Development of a novel scheme for cloud and precipitation in a global aerosol-climate model with satellite observations

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論 文 名　：　**Development of a novel scheme for cloud and precipitation in a global aerosol-climate model with satellite observations**

（衛星観測データを活用した全球エアロゾル気候モデルにおける新しい雲・降水スキームの開発）

区　　分　：　甲

論文内容の要旨

Atmospheric aerosols have an important role in the climate system via their radiative scattering and absorption properties (aerosol-radiation interaction) as well as interactions with clouds (aerosol-cloud interactions). The aerosol-cloud interaction remains elusive and is one of the most uncertain processes in general circulation models (GCMs) via its nonlinear complexity. Almost all of the current GCMs represent the aerosol effects on cloud and precipitation microphysics based on empirical formulas and simplified assumptions, e.g., diagnostic treatment of rain (DIAG). In this respect, the parameterization of the aerosol-cloud-precipitation interaction must be elaborated at fundamental process-levels.

In this dissertation, advanced cloud-precipitation scheme is developed, and implemented into MIROC-SPRINTARS aerosol-climate model. The new scheme features prognostic treatment of rain (PROG) based on the two-moment bulk representation. Sensitivity experiments are performed using a single-column model with the specific warm rain case, which suggest the best combination of the autoconversion scheme, raindrop size distribution, and sub-time step for microphysics. The both rain mass and number mixing ratios are now stored in the atmosphere across multiple time steps, and controlled strictly by the sub-time stepping iteration (~60 sec or less) while the standard model time step is 10–20 min approximately.

The performance of the new scheme is evaluated by global simulations using satellite datasets (e.g., CloudSat, MODIS, CERES, SSMI, GPCP, and ISCCP). In many respects, the PROG scheme improves model biases in the standard DIAG scheme. For example, the relative contribution of accretion is significantly enhanced against that of autoconversion, whose balance is consistent with observations. The horizontal and vertical distributions of simulated rainwater are also consistent with CloudSat observation and cloud resolving model simulation. It should be emphasized that shallow drizzle, which is frequently observed in coastal stratocumulus deck, is successfully simulated in the new scheme. Consequently, the bias in shortwave cloud radiative forcing so-called “too bright low-cloud problem” is reduced significantly, in good agreement with the CERES observation.

Furthermore, both increasing and decreasing responses of liquid water path (LWP) to aerosol perturbations are found in the new PROG scheme as observed in the A-Train satellites and large-eddy simulations in previous literatures, while the traditional DIAG approach shows only increasing LWP response so-called cloud lifetime effect. This "bidirectional" LWP response appeared in the new scheme is robustly related to the cloud life stage. These improvements support that the prognostic precipitation framework developed in this thesis has great advantages in process representations of not only cloud-precipitation microphysics and cloud radiative forcing, but also cloud system responses including the "buffered system" behaviors.

The findings and progress that have been presented in this thesis will contribute significantly to more accurate climate predictions because the main source of uncertainties in climate modeling stems from the representation of cloud and precipitation.