
# Detection and Characterization of Ionospheric Effects in ALOS PALSAR data

Advanced Land Observing Satellite


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    - Limitations, dependencies, and examples
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# Motivation

- ASF is working on an assessment of ionospheric influence on L-band SAR
  - Establish an operational monitoring/screening procedure to assist analysis of ionospheric effects and produce interesting data for ionospheric science
- Faraday rotation estimation is used as established reference technique
  - Requires full-polarimetric data sets
- A new method for ionospheric mapping from dual-pol data is presented and its performance is evaluated
  - May increase number of available data sets

# Faraday Rotation Effects on SAR

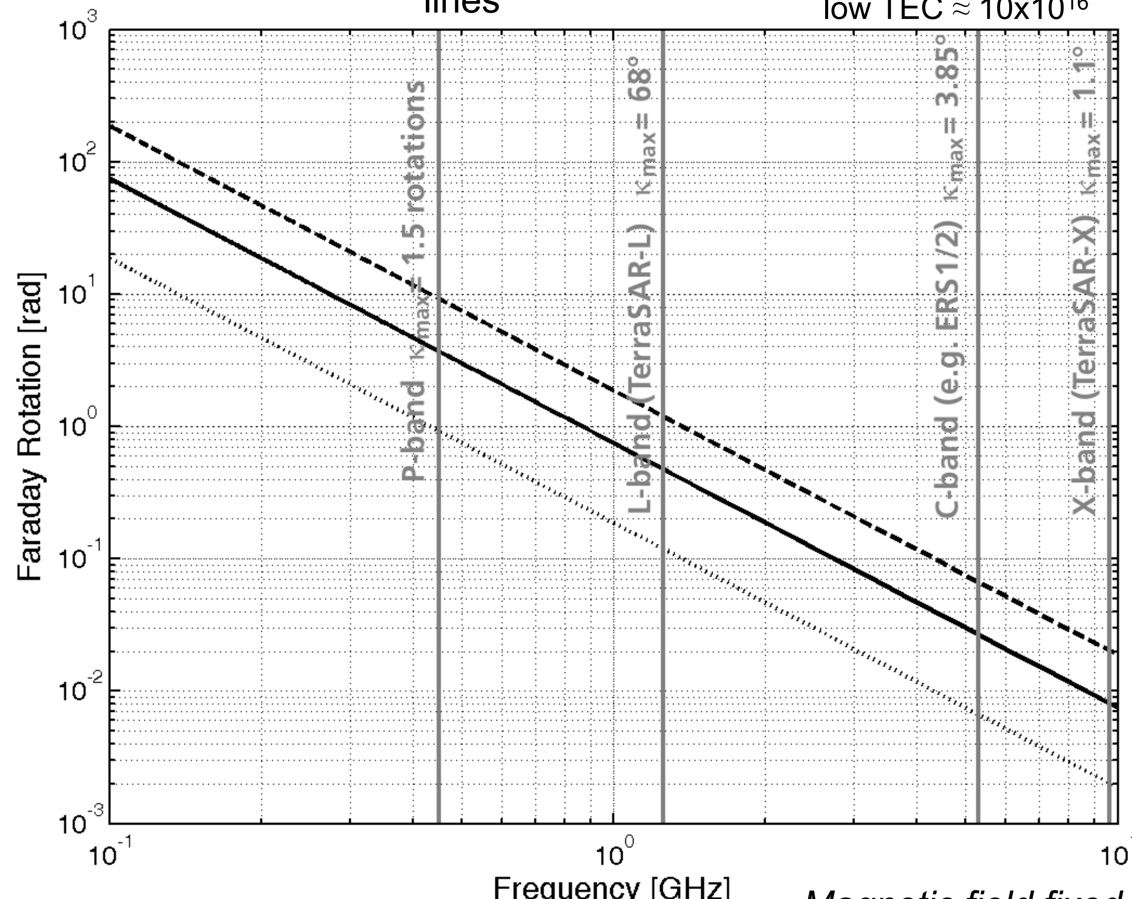
- Faraday Rotation: $\Omega = \frac{K}{f^2} B \cos\theta \sec\chi \bullet TEC$

Look angle

Angle with magnetic field lines

high TEC ≈ 100x10[16]
medium TEC ≈ 40x10[16]
low TEC ≈ 10x10[16]

- Rotates energy from co-pol channels into cross-pol channels
  - Darker images, reduced signal-to-noise ratio, increased cross-talk, …
  - Scattering matrix asymmetric
- More severe for L- and P-Band than for X- and C-Band
- Currently at solar low
  - Low TEC values dominate
  - Likely to continue for next 3 years
  - Events can still be dramatic




