Faraday rotation estimation from unfocussed ALOS-PALSAR raw data

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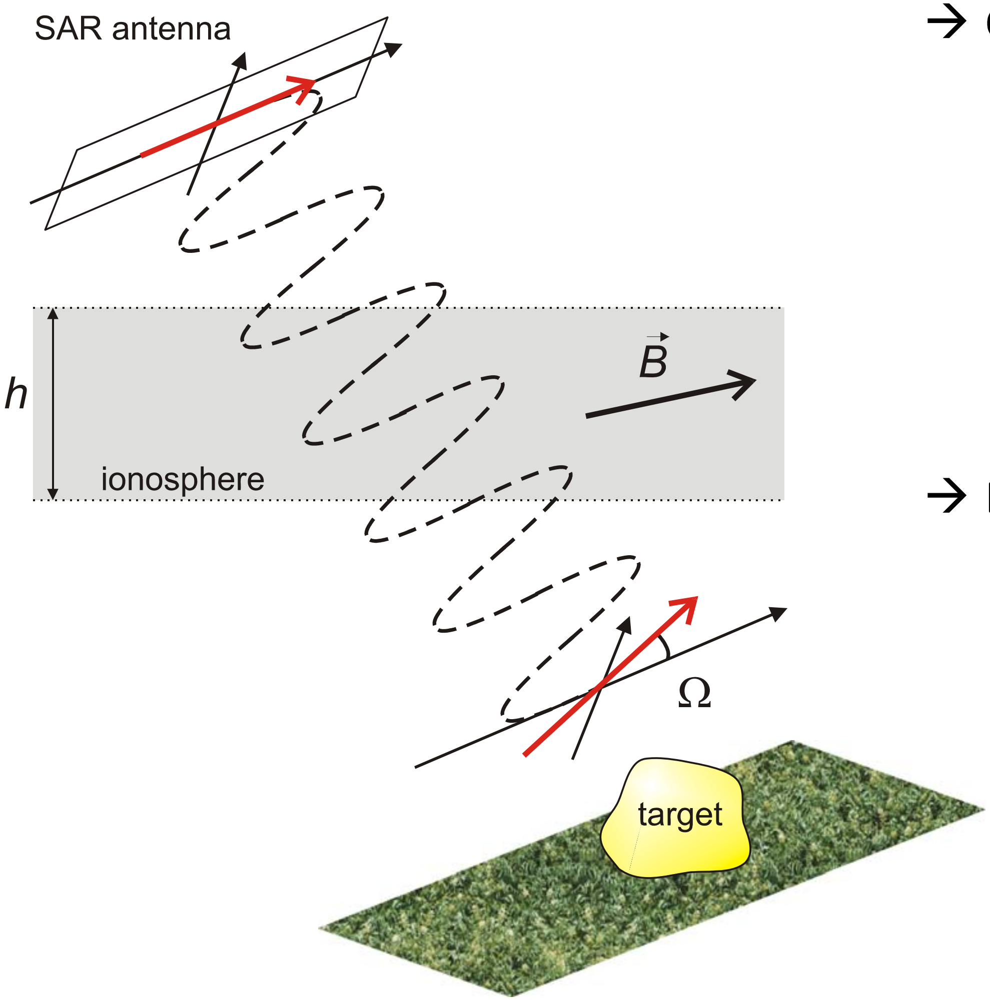
Outline

- Introduction
- FR prediction and estimation methods
- Unfocussed raw data analysis
- Results on ALOS-PALSAR
- Conclusions

Introduction

What is Faraday rotation

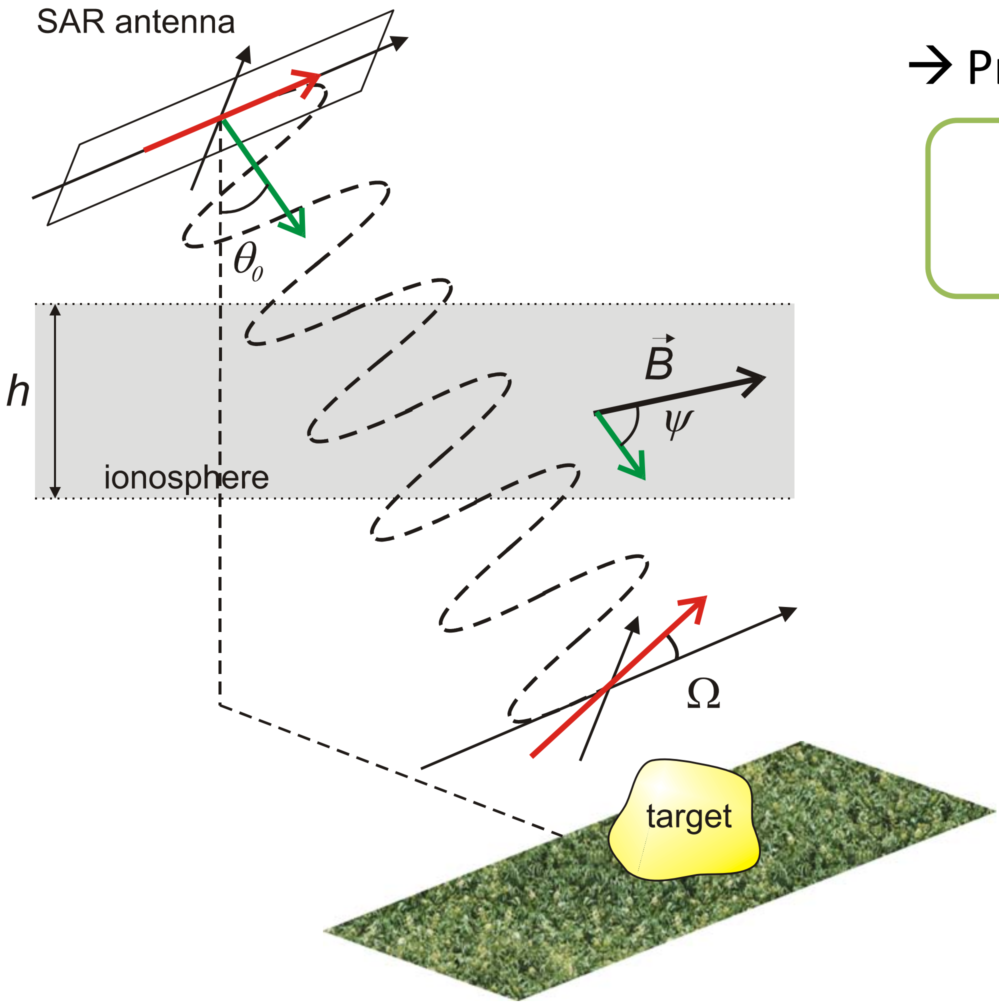


→ Cause
- → The satellite-target propagation path crosses the ionosphere
- → Ionosphere is an anisotropic medium due to the charged particles in a persistent Earth magnetic field
- → The polarization plane of the radio wave rotates

