Correction of Faraday Rotation Effects in SCA Data

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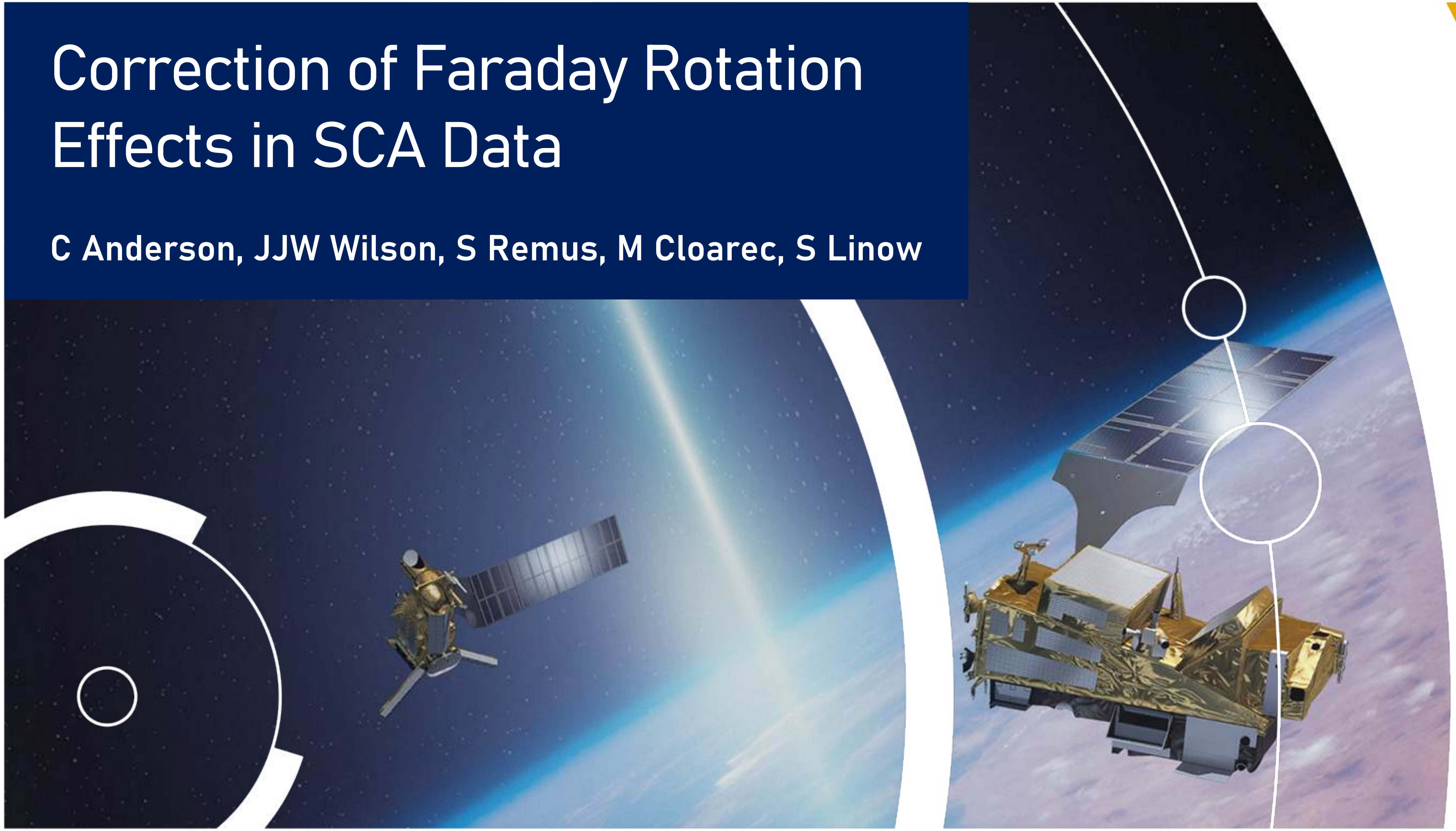


