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A study of the earth radiation budget using a 3D Monte-Carlo radiative transfer code (2)

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The purpose of this study is to evaluate the earth radiation budget when data are available from satellite-borne active sensors, i.e. cloud profiling radar (CPR) and lidar, and a multi-spectral imager (MSI) in the project of the Earth Explore/EarthCARE mission. The scientific requirement of the evaluation accuracy is less than 10 Wm-2 for the upward broadband radiative flux for the instantaneous 10kmx10km footprint of CPR (EarthCARE, 2006). For this purpose, we first developed forward and backward 3D Monte Carlo radiative transfer codes called MCsatr that treat a broadband solar flux calculation including thermal infrared emission calculation by k-distribution parameters of Sekiguchi and Nakajima (2008). We have developed Forward and Backward Monte Carlo radiative transfer codes, and we have also developed both of two types for deciding optical mean path by extinction transmittance and scattering transmittance for Forward Monte Carlo radiative transfer code.

In evaluation system, 3D extinction coefficient fields are constructed by two methods: 1) the Minimum Information Deviation Profiling Method (MIDPM) (Barker and Donovan et. al., 2011) and 2) numerical simulation by bin-spectral non-hydrostatic cloud model. In the MIDPM, we first construct a library of pair of observed vertical profiles from active sensors and collocated imager products at the nadir footprint, i.e. spectral imager radiances, cloud optical thickness (COT), effective particle radius (RE) and cloud top temperature (Tc). We select a best matched active sensor-derived vertical profiles from the library for each of off-nadir pixels of the imager where active sensor-derived vertical profile is not available, by minimizing the deviation between library imager parameters and those at the pixel, to construct the 3D cloud field. We applied this method to data of Cloudsat/CPR and AQUA/MODIS for a case of summer stratus cloud of California coast on July 2, 2007.

The second construction of 3D cloud systems is performed by numerical simulation of Californian summer stratus clouds using an non-hyderostatic atmospheric model coupled with a bin-spectral cloud microphysics model based on the NHM+ACBM model (Iguchi et al., 2008; Sato et al., 2009, 2011). Most inner region of a three-fold nesting system is an area of 30km*30km*1.5km with horizontal (vertical) grid spacing of 100m (20m) and 300m (20m). Two different cell systems were simulated for small and large cloud condensation nuclei (CCN) concentration. The area mean cloud optical thickness, <COT>, and standard deviation are 3.0 and 4.3 for pristine case and 8.5 and 7.4 for polluted case.

We then re-calculated the solar radiation field by two types of Fowrad MCstar. We compared flux reflectivities of the 3D atmospheres with those by Plane Parallel Approximation (PPA) and Independent Pixel Approximation (IPA) (Cahalan et al., 1994). As expected, the reflectivity difference between 3D and PPA clouds increases with increasing COT horizontal variability of the 3D clouds. The reflectivity difference between 3D and PPA reaches 0.078 at maximum, which is equivalent to a solar radiative flux error of 70 Wm-2.

On the other hand, the IPA result between the two cases are significantly different. We infer this difference is caused by difference in the spatial characteristic size of inhomogeneity. The mean extinction of the cloud system is of 5 to 8 km-1, so that the kilometer-size clouds in the satellite case are optically dense enough to be approximated by IPA. The difference is less than 0.010 in reflectivity or 10 Wm-2 in upward flux. On the other hand, the model simulation case is optically thin to be approximated by IPA. The error reaches 0.07 at maximum by pristine case. A future work is needed to correct this significant error utilizing the 3D structure of the cloud system.

Keywords: 3D radiative transfer, MIDPM, Monte Carlo