→ Effects
- → Reciprocity does not hold
- → Error in the estimation of calibration distortion
- → Polarimetric techniques (e.g. decompositions) can be affected

Faraday rotation

Prediction from TEC data



→ Prediction of FR:

$$\Omega \cong \frac{K}{f^2} B \cos(\psi) \sec(\theta_0)\, TEC$$

- → Ω: one-way FR angle
- → *K*: constant
- → *f:* frequency
- → *TEC*: total electron content

Faraday rotation

Estimation from SLC data

→ FR model (assuming polarimetric calibration of the system)

$$\begin{pmatrix} M_{HH} & M_{HV} \\ M_{VH} & M_{VV} \end{pmatrix} = Ae^{j\phi} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix}$$

Faraday rotation

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1. From HV-VH difference

$$\Omega = \frac{1}{2}\tan^{-1}\left(\frac{M_{HV} - M_{VH}}{M_{HH} + M_{VV}}\right)$$

2. From circular basis change (Bickel and Bates, 1965)

$$\begin{pmatrix} M_{LL} & M_{LR} \\ M_{RL} & M_{RR} \end{pmatrix} = \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix} \begin{pmatrix} M_{HH} & M_{HV} \\ M_{VH} & M_{VV} \end{pmatrix} \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix}$$

➡

$$\Omega = \frac{1}{4}\arg\left(M_{LR} M_{RL}^{*}\right)$$

Faraday rotation

Proposed approach: estimation from unfocussed raw data (A)

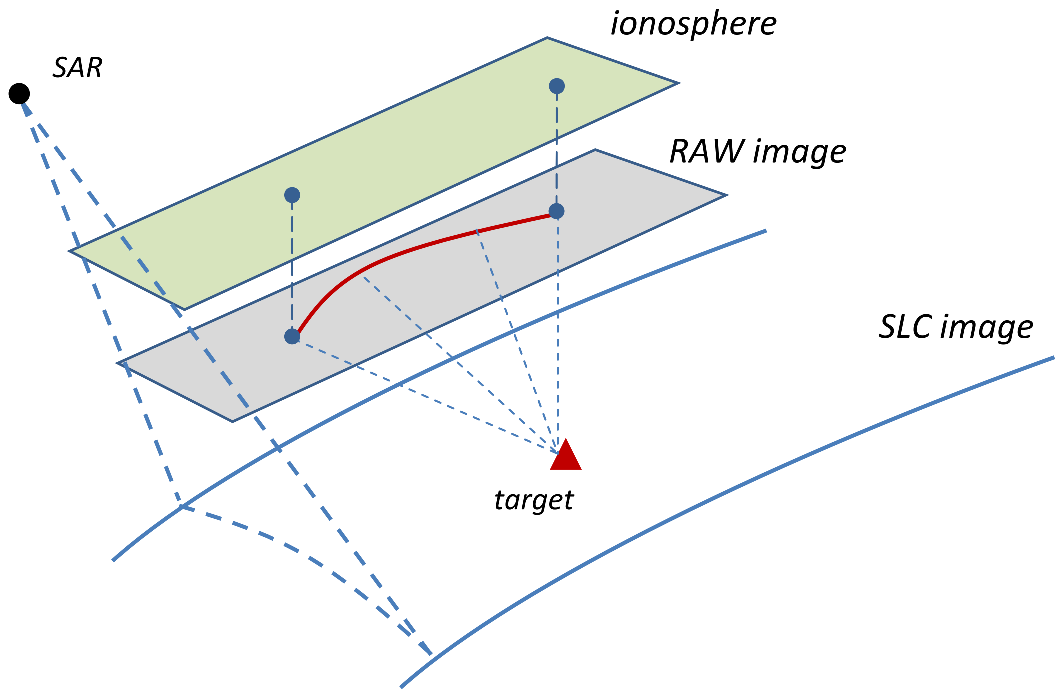
- → SLC formation involves several steps (example ESA PALSAR verification processor)
  - → Orthogonalisation of the signals
  - → Range focussing
  - → Doppler centroid estimation
  - → Azimuth focussing (Stolt interpolation)
  - → Polarization channel coregistration

- → Some operations might be nonlinear in the polarization components
  - → The Faraday rotation estimation might be corrupted (B)

Faraday rotation

Proposed approach: estimation from unfocussed raw data (A)

→ SLC formation integrates pulses coming from different portions of the ionosphere



Faraday rotation

Proposed approach: estimation from unfocussed raw data (A)

→ The physical relationship between transmitted and received pulses subject to FR is valid on each polarimetric sample of raw data

$$\begin{pmatrix} W_{HH} & W_{HV} \\ W_{VH} & W_{VV} \end{pmatrix} = \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} R_{HH} & R_{HV} \\ R_{VH} & R_{VV} \end{pmatrix} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix}$$

