SCAT wind retrieval simulator & FoM

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Outline

- Objective
- SCAT Baseline and backup concepts
- End-to-End Performance Study
  - Input winds
  - Observation geometry
  - Instrumental and geophysical noise
  - Wind retrieval simulator
  - Figure of Merit
- Test cases
- Conclusions

Objective

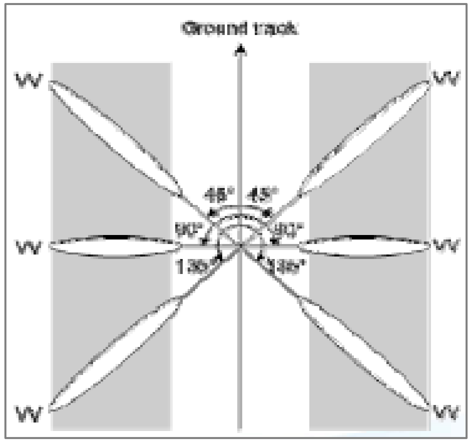
- KNMI is responsible for the End-to-End SCAT Performance Study for Post-EPS (2019):
  - *To assess the wind retrieval performance*
  - *To support parameter optimization*

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

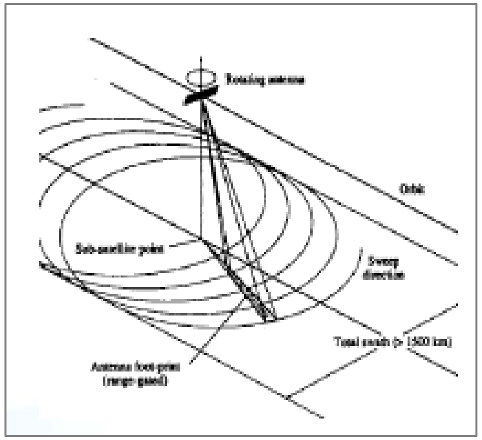
- Spatial resolution (25 km)
- Dynamic range (4-25 m/s)
- Radiometric resolution (~3-10% at 4 m/s)
- Swath coverage (95% in 48 hours for incidences between 20 and 60°)

MetOp orbit → Sun Sync with 820 km altitude

I - Fixed beam (ASCAT type)



II - Rotating beam (RFSCAT type)



<u>Discarded</u>: Ku-band, pencil beam, extended nadir coverage for ASCAT type

End-to-End Performance Study

1) Input wind vector

2) Observation geometry

GMF

Backscatter vector

3)
+ Instrumental noise
+ Geophysical noise

4) Wind retrieval

5) Figure of Merit

(function of input wind, location on swath and system noise)

SCA wind retrieval simulator (F90)

QuikSCAT Kp =20%
9 m/s @ 90 deg
Outer swath

Input wind vector

Pseudo L1B file → GMF ← Geophysical noise

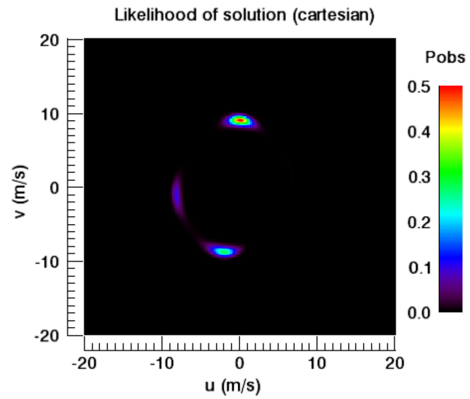
Backscatter vector observation

Wind inversion

Output wind vector
(first rank solution)

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

Observational likelihood

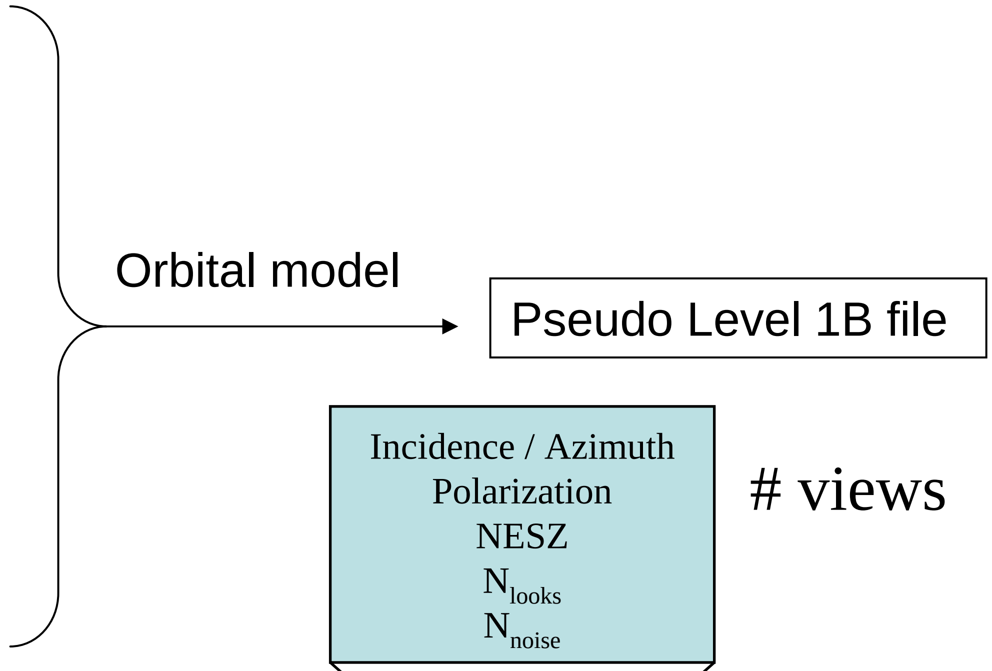


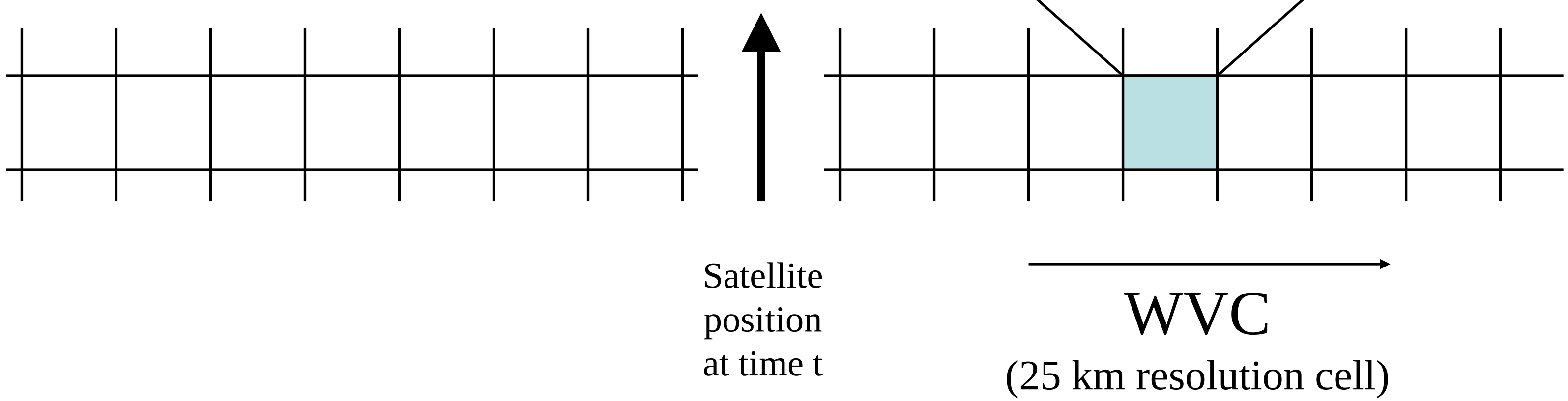
$P_{obs}(\mathbf{V}_{out}|\mathbf{V}_{in})$

