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Polarimetric Calibration of ALOS/PALSAR

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1. Introduction

This report presents the polarimetric calibration results of ALOS/PALSAR and discusses a stability of polarimetric calibration parameters during the calibration phase of ALOS and an influence of Faraday rotation on them. PALSAR is the first spaceborne polarimetric L-band synthetic aperture radar and its polarimetric data is expected to be utilized in various remote sensing applications. However, the distortions due to the radar hardware and the ionosphere are included in measurement data which consists of the scattering matrix. The influence by the radar hardware occurs as channel imbalance and crosstalk. The ionosphere causes Faraday rotation which rotates a polarization plane of radar wave. Thus, polarimetric calibration for removing the distortions from the measured scattering matrix is an important issue for PALSAR. Amazon data was used to estimate the polarimetric calibration parameters, because this area is located in the vicinity of the equator and the effect of Faraday rotation was expected to be small. Quegan method which is one of the polarimetric calibration methods was applied to the data. Although this method can not deal with Faraday rotation, the channel imbalance and the cross-talk can be derived accurately. The Amazon data showed that the channel imbalance remained stable during the calibration phase and the cross-talk was very small regardless of the descending path (daytime observation) and the ascending path (nighttime observation). Faraday rotation angle was calculated by Freeman method. This result showed that Faraday rotation angle in Amazon area was less than 1 degree. Moreover, Tomakomai data was compared with Amazon data and indicated that there was a correlation between the cross-talk and Faraday rotation. These parameters of descending path data were higher than those of ascending path data. Therefore, it was confirmed that Amazon data has little influence of Faraday rotation and is suitable for deriving the polarimetric calibration parameters.

2. Polarimetric Calibration model

The polarimetric measurement conducted by the airborne synthetic aperture radar system can be modelled as follows [1][2]:

$$\mathbf{M} = A\exp(j\phi)\mathbf{RST} + \mathbf{n}, \qquad (1)$$

where A and ϕ are the residual amplitude and phase with respect to calibration factors, and $\boldsymbol{M}$ and $\boldsymbol{S}$ are the measured and true scattering matrices. R and T are the matrices representing the distortions on receiving and transmitting systems and they are expressed as:

$$\mathbf{R} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \text{ and } \mathbf{T} = \begin{pmatrix} 1 & \delta_3 \\ \delta_3 & f_2 \end{pmatrix}, \qquad (2a,b)$$

where the diagonal terms f_1 and f_2 are channel imbalance and off-diagonal terms δ are cross-talk. $\boldsymbol{n}$ is the system noise. In calibrating the polarimetric data acquired from the spaceborne SAR system, Faraday rotation becomes significant problem. If Faraday rotation influences the SAR signal, equation (1) is modified as [3],

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$$
\mathbf{M} = A\exp(j\phi)\mathbf{RFSFT} + \mathbf{n}
$$
$$
\mathbf{F} = \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \quad (3)
$$

where ***F*** is the Faraday rotation matrix and Ω is the one-way Faraday rotation angle. Faraday rotation means the rotation of polarization plane as the radar signal travels through the ionized atmosphere. The contribution of Faraday rotation to true scattering matrix is written as follows:

$$
\begin{aligned}
M'_{HH} &= S_{HH}\cos^2\Omega - S_{VV}\sin^2\Omega \\
M'_{HV} &= S_{HV} + (S_{HH} + S_{VV})\sin\Omega\cos\Omega \\
M'_{VH} &= S_{HV} - (S_{HH} + S_{VV})\sin\Omega\cos\Omega \\
M'_{VV} &= S_{VV}\cos^2\Omega - S_{HH}\sin^2\Omega.
\end{aligned} \quad (4)
$$

It can be seen that S_{HH} and S_{VV} appear in other polarization components. The approximated one-way Faraday rotation angle is given by [4]

$$
\Omega = \frac{k}{f^2} \times B\cos\psi\sec\theta_0 \times TEC \qquad \text{[radians]} \quad (5)
$$

where k is a constant of value 2.365×10^4, B is the magnetic flux density, f is the frequency, and ψ and θ_0 are angle between earth's magnetic field and radar wave, and incident angle, respectively. *TEC* is the total electron content and depends on time of day, season, solar activity, geographical location, etc. Solar activity is changed by a cycle of approximately 11 years. Since next minimum of solar activity is forecasted around 2007, Faraday rotation is expected to be small at present.

