Polarimetric Parameters Extraction to Understand the Scattering Behavior of NASA/JPL AIRSAR Data

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Abstract:

When a SAR system operates in a full-polarimetic mode, the amount of the information one can extract is so complex that the effective presentation of the information is important. However, the information acquired from the polarimetric SAR data is often difficult to interpret by itself, because it is consisted of both the amplitude information and the phase information. Polarimetric parameters are the good way of representing the polarimetric SAR information in a quantitative manner. Also they can characterize the scattering behavior of the ground scatterer. In this research, extraction of polarimetric parameters, evaluation and interpretation of the scattering behavior of the ground with respect to polarimetric SAR signal are carried out. Using the NASA/JPL AIRSAR data, we estimated the polarimetric parameters and compared them in terms of the ground features. In general, extracted parameters well represent the characteristics of the different features on the ground.

Key words: Polarimetric SAR, Polarimetric parameters, NASA/JPL AIRSAR, Scattering Behavior

I. Introduction

Although the conventional space-borne Synthetic Aperture Radar (SAR) has the advantage of all weather condition, 24-hour operation capability, the amount of information is relatively restricted because it operates at a single polarization. In contrast, a polarimteric SAR operates with multi-polarization mode and not only the amplitude but also phase information can be obtained. For both *quantitative and qualitative representation* of the scattering information, the extraction of polarimetric parameters from the polarimetric SAR data is crucial. Boerner et al. [1] and Ulaby et al. [8] first evaluated the meaning of polarization phase difference and McNairn [6] clarified the effect of soil and crop residue characteristics using polarimetric parameters.

Polarimetric parameters provide us with the dominant scattering behavior present in the scattering scene. Furthermore, this approach can be applied to any polarimetric SAR data processing and the interpretation. Also, this information can be as *a prior* knowledge in the data processing in other related study, such as the land cover classification, soil moisture and surface roughness estimation.

In this study, we have calculated polarimetric parameters from the NASA/JPL AIRSAR data that were collected during PACRIM-II Korea Campaign. Each parameter is extracted from *Regions of Interest* (ROIs) based on terrain objects such as forest areas and the river. Extracted parameters are interpreted to explain the scattering behavior of polarimetric SAR targets.

The paper is structured as follows. In Section II, the theoretical background for the polarimetric parameters used in the analysis will be reviewed. In Section III, the polarimetric SAR data and the study area for this study is outlined. Then, the results of evaluating the variability of the polarimetric parameters and the interpretation of the results will be presented. Finally, the summary and the discussion of the results will be followed in Section VI.

II. Theoretical Background of Polarimetric Parameters

A. Covariance Matrix and Coherency Matrix

Polarimetric scattering information is represented by two different matrices; the covariance matrix and the coherency matrix. The covariance matrix is based on the lexicographic feature vector $\vec{k}_L$ and is defined as (1), where $\vec{k}_L$ means $\vec{k}_L = [S_{HH} \quad \sqrt{2}S_{HV} \quad S_{VV}]^T$ (2) and * and + denotes the complex conjugate and complex conjugate transpose, respectively. Moreover, the coherency matrix is based on the Pauli feature vector $\vec{k}_P$ and is defined as (3), where $\vec{k}_P$ is

$$\vec{k}_P = \frac{1}{\sqrt{2}}[S_{HH} + S_{VV} \quad S_{HH} - S_{VV} \quad 2S_{HV}]^T. \quad (4)$$

The basic equations (2) and (4) are defined for the monostatic backscattering case and these representations are based on the linear combinations of the cross-products.