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

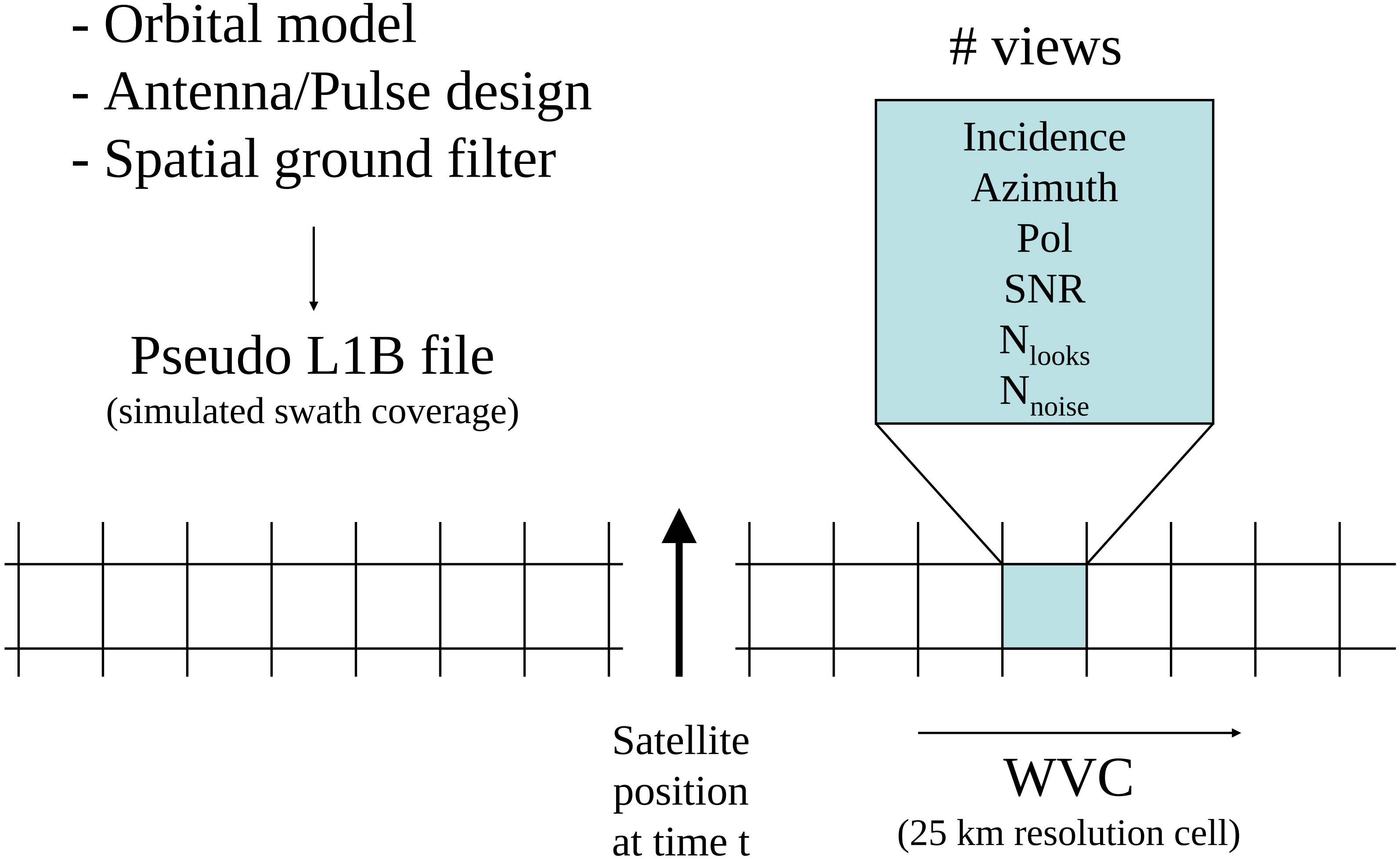




2) Observation geometry

- Orbital model
- Antenna/Pulse design
- Spatial ground filter

Pseudo L1B file
(simulated swath coverage)



Radiometric resolution (NESZ and Kp)

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

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

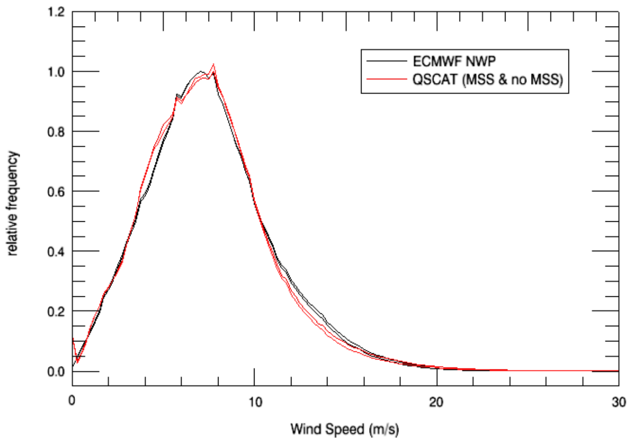
2) Number of looks per node: $N_{looks} = \frac{\Delta x \Delta y}{A_{look}}$ (reduce speckle)

3) Number of noise samples: $N_{noise} = f_s T_{noise}$ (noise estimation)

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

1) Input wind vector

- Climatology distribution of wind inputs:



Weibull distribution in wind speeds (with maximum around 8 m/s) and uniform distribution in wind direction.

