Full Wave Simulations of Vegetation and Forest Effects in Microwave Remote Sensing of Soil Moisture (TOWNER_13)

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A large fraction of the soil is covered by vegetation/forests. Thus, understanding the effects of vegetation/forests on microwaves is important for active and passive remote sensing of soil moisture: in particular, how much electromagnetic energy can penetrate through the vegetation/forests to reach the soil underneath. Two commonly used microwave models are the distorted Born approximation (DBA) and the radiative transfer equation (RTE). In RTE and DBA, the transmission through vegetation/forests is calculated as $t = exp(-\kappa_e d sec(\theta_i))$, where κ_e is the attenuation rate per unit distance, d is the vegetation/forests layer thickness and θi is the incident angle. κ_e is calculated using $\kappa_e = n_0(\sigma_a + \sigma_s)$, where n_0 is the number of scatterers per m^3, and σ_a and σ_s are the absorption cross section and the scattering cross section of a single scatterer, respectively. There are two key assumptions in this method: (1) the positions of the scatterers are statistically homogeneous in 3D; (2) each scatterer is uniformly illuminated. These two assumptions are invalid for most of the vegetation/forests. For example, the trees have trunks, branches and leaves in a correlated structure and there are gaps among branches and different trees.

Recently, we have started the advanced physical model of Numerical Maxwell Model of 3D (NMM3D) full wave simulations of vegetation/forests. We develop the hybrid method for this, based on the rigorous solutions of Maxwell equations. This method is a hybrid of the off-the- shelf technique (e.g. HFSS) and newly developed techniques. The newly developed techniques are the three key steps of the hybrid method: (1) calculating the T matrix of each single object using vector spheroidal waves, (2) vector spheroidal wave transformations, and (3) solving Foldy-Lax multiple scattering equations (FL) for all the objects. The T matrix relates the incident fields to the scattered fields for an arbitrarily-shaped scatterer. Previously, vector spherical wave expansions were used for T matrix, where a circumscribing sphere is defined. However, when the objects are closely packed, it is impractical to enclose each object by a spherical surface without overlap. In general, spheroidal surfaces are more compact to enclose closely packed objects. Thus, vector spheroidal wave expansions are used, which are more complicated than the spherical waves. To extract the T matrix for an arbitrary-shape object, the off-the-shelf technique HFSS is used. HFSS enables us to perform full wave simulations of single objects with complicated structures. It is noted that the T matrix extraction method also works for those requiring a spheroidal surface with a large aspect ratio (e.g. branches with leaves). We develop robust numerical methods to perform wave transformations for vector spheroidal waves, which is also called addition theorem. Finally, the extracted T matrices for the single objects are substituted to FL, and the FL is solved with the use of the numerical wave transformations. In solving FL, the multiple scattering of all the objects is calculated.

We illustrate the hybrid method using several complicated objects. For three objects, it is feasible to simulate them with the HFSS brute force method to provide validation. However, the HFSS brute force method is impractical computationally for large problems including lots of objects and empty space such as vegetation/forests, while the hybrid method can still operate with available computation resources. The preliminary results show that the NMM3D full wave simulation method can lead to much greater transmission through the vegetation than the conventional methods of RTE and DBA.