*Magnetic field fixed*
*Maximum expected effects are given*

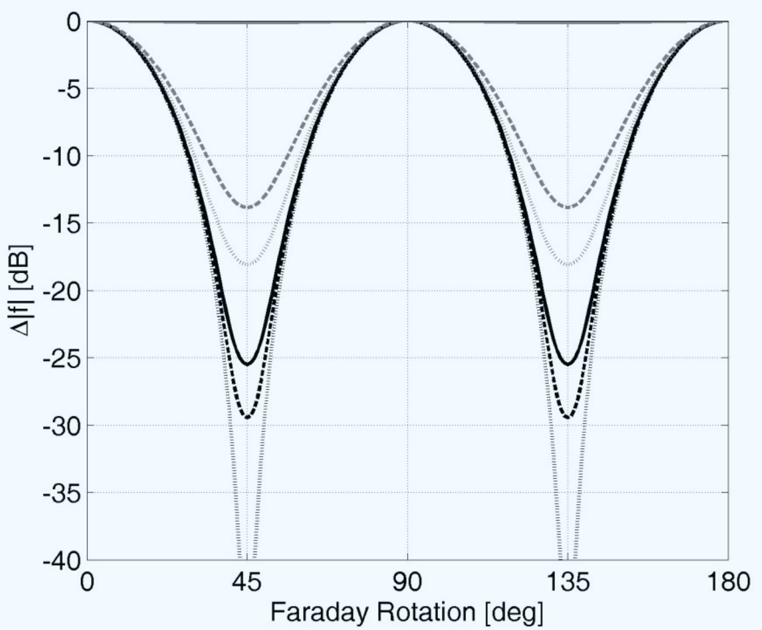
# Ionosphere Effects on Polarimetric SAR Image Calibration

- For a full-polarimetric system:

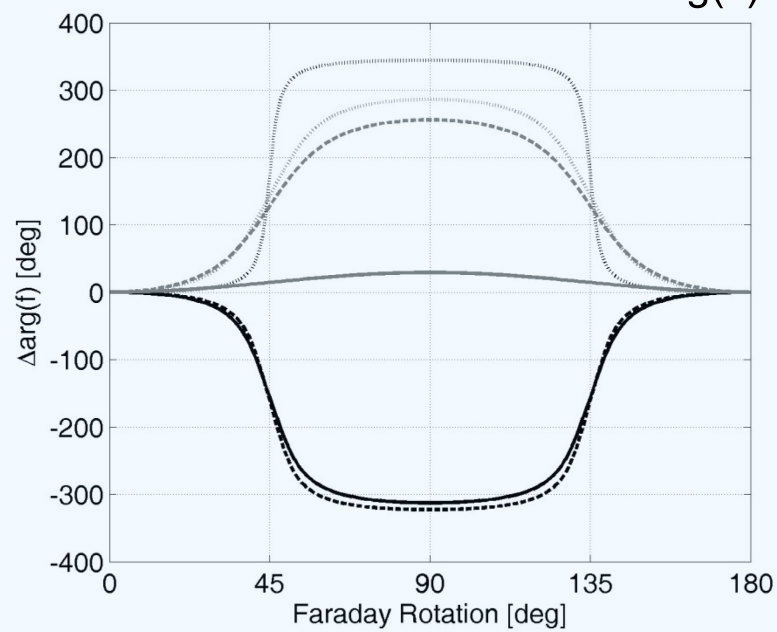
$$\begin{bmatrix} M_{hh} & M_{hv} \\ M_{vh} & M_{vv} \end{bmatrix} = Ae^{j\phi} \cdot \begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{bmatrix} \cdot \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \cdot \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \cdot \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \cdot \begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{bmatrix} + \begin{bmatrix} N_{hh} & N_{hv} \\ N_{vh} & N_{vv} \end{bmatrix}$$

- Faraday rotation creates additional channel imbalance, and cross talk

FR induced Amplitude Imbalance |δ|




FR induced Phase Imbalance arg(δ)



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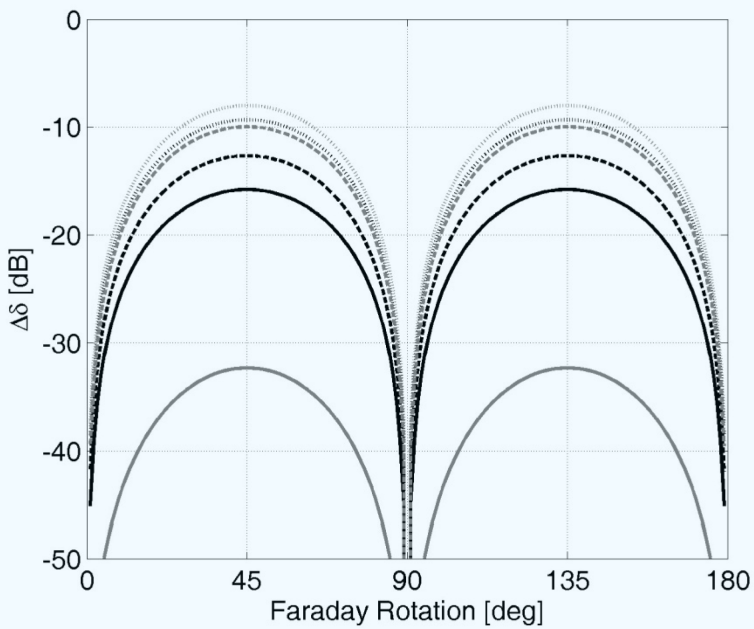
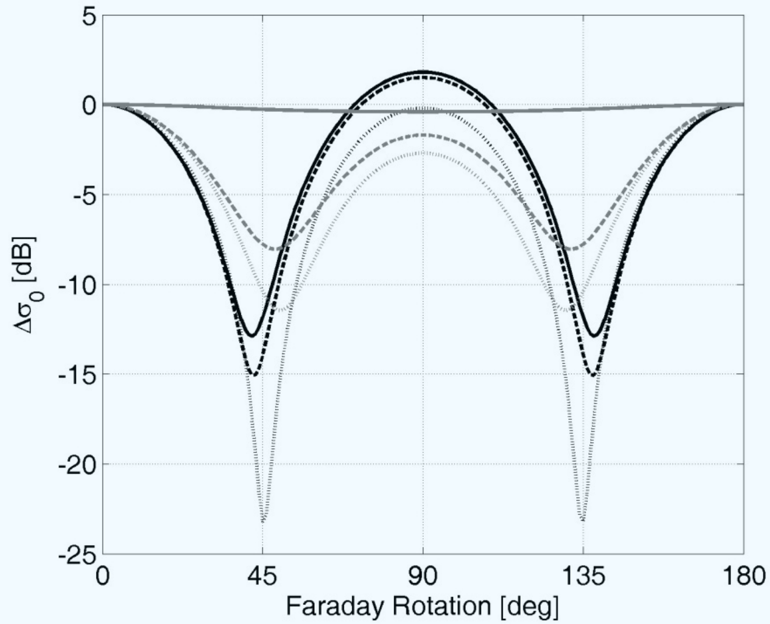
FR induced Cross Talk $\delta$