Faraday rotation

Proposed approach: estimation from unfocussed raw data

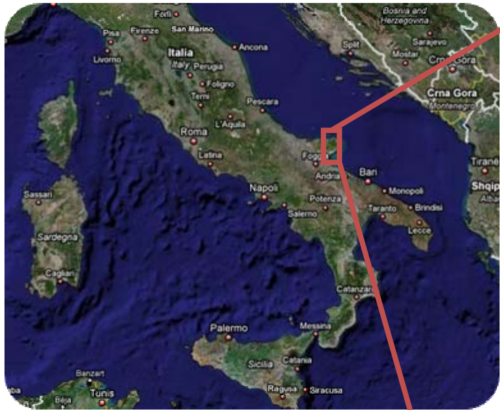
→ Same estimation methods of SLC data

→ Estimation of FR angle using the relationship of circular basis change applied to unfocussed raw data

$$\begin{pmatrix} W_{LL} & W_{LR} \\ W_{RL} & W_{RR} \end{pmatrix} = \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix} \begin{pmatrix} W_{HH} & W_{HV} \\ W_{VH} & W_{VV} \end{pmatrix} \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix}$$

$$\Omega = \frac{1}{4} \arg\left(W_{LR} W_{RL}^{*} \right)$$

Results on ALOS-PALSAR

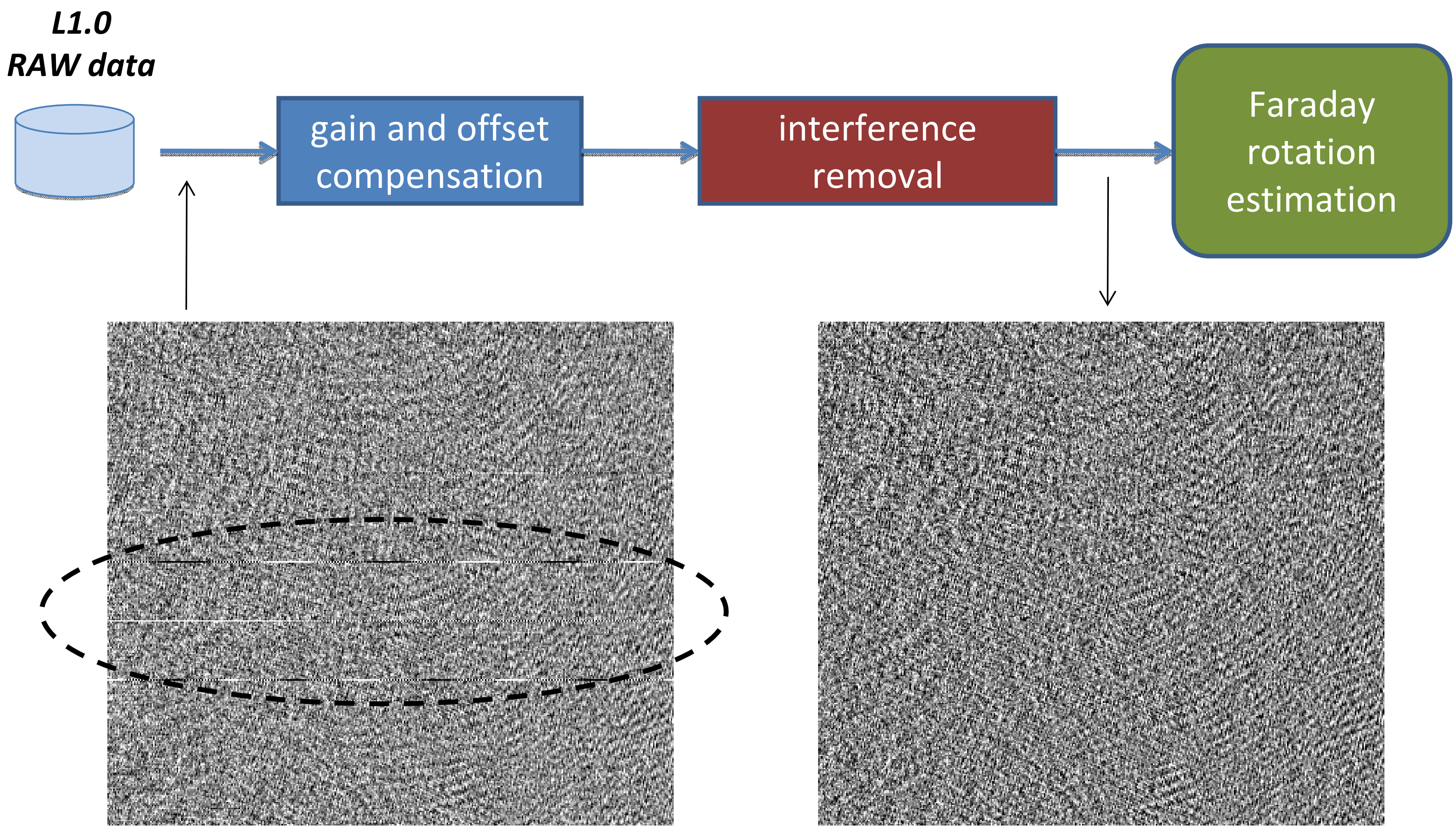


Pauli RGB of SLC product (PALSAR L1.1)

- → PALSAR acquisition
  - → South Italy
  - → DESCENDING pass
  - → Local time: 10:15 am
  - → April 2008