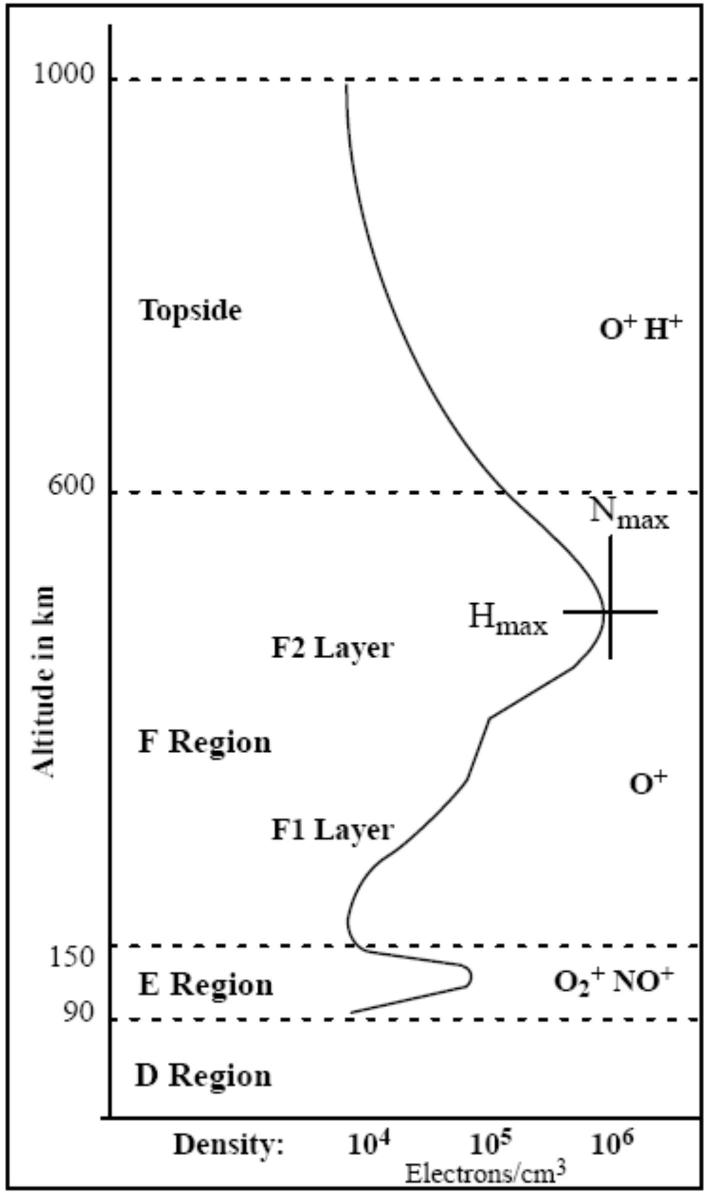
Faraday rotation effect

A scatterometer transmit pulse and its echo pass through the ionosphere

→ magnetic field and free electrons cause a rotation in the polarization: **Faraday rotation**

→ the backscatter arriving on the surface of the Earth differs from the true backscatter sent by the scatterometer

→ The backscatter measured by a scatterometer differs from the backscatter reflected off the Earth's surface

