Study of aerosol-cloud interaction phenomena from satellite remote sensing and climate modeling

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Abstract

We have analyzed AVHRR global data set for obtaining aerosol and cloud microphysical parameters, i. e., optical thickness and size index of particle polydispersions. From the results, it is found that the cloud optical thickness increases with increasing aerosol column number, which seems to be caused mainly by decreasing cloud particle radius. The cloud liquid water path was observed to be relatively constant without a significant dependence on the aerosol number. Further comparison of the satellite results with a general circulation model simulation.

1. Introduction

Aerosol-cloud interaction phenomenon is important to be studied for assessing the global warming trend. It is regarded that about 1/3 of the global warming due to increasing greenhouse gases have been compensated by cooling effect of tropospheric anthropogenic aerosols (Charlson 1992; Mitchell, 1995). There are two main mechanisms for the interaction, that are Twomey effect caused by an increase in the optical thickness due to a reduction in the cloud particle radius (Twomey, 1977), and Albrecht effect caused by increased cloud liquid water path (Albrecht, 1989). In spite of recent many studies, however, with in situ measurements, satellite remote sensing, and modeling our knowledge on this phenomenon still remains unknown and the assessed radiative forcing associated with this phenomenon has a large variety (IPCC95, 1996).

In this paper, we study the global statistics of correlation between aerosol and cloud parameters derived from a two channel aerosol retrieval algorithm of Higurashi and Nakajima (1999a) and a solar reflection cloud retrieval algorithm of Kawamoto et al. (1999) applied to NOAA/AVHRR GAC data sets. Characteritic distributions of aerosol optical thickness and Ångström exponent have been reported by Nakajima and Higurashi (1998) and Higurashi et al. (1999b).

2. Results

Figure 1 shows values of satellite-retrieved cloud optical thickness and effective particle radius as a function of aerosol column number over ocean.. In this retrieval, we have assumed an aerosol size distribution of a bimodal log-normal size distribution:

$$\frac{dV}{d\ln r} = \sum_{n=1}^{2} \frac{V_n}{\sqrt{2\pi}\sigma_n} \exp[-\frac{1}{2}(\frac{\ln r - \ln r_n}{\sigma_n})^2], \qquad (1)$$

where we have assumed r_1=0.17 μm, r_2= 3.44 μm, σ_1= 0.26, and σ_2= 1.01. In the calculation, the cloud top temperature is assumed to be larger than 273K in order to select low clouds interacting with tropospheric aerosol particles. The figure shows that the effective particle radius of low clouds decreases noticeably with increasing

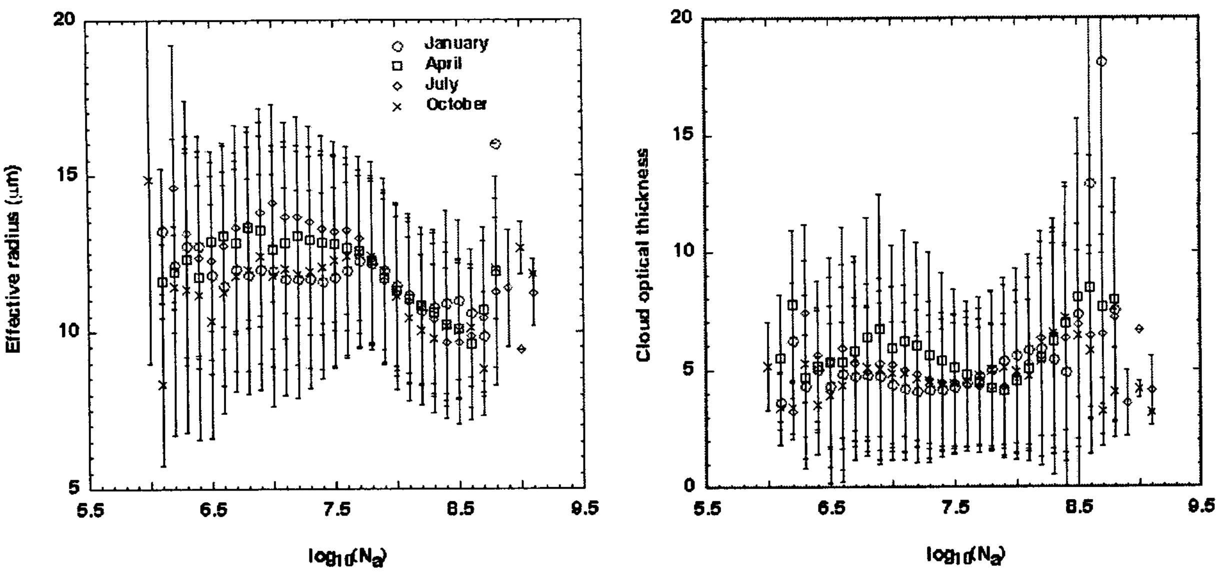

Figure 1: Satellite-retrieved values of cloud effective particle radius and optical thickness as a function of column aerosol particle number. Monthly mean values in January, April, July and October of 1990.

aerosol number when the aerosol number exceeds a critical value about d $10^{7.5}$. On the other hand, the cloud optical thickness increases with increasing aerosol number as revealed also from the figure.

From the satellite-derived optical thickness τ_c and effective radius r_e, the liquid water path can be estimated as

$$W = \frac{2\tau_c r_e}{3}. \qquad (2)$$

Although not shown in a figure, the cloud liquid water path thus calculated is found to be relatively constant without a significant dependence on the aerosol number. From Eq. (2) this fact further suggests that the cloud optical thickness is inversely proportional to the cloud effective radius. Figure 1 again shows this correlation clearly. Therefore, it will be concluded that on the global average the Twomey effect is a dominant effect for cloud - aerosol interaction over ocean, and Albrecht effect is not so important as a global mean.

3. Conclusion

A satellite remote sensing result suggested that the Twomey effect is a dominant mechanism of aerosol-cloud interaction phenomenon on global scale. The cloud optical thickness and effective particle radius characteristically depend on the aerosol number so as to keep the liquid water path unchanged.

Although the above finding will provide a very useful constraint for modeling of the phenomenon, we should note that the present satellite remote sensing technique has serious limitation, such that the technique does not give us an information of which part of the aerosol layers is interacting with clouds; it is difficult to retrieve the aerosol particle number, since it significantly depends on the aerosol size distribution assumed in the technique. It is, therefore, highly important to introduce modeling studies so as to investigate microphysical change processes associated with the phenomena observed by satellite remote sensing. We will present such a study with CCSR/NIES general circulation model in the presentation.

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