B. Backscattering Coefficient (σ^0)

Backscattering coefficient (σ^0) is a conventional representation of the strength of a radar signal backscattering from a ground target and is defined as followed;

$$\sigma^0_{HH} = \langle S_{HH} S^*_{HH} \rangle_N \quad (5)$$

$$\sigma^0_{VV} = \langle S_{VV} S^*_{VV} \rangle_N \quad (6)$$

$$\sigma^0_{HV} = \langle S_{HV} S^*_{HV} \rangle_N \quad (7)$$

$$\sigma^0_{VH} = \langle S_{VH} S^*_{VH} \rangle_N \quad (8)$$

$$\sigma^0_{HV} = \frac{\sigma^0_{HV} + \sigma^0_{VH}}{2}. \quad (9)$$

It is a normalized backscattering cross section and expressed in dB. The subscript *vh* means the vertical polarization return when the transmitted wave is horizontally polarized and $\langle \mathrm{K} \rangle$ denotes an ensemble average.

C. Polarization Ratio

Using the backscattering coefficient, polarization ratio can be estimated. r_{co} is the co-polarization ratio and r_{cross} is the cross-polarization ratio. r_{co} accentuates the differences between HH and VV scattering behavior and r_{cross} is especially sensitive to volume scattering events. r_{co} and r_{cross} are estimated from (10) and (11)

$$r_{co} = \frac{\sigma^0_{VV}}{\sigma^0_{HH}} \quad (10)$$

$$r_{cross} = \frac{\sigma^0_{HV}}{\sigma^0_{HH}}. \quad (11)$$

D. Polarization Phase Difference (PPD)

Different electrical path lengths between HH- and VV-polarized waves or the time delay between the H and V signals cause Polarization Phase Difference (PPD). The co-polarized phase difference is calculated from (12) and

$$[C_L] = \vec{k}_L \cdot \vec{k}_L^+ = \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S^*_{HV} & S_{HH}S^*_{VV} \\ \sqrt{2}S_{HV}S^*_{HH} & \sqrt{2}|S_{HV}|^2 & \sqrt{2}S_{HV}S^*_{VV} \\ S_{VV}S^*_{HH} & \sqrt{2}S_{VV}S^*_{HV} & |S_{VV}|^2 \end{bmatrix} \quad (1)$$

$$[C_P] = \vec{k}_P \cdot \vec{k}_P^+ = \frac{1}{2}\begin{bmatrix} |S_{HH}+S_{VV}|^2 & (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* & 2(S_{HH}+S_{VV})S^*_{HV} \\ (S_{HH}-S_{VV})(S_{HH}+S_{VV})^* & |S_{HH}-S_{VV}|^2 & 2(S_{HH}-S_{VV})S^*_{HV} \\ 2S_{HV}(S_{HH}+S_{VV})^* & 2S_{HV}(S_{HH}-S_{VV})^* & 4|S_{HV}|^2 \end{bmatrix} \quad (3)$$

cross-polarized phase difference is calculated from (13).

$$\varphi_{HH-VV} = \left\langle \tan^{-1}\left(\frac{\Im(S_{HH})}{\Re(S_{HH})}\right) - \tan^{-1}\left(\frac{\Im(S_{VV})}{\Re(S_{VV})}\right)\right\rangle \quad (12)$$

$$\varphi_{HH-HV} = \left\langle \tan^{-1}\left(\frac{\Im(S_{HH})}{\Re(S_{HH})}\right) - \tan^{-1}\left(\frac{\Im(S_{HV})}{\Re(S_{HV})}\right)\right\rangle \quad (13)$$

In equation (12) and (13), $\Re$ denotes the real part of a complex number, $\Im$ denotes its imaginary part.

According to Ulaby et al. [8], the phases of HH and VV polarization plays important role in characterizing the scattering target roughness.

E. Correlation coefficient

Correlation coefficient is a statistical operation of the polarimetric SAR data and it represents the amount of the correlated information within the dataset. If the value is high, two datasets have similar information and the low value represents two datasets are independently correlated. The correlation between HH and VV polarization may written as

$$\rho_{HHVV} = \frac{\left|\langle S_{HH}S_{VV}\rangle\right|}{\sqrt{\langle S_{HH}S^{*}_{HH}\rangle\langle S_{VV}S^{*}_{VV}\rangle}}. \quad (14)$$

For surface scattering, the high ρ_{HHVV} term dominates due to the large component of polarized return from surface scattering. In contrast, low ρ_{HHVV} is notable when the large component of unpolarized return is dominant from multiple scattering in the forest.