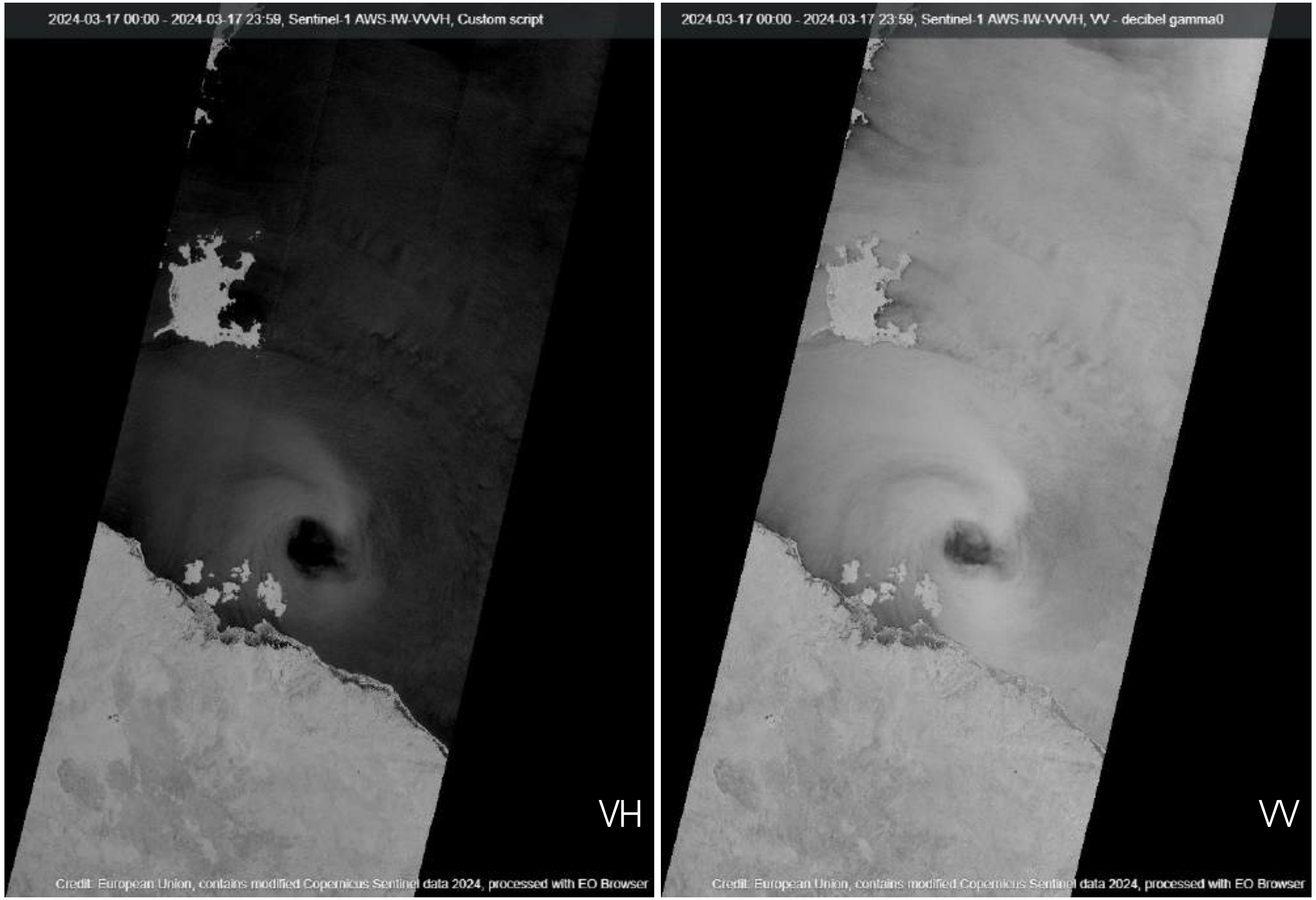


Faraday rotation effect

Over the ocean co-pol backscatter is typically much larger than cross-pol

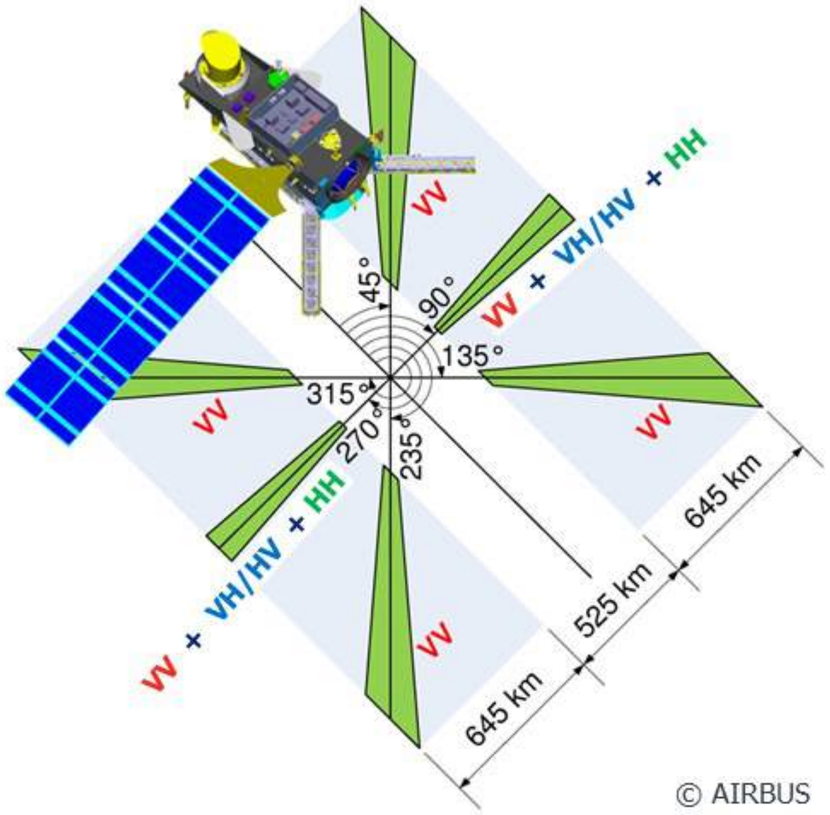
Even a small amount of co-pol rotated into the cross-pol channel can corrupt the cross-pol measurement.