FR induced HH Amplitude $\sigma_0$



# Faraday Rotation from Quad-Pol Data

Measured Scattering matrix of a sufficiently calibrated SAR system

$$\begin{bmatrix} M'_{hh} & M'_{vh} \\ M'_{hv} & M'_{vv} \end{bmatrix} = \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \cdot \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \cdot \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix}$$

Direct estimation from scattering matrix (Freeman, 2004):

$$\Omega = \frac{1}{2}\tan^{-1}\left[\frac{\left(M'_{vh} - M'_{hv}\right)}{\left(M'_{vv} + M'_{vv}\right)}\right]$$

More robust version of estimator based on averaged second-order statistics published in (Freeman, 2004)

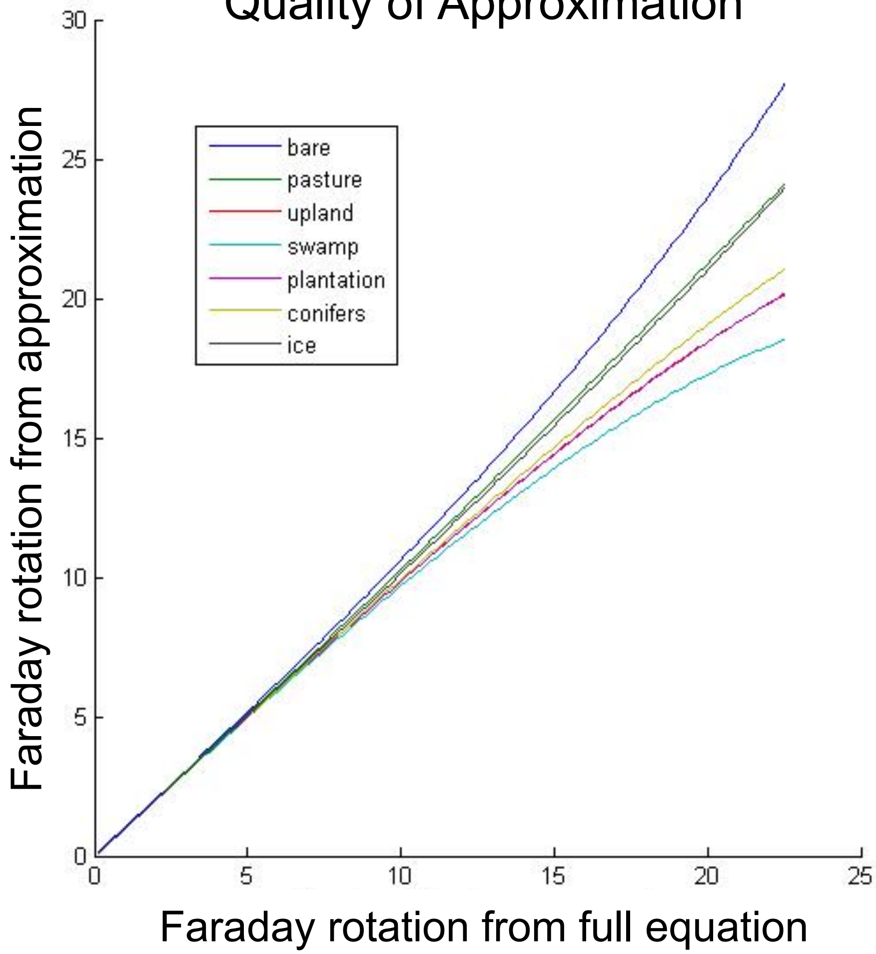
Estimation from circular basis (Bickel & Bates, 1965):

