth $B_{echo} \approx \mu(t_{FAR} - t_{NEAR}) + \Delta f_D$

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

Resolved look area:

A_{look}= 16 km x $B_{look}/[2(\mu/c)\sin(inc)]$

Inversely proportional to chirp rate, but so is SNR!



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

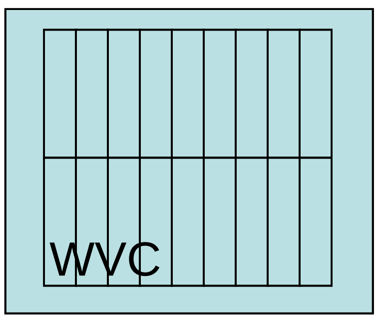
Radiometric resolution

Received signal = backscatter + speckle + emission

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

1) Accumulate independent looks to reduce speckle

$N_{looks} = N_{az} N_{el}$



Independent looks

$N_{az} = (PRF/v_{ground}) L_{WVC}$ — Maximum PRF (compatible with unambiguous range)

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

$SNR \propto P_t\sigma^0/\mu \sin(inc)$ — Minimum Pt (compatible with Kp requirements)

ITERATE

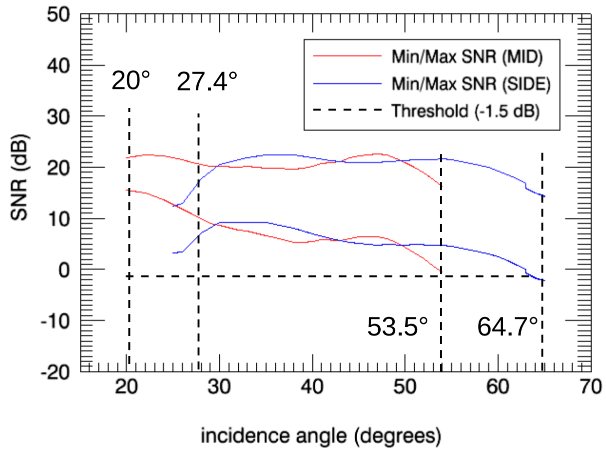
2) Noise (emission) estimation and subtraction

$N_{noise} = N_{az}B_{echo}T_N$

Where $B_{echo} = f_s/2$ sets the sampling frequency

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

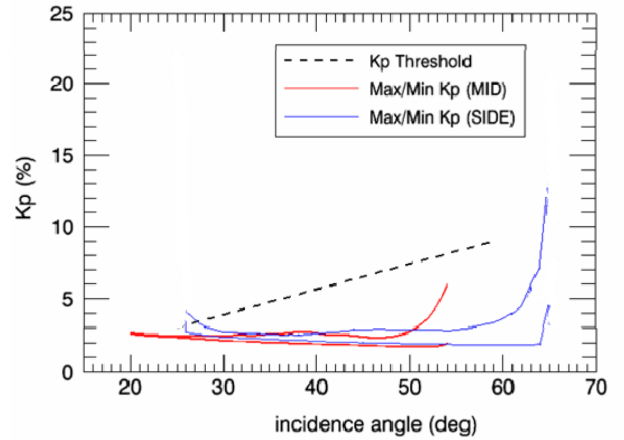
Min SNR check



Non-compliance leads to
increments in peak power

(and/or antenna pattern accommodation?)

Max Kp check



Non-compliance leads to
increments in chirp rate

Compliant SCA configurations enter the wind performance study

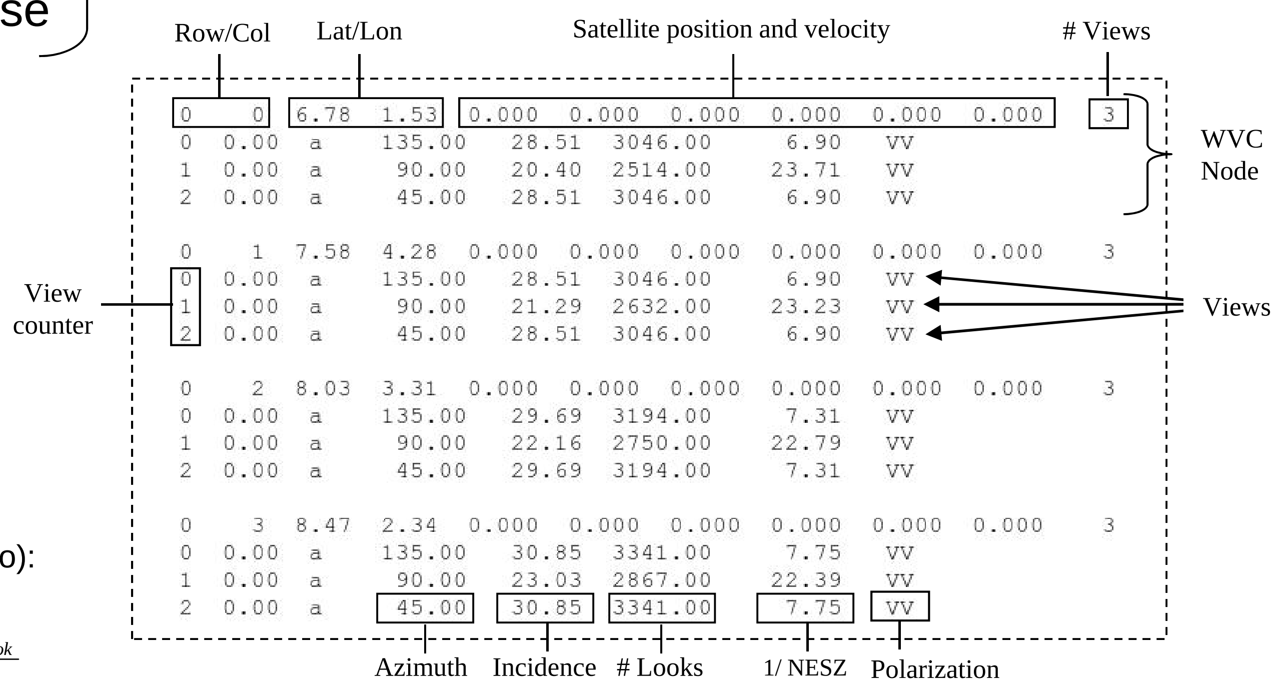
Complete SCA configuration

1) **Antenna assembly**
- total power & pattern

2) **Radar waveform**
- PRF, chirp rate & noise

Orbital model

→ Pseudo Level 1B file



NESZ (Noise Equivalent Sigma Zero):

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