Can the cross-pol data be corrected to reduce or remove the effects of Faraday rotation?



Sentinel-1: TC Megan, 2024-03-17

SCA measurements



In addition to the VV measurements, SCA will provide HH and HV/VH polarisation on the mid beams.

The SCA instrument does **not** measure the complex (amplitude and phase) polarimetric backscatter matrix, as de-correlation of the scene occurs between pulses and the phase is not preserved.

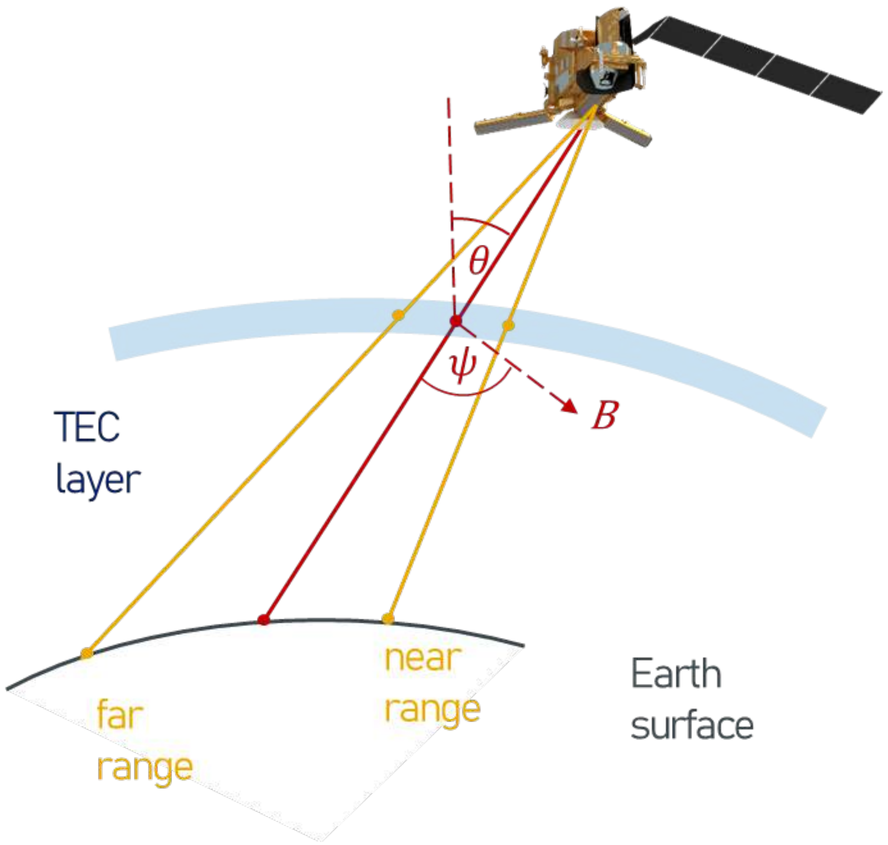
Therefore, SCA itself cannot correct for the ionosphere impact. We need external data.

Faraday rotation angle

Models of the Faraday rotation angle Ω are available, e.g. Wright et al (2003) gives

$$\Omega = \frac{k}{f^2} B \cos\psi \sec\theta \, TEC$$

Ω	Faraday rotation angle (1-way)
f	frequency
B	the magnetic field strength
ψ	angle with magnetic field
θ	incidence angle
TEC	total electron content (vertical)



The TEC is mapped to a single layer at 400 km height

Assuming TEC = 150 TECU gives a rotation angle of around 2.5°

Effect of Faraday rotation on backscatter

The Freeman and Saatchi (2004) model leads to

$$
\begin{aligned}
m_{vv} &= \sigma_{vv}c^4 - 2\rho\sqrt{\sigma_{vv}}\sqrt{\sigma_{hh}}s^2c^2 + \sigma_{hh}s^4 \\
m_{hh} &= \sigma_{hh}c^4 - 2\rho\sqrt{\sigma_{vv}}\sqrt{\sigma_{hh}}s^2c^2 + \sigma_{vv}s^4 \\
m_{hv} &= \sigma_{hv} + \left(\sigma_{hh} + \sigma_{vv} + 2\rho\sqrt{\sigma_{vv}}\sqrt{\sigma_{hh}}\right)s^2c^2 \\
m_{vh} &= m_{hv}
\end{aligned}
$$