3) Instrumental & geophysical noise

- Instrumental (radiometric) noise

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

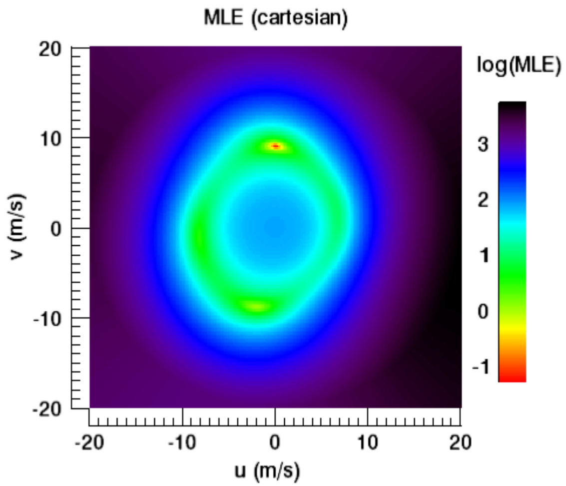
- Geophysical noise

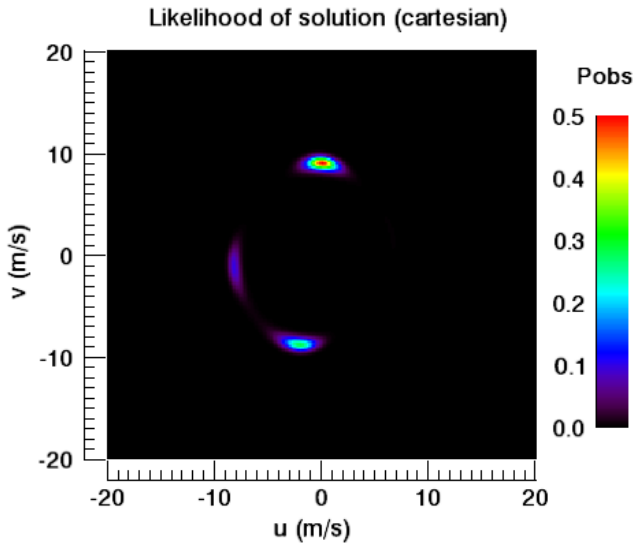
$$k_g^2 = \frac{\mathrm{var}\{\sigma^0\}}{\left(\sigma^0\right)^2} = 0.064\left(\left|\vec{v}\right| - 16\right)^2$$

Simulated observations ⟶ $\sigma^0 = \sigma^0_{GMF}(1 + \sqrt{k_p^2 + k_g^2} \cdot N[0;1])$

4) Wind retrieval – MLE and likelihood

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



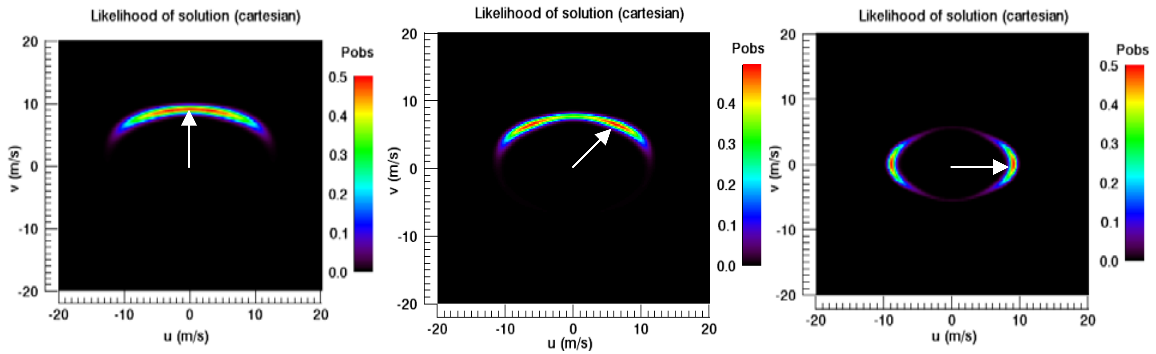


$$P_{obs}\left(\sigma^0; u, v\right) = \chi_{N-2}^2\left[MLE(u,v)\right]$$

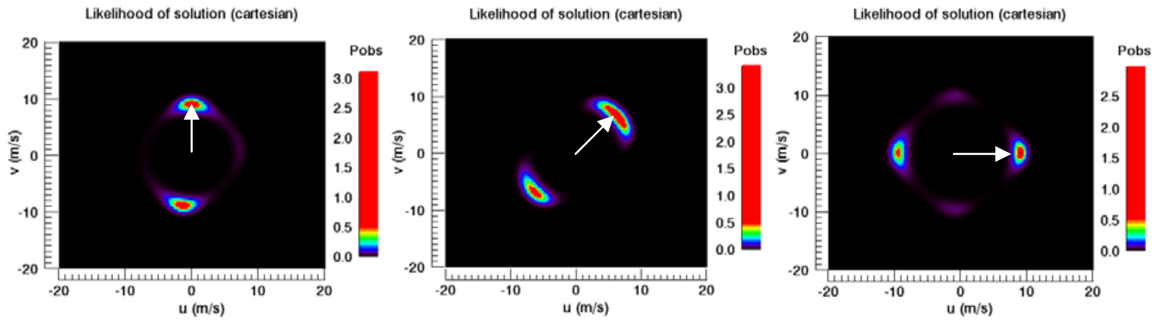
• Multiple ambiguous solutions and broad maxima are limiting factors in wind retrieval performance.

4) Wind retrieval – worst cases

- Rotating beam (SeaWinds WVC=0)

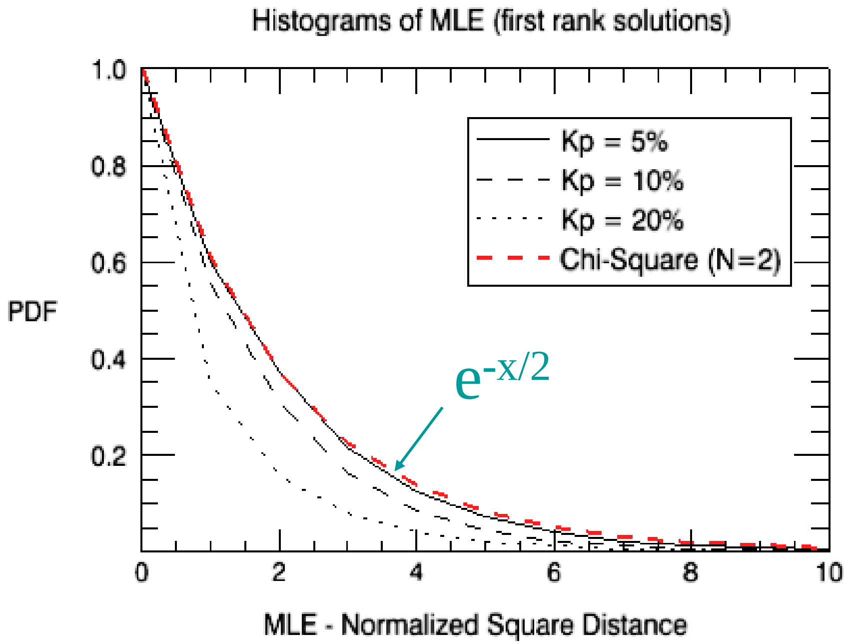


- Fixed antennas (ASCAT WVC =0)



SCAT simulator verification tests

1) Verifying MLE statistics (“chi-square assumption”)