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \cdot \begin{bmatrix} M'_{hh} & M'_{vh} \\ M'_{hv} & M'_{vv} \end{bmatrix} \cdot \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

$$\Omega = \frac{1}{4}\arg\left(Z_{12}Z^{*}_{21}\right)$$

# Faraday Rotation Estimation

Quality of Approximation




$$\Omega \approx \tan^{-1}\left(\frac{\left|\frac{\langle M_{hh}M_{hv}^*\rangle}{\langle M_{hh}M_{hh}^*\rangle}\right|}{1+n}\right)$$

where:

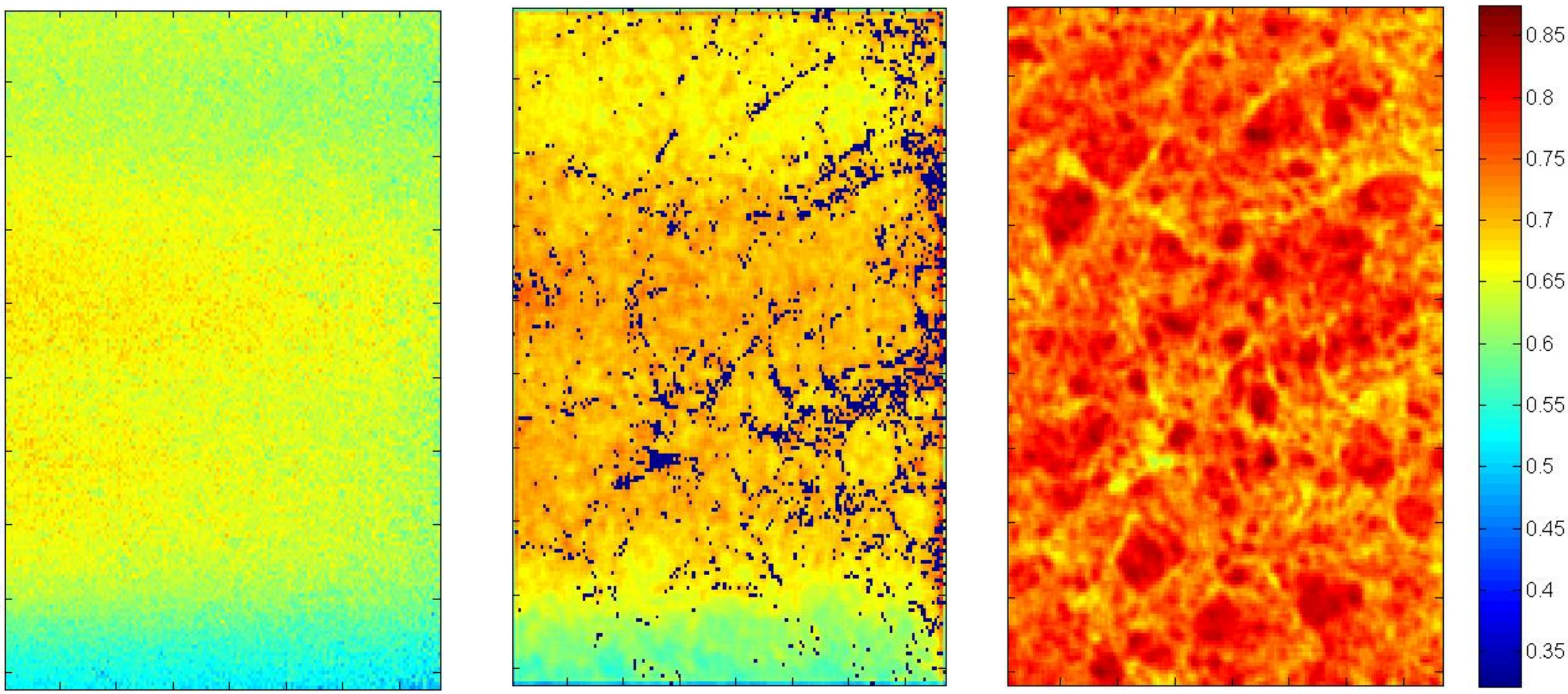
$$\frac{\langle S_{hh}S_{vv}^*\rangle}{\langle S_{hh}S_{hh}^*\rangle} = n = \frac{\sigma_{vv}^0}{\sigma_{hh}^0}\cos(\phi_{hh-vv})\rho_{hh-vv}$$

*n* represents surface dependent scattering properties

*n* can be derived in two ways:

- Calculated from full-pol data
- Extracted from scattering models

# Comparison of quad-pol and dual-pol methods assuming known *n*




FR from Full-pol data

FR from dual-pol data

(Dark blue areas are masked out)

