Applying Computational EM to Remote Sensing and Characterization of Atmospheric Precipitation in Snow and Rain Observation Campaigns

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This paper addresses application of computational electromagnetics (CEM) to remote sensing, characterization, and radar-based classification of atmospheric precipitation in snow and rain observation campaigns. Our CEM approach to precipitation particle scattering is based primarily on the higher order method of moments (MoM) in the surface integral equation (SIE) formulation. For simulations of inhomogeneous scatterers, we also use higher order MoM volume integral equation (VIE) modeling. While particle models/solutions for spheroidal shapes have been extensively used in such applications, especially if only the reflectivity computation is involved, it is impossible to explain and take advantage of polarimetric radar measurables based on spheroidal shape models, even at S-band. For atmospheric precipitation scattering analysis of nonspheroidal particles, there clearly are two major approaches that are conventionally and almost exclusively used in atmospheric science, weather scattering, radar meteorology, and remote sensing: the T-matrix method and the discrete dipole approximation (DDA) method.

We show that full-wave CEM MoM-SIE/VIE approach is – in many cases – much more efficient, accurate, general, and robust than the T-matrix and DDA methods, and promote it as an alternative and addition to the conventionally used tools. We also present examples where the conventional methods exhibit major numerical problems. In addition, we further demonstrate the necessity for accurate and efficient full-wave CEM modeling in weather scattering applications, which is becoming even more important as the sensor frequencies of radar/radiometric systems are increasing. Furthermore, we discuss numerical issues specifically related to higher order MoM-SIE/VIE precipitation particle modeling in terms of integration, conditioning, fast monostatic scattering calculation, parallelization, and high performance computing.

We then apply the presented CEM approach to scattering analysis of real data collected in our 2014/2015 snow and rain observation campaigns in Colorado, through a synergistic use of advanced optical imaging disdrometers performing microphysical and geometrical measurements of snow, ice, and rain particles, image processing techniques to reconstruct realistic particle shapes, CEM, and state-of-the-art polarimetric radars. For snow, we use a multi-angle snowflake camera (MASC) to capture multiple high-resolution views of a snowflake in free-fall, along with fall-speed, apply visual hull techniques to reconstruct 3D particle shapes based on the MASC images, convert these shapes into quadrilateral meshes suitable for MoM-SIE analysis, use the fall speed and particle volume to estimate the permittivity, calculate "particle-by-particle" scattering matrices to obtain polarimetric radar observables, and compare and analyze them against measurements by CSU-CHILL Radar. For rain and hail, we use a two-dimensional video disdrometer (2DVD) along with MoM-SIE/VIE computations and radar observations. We present and discuss scattering results from several interesting events observed during the 2014/2015 winter and summer campaigns at our snow/rain field instrumentation site in Colorado.