Modeling Snowpack Scattering and Emission Using a Fully Coherent Model

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Snow is a dense volumetric random media comprised of ice grains densely packed together. These ice grains are on the order of tenths of wavelengths in the microwave regime and actively interacts with microwave. These interactions create microwave signatures that can be utilized to retrieve snowpack parameters from microwave measurements. The traditional approach to deal with snow scattering is to involve a partially coherent approach of dense media radiative transfer (DMRT). In DMRT, Maxwell's equations are solved over snow blocks of several wavelengths to derive the effective permittivity, the extinction coefficient and the phase matrix of the snow volume. These effective parameters homogenize the snowpack and include coherent wave interactions within several wavelengths. In the second step, these parameters are substituted into the radiative transfer equation, which accounts for incoherent far field interactions and volume / surface interactions. Such theory has proved to be useful when only the radiated or scattered power from the snowpack is of interest, and when the snowpack is thick and homogeneous. However, the absolute phase information of the electric field is lost in the radiative transfer theory, and this greatly hampers the theory in characterizing the coherent signatures of the snowpack. Moreover, the theory fails to predict backscattering enhancements unless cyclical corrections are explicitly imposed accounting coherent far field interactions; it also fails to predict coherent thin layer effects from coherent volume / surface scattering interactions.

In this paper, we summarize the fundamentally new approach that we recently developed by solving Maxwell's equations directly over the entire snowpack including a dielectric half-space. No radiative transfer approximation is involved at all in this approach. The solution of Maxwell's equation includes all the fully coherent wave interactions entirely, and naturally captures the backscattering enhancement effects and coherent layer effects. The scattering matrices of the snowpack, including both amplitude and phase, are directly computed. These complex scattering amplitudes can be further used to calculate the coherency matrices and speckle statistics of the snowpack, as well as to formulate microwave images of the snowpack and to estimate vertical structures of the snowpack.

We solve the volume integral equation over a finite volume of snowpack as represented by bicontinuous medium. The half space dyadic Green's function is used as the propagator, accounting for coherent volume/volume and volume/surface interactions. Periodic boundary conditions are applied in the two horizontal directions to simulate an infinite layer of snowpack. The snowpack is impinged by an incoming plane wave. The application of the periodic boundary condition not only removes the edge refraction effects, but also allows to derive the brightness temperatures of the snowpack from the reciprocity principle and the fluctuation dissipation theorem. Excellent energy conservation is achieved. Discrete dipole approximation (DDA) is used to solve the volume integral equation, where parallel fast Fourier transform (FFT) techniques are used to accelerate the matrix-vector multiplications. The distinct results of the full wave simulation are illustrated in this paper and compared to the results of DMRT under various snowpack and bottom half-space configurations.