FARADAY ROTATION ESTIMATION FROM UNFOCUSSED RAW DATA: ANALYSIS USING ALOS PALSAR DATA

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ABSTRACT

We propose to estimate Faraday rotation (FR) from SAR unfocused raw data rather than focussed Single Look Complex (SLC) data. The main issue of the previous approaches presented in literature is the inherent averaging of the FR angle with the focussing process. This averaging might lead to wrong estimation of FR especially in the case of rapid spatial variation of Total Electron Content (TEC) in the ionosphere. The presence of nonlinear operations in the SAR processor is a second issue that might affect the FR estimation from SLC data. We show the comparison between the two approaches using ALOS-PALSAR data and the ESA PALSAR verification processor.

1. INTRODUCTION

A radio wave propagating through the ionosphere undergoes Faraday rotation, i.e. the rotation of its polarization plane. Faraday rotation is caused by the anisotropy of the ionospheric tenuous plasma in presence of a persistent magnetic field and can significantly impact the performance of a Synthetic Aperture Radar (SAR). Propagation in an anisotropic medium is not reciprocal, hence the HV return deviates from VH return, causes errors in the estimation of polarimetric calibration parameters and therefore impacts current PolSAR /PolInSAR applications. SAR sensors, such as ALOS-PALSAR that operates at L-band, are more affected by FR than higher frequency SAR systems. Once detected and estimated, FR must be compensated over the SAR scene. Apart from the use of reference point targets, such as trihedral corner reflectors, Faraday Rotation angle can be estimated from full-pol data by considering the difference between the cross-polarized acquisitions HV and VH [1]; estimated from full-pol data by simulating the circularly polarized wave in transmission and reception [2]; estimated from full-pol data by simulating the circularly polarized wave in transmission and reception [2];

predicted from model simulations using real measurements of total electron content in the ionosphere.

In previous works, the first two approaches above have been applied to each sample of focussed SLC data. Hence they have high spatial accuracy, but rely on the phase and cross-talk calibration of the SLC data [3]. The third approach makes use of an external information (TEC maps) that usually has lower spatial resolution. In this paper, we argue that the estimation of the Faraday rotation from SAR data is more appropriate using unfocused raw data than SLC data. Since the FR is estimated from a single received echo, this approach is more physical with respect to the usual approach. Next sections describe the procedure for the estimation of FR from raw data and show the results of an extensive analysis over more than 30 PALSAR products. In addition, our analysis indicates fairly low values of FR for ALOS-PALSAR (lower than 8 deg), acceptable for the present polarimetric applications. However, this value might increase in the next years as a consequence of the cyclic solar activity that will increase the average TEC in the ionosphere [4].

2. FARADAY ROTATION ESTIMATION: FROM SLC TO UNFOCUSSED RAW DATA

SAR data exploitation requires radiometric and polarimetric calibration as well as Faraday rotation correction. If we assume that system distortions are negligible or have been compensated with a specific calibration procedure, the relationship between the measured scattering matrix \([M]\) of the target and true scattering matrix \([S]\) subject to Faraday rotation can be expressed by

\[
[M] = [F][S][F]\]

\[
= \begin{pmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{pmatrix}
\begin{pmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{pmatrix}
\begin{pmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{pmatrix}
\] (1)

Matrix \([F]\) is responsible for the rotation of the scattering matrix and contains the FR angle \(\Omega\). The knowledge of \(\Omega\) entails the full knowledge of Faraday rotation and

\[
\begin{pmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{pmatrix}
\begin{pmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{pmatrix}
\begin{pmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{pmatrix}
\]
the possibility to compensate for it. The prediction of FR angle from TEC data can expressed by the following approximation [5]

\[ \Omega = \frac{K}{f^2} B \cos \psi \sec \theta_0 TEC \] (2)

where the frequency \( f \) appears at denominator, \( B \) is the magnitude of the Earth magnetic field, angles \( \psi \) and \( \theta_0 \) expresses the relative orientation of the magnetic field with the wave propagation direction and TEC is the total electron content of the ionosphere. The magnetic field is usually known from specific models, the TEC spatial distribution is measured by GNSS network. Expression (2) is also used for the generation of TEC map from SAR data, once FR angle is known.