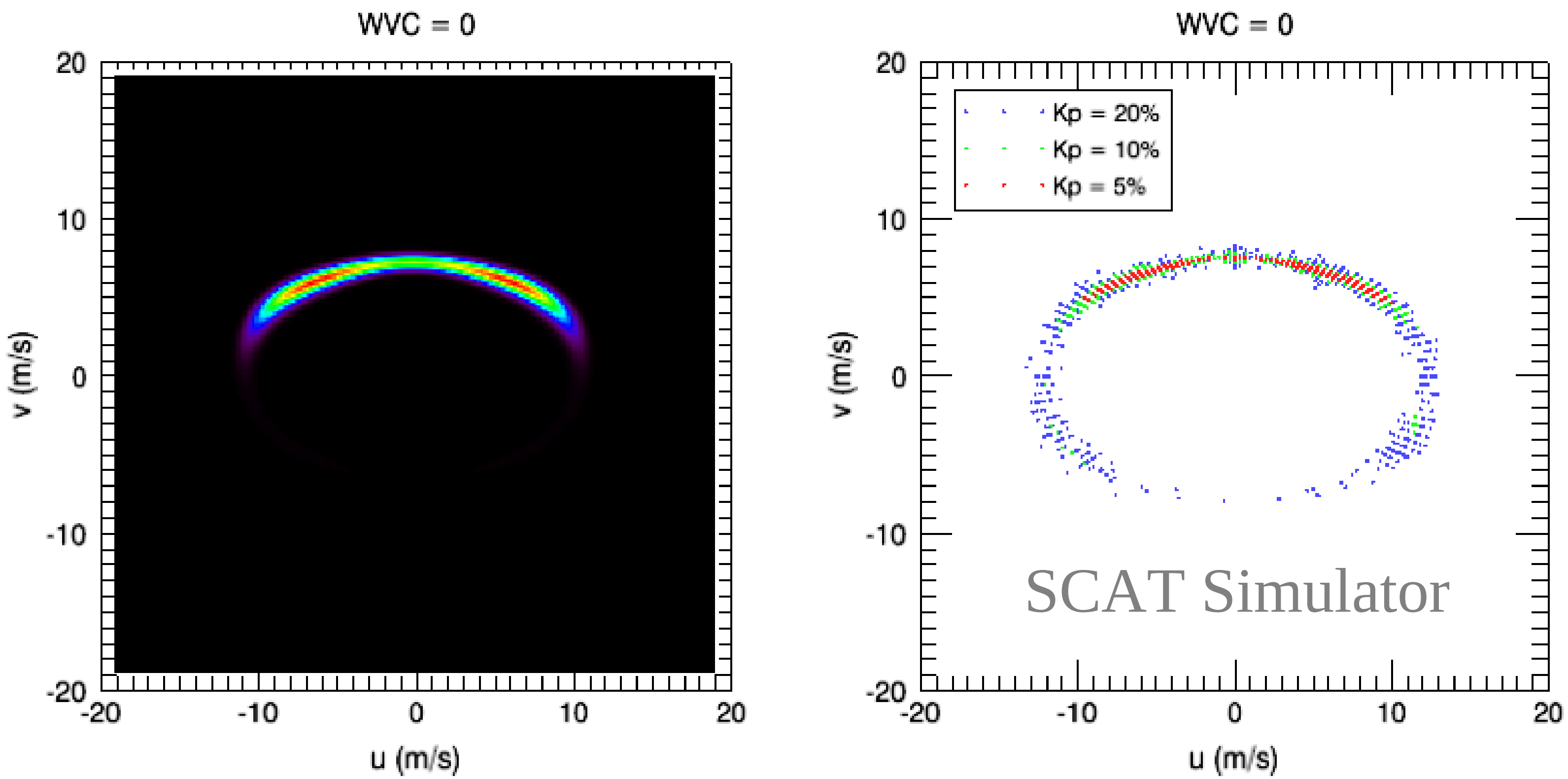


QSCAT (N = 4 views)

- Simulator MLE statistics follow χ^2 assumption at low noise levels.
- At higher noise levels GMF loses its 2D surface quality and statistics are modified accordingly!

SCAT simulator verification tests

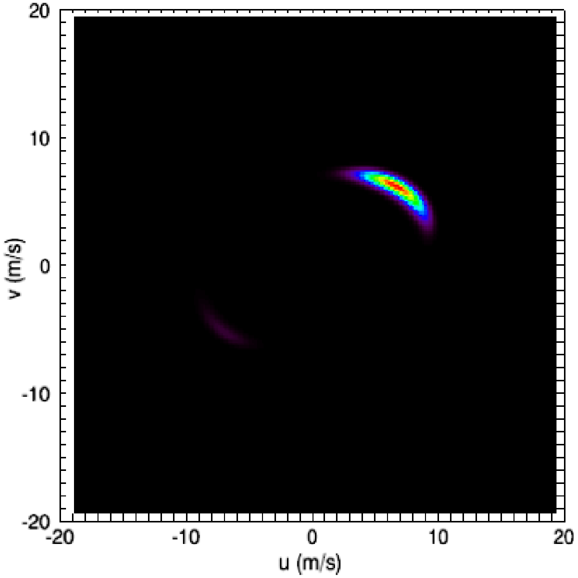
2) Verifying observational likelihoods

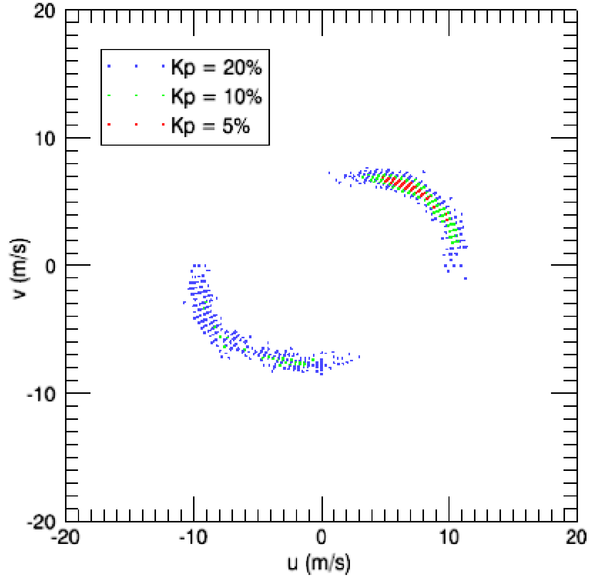


(True wind input is 9 m/s @ 45 deg, 1000 simulator runs)

