GCM-simulated and satellite-retrieved cloud-aerosol interaction

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1 Introduction

Clouds are known to have a fundamental role in forming the earth's climate through their effect on radiation and hydrologic cycle.

Atmospheric aerosols have significant effect of modifying the cloud microphysical and thus optical properties by acting as cloud condenstion nuclei (CCN) (indirect effect) in addition to absorption and scattering by themselves (direct effect). The increase in aerosol particle number may increase cloud droplet number concentration and reduces the cloud particle size, leading to the enhancement of optical thickness and thus cloud reflectivity (radius effect or indirect effect of first kind). Furthermore, aerosol-induced reduction of cloud particle size inhibits the production of rain drops and leads to the longer cloud lifetime (lifetime effect or indirect effect of second kind).

Although the plausible estimate of the aerosol indirect radiative forcing is necessary for the prediction of global climate change, satisfactory understanding of the cloud-aerosol interaction phenomena has not yet been achieved. Recently, some works are devoted to the global satellite remote sensing of clouds and aerosols, and provide us with the useful products. These satellite-derived global data offer the motivation for the modeling study to interpret and understand them with general circulation model. Since current GCMs have lots of problems in the treatment of clouds, the GCM-simulated cloud microphysics field needs to be compared with satellite observation, although such comparison has not extensively performed. In this study we examines the effect of aerosols on cloud microphysics by a combined use of both satellite-derived data and the GCM, focusing on the comparison of GCM-simulated cloud microphysics with AVHRR retrieval.

2 Model Description

We used the special version of CCSR/NIES AGCM which incorporates the indirect effect of aerosols. Aerosol indirect effect is treated in the condensation process which represents the non-convective water clouds. The procedure of calculation is as follows :

1. Diagnosis of cloud droplet number concentration

   Cloud droplet number concentration N_c is diagnostically determined by 3-dimensional distribution of aerosol particle number concentration N_a on earh time step as follows :

   $$Nc = \frac{\epsilon N_a N_m}{\epsilon N_a + N_m},$$

   where $\epsilon = 1$ and $N_m = 4 \times 10^8 m^{-3}$. We used the output from the global aerosol transport model.

2. Evaluation of auto-conversion rate

   Conversion rate from cloud water into rain water $\partial l/\partial t$ is evaluated depending on the cloud droplet particle number following the Berry's formula :

   $$\frac{\partial l}{\partial t} = -\frac{l}{\tau_p}$$

   $$\tau_p = \frac{\beta + \gamma N_c/\rho l}{\alpha \rho l},$$

   where ρ denotes the air density.

   In this study we examined the another parameterization known as Kessler's formula which does not include the information of cloud particle number.

   $$\tau_p = \frac{\tau_0}{1 - \exp[-(l/l_c)^2]}$$

3. Determination of cloud particle radius

   Remaining cloud water content after the precipitation l and the diagnosed cloud droplet number concentration N_c enables us to determine cloud particle radius as follows :

   $$R_c = \left(\frac{3}{4\pi}\frac{\rho l}{\rho_w N_c}\right)^{1/3},$$

   where ρ_w denotes liquid water density.

3 Comparison with satellite retrieval

GCM-simulated cloud droplet radii are compared with AVHRR-retrieved cloud effective radii. Fig.1 shows the GCM-simulated (lower panel) and AVHRR-retrieved (upper panel) cloud effective radii. Simulated cloud droplet radii over the land are systematically smaller than over the ocean in accordance with AVHRR retrieval. Over some coastal regions known to be exposed to aerosol outflow from the adjacent continent, GCM simulated smaller cloud droplet radii than over remote oceanic area.

Over the tropical region, however, calculated and retrieved particle radii do not well agree. AVHRR retrieval shows belt-like zonal area of large particle size along the equator, while GCM does not give such character. This may be because our GCM does not calculate cloud particle radii for the deep convective clouds prevailing over the tropics. There is an another possibility that the AVHRR retrieval is not free from the error due to the sub-pixel scale partial cloudiness and the contamination of signals coming from large-sized particles such as ice particle and drizzle drops.

We also compared the results simulated by two types of parameterization for auto-conversion process. Correlation between cloud properties and aerosol particle number is investigated globally for two types of simulation and satellite observation. The correlation pattern for the case with Berry's parameterization (including lifetime effect) shows the feature closer to AVHRR retrieval than the case with Kessler's formula (not including lifetime effect).

4 Conclusion

Our GCM incorporating the aerosol indirect effect simulated the global distribution of cloud microphysics which is consistent with AVHRR retrieval in land-sea contrast and coastal region feature. There is a difference between GCM and satellite observation over tropical region. Comparison of correlation pattern of cloud and aerosol acquired from two types of simulations and satellite retrieval implys the significant role of aerosol lifetime effect in forming the global cloud field.

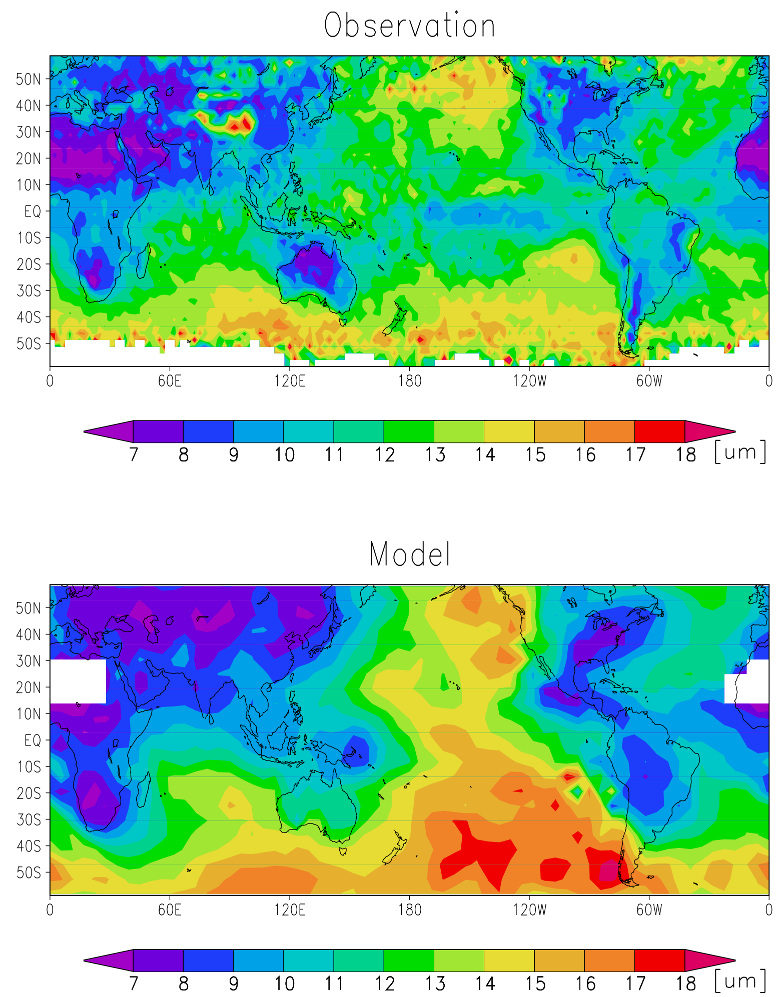

Figure 1: AVHRR-retrieved cloud effective radius (upper panel) near the cloud top and GCM-calculated cloud particle radius (lower panel) at the height of about 0.5-1km for annual mean condition. Unit is μm for both panels