III. Application and Results

NASA/JPL airborne SAR (AIRSAR) L-band (1.25GHz/24 cm wavelength) imagery, which was acquired during PACRIM-2000 Korea campaign on September 30, 2000, was used for estimating the above polarimetric parameters and evaluating scattering behavior.

The AIRSAR data of Kangdong-myon, Kyungsang Province [Figure 1.] was selected for the study area. The

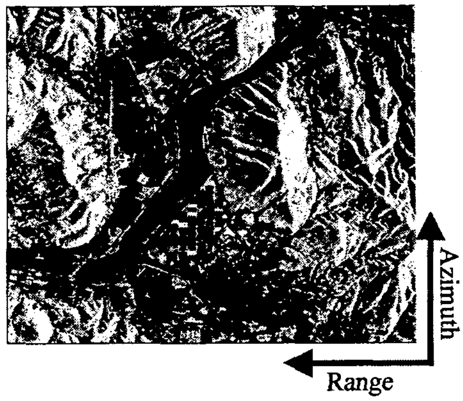

Figure 1. The L-band AIRSAR span image of the covariance matrix over an study area.

dataset covers an area of 2000*1700 pixels and contains various land cover types such as river, rice field and forest.

The original data was in a compressed Stokes matrix format and is 5-look averaged data. As the preprocessing step, the data was decompressed into the Stokes matrix and the elements of the covariance matrix and the coherency matrix was derived. Furthermore, the polarimetry preserving speckle filter [Lee et al., 1999] was applied for speckle reduction.

To evaluate and interpret the polarimetric parameters, *Regions of Interest* (ROIs) were drawn over an area with both river and forest. Most ROIs were comprised of about 200 pixels and we selected 3 sites for the ROIs for both types of ground targets, respectively. Since most of the study area is composed of rice fields, farms, peach orchards, vinyl houses and the bare soil, many ambiguities are found in defining the characteristics of the ground surface without good-quality ground truth data. Therefore, the evaluation and the interpretation of those parameters are compared in terms of the different scattering behaviors of the river and the forest.

The relative frequency of the backscattering coefficient of two different targets is shown in Figure 2. The VV-polarized backscattering coefficient of the river is greater than the HH-polarized backscattering coefficient.

On the other hand, the values of HH- polarized and

Table 1. The quantitative comparisons of polarimetric parameters between dominant scattering mechanisms of the river and the forest.

Figure\Parameter		Co-polarization Ratio	Cross-polarization Ratio	Co-polarized Phase Difference	Co-polarized Correlation Coefficient
River	Mean	1.0628	0.8814	0.0338	1.0445
	STD	0.0475	0.0462	0.5013	0.1880
	Max	1.1738	0.9780	1.2550	1.762
	Min	0.9221	0.07277	-1.0621	0.6593
Forest	Mean	1.0120	1.0728	-2.3908	0.1351
	STD	0.0375	0.0882	70.2008	0.0263
	Max	1.1522	1.3185	176.5953	0.2184
	Min	0.9304	0.8687	-172.1958	0.0514

VV-polarized backscattering coefficient over forest areas have almost same distribution. It explains that the river is represented by Bragg surface scattering characteristics (i.e., $|S_{HH}| < |S_{VV}|$ [Elachi, 1987]).

Table 1. summarizes the results of the co-polarization ratio, the cross-polarization ratio, the co-polarized phase difference and the co-polarized correlation coefficient. It compares the polarimetric parameters between dominant scattering behaviors of the river and the forest in a quantitative way. As shown in the table, the river shows high co-polarization ratio, high co-polarized correlation coefficient and the co-polarized phase difference is centered at 0°.