QSCAT

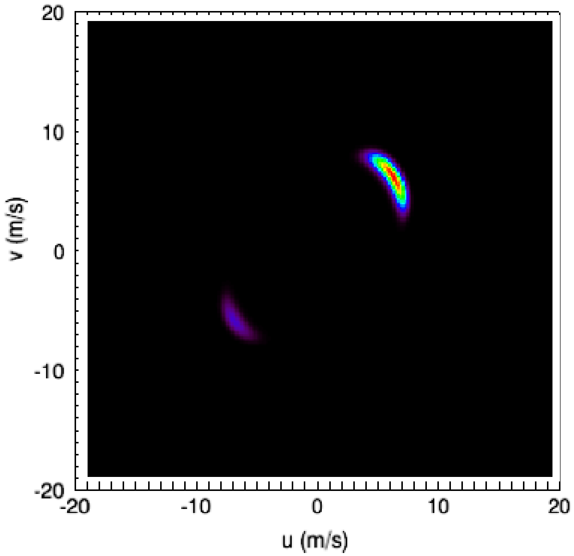
WVC =13

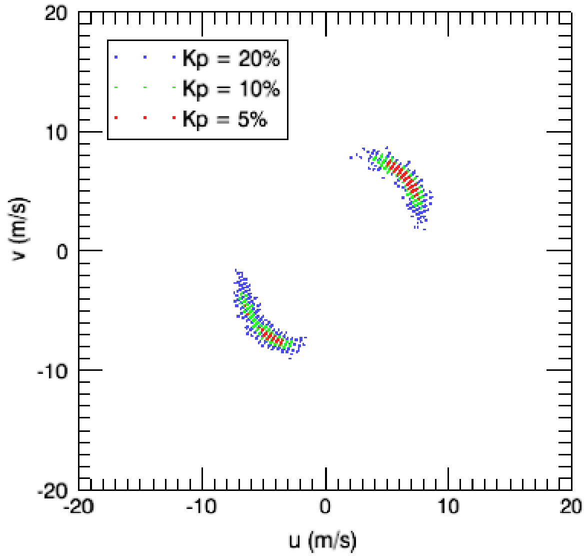




QSCAT

WVC =26



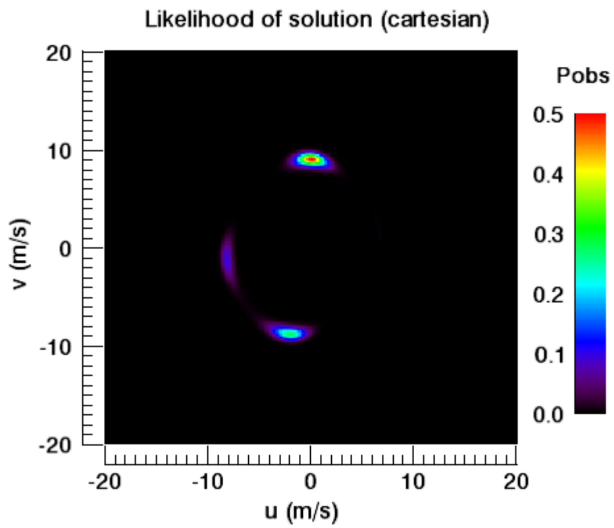


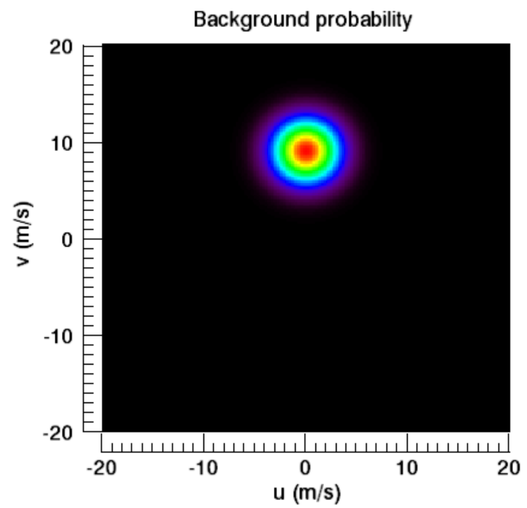
- SCAT Simulator is more realistic “than expected”.

4) Wind retrieval – background info

- Combined observation and NWP background cost functions:

$$J = -2\ln(\text{Probability}) = J_{obs} + J_{bg} = -2\ln\left(\chi^2_{N-2}\left[MLE(\vec{v})\right]\right) - 2\ln\left(N\left[\vec{v} - \vec{v}_{bg}; \sigma_{bg}\right]\right)$$





$$p_{obs}(u,v) = C\chi^2_{N-2}\left[MLE(u,v)\right]$$

$$p_{bg}(u,v) = N\left[\vec{v} - \vec{v}_{bg}; \sigma_{bg}\right]$$

Best wind estimate ⟶ Maximum likelihood

5) Figure of Merit - definition

- Enable the comparison of different SCAT configurations

1) Vector RMS error: $$FoM = \frac{RMS_{obs}}{RMS_{bg}} \subset [0,1]$$

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

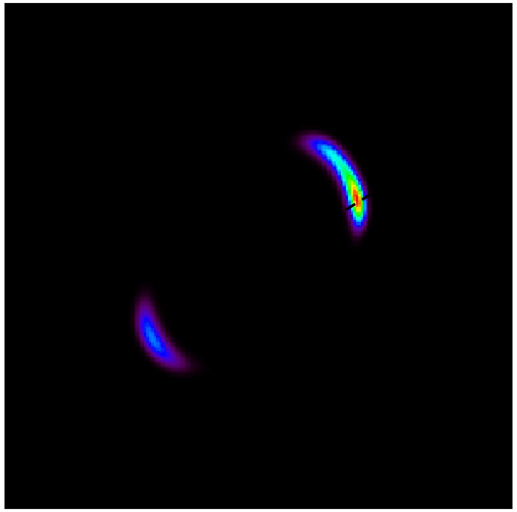
$$RMS_{bg} = \left(\int \left| \vec{v} - \vec{v}_{true} \right|^2 \, p_{bg}(u,v) du dv \right)^{1/2} = \sqrt{2}\sigma_{bg}$$

2) Ambiguities:

$$FoM_{amb} = \frac{\int p_{obs}(u,v)(1 - p_{bg}(u,v)) du dv}{\int p_{obs}(u,v)\, p_{bg}(u,v) du dv} \subset [0,\infty]$$

Systematic biases

Determined by skewness in observational likelihood:



skewness = mode - mean
(in wind speed and direction)

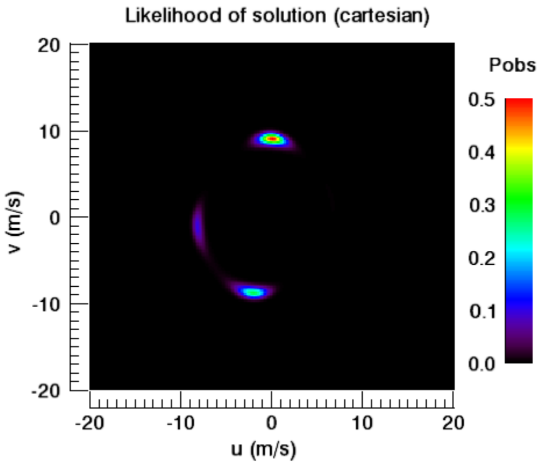
$$skew_{speed} = v_{true} - \int v \cdot p_{obs}(v, \phi_{true})\, p_{bg}(v, \phi_{true})\, dv$$

$$skew_{dir} = \phi_{true} - \int \phi \cdot p_{obs}(v_{true}, \phi)\, p_{bg}(v_{true}, \phi)\, d\phi$$

• Example: True wind input with 9 m/s @ 30 deg features small wind speed bias but output wind direction seems drawn to 45 deg solution!