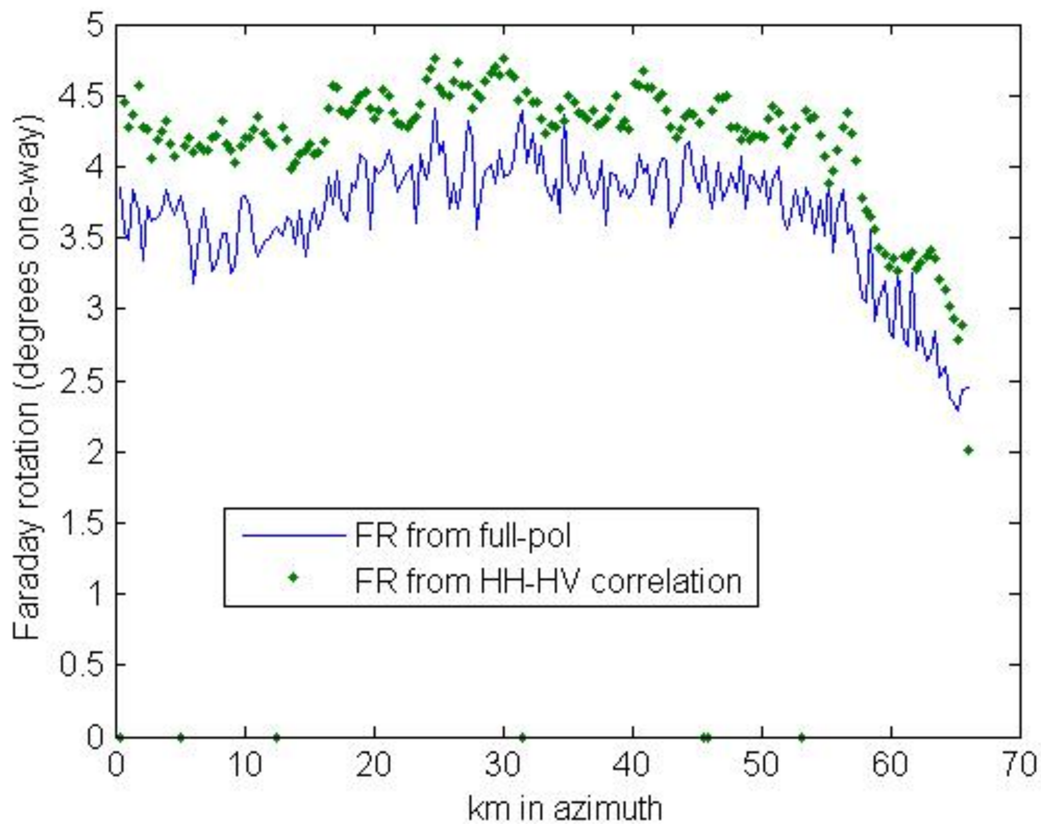
*n* calculated from full-pol data

# FR from quad-pol and dual-pol methods

## Assuming known *n*

Transect along azimuth at mid-range:

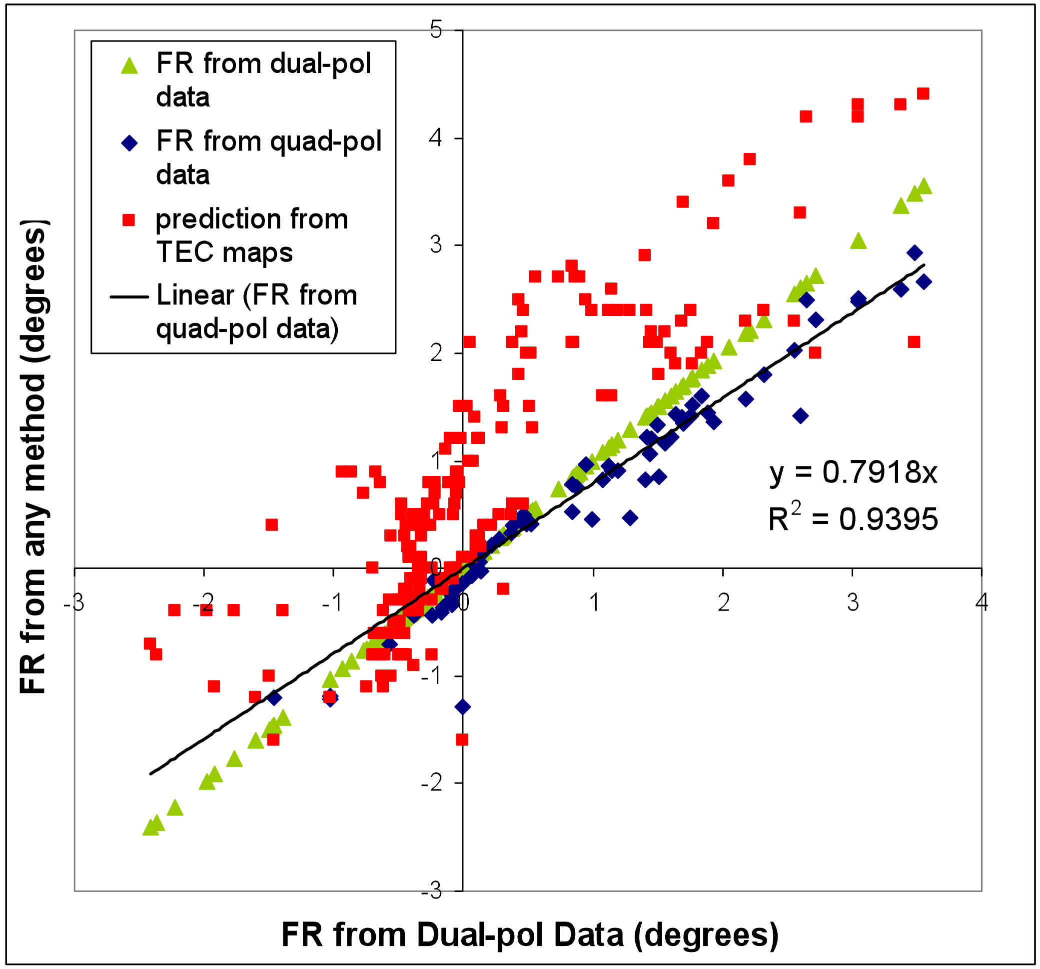
- Strong agreement of applied methods
- Estimates follow the same trend
- Offset caused by approximations in FR equation (see slide 8)