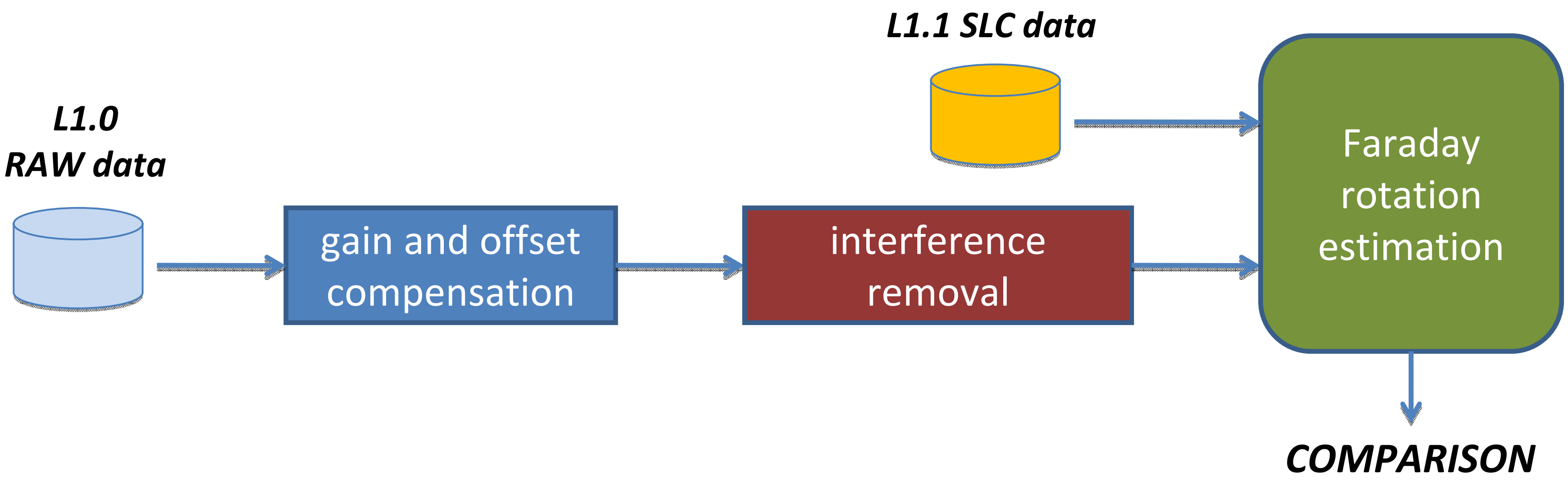
Comparison RAW vs. SLC

RAW data preprocessing



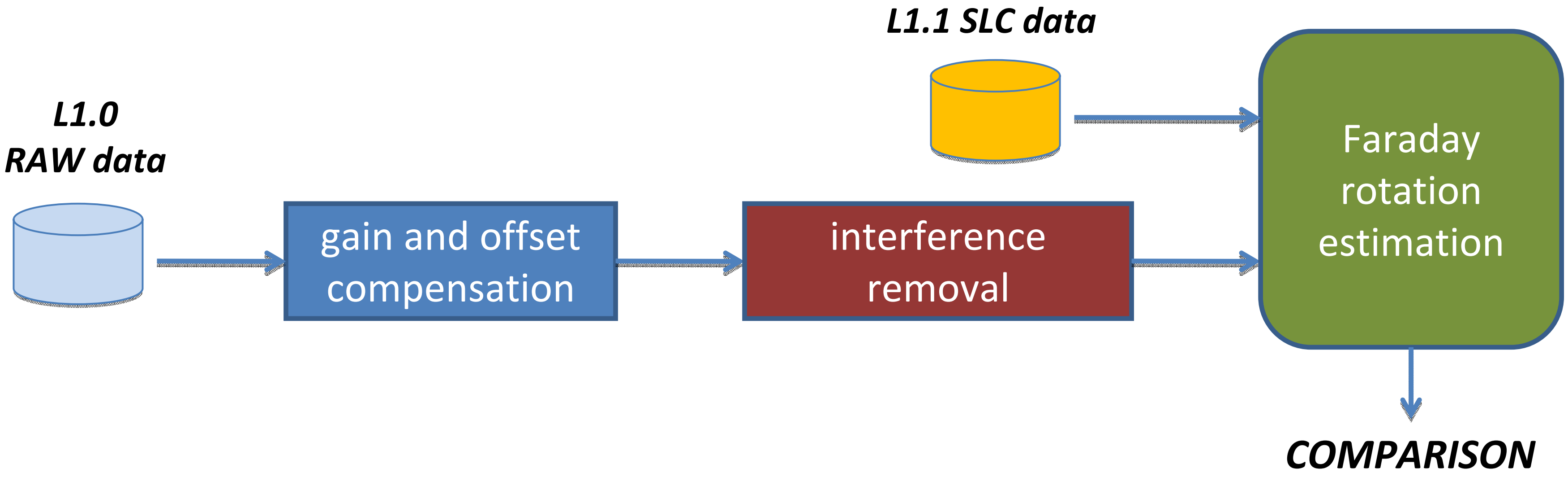
Comparison RAW vs. SLC

Faraday rotation maps



Comparison RAW vs. SLC

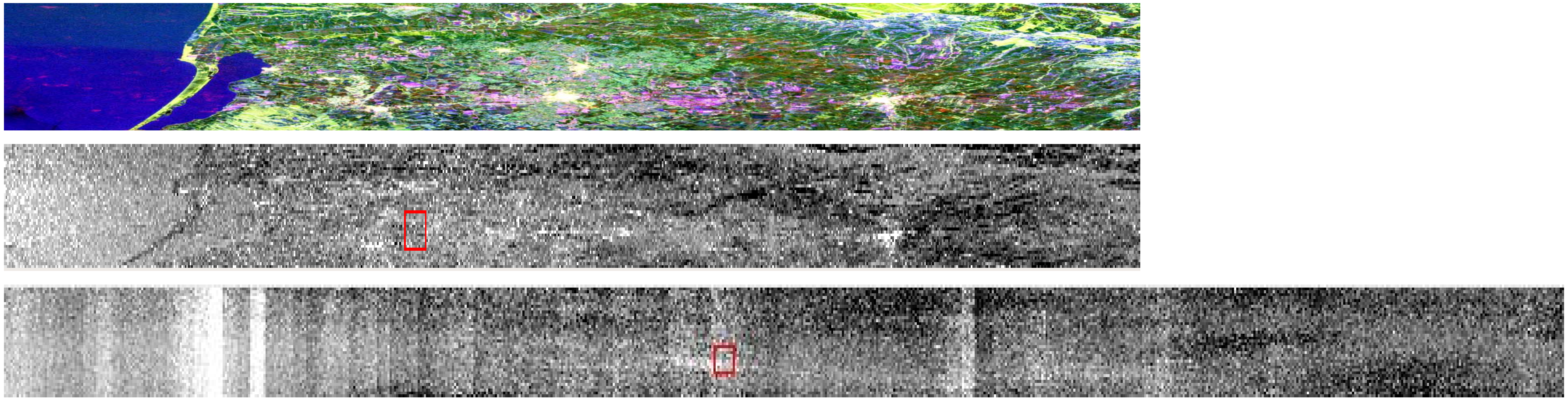
Faraday rotation maps