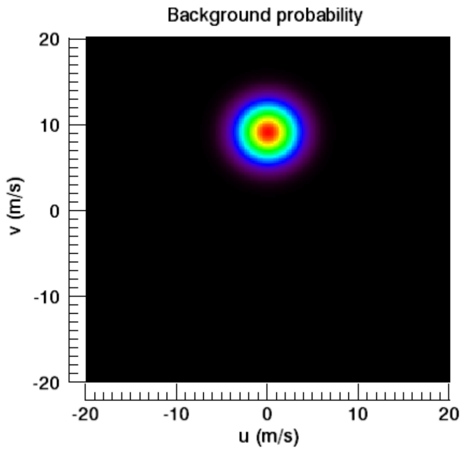
Wind retrieval performance

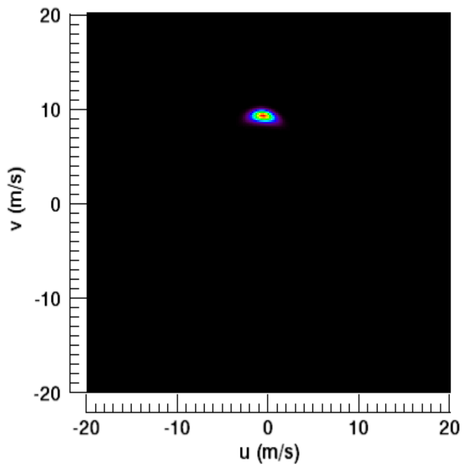
$P_{obs}(\mathbf{V}_{out}|\mathbf{V}_{in})$



$\otimes$

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





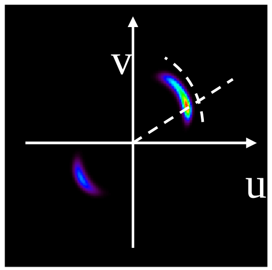


Figure of Merit

1) Wind Vector RMS error

2) Ambiguity susceptibility

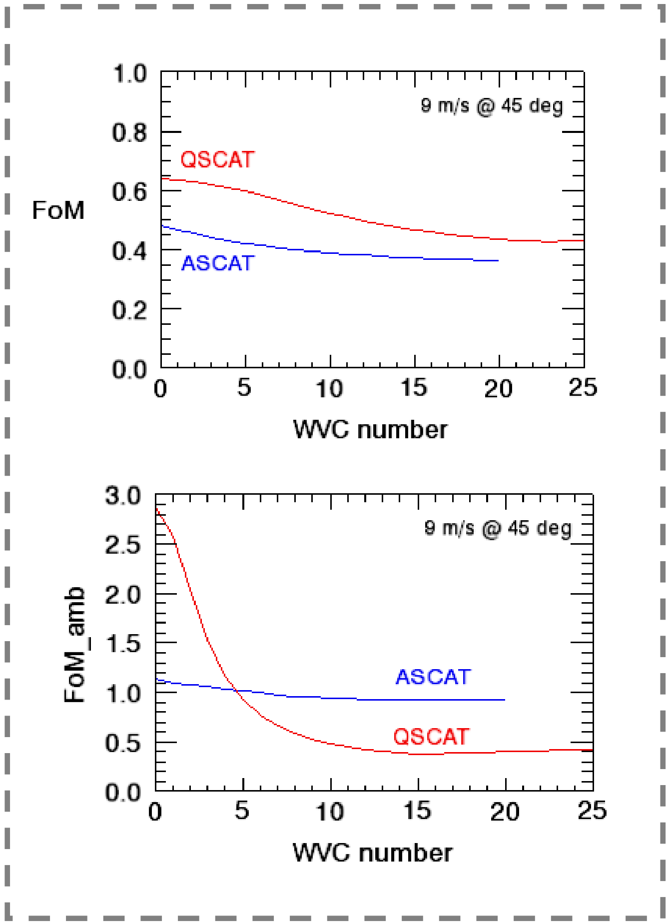
3) Wind biases (skewness)

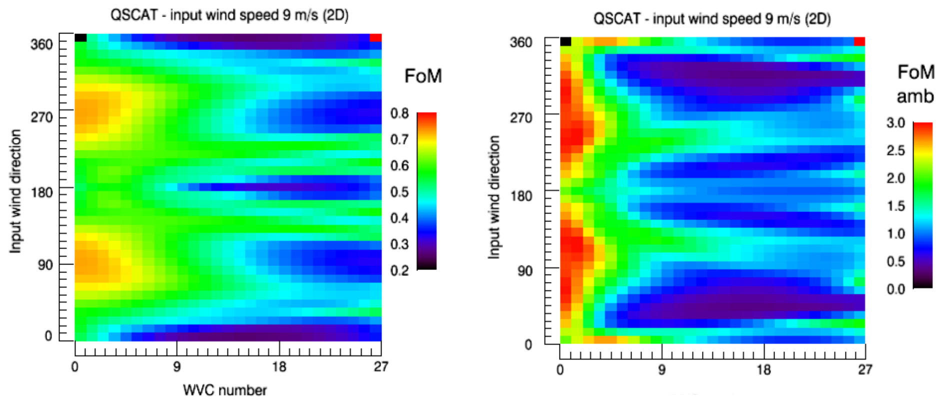
For instance:

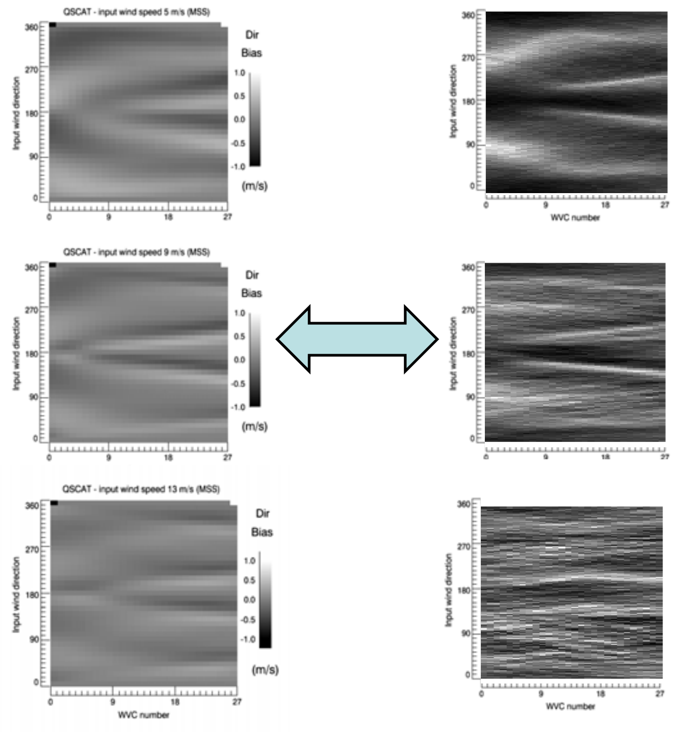
$$RMS_{obs} = \left(\int \left| \vec{v} - \vec{v}_{true} \right|^2 p_{obs}(\vec{v})\, p_{bg}(\vec{v})\, d^2 v \right)^{1/2}$$

