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APPLICATION OF SYMMETRY PROPERTIES TO POLARIMETRIC REMOTE SENSING WITH JPL AIRSAR DATA

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1. INTRODUCTION

Based on symmetry properties, polarimetric remote sensing of geophysical media is studied in this paper. From the viewpoint of symmetry groups, media with reflection, rotation, azimuthal, and centrical symmetries are considered. The symmetries impose relations among polarimetric scattering coefficients, which are valid to all scattering mechanisms in the symmetrical configurations. Various orientation distributions of non-spherical scatterers can be identified from the scattering coefficients by a comparison with the symmetry calculations. Experimental observations are then analyzed for many geophysical scenes acquired with the Jet Propulsion Laboratory (JPL) airborne polarimetric SAR at microwave frequencies over sea ice and vegetation. Polarimetric characteristics of different ice types are compared with symmetry behaviors. The polarimetric response of a tropical rain forest reveals characteristics close to the centrical symmetry properties, which can be used as a distributed target to relatively calibrate polarimetric radars without any deployment of man-made calibration targets.

2. SYMMETRY PROPERTIES

Relations among polarimetric backscattering coefficients have been derived *(Nghiem et al. 1992)* for both reciprocal and non-reciprocal geophysical media with reflection, rotation, azimuthal, and centrical symmetries. The corresponding symmetry groups can be constructed from three fundamental operations: mirror reflection, axial rotation, and linear translation *(Hamermesh, 1972)*. The derivations are based on the invariance of the scattering coefficients under the symmetry transformations and applicable to all scattering mechanisms in the symmetrical configurations. These symmetries impose on the scattering coefficients a number of equations, which reduce the number of independent parameters in the covariance or Mueller matrix as summarized in Table 1. Centrical symmetry inherits azimuthal symmetry characteristics at all incident angles.

Table 1: Number of Independent Parameters in Covariance Matrix or Mueller Matrix

	Non-reciprocal	Reciprocal
No symmetry	16	9
Reflection Symmetry	8	5
Rotation Symmetry	6	3
Azimuthal Symmetry	3	2

3. ORIENTATION DISTRIBUTIONS

Non-spherical scatterers can take on needle-like shape or disc-like shape. The distribution of scatterer orientations is dependent on the scatterer species, environmental effects, and physiologic conditions. For species with no azimuthal preference such as leaves in trees, several distributions have been reported including spherical, uniform, planophile, plagiothile, erectophile, or extremophile distributions *(Goel and Strebel 1984)*. Probability density functions of orientations are given in terms of inclination angles θ from 0 to 90°. These orientation distributions have certain symmetries which affect polarimetric scattering coefficients. In each case of the distributions, the ratio $\epsilon = \sigma_{hv}/\sigma_{hh}$ is calculated under independent scattering assumption from a theoretical model *(Tsang et al. 1985)* and then compared with the quantity $\epsilon_0 = (1 - |\rho|)/2$ as suggested by the centrical symmetry where ρ is the correlation coefficient between the hh and vv returns. For centrical symmetry, $\epsilon = \epsilon_0$ at arbitrary incident angles. Referred to this symmetry, the deviation of ϵ from ϵ_0 therefore indicates how the scatterers are structured. The results for the aforementioned orientation distributions show that, in general, ϵ/ϵ_0 is larger for more vertical orientation regardless of scatterer shape. For spherical distribution, $\epsilon/\epsilon_0 = 1$ manifests the centrical symmetry.

4. APPLICATIONS TO JPL SAR DATA

In this section, an analysis based on the symmetry is applied to JPL SAR data for sea ice and vegetation. Polarimetric SAR scenes of sea ice in the Beaufort sea were acquired during March 1988 in a series of NASA DC-8 airborne flights *(Cavalieri, 1988)*. Weather and sea ice characteristic data were collected continuously during March at the Applied Physics Laboratory's drifting ice station (APLIS'88) located north-east of Prudhoe Bay, Alaska. Meteorological reports and ice measurements were recorded *(Wen et al. 1989)*. Sea ice conditions consist of a transition from the extensive coastal first-year ice region to multi-year ice pack to the north. Air temperatures varied between −12° and −18° on March 11 and colder (below −25°) during an earlier period in March. First-year ice in the vicinity of the ice station was 1.5-m to 2.4-m thick and covered by a snow layer of 15.0-cm average depth. Multi-year ice was also covered by snow and hummocked up to 6.0-m height. Ice divergence occurring close to the period of data collection was experienced on March 10 when high ice drift velocities were recorded. Sea ice scenes on March 11 reveal images of new cracks and leads created by the divergent ice motion. Leads rapidly frozen under the cold condition became new thin ice formations. The results indicate that first-year ice signatures quite depart from centrical symmetry behavior as compared to multi-year ice. Structurally, first-year ice has a preferential vertical orientation of brine inclusions *(Weeks and Ackley 1982)* while scatterers in multi-year ice are more randomly distributed. Comparisons of the measured values for the polarimetric returns from sea ice with the symmetry calculations reveal the structural information which helps identify the ice types.

For vegetation, SAR scenes acquired over various forest types, including pine, mixed, and tropical rain forests, are considered. In the 1989 MAESTRO-1 Campaign, an experiment was conducted in Les Landes pine forest, south-west France, where the JPL SAR data were collected to relate SAR measurements and forest biophysical parameters *(Le Toan et al. 1991)*. This scene consists of maritime pine trees at different ages from young to mature stages (more than 40 years). Also in June 1989, SAR images were obtained for Mt. Shasta in northern California. Forest areas in Mt. Shasta are dominated by ponderosa pine and white fir species

(Zebker et al. 1991). In Belize, a tropical rain forest was imaged. The forest in this scene has dense canopy and understory with various tropical species. At C-band frequency, the relation $\epsilon = \epsilon_0$, small phase of ρ, and the balance between hh and vv returns are well satisfied at all incident angle, especially for the Belize forest. This can be explained based on the symmetry properties. Azimuthal symmetry is often observed on leaves' orientation in forest canopies. For elevation orientations of vegetation elements, the distributions have been discussed in the last section. Foliage composed of leaves with spherical orientation distribution has centrical symmetry which requires the polarimetric scattering coefficients to satisfy $\epsilon = \epsilon_0$, $\text{Im}\,\rho = 0$, and $\gamma = \sigma_{vv}/\sigma_{hh} = 1$ at arbitrary incident angles. These relations are the direct consequence of the centrical symmetry due to the random orientation of leaves (spherical distribution). When the frequency is low such that the electromagnetic wave can penetrate through the foliage canopy, the centrical symmetry can be destroyed due to the horizontal branches or other structures of tree elements. From natural distributed targets, reflection together with centrical symmetries will allow the full relative calibration, including the cross talk and the channel imbalance, to all incident angles without the deployment of man-made calibration targets.

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