Analysis of Scattering Characteristics of Ice and Water Rain Particles Using Surface Integral Equation Method and Radar Observations

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This paper presents our ongoing studies of scattering from rain and melting hail at different radar bands, and in particular in some unusual and intriguing situations and cases. The differences in physical properties, such as shapes, sizes, and internal material compositions, of hydrometeors result in differing scattering and propagation characteristics depending on radar frequency. For example, a model of melting hail where a torus of melted water forms around the equator of the ice core can show significant differences in scattering/propagation results from those normally expected, most likely due to resonant scattering by such complex two-layer shapes.

Hence it is important to be able to numerically predict and compare electromagnetic scattering properties between different rain/hail hydrometeors. Our numerical solutions are based on a double higher order large-domain surface integral equation method of moments (SIE-MoM). The higher order generalized curvilinear quadrilateral elements give flexibility in modeling geometry of hydrometeors, while the hierarchical-type higher-order polynomial basis functions decrease the number of unknowns in the analysis. SIE-MoM is one of the most powerful and versatile numerical tools for scattering computations based on discretizing integral equations in electromagnetics. It has been especially effectively used in simulations of arbitrary shaped electromagnetic structures with different dielectric regions in the frequency domain. This feature enables accurate and fast scattering matrix computation of the rain particles of arbitrarily shapes and electrical sizes composed of water and ice. The entire electromagnetic system is divided into subsystems: interior subsystems modeling different dielectric regions in the particle and exterior subsystem containing air as dielectric medium. Equivalent surface electric and magnetic currents are placed on the boundary surfaces and boundary conditions for the tangential components of the total electric and magnetic field vectors are imposed. Galerkin testing method is applied to get final matrix equation to be solved. In particular, we extend the previous analysis by a numerical study that compares results obtained with models of different geometrical and current approximation orders and discuss additional examples of layered rain/hail hydrometeors.

We continue our investigations of polarimetric radar observables and scattering and propagation/attenuation properties for large rain drops and melting hail at C band (Thurai, M., E. Chobanyan, V. N. Bringi, and B. M. Notaroš. "Large raindrops against melting hail: calculation of specific differential attenuation, phase and reflectivity." *Electronics Letters* 51, no. 15 (2015): 1140-1142). We perform extensive simulations and analyses at X- and S-bands as well, and focus here on multiple important details of numerical modeling and computation of rain and hail hydrometeors. The validation of simulation results is done through comparison with radar observations of the same kind of precipitation and 2D-video disdrometer measurements. Our analyses show, for example, much larger differential attenuation between horizontal and vertical polarizations for two-layer melting hail when compared with that expected for rain. This is confirmed by observations by the dual-polarization CSU-CHILL S- and X-band radar.