Faraday rotation angle can be also estimated pixel-by-pixel from SAR data using the linear cross-polarized returns HV-VH or from a circular basis transformation. The latter method is used in this paper to compare FR estimation from raw data and from SLC data. There are some advantages in estimating FR from unfocussed raw data instead of SLC data:

1. received echoes travel through different portions of the ionosphere, they are potentially affected by different FR angles and their integration in the SAR processor might lead to wrong estimation of FR when performed from SLC data;
2. some operations in the SAR processor can be nonlinear with respect to the polarimetric channels and this might corrupt the estimation of FR angles from SLC data;
3. the spatial distribution of TEC in the ionosphere corresponds more closely to the raw data than SLC data and hence the generation of TEC map is more realistic.

From electromagnetic point of view, the pure scattering matrix that relates the transmitted wave to the received wave is embedded in the raw data more than SLC data. It follows that the FR model 4 applies straightforward to raw data, and it is more appropriate since we consider each received echo and not the focussed scattering matrix. The relationship between the raw scattering return [\( W \)] and the true scattering return [\( R \)] is

\[ [W] = [F][R][F]. \] (3)

Therefore, we use the following estimates for the FR angle from raw data

\[ \Omega = \frac{1}{4} \arg (W_{lr}, W_{rl}) \] (4)

where \( W_{lr} \) and \( W_{rl} \) are the left-right and right-left polarized scattering elements respectively. Next section shows some observations over PALSAR data of the expression (4).

![Figure 1: Pauli image of the PALSAR polarimetric (top), Faraday rotation map from SLC data (middle) and Faraday rotation map from raw data (bottom).](image)

3. PALSAR DATA OBSERVATIONS

We compared the two estimates of FR from SLC and raw data using L-band ALOS PALSAR data. The considered polarimetric product has been acquired over South of Italy on April 2008 at 10:15 local time. Fig. 1 shows the Pauli image of the product. The scene is dominated by hilly vegetated areas. Sea surface and urban areas are also present in the scene. In the same figure the two maps of Faraday rotation are shown. Both maps are obtained directly by averaging the expression (4) over \( 7 \times 7 \) pixels. A preprocessing of raw data has been performed for gain/offset compensation and interference removal. The mean value of FR angle from SLC data results \(-8.10\) deg and from raw data results \(-7.94\) deg. The standard deviation of the estimates is \(0.93\) deg from SLC and \(0.85\) deg from raw data. The accordance of the two values confirms that the PALSAR SAR processor does not corrupt the estimation of Faraday rotation. However, the local variations of FR angle estimation are also of interest. Fig. 2a and fig. 2b shown the averaged range and azimuth profiles respectively. Range profiles are almost preserved in the focussing process and FR estimation. Azimuth profiles have also a mean value around \(8\) deg, but shows local deviation due to the fact the the FR angle on raw have not been averaged by the focussing process. One example of such variation is centered around the row 5000 in fig. 2b. However, the origin of such variation can be the effect of uncompensated interference removal or rapid spatial variation of TEC in the ionosphere. The same procedure described for the product of fig. 1 has been applied to an extensive analysis of 30+ PALSAR data. Fig. 3a shows the mean value of the FR angle estimated from SLC and raw data. The linear trend confirms that the mean estimated value of FR from raw data is in good agreement with the mean value of the FR angle estimated form SLC data. In the analysis above, the system has been considered calibrated, i.e. the polarimetric distortion matrices on receive and transmit has been neglected. Fig. 3b shows the Faraday rotation estimates from calibrated and uncalibrated SLC data and confirms that the PALSAR system distortions can be neglected for the purpose of FR estimation.
4. CONCLUSIONS

We propose to estimate Faraday rotation from raw data, i.e. before the focussing process. Our new approach is important when rapid spatial variations of total electron content occur in the ionosphere. A comparison of azimuth profiles of FR estimated from PALSAR products reveals some differences between raw data and SLC data estimation. The PALSAR processor that we have used can be considered linear with respect to the polarimetric channels, hence the mean value of FR estimated from raw data is well in accordance with the one estimated from SLC data. As further consequence, FR angle can be used to improve the focussing as well as to provide an additional information in the annotations of raw data products.

ACKNOWLEDGMENTS

The authors would like to thank the European Space Agency for providing the PALSAR verification processor.

REFERENCES