# FR from quad-pol and dual-pol methods

## Fixed Value for *n*

- FR from dual-pol data estimated with n fixed to n=0.7
  - *n* estimated empirically through minimization of estimation errors
- Comparison of dual-pol results to quad-pol estimates and predictions from global TEC maps
  - Dual-pol results are used as reference
- High correlation between dual-pol and quad-pol estimates
  - Slight bias with increasing Ω



# FR from quad-pol and dual-pol methods

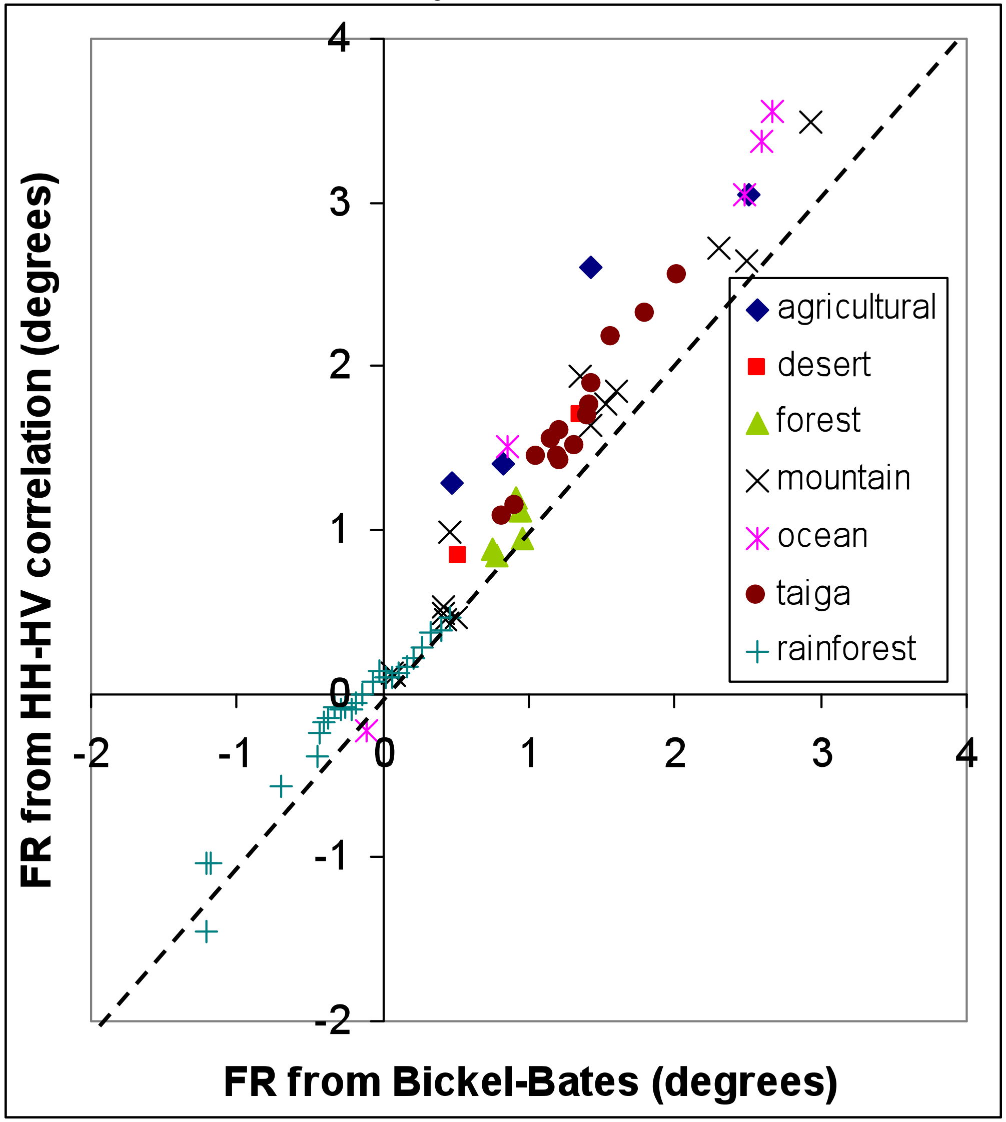
## Fixed Value for *n*

**Sensitivity to model errors**

- *n* varies with surface type
- Model fixes *n* to 0.7 → surface type dependent model errors