Where:

m measured backscatter
σ true backscatter
ρ HH-VV correlation

$c = \cos\Omega$
$s = \sin\Omega$

- Cross-pol backscatter is most strongly affected when $\rho = 1$
- For typical values, the above equations show that the measured cross-pol backscatter can differ from its true value by around 0.15 dB

Retrieving the true backscatter

- The Freeman and Saatchi model leads to 3 equations with 5 variables $(\sigma_{hh}, \sigma_{vv}, \sigma_{vh}, \Omega, \rho)$
- Given Ω and ρ we can solve for the true backscatter values
- Ω can be determined from viewing geometry, Earth magnetic field model and near real time estimates of TEC
- ρ is more difficult to establish but we can assume
  - $\rho = 0$: calculate a partial correction, or
  - $\rho = 1$: calculate worst case effect, set a flag if it exceeds a threshold

→ Decided to set $\rho = 1$

Solving the 3 equations

Setting $\sigma_{hh} = \mu^2 \sigma_{vv}$ allows the three equations to be solved and lead to the quadratic

$$\left(m_{vv}c^4 - m_{hh}s^4\right)\mu^2 + 2\rho s^2 c^2 \left(m_{hh} - m_{vv}\right)\mu + \left(m_{vv}s^4 - m_{hh}c^4\right) = 0$$

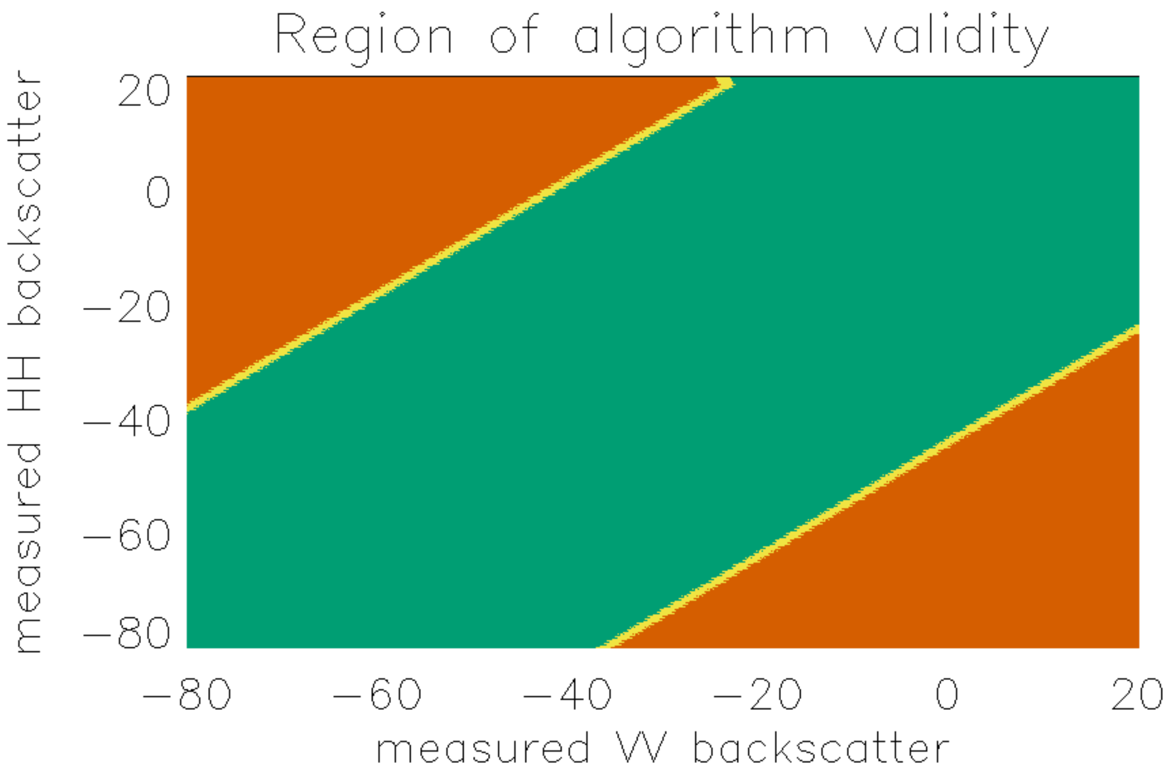
There are some restrictions on the solutions for μ

- it must be real and positive (to give physically relevant backscatter)
- only one of the two solutions must be real and positive (to give an unambiguous result)

Parameter space investigation

When does μ have a physically relevant solution?