Wind retrieval performance

9 m/s







5 m/s

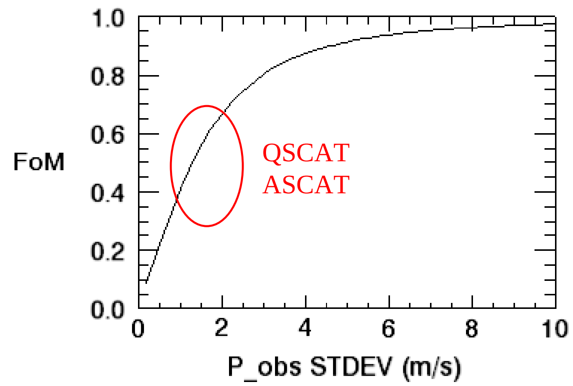
9 m/s

13 m/s

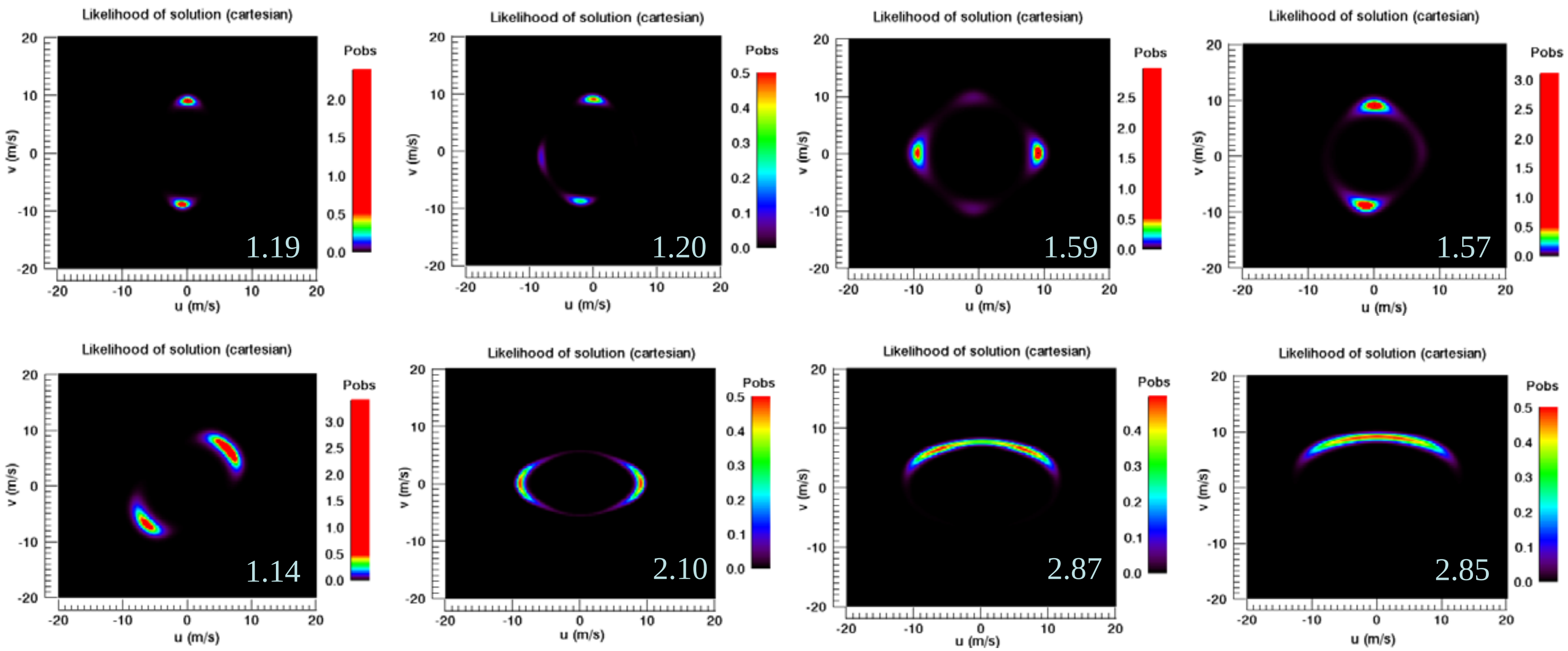
examples

CFOSAT

FoM – Test cases

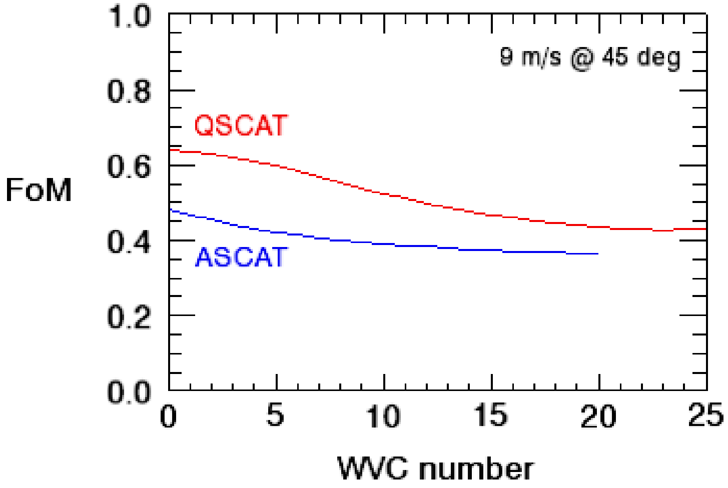


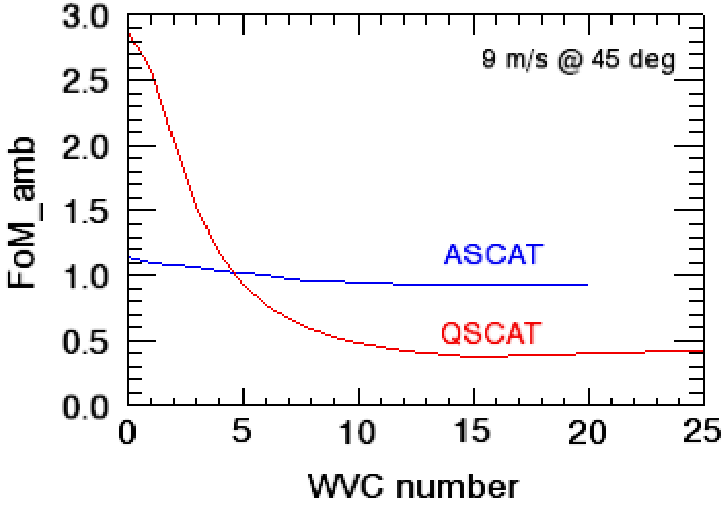
better



worse

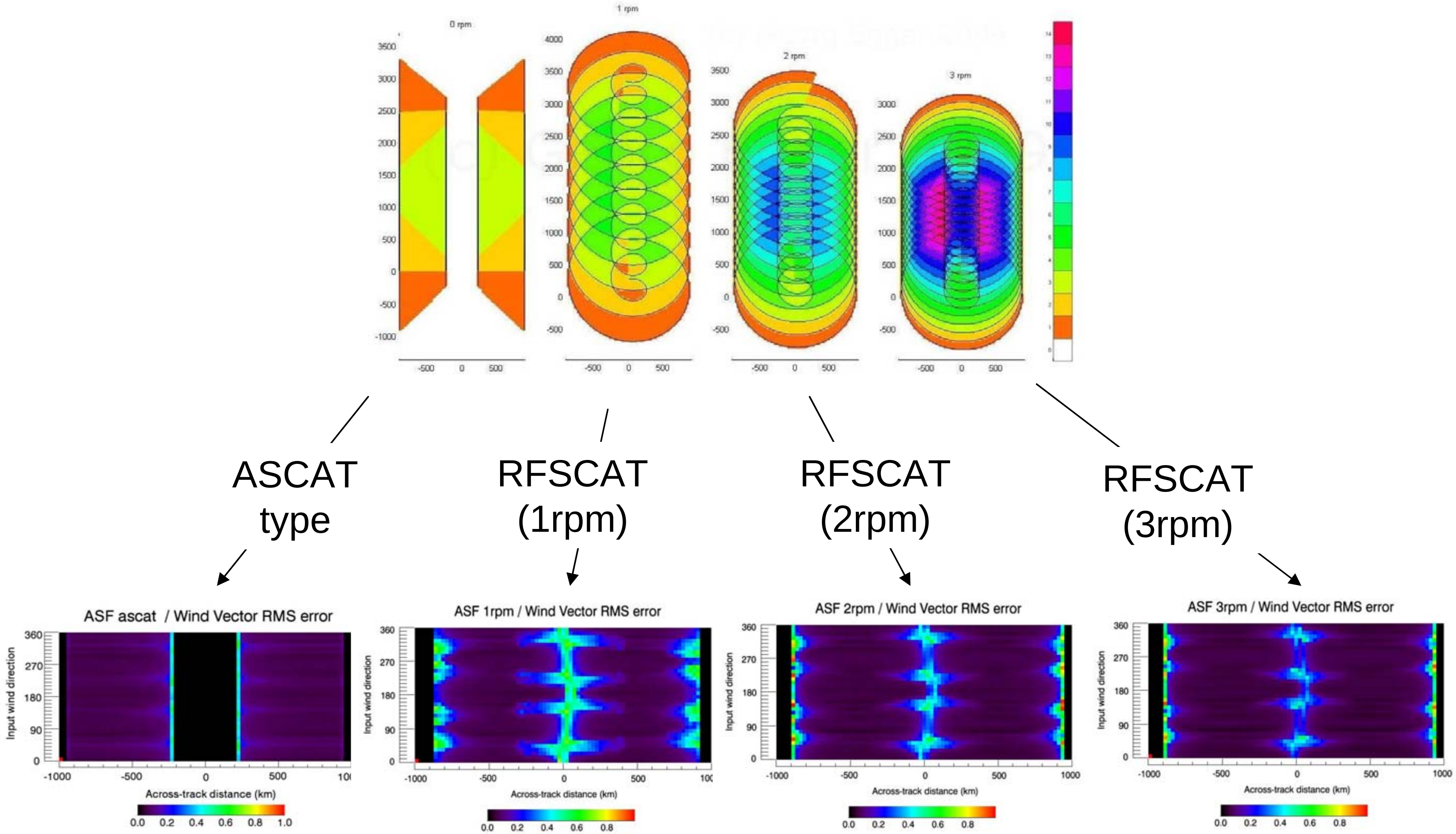
FoM – Test cases





