Penetration property of the L-band SAR and its coherence (JAXA PI-193)

Masanobu Shimada and Manabu Watanabe
Earth Observation Research and application Center (EORC)
Japan Aerospace and Exploration Agency, (JAXA) Sengen 2-1-1, Tsukuba, Ibaraki, Japan, 305-8505, Voice 81-29-868-2474, Fax: 81-29-868-2961, shimada.masanobu@jaxa.jp

Abstract L-band signal has excellent penetration property to the natural targets, i.e., forest and desert, and thus the SAR interferometry in the forest region is made available. Since the penetration property depends on the polarization, the distributed targets in the Amazon cannot be used for the polarimetric calibration source unless the polarization dependence can be clarified. Use of dense forest for the polarimetric calibration was developed and the method clarified the polarization dependence of the penetration property for the uniform forest region. We applied the method and derived the penetration characteristics of the Amazon rainforest.

Keywords *Polarimetric SAR calibration, Polarimetry, penetration*

I. INTRODUCTION

Polarimetric calibration (POLCAL) is essential (but difficult) to make polarimetric SAR data fully usable to derive the geophysical parameters. Other than the representative POLCAL methods using the corner reflector and the depolarized area [1][2], use of forest data was desired because back scattering components are much more than those from the corner reflectors. Luscombe [3] applied C-band SAR data over Amazon to POLCAL, and successfully showed that the scattering matrix depends on the incidence angle. Difficulty of the L band SAR is to overcome the penetration dependence on polarization. Two types of target decomposition theories have been developed, incoherent decomposition (ITD) and the coherent target decomposition (CTD). In ITD method, scattering power at polarization combination is expressed theoretically. We apply the ITD modeled by Freeman and Dursen [4] as one of the assumption for solving the problem. New approach was developed for using the uniform distributed target for calibrating the L-band SAR in a way to parameterizing the polarization dependency of the penetration to the forest as well as the distortion matrices [5]. Using this method, we will analyze the polarization and its penetration to the forest for Amazon uniform target. The calibration of the ALOS PALSAR is well conducted and PALSAR showed the very good stability. Thus, the penetration analysis can be conducted successfully [6], [7].

II. SCATTERING FROM THE FOREST AND ITS MODEL

The measured scattering matrix can be expressed by

$$\begin{pmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{pmatrix} = A\frac{1}{r}e^{\frac{-4\pi r}{\lambda}}\begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix}\begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix}\begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \quad (1)$$

where $\mathbf{Z}_{ij}$ is the measurement matrix, i is the transmission polarization, j is the reception polarization, A is the amplitude, r is the slant range, $\mathbf{S}$ij is the true scattering matrix of the target, $\mathbf{f}_1$ is the channel imbalance of the transmission distortion matrix, $\mathbf{f}_2$ is that for the reception matrix, δ_1 (δ_2) are the cross talks of transmission, and δ_3 (δ_4) are the those for the reception. Here, noise is ignored.

A covariance matrix of the measured scattering matrix

$$\left\langle \mathbf{Z}\cdot\mathbf{Z}^* \right\rangle = \left\langle \begin{matrix} z_{hh}z_{hh}^* & z_{hv}z_{hh}^* & z_{vh}z_{hh}^* & z_{vv}z_{hh}^* \\ z_{hh}z_{hv}^* & z_{hv}z_{hv}^* & z_{vh}z_{hv}^* & z_{vv}z_{hv}^* \\ z_{hh}z_{vh}^* & z_{hv}z_{vh}^* & z_{vh}z_{vh}^* & z_{vv}z_{vh}^* \\ z_{hh}z_{vv}^* & z_{hv}z_{vv}^* & z_{vh}z_{vv}^* & z_{vv}z_{vv}^* \end{matrix} \right\rangle \quad (2)$$

can be linked with the Freeman based scattering model.

