

## Vegetation/Forest Effects in Microwave Remote Sensing of Soil Moisture

My research includes (1) the distorted Born approximation (DBA) and coherent model for vegetated surfaces at L-band for data-cube based soil moisture retrieval; (2) a unified approach for combined active and passive remote sensing of vegetated surfaces with the same input physical parameters; (3) Numerical Maxwell Model in 3D (NMM3D) simulations of a vegetation canopy comprising randomly distributed dielectric cylinders; (4) hybrid method based on generalized T matrix of single objects and Foldy-Lax equations for NMM3D full wave simulations of the realistic vegetation/forests.

The DBA is used to compute the backscattering coefficients for various kinds of vegetated surfaces such as pasture, wheat and canola fields. For the soybean fields, an improved coherent branching model is used by taking into account the correlated scattering among scatterers. The novel feature of the analytic coherent model consists of conditional probability functions to eliminate the overlapping effects of branches in the former branching models. In order to make use of the complex physical models for real time retrieval for satellite missions, the outputs of physical model are provided as lookup tables (with three axes; therefore, called data cube). The three axes are: vegetation water content (VWC), root mean square (RMS) height of the rough soil surface and soil permittivity directly related to the soil moisture, each of, which covers the wide range of natural conditions. By inverting the data cubes, time-series retrieval of soil moisture is performed. Next, the DBA is extended to calculate the bistatic scattering coefficients. Emissivities are calculated by integrating the bistatic scattering coefficients over the hemispherical solid angle. The backscattering coefficients and emissivities calculated using this approach form a consistent model for combined active and passive microwave remote sensing. This has the advantage that the active and passive models are founded on the same theoretical basis and hence allow the use of the same physical parameters. In comparison, current approaches generally use different models and different parameters for active and passive with the tau-omega model most frequently used as the passive model with empirical input parameters. The modelled backscattering coefficients, brightness temperatures and soil moisture retrieval results are validated with the measurements from the Soil Moisture Active Passive Validation Experiment 2012 (SMAPVEX12).

In the analytical physical models mentioned above and another commonly used approach of radiative transfer equation (RTE), the attenuation rate per unit distance  $\kappa_e$  is used which originates from the view of an “effective medium” and does not physically exist for vegetation canopy.  $\kappa_e$  is calculated using  $\kappa_e = n_0(\sigma_a + \sigma_s)$ , where  $n_0$  is the number density, and  $\sigma_a$  and  $\sigma_s$  are the scattering cross section and the absorption cross section of a single scatterer, respectively. In calculating the scattering cross section, the scatterers are assumed to be illuminated uniformly which is not true due to the influence of other scatterers. Moreover, RTE/DBA does not account for gaps and gives the same results independent of the existence of gaps. Because of these issues, NMM3D full wave simulations of vegetation are studied. At first, the scattering of a vegetation canopy consisting of cylindrical scatterers is calculated. The approach for solving Maxwell equations is based on the Foldy-Lax multiple scattering equations (FL) combined with the body of revolution (BOR). For a layer of extended-cylinders distributed in clusters, the NMM3D simulations at C-band show very different results from DBA/RTE and NMM3D gives much larger transmission (i.e much smaller optical thickness  $\tau$ ). The quantity  $\tau$  has been used in active and passive microwave remote sensing. For example, the radar sensitivity to soil moisture of vegetated surfaces depends strongly on the  $\tau$  of the vegetation canopy. The method FL-BOR is limited for rotationally symmetric objects such as cylinders and circular disks. The realistic vegetation/forests, which are what we see with our eyes (unlike the models generated using Lindenmayer Systems), consists of arbitrarily-shaped scatterers. To perform NMM3D full wave simulations for the realistic vegetation/forests, a hybrid method is used, which is a hybrid of the off-the-shelf techniques (e.g. HFSS) and newly developed techniques. The newly developed techniques are the three key steps of the hybrid method: (1) extracting the generalized T matrix of each single object using vector spheroidal waves, (2) vector spheroidal wave transformations, and (3) solving FL for all the objects. The hybrid method is much more efficient than the HFSS brute force (FEM) and MoM methods for vegetation scattering and applicable to large problems such as full wave simulations of trees.