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Interpretation of satellite-retrieved cloud droplet effective radii in terms of in-cloud vertical structure using a spectral-bin microphysics cloud model

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Cloud droplet effective radius (CDR) for water cloud is the most important parameter to characterizes in-cloud droplet size distribution, and changes with water cloud growth processes in cloud lifetime such as nucleation of aerosol, condensational growth, and collection processes. The importance of CDR has motivated the developments of various remote-sensing techniques for the satellite-based passive instruments.
CDR and cloud optical thickness (COT) for water cloud are determined uniquely from solar-reflected measurements at two bands of passive radiometer (such as MODIS and EarthCARE/MSI), typically one in non-water-absorbing visible/near-infrared region (typically centered around 0.66 or 0.86μm) that is rather sensitive to COT, and the other in water-absorbing shortwave infrared (1.6 and 2.1μm) or mid-wave infrared region (3.7μm) that is rather sensitive to CDR, under the assumptions of plane-parallel cloud structure, a mathematical droplet size distribution function and 1D radiative transfer process. However, the previous studies showed the significant differences among three CDR retrievals for marine water clouds derived from 1.6, 2.1 and 3.7 μm band observations of MODIS (hereafter, designed as R16, R21, R37); R37 is generally smaller than R16 and R21. The variation of R16-R21 is not random but appears to broadly vary with cloud type.
The previous studies pointed out that real cloud situations not satisfying the assumptions in the retrieval algorithms, namely, (1) vertical inhomogeneity of cloud droplet size distribution, (2) multimodal size distribution including drizzle mode, (3) horizontal inhomogeneity of cloud structure in sub-pixel and (4) 3-D radiative transfer effects cause uncertainties and bias in CDR retrievals. Several previous studies further attempted to explain the CDR discrepancies based on the dependency of the real cloud impact on the scattering/absorbing characteristics of the 1.6, 2.1 and 3.7 μm bands, namely, (a) penetration efficiencies into clouds, (b) dependency of scattering intensity on droplet size, and (c) nonlinear sensitivity of satellite-observed reflectance to CDR and COT.
In this study focusing on the effect of (1), (2), (a) and (b), we interpret R16, R21, R37 and differences among them in terms of in-cloud vertical structure using a spectral-bin microphysics cloud model. First, we simulated the R16, R21 and R37 retrievals from the model-predicted numerical water clouds using a satellite remote sensing simulator under the assumptions of horizontal homogeneous and 1D radiative transfer. Then we estimated the 2-D weightings of R16, R21 and R37 as functions of cloud optical depth and droplet size from the combined analysis of the model-predicted cloud droplet size distribution functions and the CDR retrievals. The 2-D weighting functions shows the mechanism under which the R16, R21 and R37 values are set from the cloud droplet size distribution, and that the sign of R16-R21 are dependent on the vertical profiles of the drizzle mode. The results in this study are consisted with the Aqua/MODIS and Cloudsat combined observations.