Detection and Characterization of Ionospheric Effects in ALOS PALSAR data

Franz Meyer, PhD
Jeremy Nicoll
Rayjan Wilson
Alaska Satellite Facility
Nov 9, 2009
Outline

• Motivation
  – Project purpose
  – FR from Full-Pol data
    • Limitations and examples
  – FR from Dual-Pol data
    • Limitations, dependencies, and examples

• Background
  – Ionosphere effects on Polarimetric SAR image calibration
  – Methods to estimate Faraday Rotation

• Evaluation
  – Comparison of methods
  – Comparison of different land classes
  – Full vs Dual Pol stats
  – Dual-pol attempts
    – Mountains
    – Oceans

• Conclusion
• Future
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: \( \Omega = \frac{K}{f^2} B \cos \theta \sec \chi \cdot TEC \)

- 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
Ionosphere Effects on Polarimetric SAR Image Calibration

- For a full-polarimetric system:

\[
\begin{bmatrix}
M_{hh} & M_{hv} \\
M_{vh} & M_{vv}
\end{bmatrix} = A e^{i\phi} \cdot \begin{bmatrix}
1 & \delta_1 \\
\delta_2 & f_1
\end{bmatrix} \cdot \begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix} \cdot \begin{bmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{bmatrix} \cdot \begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix} \cdot \begin{bmatrix}
1 & \delta_1 \\
\delta_2 & f_1
\end{bmatrix} + \begin{bmatrix}
N_{hh} & N_{hv} \\
N_{vh} & N_{vv}
\end{bmatrix}
\]

- Faraday rotation creates additional channel imbalance, and cross talk
Ionosphere Effects on Polarimetric SAR Image Calibration

• For a full-polarimetric system:

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

• Faraday rotation creates additional channel imbalance, and cross talk
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):

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

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

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

\[
\Omega = \frac{1}{4} \arg(Z_{12}Z_{21}^*)
\]
Faraday Rotation Estimation

where:

\[
\begin{align*}
\Omega & \approx \tan^{-1} \left( \frac{\left< M_{hh}^* M_{hv} \right>}{\left< M_{hh}^* M_{hh} \right>} \right) / (1 + n) \\
\left< S_{hh} S_{hv}^* \right> & = n = \frac{\sigma_{vv}^0}{\sigma_{hh}^0} \cos(\phi_{hh-vv}) \rho_{hh-vv}
\end{align*}
\]

\( n \) 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 $\Omega$
Sensitivity to model errors

- $n$ varies with surface type
- Model fixes $n$ to 0.7 $\rightarrow$ 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
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
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
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!!

Contact:
@: fmeyer@gi.alaska.edu
@: rmwilson2@alaska.edu