DENSE MEDIUM RADIATIVE TRANSFER THEORY IN POLARIMETRIC AND MICROWAVE REMOTE SENSING FOR MEDIUM WITH MULTIPLE SPECIES OF PARTICLES

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Generally, the geophysical terrain such as snow, ice-covered land or water consists of densely distributed particles of different species. The different species refers to the fact that particles can be of different shapes, sizes, and permittivities. Electromagnetic waves propagation and scattering in such a medium are governed by the Dyson's equation for the first moment of the field and the Bethe–Salpeter equation for the second moment of the field. To study the volume scattering effects, a set of dense medium radiative transfer equations has been derived from the analytic wave theory [1,2]. The derivation is based on the quasicrystalline approximation with coherent potential for the first moment and the ladder approximation modified with pair distribution functions on the second moment. The energy conservation is satisfied exactly under the combination of these two approximations.

In this theory, the extinction rate, the albedo, and the phase matrices are expressed in terms of the physical parameters of the medium such as sizes, concentrations and dielectric properties of the particles that constitute the medium. The dense medium radiative transfer theory takes into account (i) the correlated scattering between different particles, (ii) the pair distribution functions of particles positions, and (iii) the effective propagation constant of a dense medium. The dense medium radiative transfer equations also preserve the merits of the conventional radiative transfer equations that (i) multiple scattering of the incoherent intensities are included (ii) energy conservation and reciprocity are obeyed (iii) the form of the improved equations remains the same as the conventional one so that numerical solutions can be calculated in the same manner.

The dense medium radiative transfer theory has been used to explain the phenomena observed in a controlled laboratory experiment [3,4] (Figure 1). The experimental data shows that, in a dense medium with small particles, the bistatic scattered intensity first increases with the volume fraction of particles until a maximum is reached, and then decreases as the volume fraction further increases. Comparing with both the conventional and dense medium radiative transfer theories indicates that the results of dense medium transfer theory contain these experimental features, while the results of conventional radiative theory predict a monotonic increase with particle concentration. They have been applied to study the passive microwave remote sensing and the multiple scattering of electromagnetic waves in a slab containing densely distributed particles [4,5]. The theoretical results are used to interpret backscattering coefficient measurements of snow and the polarimetric signatures are also calculated.

Recently the theory has been extended to treat media with multiple species of particles

[6,7]. The pair distribution functions for a multi-species dense medium can be calculated in terms of physical parameters of the medium. Figure 2 illustrates the pair distribution functions for a medium with particles of three different sizes. The particles in natural geophysical terrain usually follow a size distribution, very often the ground truth data is given in terms of a histogram of particle size distribution. Therefore, it is important to have a dense medium model with size distribution. The continuous size distribution can be discretized to incorporate the multiple species theory. Dense medium radiative transfer theory is applied to the polarimetric signature for a slab medium with modified gamma size distributions. Figures 3 and 4 illustrate the co-polarization signature and the degree of polarization as functions of orientation and ellipticity angles of the polarization of incident wave. It is interesting to note that the multiple scattering effects can significantly decrease the degree of polarization so that the backscattered signal is no longer completely polarized. The calculations also show that there is a pedestal in the co-polarization return which has been observed in polarimetric SAR data [8].

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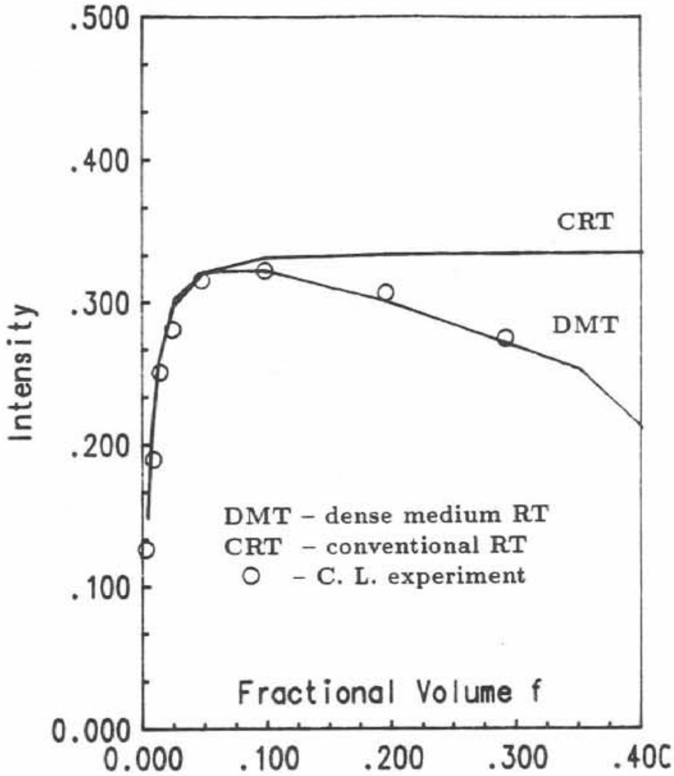

Figure 1. Theoretical results of normalized bistatic intensities as a function of fractional volume f are compared with controlled laboratory experiment. DRT and CRT denote the results of dense medium radiative transfer theory and conventional radiative transfer theory respectively, circles represent the experimental data.