3. Polarimetric Calibration Method

We consider two polarimetric calibration methods to estimate the polarimetric calibration parameters for PALSAR. One is Quegan method. Since this method is based on the airborne SAR polarimetric calibration, Faraday rotation angle can not be considered. The other is Freeman method which is constructed based on (3), and Faraday rotation can be estimated.

Quegan method uses a trihedral corner reflector and natural distributed targets in the scene. The natural distributed targets are used to estimate the crosstalk parameters and are required to satisfy the azimuthal symmetry, which means the co- and cross-polarized responses are uncorrelated.

$$
\langle S_{HH} S^*_{HV} \rangle = \langle S_{HV} S^*_{VV} \rangle = 0 \quad (6)
$$

(1) can be rewritten as:

$$
\begin{pmatrix} M_{HH} \\ M_{VH} \\ M_{HV} \\ M_{VV} \end{pmatrix} = Y \begin{pmatrix} \alpha & v+\alpha w & vw \\ \alpha u & \alpha & v \\ \alpha z & 1 & w \\ \alpha u z & u+\alpha z & 1 \end{pmatrix} \begin{pmatrix} k^2 & 0 & 0 \\ 0 & k & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} S_{HH} \\ S_{HV} \\ S_{VV} \end{pmatrix} + \begin{pmatrix} n_{HH} \\ n_{VH} \\ n_{HV} \\ n_{VV} \end{pmatrix}, \quad (7)
$$

where the targets used for polarimetric calibration are assumed to satisfy the reciprocity principle ($S_{HV} = S_{VH}$). Y is the overall system gain in channel V and is similar to $A\exp(j\phi)$ in (1). u, v, w, and z are the crosstalk ratios and are related to δ_i.

$$u = \delta_2,\ v = \delta_4 / f_2,\ w = \delta_1 / f_1,\ z = \delta_3 \qquad (8)$$

α is the ratio of the receiving and transmitting channel imbalance (f_1/f_2). k is the receiving channel imbalance and equivalent to $1/f_1$. By using the observed corner reflector scattering matrix $\boldsymbol{Z}^{\text{tri}}$ and α, k is obtained as:

$$k = \pm\sqrt{Z_{HH}^{Tri} / \alpha Z_{VV}^{Tri}} \quad . \qquad (9)$$

Freeman method is similar to Quegan method and uses a trihedral corner reflector and natural distributed targets in the scene. However, this method assumes that the contribution of cross-talk is ignored. Faraday rotation angle is derived as follows:

$$\Omega = -\frac{1}{4} Arg\left(Z_{12} Z_{21}^{*}\right), \qquad \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} M'_{HH} & M'_{HV} \\ M'_{VH} & M'_{VV} \end{bmatrix} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \qquad (10)$$

where M ‘is the element of measured scattering matrix as eq.(4).

4. Polarimetric Calibration Results

In the calibration phase of ALOS, PALSAR observed many calibration sites in the world where the corner reflectors were deployed. In order to estimate the polarimetric calibration parameter, we use Rio Branco data in Amazon area. The effect of Faraday rotation is expected to be small, because Amazon area is located in the vicinity of the equator. Moreover, it is possible to use Quegan method due to Faraday rotation is neglected. In this area, there is a tropical rain forest and it is expected that the forest has the polarimetric scattering property of azimuthal symmetry. The analysis data consist of three descending path data and three ascending path data. Table 1 indicates the observation date and the off-nadir angle of each data. The channel imbalance and the cross-talk level are shown in Fig.1 and 2. The amplitude and phase of channel imbalance remains stable during the calibration phase, and the cross-talk is very small regardless of the descending path (daytime observation) and the ascending path (night time observation). These results show that PALSAR system is stable and has good performance. Next, we estimate Faraday rotation angle using Freeman method. Since it is confirmed that the cross-talk level of PALSAR is very small, PALSAR satisfies Freeman method’s requirement that the cross-talk is neglected. Figure 3 shows the results of the cross-talk in Rio Branco. The estimated Faraday rotation angles are less than 1 degree and correspond to the expected Faraday rotation angle [4].

