Modeling active microwave remote sensing of multilayer dry snow using dense media radiative transfer theory

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Abstract: The dense media radiative transfer (DMRT) theory has been applied in studying both passive and active microwave remote sensing signatures [1], [2]. Because snow is a dense media in which the ice particles lie in close proximity of each other, the particles do not scatter independently. The DMRT theory takes into account the collective scattering effects of the particles by including the wave interactions among the particles. In the DMRT theory, quasi-crystalline approximation (QCA) can be used in the Dyson equation for the coherent field, and the correlated ladder approximation is used for the Bethe Salpeter equation for the incoherent field [2], [3]. The pair distribution functions of the Percus-Yevick approximations are used to describe relative positions and the adhesion of ice grains to form aggregates [4]. The QCA/ DMRT model gives different results when compared to classical independently scattering theory: 1) The extinction saturates at high fractional volume, 2) The scattering coefficient has a frequency dependence that is weaker than the fourth power, 3) The mean cosine of the phase matrix is not zero, and 4) The phase matrix shows more forward scattering and has a larger mean cosine than the classical Mie scattering theory of the same grain size. The same set of DMRT equations are used for both active and passive remote sensing in QCA/DMRT model. In a previous paper [1], we consider a single layer of homogeneous terrestrial snowpack in active remote sensing. In this paper, we use QCA/DMRT with sticky particle Mie scattering model to study the backscattering coefficients of multiple layers of snow. The multilayers are a result of varying grain size and snow densities from layer to layer as a result of the accumulation process in the hydrological model. In this paper, we also use Numerical Maxwell model to calculate the phase matrix of dense media.

To solve the dense media radiative transfer equation for layered snow, we decompose the specific intensity in the equation as a sum of the reduced intensity and diffuse intensity. The reduced intensities in every layer can be solved analytically. The diffuse intensities are decomposed into Fourier series in the azimuthal direction, and then using the eigen-quadrature approach solves every harmonic. We consider full multiple scattering effects with 16 Gaussian quadrature angles. The same 16 angles are used in every layer. Because the intensities satisfy Snell's law at boundaries:

they deviate the original Gaussian quadrature angles after refraction, we use a cubic spline interpolation to interpolate refractive intensities at Gaussian quadrature angles from those deviated intensities.

We illustrate the model simulation of backscattering coefficients at 10GHz and 17GHz for different multi-layer snowpack structures. The snow thickness, densities and grain sizes vary among different layers.

We compare the backscattering coefficients model predictions with ground-based Ku band (15.25-15.75 GHz) polarimetric scatterometry observations carried out at Fraser experimental forest headquarters, Colorado, USA, in Feb. and Mar. 2003. We find that the results from QCA/DMRT model are in good agreements with the co-polarization of experimental observations. However, the QCA/DMRT model underestimates the cross-polarization. This is because the cross-polarization of the phase matrix of spheres predicted by QCA/DMRT theory is zero. The analytical theory of QCA uses the single scattering of the coherent field to get the incoherent field. Since the coherent field has no cross polarization, the single scattering of the coherent field also has no cross polarization. In this paper, we also apply the 3-dimensional numerical solutions of Maxwell equations [NMM3D], which predicts non-zero cross-polarization in the phase matrix for densely packed spheres [5]. The simulated NMM3D phase matrix is used in the DMRT equations. Results of the cross polarization backscattering based on this approach are studied.

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Key words: snow, active microwave remote sensing, dense media, multiple scattering, DMRT, numerical solutions of Maxwell equations

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