Pauli

FR SLC

FR RAW



Comparison RAW vs. SLC

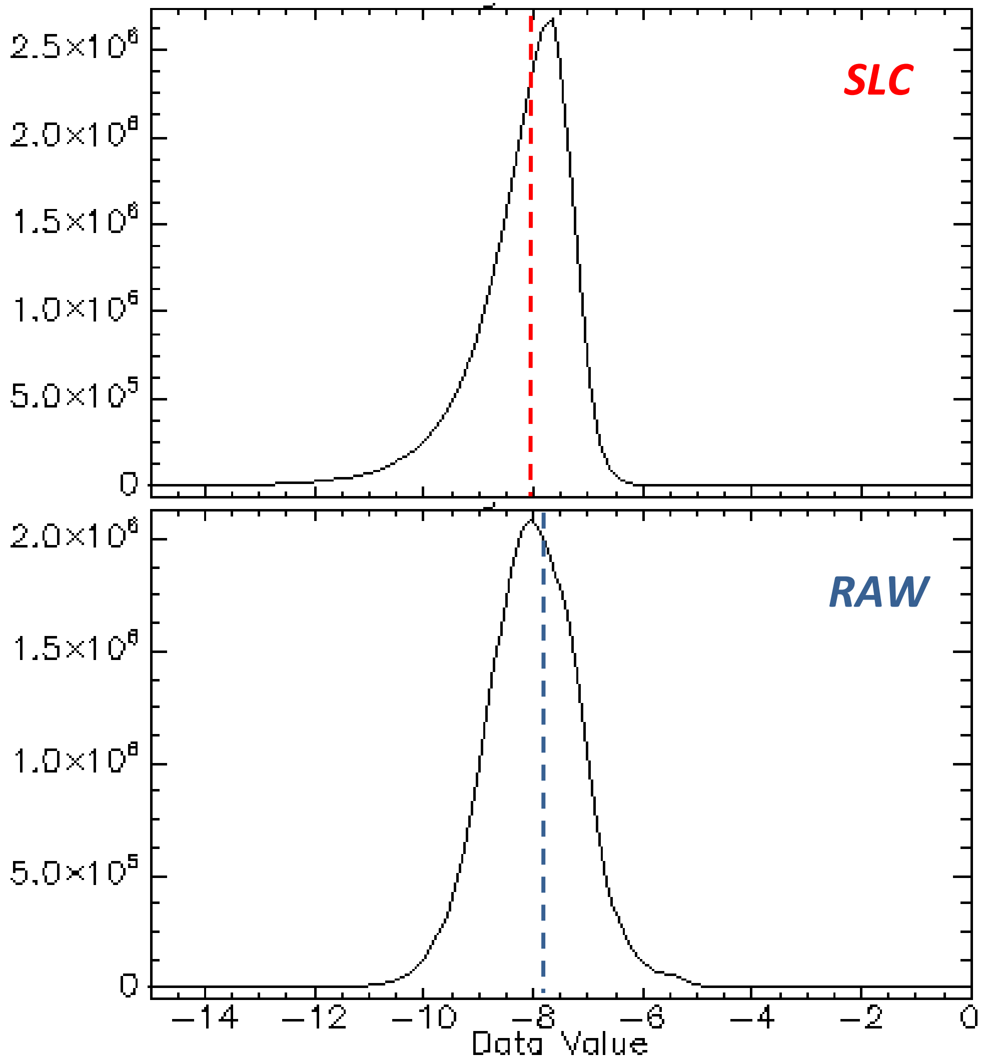
Histograms of estimated FR

→ SLC data (PALSAR L1.1)

$$\Omega = -8.10^\circ$$
$$\sigma = 0.93^\circ$$

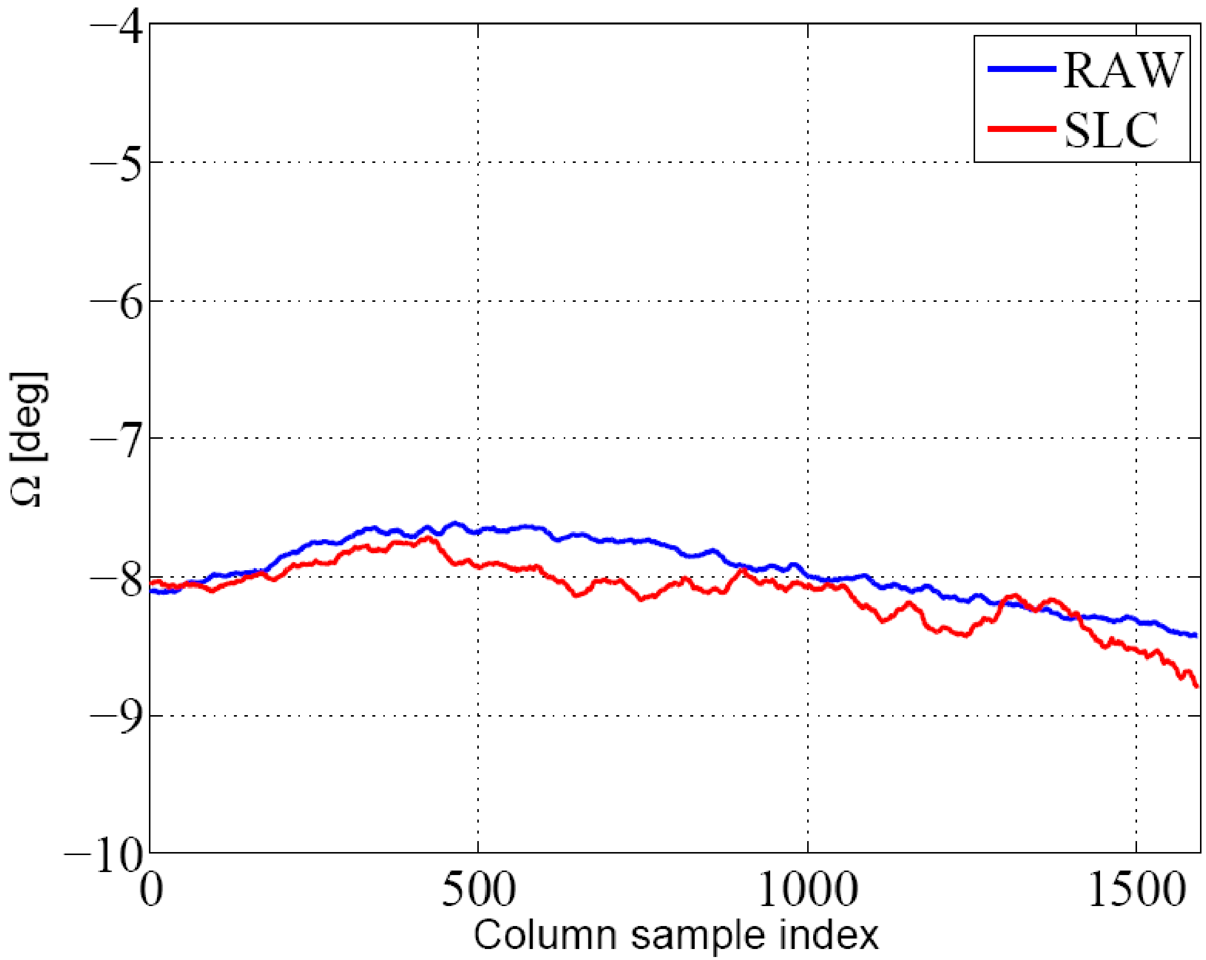
→ RAW data (PALSAR L1.0)