Moreover, we examined the data observed in Tomakomai area, Japan. The channel imbalance in Tomakomai is similar to that in Rio Branco. However, the cross-talk and Faraday rotation angle are slightly varied with the descending path and the ascending path. For example, the cross-talk in Tomakomai is shown in Fig. 4. Therefore, Faraday rotation effect is influenced to PALSAR data, and it is confirmed that there is possibility to remove Faraday rotation effect from PALSAR data when the sun activity level is high.

5. Conclusions

We examined the polarimetric calibration of ALOS PALSAR. In order to estimate the polarimetric calibration parameters of PALSAR, we used Amazon data, because the effect of Faraday rotation is expected to be small. It was confirmed that Amazon data has little influence of Faraday rotation and is suitable for deriving the polarimetric calibration parameters.

References

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Table 1: Rio Branco (Amazon) data

No.	Obs. date	Path (D/A)	Off-nadir angle[deg.]
1	6/ 20, 2006	A	21.5
2	6/ 21, 2006	D	21.5
3	9/ 4, 2006	A	21.5
4	9/ 5, 2006	D	21.5
5	10/20, 2006	A	21.5
6	10/21, 2006	D	21.5

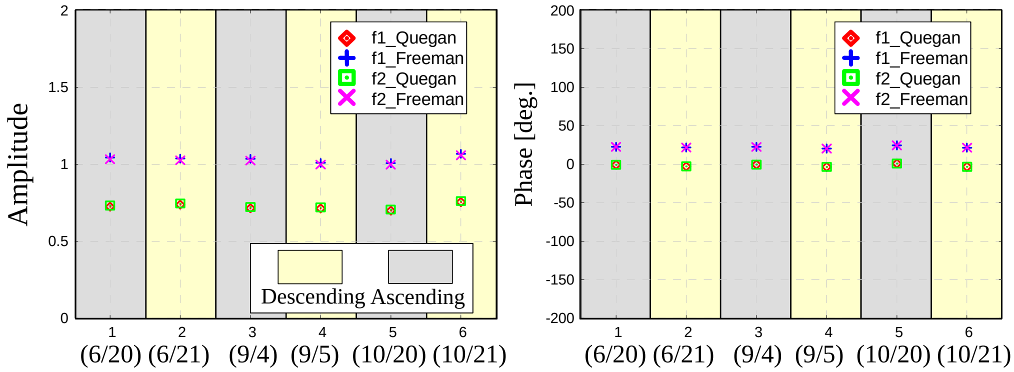

Figure 1: Amplitude and phase of channel imbalance (Rio Branco)

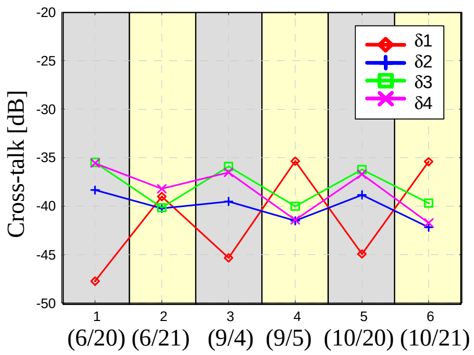

Figure 2: Cross-talk (Rio Branco)

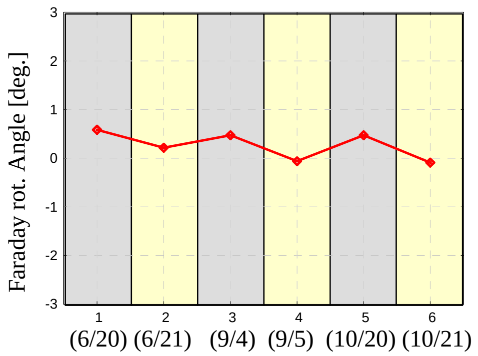

Figure 3: Faraday rotation angle (Rio Branco)

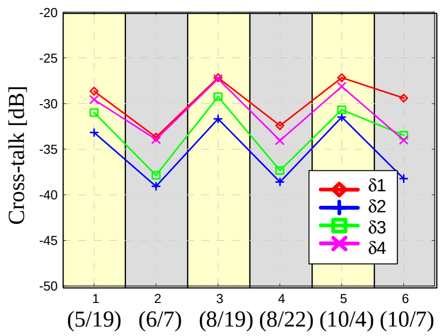

Figure 4: Cross-talk (Tomakomai)