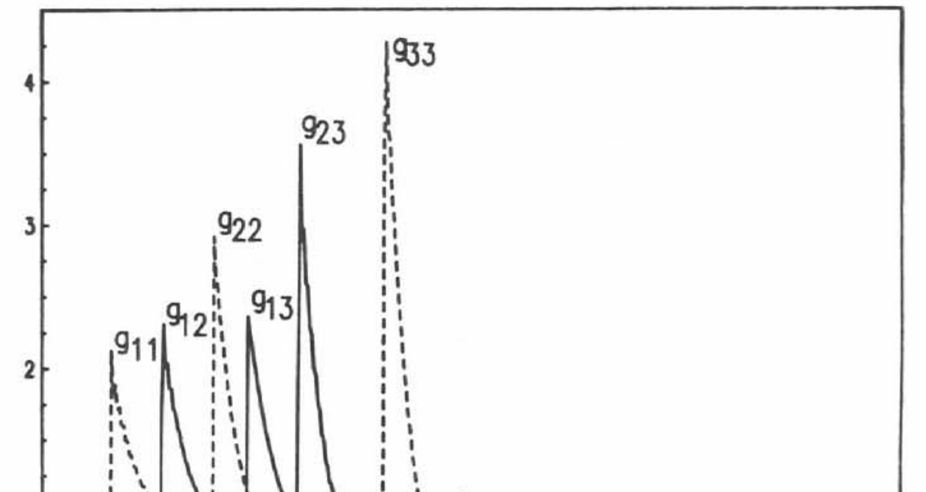

Figure 2. Pair distribution functions g_{ij} for a medium with spherical particles of three different sizes.

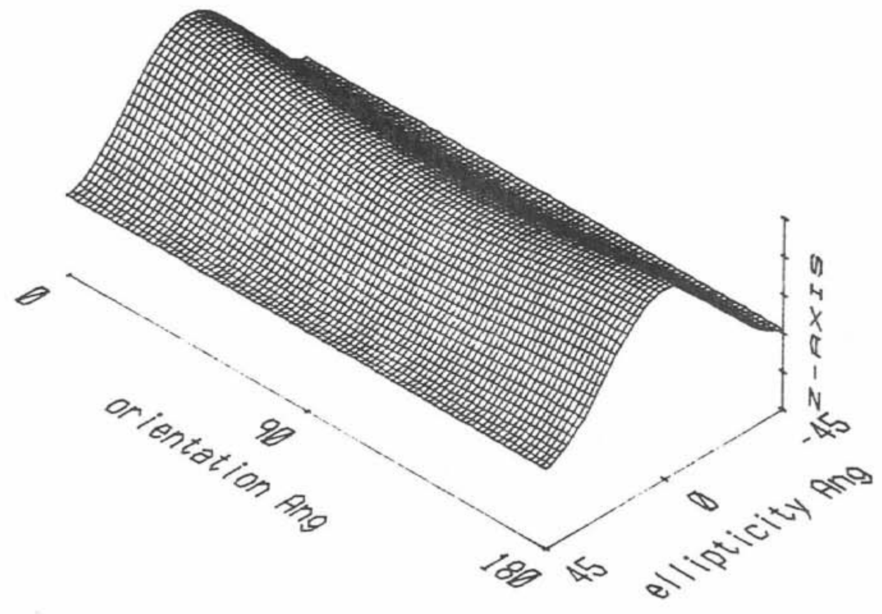

Figure 3. Co-polarization signatures of multiple scattering as functions of orientation and ellipticity angles of the incident polarized wave at 40^o and frequency $17GHz$.

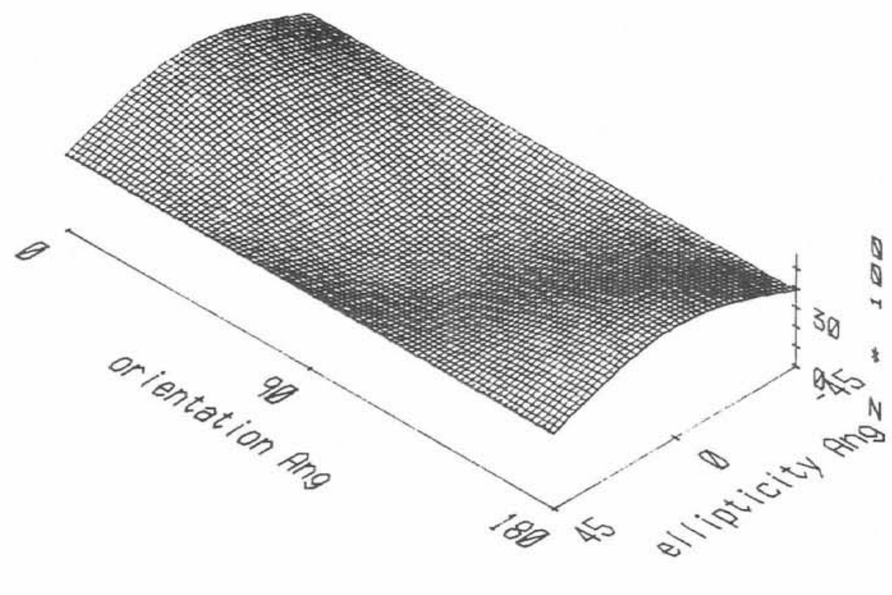

Figure 4. The degree of polarization for multiple scattering as functions of orientation and ellipticity angles of the incident polarized wave at 40^o and frequency $17GHz$.