Inserting the three scattering components, i.e., volume scattering, double bounce, and surface scattering, and a parameter expressing a complex ratio of double bounce in HH to that in VV, to (1) and screening gives the first order terms. Since (2) is a Hermecian matrix, the independent components are upper triangular, ten components are independent. We need a surface scattering target, i.e., use of corner reflector of finding low vegetation target, to balance number of unknowns and equations. We now collect the first order terms [5] and use the new abbreviations, i.e.,

$$\begin{aligned} &a = z_{hh}z_{hh}^*, \quad b = z_{vv}z_{hh}^*, \quad c = z_{hv}z_{hv}^* \\ &d = z_{hv}z_{vh}^*, \quad e = z_{vh}z_{vh}^*, \quad f = z_{vv}z_{vv}^* \\ &F_i = |f_i| \\ &\theta_i = \arg(f_i), (i = 1,2) \end{aligned} \quad . \quad (3)$$

III. Solution of the Equations

A. Channel imbalances and the other 1st order terms

After subtracting the noises in Eq. (4), we have the following equations

$$
\begin{aligned}
& f_v + |\mathbf{x}|^2 f_d = a' \\
& F_1F_2\left(\frac{f_v}{3} - f_d x\cos\theta_x - f_d x sin\theta_x j\right) \\
& \cdot\{\cos(\theta_1+\theta_2) + j sin(\theta_1+\theta_2)\} = \mathbf{b} \\
& f_v F_1 F_2 = 3d \\
& \theta_2 - \theta_1 = \arg(\mathbf{d}) \\
& \theta_2 + \theta_1 = \arg(\mathbf{b}_s) = \theta_s \\
& (f_v + f_d)F_1^2F_2^2 = f
\end{aligned}
\qquad (4)
$$

(4-5) is valid for the surface scatterers, i.e., corner reflector, sea surface, and lawn. Here the unknowns are, f_v, x, f_d, F_1, F_2, θ_x, θ_1 and θ_2. They can be obtained deterministically from equation (4).

Although the parameters are complex, the parameters on the polarization dependence of penetration is **x**. From after, we mainly focus on this parameter.

IV. Experiment and Discusssion

We selected the dense forest for the penetration analysis. The area is the forest of the Rio Branco, west of the Amazon, where the PALSAR calibration site was established. As seen in the Fig. 1, the area is mixed with the dense forest and the clear-cut regions some of where corner reflectors were deployed.

1) Phase difference of HH/VV and HV/VH

Fig. 2 shows the incidence angle dependence of the phase difference between HH ad VV and HV and VH. Since the polarimetry has a narrow range of the incidence angle, i.e., 3 degrees, the figure does not show the large range of the dependence. HH and VV have almost the same values as HV and VH. This means that the scattering mechanisms of these polarizations are almost the same. The fact that HV = VH means the data are almost calibrated in phase.

2) Penetration parameters

As expected before, the volume scattering components are dominant in the scattering, double bounce of V polarization shares 10% of the total scattering power. X2 stands for the ratio of the double bounce in HH to that in VV. This means the ratio deviates around 30%. Thus the signal penetration of HH and VV are almost the similar but 30% larger than VV. This is slightly different from the story that the HH has much larger penetration than VV. Red dot showing the fv and fd is less than 1.0. This is because that the fd stands for the double bounce of the VV polarization.

3) Power balance of the other components

Although the correlation of <hhhh> is not shown, the second largest power is vvvv and showing 0.8. This means that the power difference of the HH and VV are the component of the double bounce. It may give us the foreseen that the scattering power difference in HH and VV is the double bounce component. The power is only 20% and its is .96 dB. The covariance of the other components is smaller than 0.3 and meaning that these two values are less coherent.

