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Development of a radiative flux evaluation program by a 3D Monte Carlo radiative transfer code

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For this research purpose, we have developed a 3D Monte-Carlo radiative transfer code. This program is implemented, for broad band solar flux calculation, with k-distribution parameters of Sekiguchi and Nakajima (2008) adapted from OpenCLASTR Rstar radiation code. We used this code for generating the radiative flux profile and heating rate profile in the atmosphere including broken clouds. In order to construct 3D extinction coefficient fields, we tried three methods: 1) stochastic clouds generated by randomized extinction coefficient distribution, 2) A minimum cloud Information Deviation Profiling Method (MIDPM) of Howard Barker, Meteorological Service of Canada, and David Donovan, KNMI (private communication) and 3) numerical simulation by a non-hydrostatic model with bin cloud microphysics model.

In the MIDPM method, we first constructed a library of the pair of observed parameters from CLOUDSAT/CPR and collocated AQUA/MODIS imager products at the footprint of CPR along the EarthCARE orbit, i.e. the profile of effective radar reflectivity factor, dBZe(z), spectral MSI radiances, cloud optical thickness (COT), effective particle radius (RE) and cloud top temperature (Tc) for a case of summer stratus cloud off California coast on July 2, 2007. We then selected a best matched radar reflectivity factor profile from the library for each of off nadir pixels of MSI where CPR profile is not available, by minimizing the deviation between library MSI parameters and those at the pixel.

The third construction of 3D cloud systems was performed by numerical simulation of Californian summer stratus clouds using an non-hydrostatic atmospheric model with a bin-type cloud microphysics model based on the JMA NHM model (Iguchi et al., JGR 2008; Sato et al., JGR 2009, JAS 2011). Most inner region of the three-fold nesting system is an area of 30km$\times$30km$\times$1.5km. Two different cell systems were simulated depending on the cloud condensation nuclei (CCN) concentration. The area mean cloud optical thickness, <COT>, and standard deviation, σCOT, are 3.0 and 4.3 for pristine case and 8.5 and 7.4 for polluted case.

Using these constructed 3D cloud systems, we calculated the radiation field by our Monte-Carlo radiative transfer code at wavelengths of 0.5, 1.6 and 2.2 microns. As expected, the reflectivity difference between 3D cloud and equivalent plane parallel cloud cases increases with increasing COT dispersion of the stochastic clouds. The reflectivity difference for the polluted case of numerical simulation reaches a value up to 0.078, whereas clouds constructed by the MIDPM with CLOUDAT and MODIS data show a much small reflectivity difference as 0.011. We infer this difference is caused by difference in the spatial size of inhomogeneity, i.e. 20m for the polluted cell and 1km for CPR and MODIS case, because the mean extinction coefficient is of 3 to 5 /km and the target cloud in the satellite case is optically dense enough to be approximated by the independent column approximation.