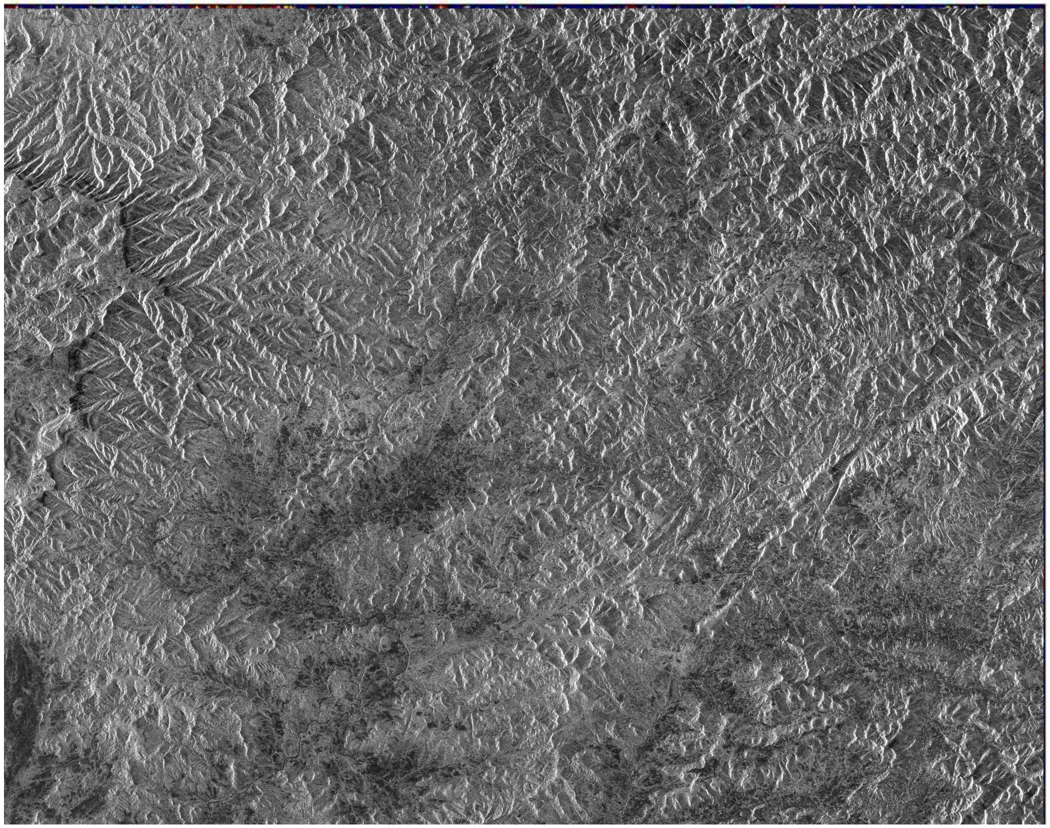
- No significant differences based on land type
  - Some classes are not well-sampled
  - Need more full-pol data to compare methods

Sensitivity to model errors



# Influence of Scattering Asymmetry

- In contrast to full-pol based FR estimation using Bickel&Bates methods, dual-pol method is sensitive to scattering asymmetry
- Slopes in azimuth direction cause scattering asymmetry
- Adds variation to the measurement
- If averaged over large areas, bias averages out
  - no apparent bias