$$\Omega = -7.94^\circ$$
$$\sigma = 0.85^\circ$$



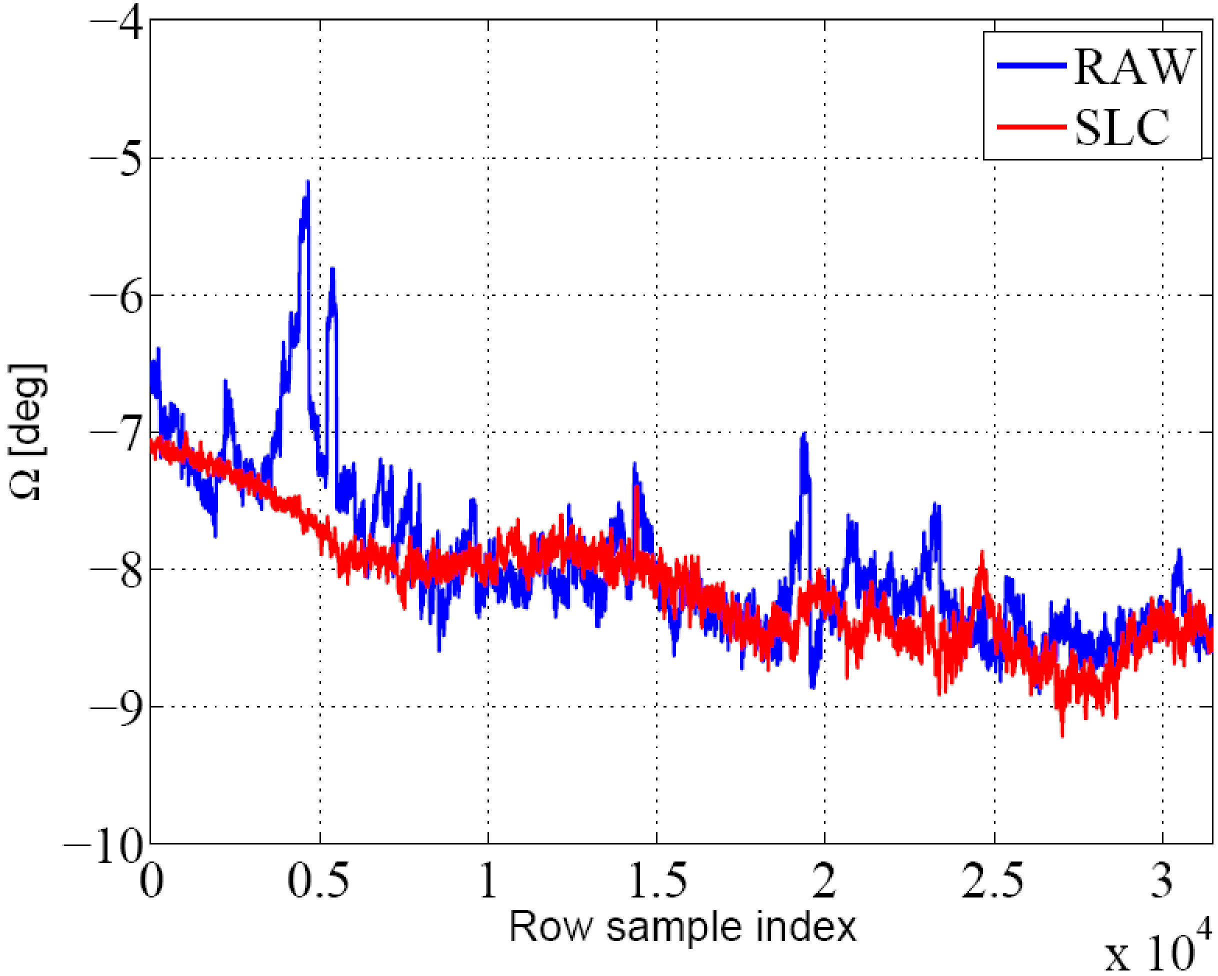
Comparison RAW vs. SLC

Range profiles



Comparison RAW vs. SLC

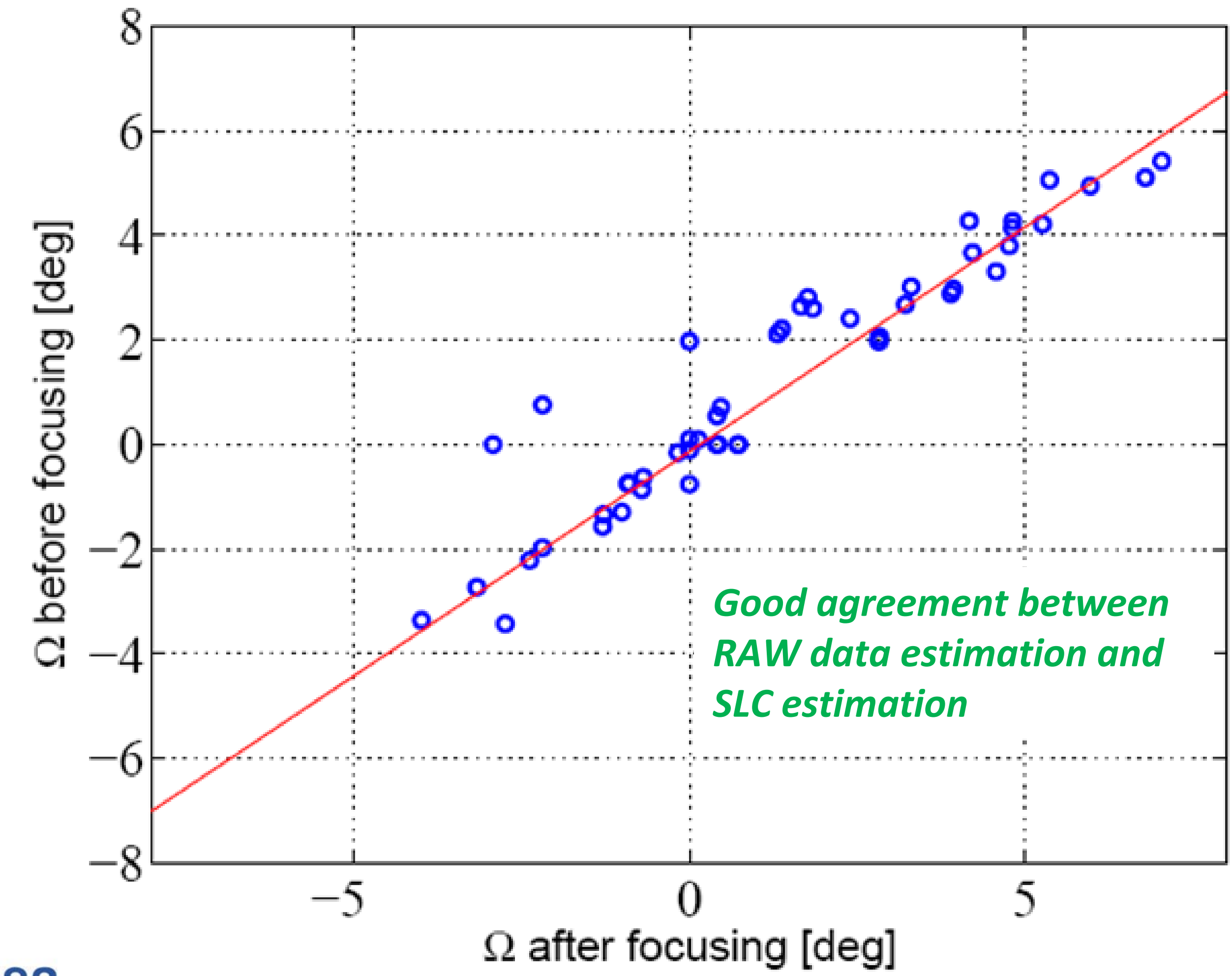
Azimuth profiles



Comparison RAW vs. SLC

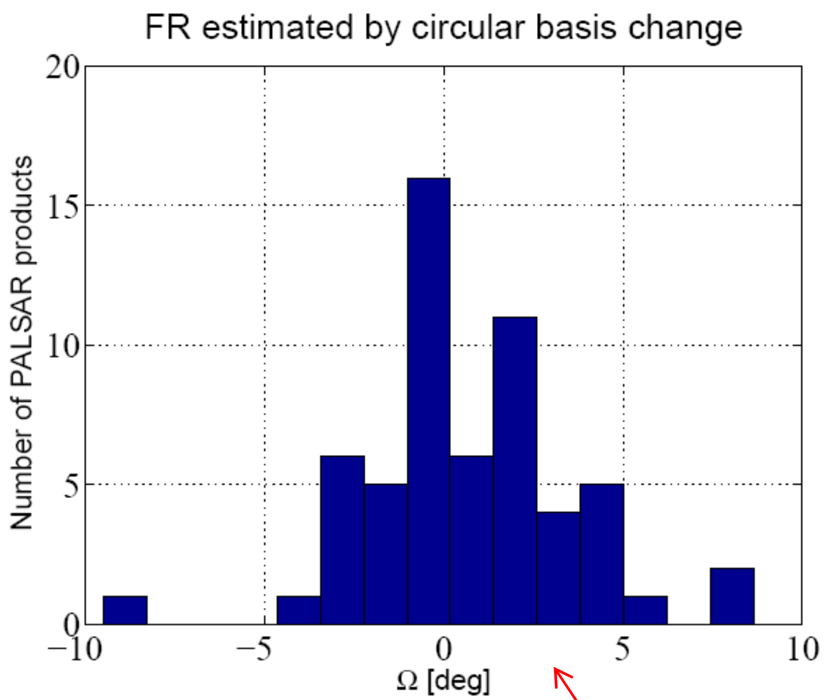
Extensive analysis

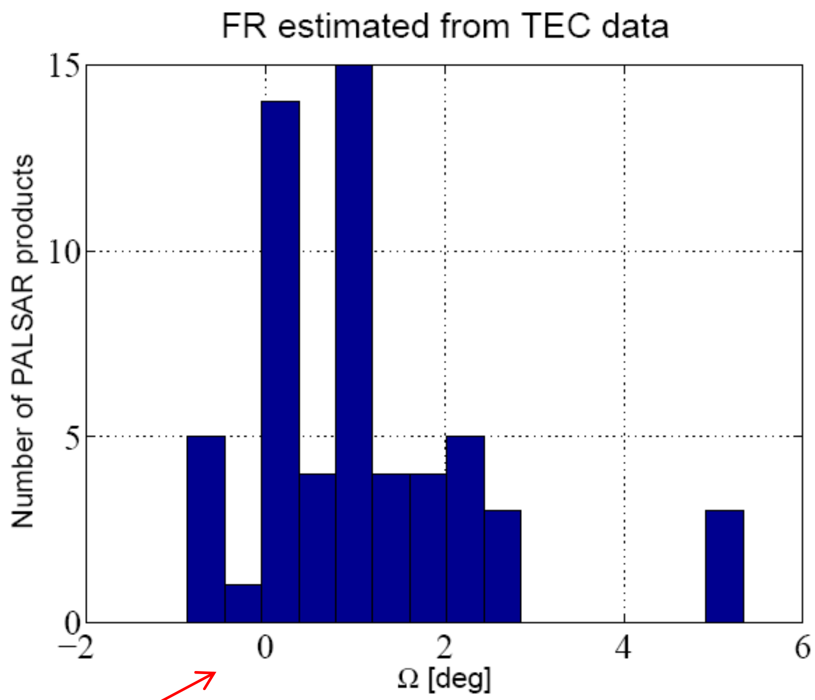
→ 30+ polarimetric PALSAR products



Comparison with TEC data

→ 30+ polarimetric PALSAR products
→ TEC data from *ftp.aiub.ch*

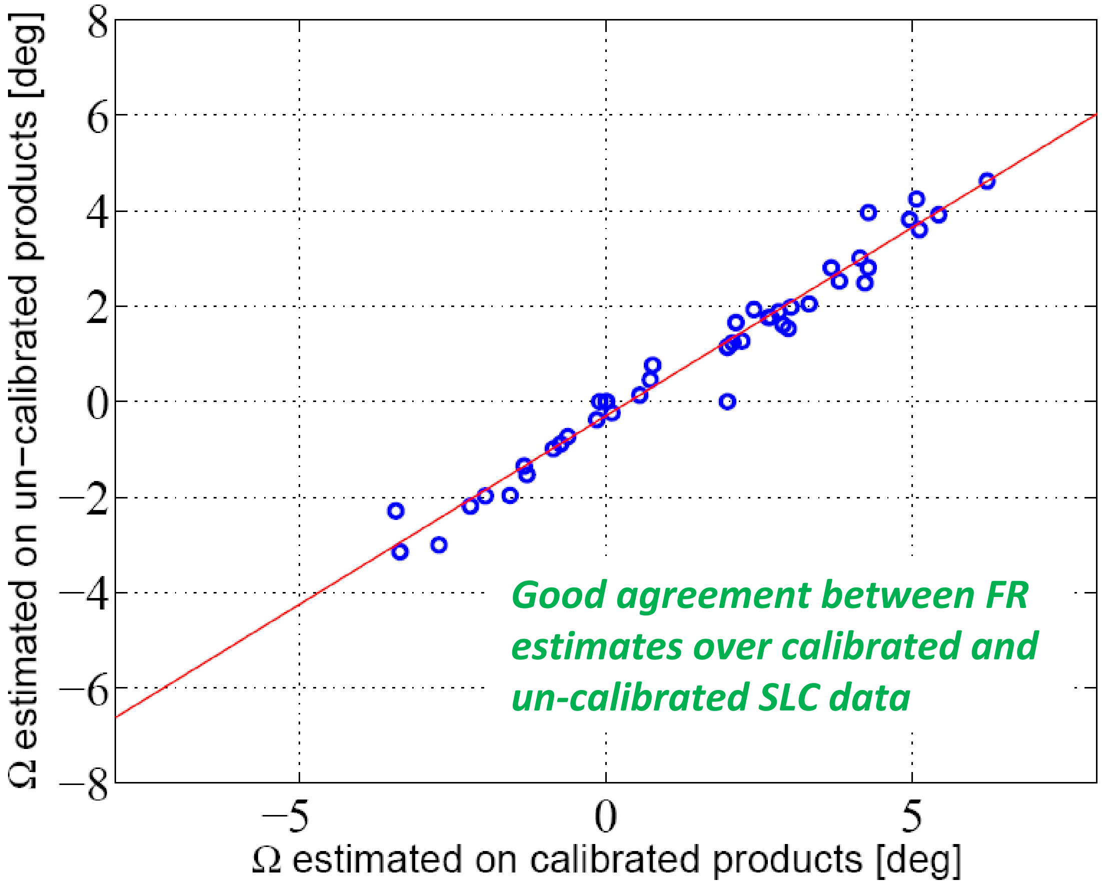




TEC prediction is biased with respect to FR estimation from data products

Effect of the polarimetric calibration

→ Comparison between un-calibrated and calibrated products using the distortion matrices written in the product header (Shimada, 2007)



Conclusions

→ FR estimated from RAW data vs. SLC data

- FR model and estimation methods are the same for RAW and SLC estimation
- Mean value and variance of FR angles are very close
- No particular range/azimuth trend has been observed
- Impact of the distortion matrices is negligible
- Prediction from TEC data is slightly biased
- Investigation of the spatial variation of TEC from RAW data is in progress

→ Practical implications

- FR estimated from RAW data can be used to improve the focusing in low frequency SAR
