Simulations of 3D Cloud Radiation Fields Using the Horizontally Inhomogeneous Unified Microwave Radiative Transfer Model

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Three-dimensional (3D) cloud radiation fields are necessary to be rapidly and accurately computed for the assimilation of satellite microwave radiance to numerical weather forecast models. To this end, a horizontally inhomogeneous unified microwave radiative transfer (HI-UMRT) model has been developed to study 3D effects of horizontal inhomogeneous clouds on computed microwave radiances and facilitate satellite radiance assimilation over horizontally inhomogeneous weather conditions. HI-UMRT provides a coupled two-Stokes parameter numerical radiance solution of the 3D radiative transfer equation by embedding the existing 1D UMRT model into an iterative perturbation scheme. The horizontal derivatives in radiances of lower perturbation order are treated as the source functions of azimuthal harmonic perturbation radiative transfer equations that are readily solved using the planar-stratified 1D UMRT algorithm. The existing 1D UMRT algorithm attains unconditional numerical stability and high computational efficiency for all matrix operations as needed in the discrete-ordinate eigenanalysis method. These computational advantages are obtained by applying analytic factorization of the symmetric and positive definite submatrices of the transition matrix in the 1D radiative transfer equation based on spherical polydispersive hydrometeors. The horizontal radiance derivative is estimated by central differencing. A perturbation source function analysis shows that the increase in computing time for the 3D HI-UMRT model relative to the 1D UMRT model is moderate since (i) the computationally efficient UMRT engine is applied only to the perturbation equations with non-trivial solutions, and (ii) the layer parameters for the 1D solution are reused for higher perturbation orders. Numerical simulations using HI-UMRT based on 3D cloud profiles simulated by the WRF numerical weather model illustrate the convergence of the iterative perturbation series. An intercomparison of top-of-atmosphere brightness temperature images for HI-UMRT versus the planar-stratified UMRT model illustrates considerable effects of cloud horizontal inhomogeneities on the computed microwave radiances.