Scattering Calculations for Asymmetric Rain Drops Undergoing Mixed Mode Oscillations

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Knowledge of rain drop shapes and drop oscillations is of central importance for deriving retrieval algorithms for drop size distribution (DSD) parameters and rain rates as well as for attenuation-corrections for polarimetric weather radars. While for vast majority of the cases, drop shapes are well characterized from previous work (and are rotationally symmetric) (M. Thurai, G. J. Huang, V. N. Bringi, W. L. Randeu, and M. Schönhuber, "Drop shapes, model comparisons, and calculations of Polarimetric radar parameters in rain," *Journal of Atmospheric and Oceanic Technology*, vol. 24, no. 6, pp. 1019–1032, Jun. 2007), other studies have shown that drop collisions can give rise to mixed mode oscillations and that for some high collision rate scenarios a significant percentage of drops can become 'asymmetric' at a given instant in time (M. Thurai, V. N. Bringi, A. B. Manić, N. J. Šekeljić, and B. M. Notaroš, "Investigating raindrop shapes, oscillation modes, and implications for radio wave propagation," *Radio Science*, vol. 49, no. 10, pp. 921–932, Oct. 2014).

In this paper, we consider (a) reconstructed drop shapes from 2D video disdrometer (2DVD) measurements during a previously reported rain event (M. Thurai, V. N. Bringi, W. A. Petersen, and P. N. Gatlin, "Drop shapes and fall speeds in rain: Two contrasting examples," *Journal of Applied Meteorology and Climatology*, vol. 52, no. 11, pp. 2567–2581, Nov. 2013), and (b) simulated drop shapes undergoing mixed-mode oscillations. For the reconstruction of the 2DVD-based drops, we have used the method described in Schönhuber et al., 2016 (M. Schönhuber, M. Schwinzerl and G. Lammer, "3D Reconstruction of 2DVD-measured Raindrops for Precise Prediction of Propagation Parameters," *10th European Conference on Antennas and Propagation, EuCAP 2016*, Davos, Switzerland, doi: 10.1109/EuCAP.2016.7481929). Scattering calculations are performed using the efficient and accurate higher order method of moments solution to the electric and magnetic field surface integral equations (MoM-SIE) (M. Djordjevic and B. M. Notaros, "Double Higher Order Method of Moments for Surface Integral Equation Modeling of Metallic and Dielectric Antennas and Scatterers," *IEEE Transactions on Antennas and Propagation*, vol. 52, August 2004, pp. 2118-2129). The polarimetric radar parameters are computed based on the MoM-SIE surface current density results.

For verification, we employed methods that use 3-D discretizations: low-order HFSS code (industry standard utilizing the finite element method) and/or higher order volume integral equation technique with curvilinear hexahedral elements. Calculations are performed for S, C, and X bands. The single-particle differential reflectivity (Z_{dr}) derived from the scattering amplitudes show variation with the 'look angle' ϕ, in the horizontal plane, unlike rotationally symmetric drops which are ϕ-independent. While S and X band Z_{dr} values are similar to each-other, C band results show significantly different values. The ϕ angle variation is also more pronounced at C band. Apart from single-particle Z_{dr}, the paper also discusses parameters affecting the forward propagation such as specific differential phase and specific differential attenuation as well as single-particle linear polarization ratio. Comparisons are made with the results corresponding to equi-volume rain drops with rotationally symmetric (and most-probable) shapes.