- Mean value of FR angle can be annotated in the product header of RAW data and copied into the header of SLC data

Introduction

Dual Polarimetry VS Full Polarimetry

$$\Omega = \frac{K}{f^2} \int_0^h N B \cos\psi \sec\theta_0 \, dh \text{ [radians]} \qquad (1)$$

where K is a constant of value 2.365×10^4 in S.I. units, B is the magnetic flux density, N is the electron density, and ψ and θ_0 are the angles the wavenormal makes with the earth's magnetic field and the downward vertical, respectively [see Fig. 1(c)]. From (1), it is obvious that FR increases with increasing wavelength (the FR magnitude is 16 times greater at L-band than at C-band). It should be noted that the microwave signal is rotated by Ω in the same sense each time it traverses the ionosphere (see Section V). For SAR, the total FR will, therefore, be double the one-way FR experienced by a passive microwave sensor.

A good approximation to Ω is given by

$$\Omega = \frac{K}{f^2} \times \overline{B \cos\psi \sec\theta_0} \times \text{TEC} \qquad (2)$$

$$\begin{bmatrix} M_{hh} & M_{vh} \\ M_{hv} & M_{vv} \end{bmatrix} = \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \cdot \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \cdot \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \qquad (3)$$

Nonzero Faraday rotation causes the cross-pol measurements M_{vh} and M_{hv} to be non-reciprocal, an effect that can be exploited for Faraday rotation retrieval. In this paper two different Faraday rotation estimation methods are applied. One of the approaches extracts the Faraday rotation angle Ω by solving the equation system in equation 2 directly (see [8]):

$$\Omega = \frac{1}{2} \tan^{-1} \left[\frac{(M_{vh} - M_{hv})}{(M_{hh} + M_{vv})} \right] \qquad (4)$$

A more robust version of this approach uses spatial averaging to reduce the influence of speckle on the estimated Ω angle. The second approach introduced by Bickel and Bates [9] transforms M to a circular basis Z via

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{12} & Z_{22} \end{bmatrix} = \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \cdot \begin{bmatrix} M_{hh} & M_{vh} \\ M_{hv} & M_{vv} \end{bmatrix} \cdot \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \qquad (5)$$

From Equation (5) Ω can be derived by calculating

$$\Omega = \frac{1}{4} \arg\left(Z_{12} Z_{21}^*\right). \qquad (6)$$

A dual-pol mode has the same transmitting charc
same receiving characteristics of a quad-pol mod.