- For this wind input, ASCAT gives better background constrained information, although with more ambiguity.

Preliminary SCA assessment

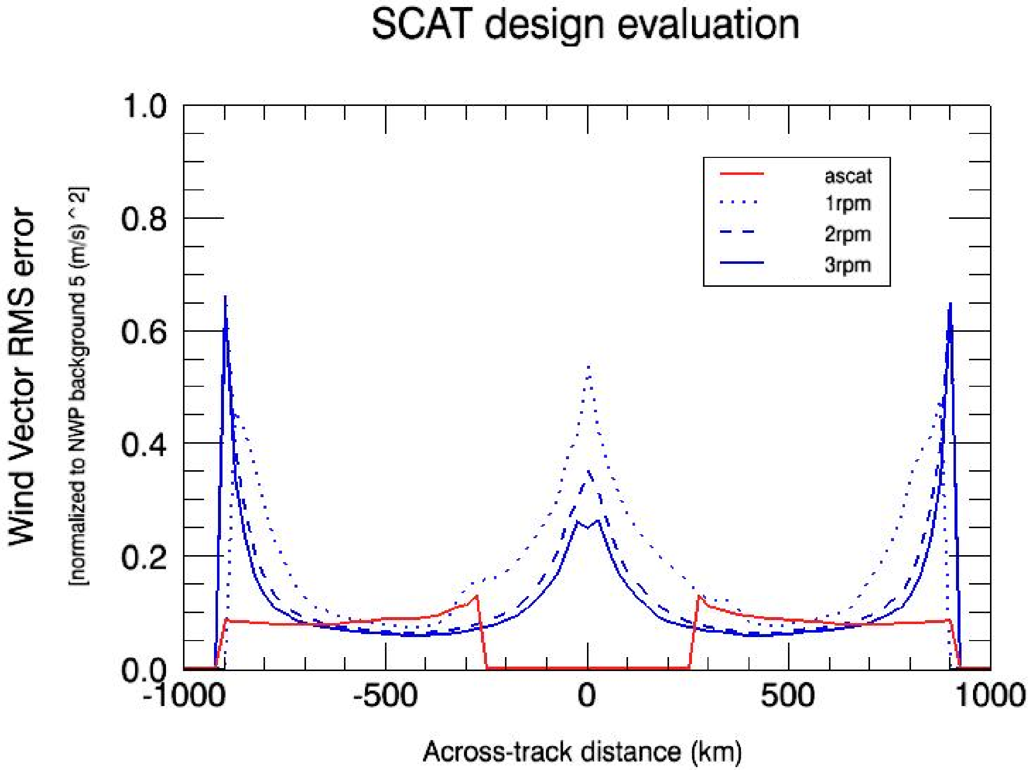


Wind Vector RMS error across swath

CFOSAT, Oct 2009

Conclusion

• Post-EPS RFSCAT can equal ASCAT quality and close the nadir gap
• **Accomodation cost ?**



To consider: additional sensitivity studies, like the dual-polarization option.