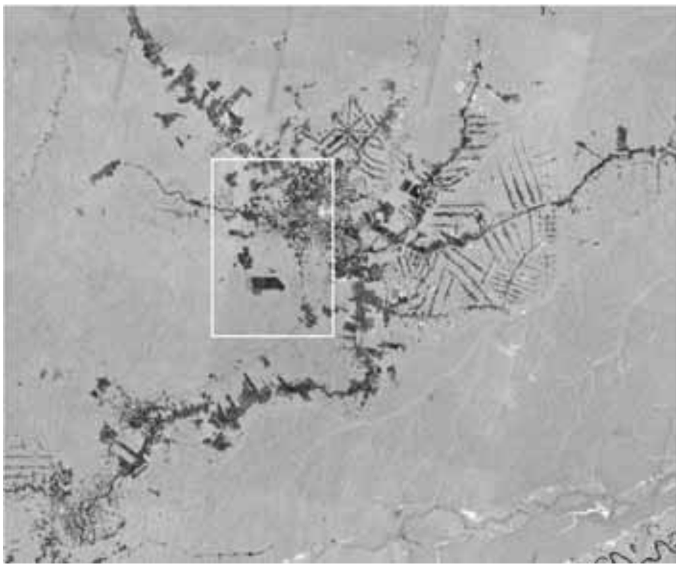

Fig. 1 Amazon Mosaic image using the JERS-1 SAR data. The rectangular area surrounded by a white line is the target area. The dark area is clear-cut area and gray area is fully forested area.

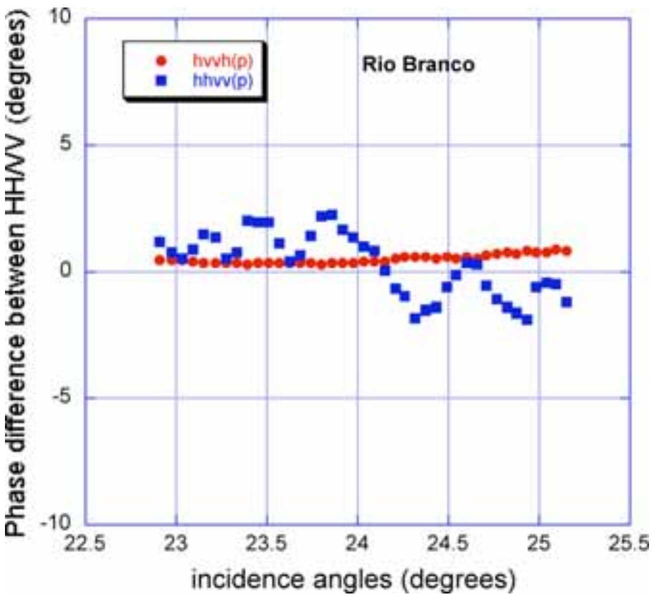

Fig. 2 Incidence angle dependence of HVVH and HHVV.

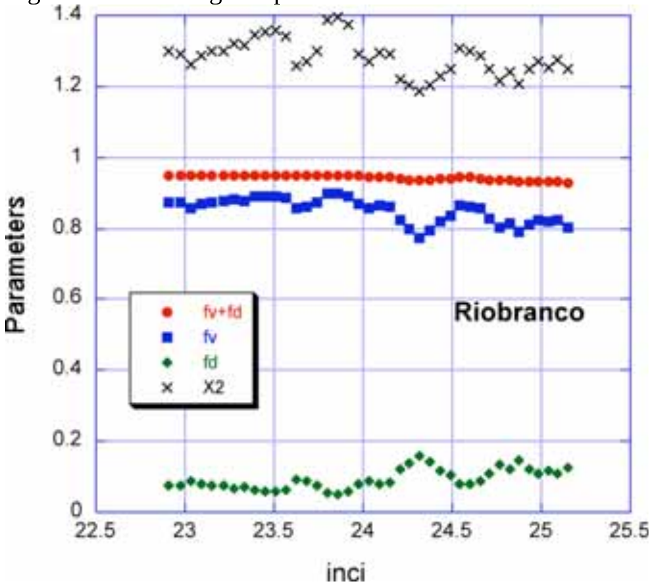

Fig. 3 Incidence angle dependence of the penetration parameters.

