

Polarimetric calibration and validation for ALOS/PALSAR

Toshifumi Moriyama

Nagasaki University, 1-14 Bunkyo-machi, Nagasaki-shi, Japan, E-mail: t-moriya@nagasaki-u.ac.jp

Abstract

The objectives of my proposal are to calibrate and validate the polarimetric data acquired by ALOS (Advanced land observing satellite)/PALSAR (Phased array type L-band synthetic aperture radar). In this report, we show the polarimetric calibration parameter of PALSAR derived by Quegan method and Amazon data. Moreover, we confirm the accuracy of Faraday rotation angle derived from PALSAR data as compared with Faraday rotation angle derived from TEC data.

Keywords: This is a sample, this is a sample.

1. INTRODUCTION

The objectives of my proposal are to calibrate and validate the polarimetric data acquired by ALOS (Advanced land observing satellite)/PALSAR (Phased array type L-band synthetic aperture radar). PALSAR is the first spaceborne polarimetric synthetic aperture radar, and it is expected that the polarimetric data is regularly acquired in conformity with an observation scenario and practically used for many applications as compared with an airborne polarimetric SAR case. However, the PALSAR polarimetric data is influenced by not only the distortions of polarimetric system but also the effect of Faraday rotation. The former distortions are caused by the radar hardware, and the latter effect is due to the ionosphere. Since an environment of ionosphere varies with solar activity which is 11-year cycle, similarly the polarimetric data measured by PALSAR is affected by its variation. If the polarimetric distortions on radar system are very small or calibrated, Faraday rotation becomes a main cause to reduce the data quality.

In this report, I show the polarimetric calibration parameters of PALSAR by using the data acquired in Amazon and Tomakomai. It was confirmed that the cross-talks, which were estimated by Quegan method, were below -35 dB and the channel imbalances were stable. Moreover, Faraday rotation angles were derived by Freeman method and compared with the angle derived from TEC data. The estimated Faraday rotation angle was small and both angles calculated from SAR data and TEC data agreed.

2. Polarimetric Calibration

2.1. Polarimetric Calibration model

The polarimetric measurement conducted by the airborne

synthetic aperture radar system can be modelled as follows [1][2]:

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

where A and ϕ are the residual amplitude and phase with respect to calibration factors, and M and 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:

$$\mathbf{R} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \quad \text{and} \quad \mathbf{T} = \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix} \quad (2a,b)$$

where the diagonal terms f_1 and f_2 are channel imbalance and off-diagonal terms δ are cross-talk. 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],

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

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]

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

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 maximum of solar activity is forecasted around 2011 and 2012, Faraday rotation is expected to be increasing at present.

2.2. 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. If Quegan method is used for the polarimetric calibration of spaceborne SAR, the data, which is not affected by Faraday rotation, is needed. 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:

$$\begin{pmatrix} M_{HH} \\ M_{VH} \\ M_{HV} \\ M_{VV} \end{pmatrix} = Y \begin{pmatrix} \alpha & v + \alpha w & vw \\ \alpha u & \alpha & v \\ \alpha z & 1 & w \\ \alpha u z & u + \alpha z & 1 \end{pmatrix} \quad (7)$$

$$\begin{pmatrix} k^2 & 0 & 0 \\ 0 & k & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} S_{HH} \\ S_{HV} \\ S_{VV} \end{pmatrix} + \begin{pmatrix} n_{HH} \\ n_{VH} \\ n_{HV} \\ n_{VV} \end{pmatrix}$$

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 .

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

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 Z_{tri} and α , k is obtained as:

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

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:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} M'_{HH} & M'_{HV} \\ M'_{VH} & M'_{VV} \end{bmatrix} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \quad (10)$$

$$\Omega = -\frac{1}{4} \text{Arg}(Z_{12} Z_{21}^*)$$

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

3. 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 used Quegan method and Rio Branco data in Amazon area where the effect of Faraday rotation is expected to be small. Amazon area is located in the vicinity of the equator and the angle ψ becomes about 90 degrees. 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 Faraday rotation angle 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. Figure 4,5 and 6 shows the calibration parameters estimated from Tomakomai data. 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. Therefore, it is confirmed that Faraday rotation effect influences PALSAR data observed in Tomakomai.

Moreover, we compared Faraday rotation angles derived from SAR data and TEC data. The angle derived from TEC data is calculated by the below equation.

$$\Omega = -0.299 \times \text{TECU} \times g(\theta, \phi) / f_{\text{GHz}}^2 \text{ [deg.]} \quad (11)$$

$$g(\theta, \phi) = 2 \left[\sin \theta_m \sin \theta \cos(\phi_m - \phi) + \cos \theta_m \cos \theta \right] \\ + \tan \theta_0 \left[\sin \theta_m \sin \lambda \sin(\phi_0 - \phi_m) - \cos \theta_m \cos \lambda \right]$$

The results of Tomakomai and Amazon are shown in Table 3. In both areas, Faraday rotation angle derived from SAR data is close to that derived from TEC data. Thus, it is shown that Faraday rotation angle can be estimated and the ionosphere environment information can be obtained from PALSAR data.