In a different manner, the forest shows high cross-polarization ratio, low co-polarized correlation coefficient and the co-polarized phase difference of uniform distribution over ±180°.

This difference may be explained by the difference scattering mechanisms over the river and the forest. Ulaby et al. [8] reported in their paper that different surface roughness cause different results of this types of experiments. Over forest areas, phase differences show dramatically big change from one scatterer to the next because of the dominant multiple scattering by the target. Significant difference between the minimum value and the maximum value of the co-polarized phase difference and low correlation coefficient also support this phenomenon. Another characteristic of the forest is

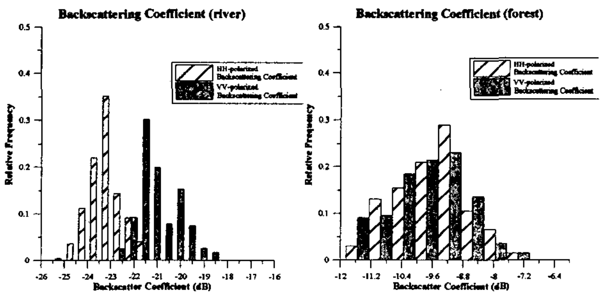

Figure 2. Comparisons between the backscattering coefficient of the river and the backscattering coefficient over forest areas.

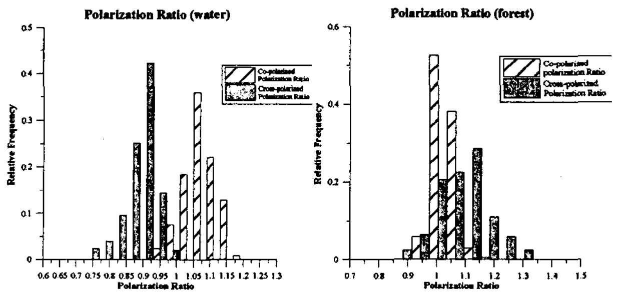

Figure 3. Comparisions between the polarization ratio of the river and the polarization over forest areas.

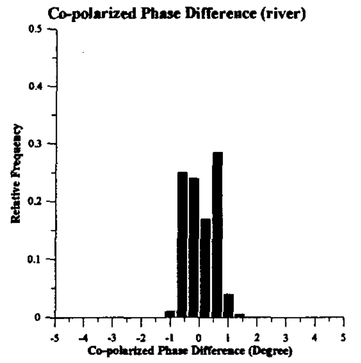

Figure 4. Co-polarized Phase Difference of the river.

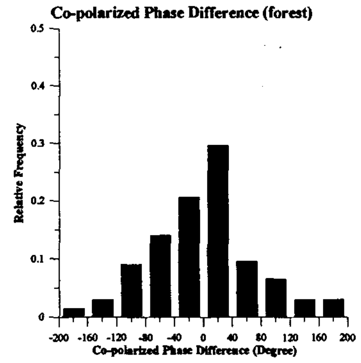

Figure 5. Co-polarized Phase Difference over forest areas.

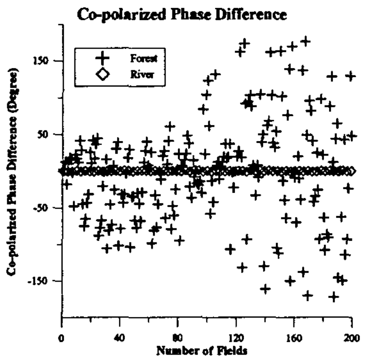

Figure 6. Co-polarized Phase Differences of the river and forest areas.