Normalized cross-correlation coefficient for dual-pol scene ALPSRP073340230

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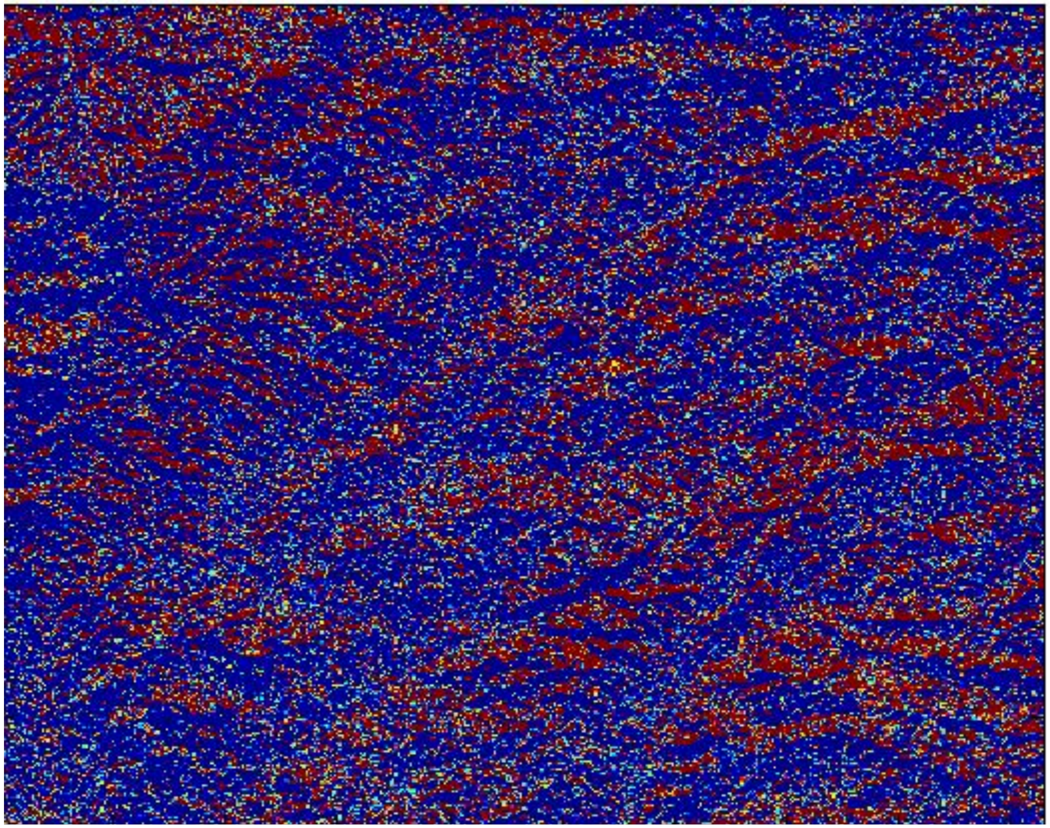
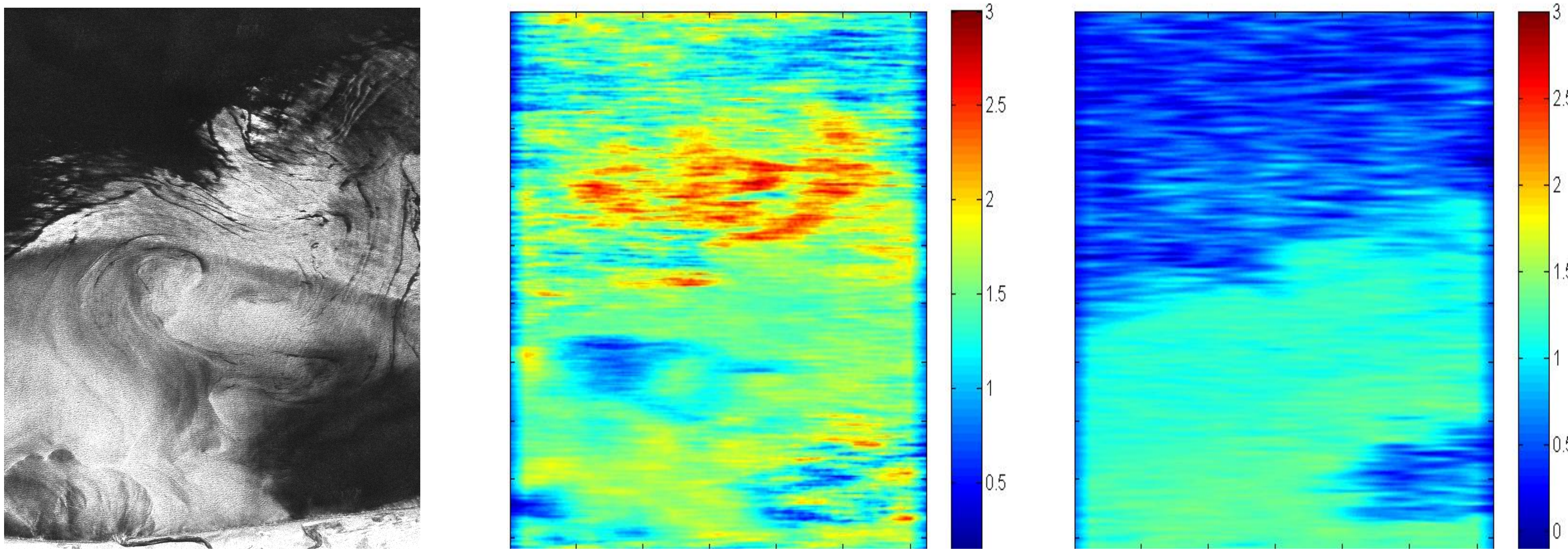


Normalized cross-correlation coefficient for dual-pol scene ALPSRP073340230

# Influence of Signal-to-Noise Variations




Original (left), FR from cross-channel (mid) and Bickel-Bates (right) for a scene with water and land.

Note that Bickel-Bates underestimates water (due to low signal to noise)
Dual-pol estimate doesn’t show the same behavior → under investigation

ALPSRP063051200

# Conclusions

- Ionospheric effects influence the calibration quality of SAR and PolSAR data
- Significance of ionospheric influence is currently largely unknown due to missing statistical parameters

- ASF is preparing a system for continuous ionospheric mapping from PALSAR data to provide these statistical parameters

- Main estimation methods is Faraday rotation
- HH/HV Correlation applies to dual-pol data and increases number of available data sets

- First analyses show that Bickel & Bates as well as HH/HV correlation methods produce reliable results
- Influence of surface type variation appears to be limited for low FR

# Future Work

- Finalizing of performance analysis of HH/HV Cross correlation
- Finalizing operational implementations of mapping techniques
- Processing full-pol and dual-pol data in the data pool over high-latitude areas to assess effects of more turbulent and less predictable polar ionosphere
- Additionally, processing of all new datasets that are transferred to the data pool

- Implementation of additional estimation methods (e.g. incoherent autofocus techniques) will be prepared

Thanks for your attention!!

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