4. Conclusions

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

Acknowledgement

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Sample References

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Table 1: Rio Branco (Amazon) data

No.	Obs. date	Path (D/A)	Off-nadir angle[deg.]
1	7/20, 2006	A	21.5
2	7/21, 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

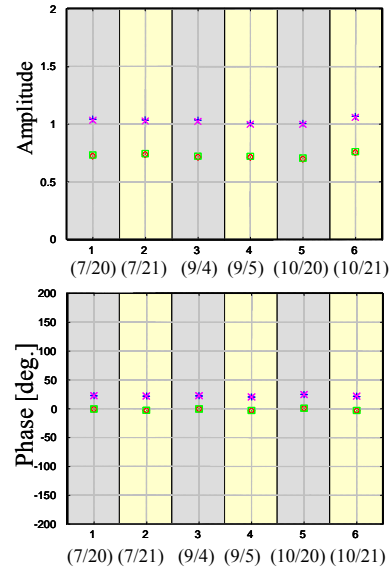


Figure 1 Channel imbalance derived from Amazon data.

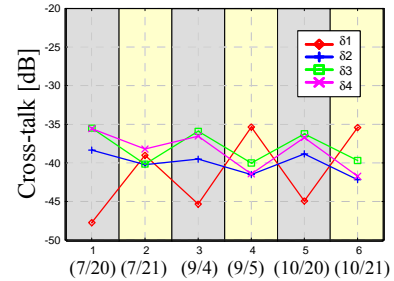


Figure 2 Cross-talks derived from Amazon data.

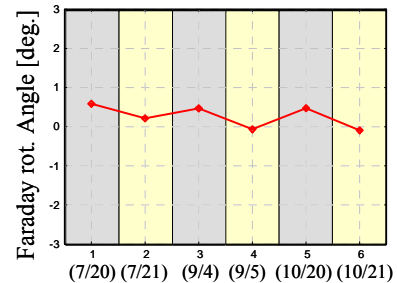


Figure 3 Faraday rotation angle derived from Amazon data.

Table 2: Tomakomai data

No.	Obs. date	Path (D/A)	Off-nadir angle[deg.]
1	5/19, 2006	D	21.5
2	7/7, 2006	A	23.1
3	8/19, 2006	D	23.1
4	8/22, 2006	A	23.1
5	10/4, 2006	D	23.1
6	10/7, 2006	A	23.1

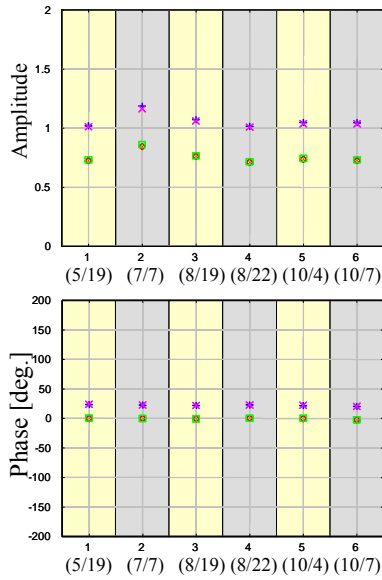


Figure 4 Channel imbalance derived from Tomakomai data.

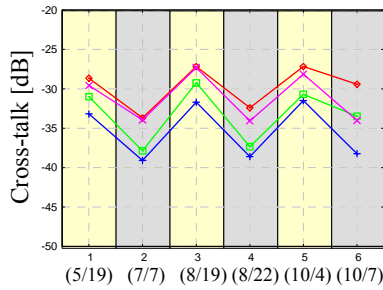


Figure 5 Cross-talks derived from Tomakomai data.

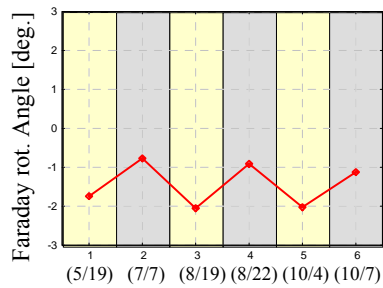


Figure 6 Faraday rotation angle derived from Tomakomai data.

Table 3: Comparison between Faraday rotation angles derived from SAR data and TEC data

(a) Amazon

No.	Obs. date	SAR FR.	TEC FR.
1	7/20, 2006	0.59	0.03
2	7/21, 2006	0.22	-0.08
3	9/4, 2006	0.47	0.05
4	9/5, 2006	-0.06	-0.10
5	10/20, 2006	0.47	0.09
6	10/21, 2006	-0.09	-0.16

(b) Tomakomai

No.	Obs. date	SAR FR.	TEC FR.
1	5/19, 2006	-1.74	-1.68
2	7/7, 2006	-0.77	-0.94
3	8/19, 2006	-2.05	-1.52
4	8/22, 2006	-0.91	-0.76
5	10/4, 2006	-2.02	-2.3
6	10/7, 2006	-1.1	-0.39