- μ depends on measured co-pol backscatter, ρ and Ω
- Numerical investigations of this parameter space show that a solution can be found when the measured backscatter values are within 10 to 20 dB of each other (depending on the value of Ω)



Example numerical results when Ω = 2.5° and ρ = 1.

Green shows the region where μ has one unambiguous physically relevant solution

SCA processing

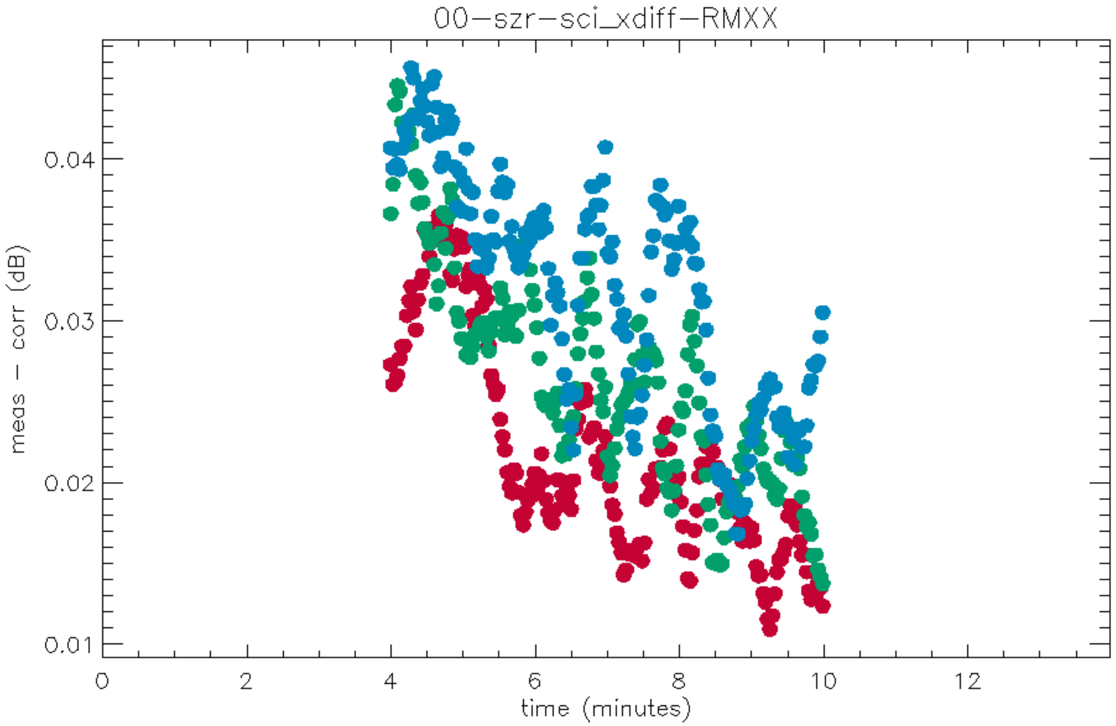
- SCA data will be processed at EUMETSAT into two backscatter products:
    - full resolution (SZF)
    - spatially averaged (SZR).

- The SZR product contains original and corrected cross-pol backscatter

- The correction assumes $\rho = 1$ (worst case Faraday rotation) so the user has the option of examining the difference between original and corrected and rejecting the data if it exceeds a threshold

Processor testing

- Prototype SCA processors and simulated SCA data are available
- Plot shows the difference between measured and corrected cross-pol in SZR product
- The difference is small (< 0.05 dB) but the available test data is not representative of real ocean backscatter



Difference in cross-pol backscatter at near, mid and far swath (simulated SCA data around -7 dB, simulated TEC values > 100 TECU)

Summary

- The backscatter measured by SCA is affected by Faraday rotation
- If the rotation angle and correlation coefficient are known, then the backscatter can be corrected
- The SCA processer estimates the rotation angle (using near real time TEC data) and assumes worst case correlation
- Original and corrected cross-pol backscatter are provided in the near real time level 1b SZR product