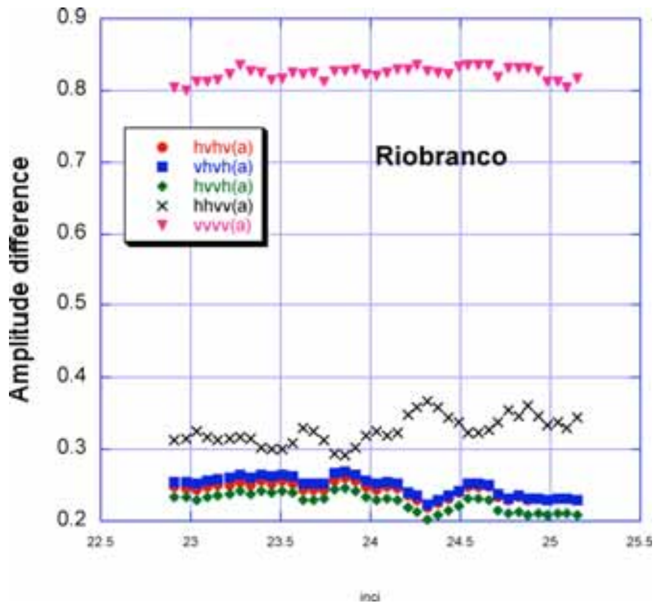

Fig. 4 Incidence angle dependence of the other covariance.

Approach to the InSAR among the difference polarization was examined. From the above interpretation, Hh and VV are quite similar and this means that the coherence of the HH and VV could be similar. We confirmed that this assumption using the Amazon data through the InSAR processing. Fig. 5 shows the combination of the coherence for thee polarimetric combinations, i.e., (HH) means HH and HH InSAR, (VV) means VV-VV InSAR, and so on. From these values, we can say that the (HH) and (VV) are almost the same because the back scattering property are the same. Those for HV and HV are low since these are the diffuse scatteres. Lower three figures show the coherence of the PAULI basis components, i.e., HH+VV, HV+VH, and HH-VV. As shown from these, we can say that HH+VV shows the largest coherence. This is because the PAULI component (First one) contains the largest double bounce than the other two.

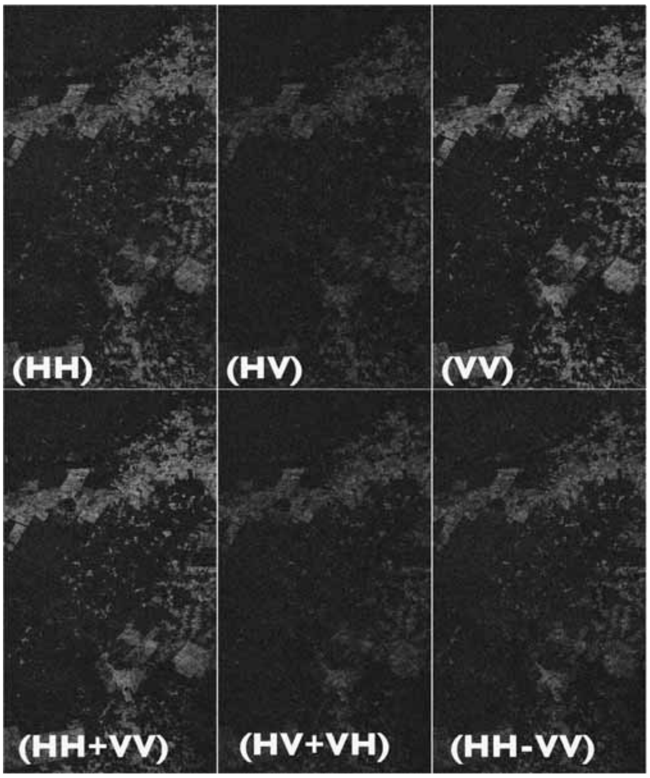

Fig. 5 Coherence of three polarization components.

V. CONCLUSION

We conduct the penetration property of the L band SAR signal to the dense forest. Using the a parameterized calibration algorithm developed by the authors in 2002 and the dense forest in the Amazon, we can conclude that the HH and VV are almost the same scattering property and thus the interferometric coherence is almost the same of them. BY the literature in 1990, it was written that HH has largest penetration and HV and VV are the same characteristics of less penetration. But the measurement and theory showed that HH and VV have the similarity and they have a good similarity in coherence. The application of the Pauli basis is one of the optimization phases.

ACKNOWLEDGMENT

The authors thank to the engineering staffs of the remote sensing technology center of Japan for processing of the Data.

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