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Relevance of multiple scattering effectsin space-borne radar-based rainfall retrievals

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Space-borne radars are invaluable tools for characterizing clouds and precipitation, as demonstrated by the Tropical Rainfall Measuring Mission (TRMM) precipitation radar (PR) in retrieving rain rate profiles at 13.8 GHz and by the planning of the upcoming global precipitation measurement (GPM) and Cloudsat missions. At the higher frequencies envisioned for the space-borne radars on the latter missions (35.5 and 94 GHz) attenuation due to hydrometeors increasingly becomes an issue. Radar measurements are typically interpreted on the basis of the radar equation with the fundamental assumption of the absence of noticeable multiple scattering. However, multiple scattering effects may become significant due to the increase of the single scattering albedo and the asymmetry parameter of hydrometeors with increasing frequency. Numerical simulations based on the forward fully polarized Monte Carlo technique are performed to evaluate the importance of multiple scattering effects in co- and cross-polar radar returns in realistic vertically inhomogeneous scenarios involving rainfall, snow, graupel and ice crystals. GPM and Cloudsat antenna patterns and expected minimum detection thresholds are considered as reference values. The multiple scattering enhancement becomes a real issue for Ka band radars for medium to heavy precipitation and for W band radars already in the presence of light precipitation. Multiple scattering is generally negligible at the Ku band. Multiple scattering effects can reach tens of dB when heavy cold rain systems are considered, i.e. profiles including rain layers with high-density ice particles aloft. The reflectivity enhancement is accompanied with high values of the linear depolarization ratio, which cannot be explained even by the presence of non-spherical particles. In these situations single scattering based algorithms will be generally burdened by substantial positive biases.