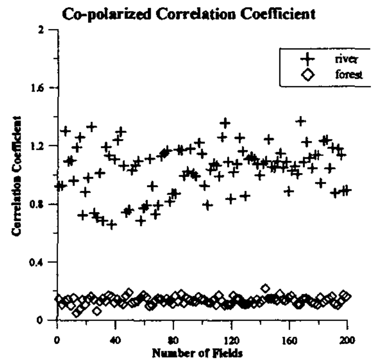

Figure 7. Co-polarized Correlation Coefficient of the river and forest areas.

shown in the polarization ratio. High cross-polarization ratio means that HV-polarization is dominant in the forest areas. Multiple interaction within the rough surface at the forest shows the characteristic, which are explained above.

Figure 3 shows the comparison of the relative frequency of co-polarized polarization ratio over the river and forest areas. Moreover, Figure 4 and 5 show the co-polarized phase differences of two features and the co-polarized correlation coefficient with respect to the number of fields, respectively.

VI. Conclusions

In this study, we studied the theoretical background of polarimetric parameters and applied the concept of the results to the NASA/JPL AIRSAR dataset. Interpretation of the results with respect to the computed parameters was also carried out. Two different ground features, the river and the forest, are selected in this experiment. As we expected, two features show different backscattering characteristics and different parameters.

As the river represents Bragg surface scattering characteristics and the forest shows multiple scattering events within the target, each targets show significantly different properties of the polarization parameters. However, all the polarization parameters in each target are strongly correlated each other. Especially the surface roughness is an important element to characterize the polarization parameters. In addition, this experiment has proved that the VV-polarization is strong in the river and the HV-polarization is dominant over the forest areas.

Another point which should be mentioned is the phase information. Additional phase information provided by the polarimetric SAR data is suitable for characterizing additional features on the ground.

Polarimetric parameters are the effective measures of polarimetric SAR data as Zyl J. J. et al [10] emphasized the importance of polarimetric parameters in their paper. Also, it provides us with a quick view of dominant scattering patterns of a polarimetric SAR image. The results studied in this study play an important role in providing us with better understanding of the polarimetric SAR data.

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References

[1] Boerner W. M., Foo B. Y., and Eom H. J., 1987, Interpretation of the Polarimetric Co-polarization Phase Term in Radar Images Obtained with the JPL Airborne L-band SAR System, *IEEE Trans. Geosci. Remote Sensing*, Vol. GE-25, pp. 77-82

[2] Elachi C, "Introduction to the Physics and Techniques of Remote Sensing", John Wiley and Sons Inc., New York, 1987

[3] Henderson F. M., and Lewis A. J., 1998, *Principles and Applications of Imaging Radar: Manual of Remote Sensing*, New York, John Wiley & Sons, Inc.

[4] Kim Y. J., Zyl J. J., 2000, On the Relationship between Polarimetric Parameters, *Proceeding of IGARSS 2000*, Vol. 3, pp. 1298-1300

[5] Lee J. S., Grunes M. R., and Grandi G. De., 1999, Polarimetric SAR Speckle Filtering and Its Implication for Classification, *IEEE Trans. Geosci. Remote Sensing*, Vol. 37, pp. 2363-2373

[6] McNairn H., Duguay C., Brisco B., and Pultz T. J., 2002, The effect of soil and crop residue characteristics on polarimetric radar response, *Remote Sensing of Environment*, Vol. 80, pp. 308-320

[7] Sang-Eun Park, 2002, Polarimetric Target Decomposition and Physical Interpretation of NASA/JPL AIRSAR Data, M.S. Thesis

[8] Ulaby F. T., Held D., Dobson M. C., Mcdonald K. C., and Thomas B. A., 1987, Relating Polarization Phase Difference of SAR Signals to Scene Properties, *IEEE Trans. Geosci. Remote Sensing*, Vol. GE-25, pp. 83-92

[9] Zebker H. A., and Zyl J. J., 1991, Imaging Radar Polarimetry: A Review, *Proceeding of the IEEE*, Vol. 79, pp. 1583-1606

[10] Zyl J. J., 1989, Unsupervised Classification of Scattering Behavior Using Radar Polarimetry Data, *IEEE Trans. Geosci. Remote Sensing*, Vol. 27, pp. 36-45