P 1.4

MODELING EFFECTS OF ATMOSPHERIC AEROSOLS ON MICROPHYSICAL PROCESSES OF WARM CLOUD

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1. Introduction

It is becoming increasingly evident that aerosol particles play an important role in the processes leading to precipitation. Several studies support this argument that the composition and size distribution of the aerosol particles are important to the number and size of could droplets activated from cloud condensation nuclei (CCN), which in turn has an impact on the formation of precipitation (Hudson and Yum 1999; Yin et al. 2000; Rosenfeld 1998, 2000; Segal *et al*. 2004). Twomey *et al*. (1977) suggested that an increase in pollution emissions, such as sulphate CCN, would lead to a reduction in the effective radius of cloud droplets with increase of could albedo. Increasing aerosol concentration leads to a decrease in precipitation from single clouds both under continental and maritime conditions (Khain *et al*.,2004), while an increase in the concentration of large CCN, as well as giant and ultra-giant CCN, may lead to acceleration of raindrop formation (Segal.*et al*., 2004). Many studies suggest that detailed microphysical schemes to simulate the activation of the CCN and time evolution of drop spectra are better than bulk microphysical schemes (Khain, 2000). In order to improve our understanding of the complex interaction between aerosol particles and clouds, we developed a three-dimension warm cloud model with spectral microphysics of aerosols based on the CAMS (Chinese Academy of Meteorological Sciences) model. This paper presents the results of the initial sensitivity study on the effect of the aerosol size distribution and the presence of the giant nuclei on warm cloud coupled with the observed aerosol data for Beijing.

2. Model description

The microphysics used in this current model is based on warm cloud schemes of CAMS model with the addition of improvement for CCN formation from aerosol particles. For a detailed description of CAMS Model one can refer to the study by Hu and Yan (1986). With the objective of investigating the effect of different initial aerosol particles spectra on the microphysical processes of the warm cloud field, the model was extended to the spectral microphysical processes of aerosols activated as CCN. Given the aerosol size distribution and relative humidity, the number of aerosols activated as CCN for initializing could formation can be estimated. In this study, to avoid the issues of dealing with complicated aerosol parameterization, several assumptions were made for incorporating this warm cloud scheme. All the aerosol particles were assumed as ammonium sulfate and with tri-modal lognormal size distribution; aerosols with sizes larger than a critical size descried by the KÖhler theory is activated as CCN. The critical radius was chosen as a cutoff radius, which separates the original aerosol size into two parts: the part available and the other part unavailable for activation according to Cheng (2004). Thus, cutoff radius and aerosol size distribution before activation can provide enough information to estimate the amount of aerosols available for activation. Initially the aerosol particles were distributed in the first 7 bins, between 0.02μm to 2.56μm as the continental type size distributions

In the fist part of this study, we simulated the formation and evolution of warm clouds observed during summer of 2003 on 8th and 21st of August as fixed dates with strong and mean pollution respectively and compared these modeled results with some observations made during the same. Sensitivity analysis was done with respect to the initial dry aerosol particle spectrum.

3. Results and discussions

3.1 Case studies of 8 August and 21 August 2003

Figure 1 illustrates the observed aerosol spectra for the two days of the experiment. The maximum concentration of aerosol was 7.668×10^3 cm^{-3} with particle radii less than 0.16μm recorded on 8th of August, whilst on the 21st of August the concentration recorded was of 3.589×10^3 cm^{-3} with particle radii larger than 0.16μm. There seems to be an inverse relationship between the size and concentration of the aerosols as per the experimental data we studied.

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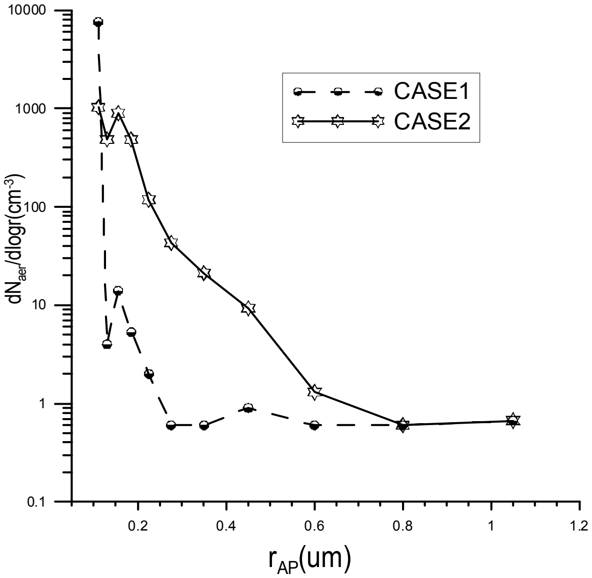

Fig.1. Aerosol particles spectra measured for 8 August 2003 (case-1) and 21 August 2003 (case-2).

Cloud water content $Q_{c,}$ after 10 min of model integration, was found to be a maximum of 0.27 g/kg for CASE-1 and 0.41 g/kg for CASE-2, whilst the maximum simulated cloud droplets concentration (N_{cdn}) at 1800m altitude were around $1.1\times10^3/cm^{-3}$ and $5.7\times10^2/cm^{-3}$ for CASE 1&2 respectively. These results were compared with the observational data as enlisted in Table 1. We noted that the microscopic characteristics of the simulated warm clouds were in reasonable agreement with observations during the campaign.

The simulated vertical profiles of CCN as shown in Figure 2 (on Page 4) were also in good agreement with the measured ones. Comparison of the simulated results indicated that the cloud drop number strongly depends on the aerosol concentration because the later decides the number of CCN. More aerosols provided more CCN, resulting in more cloud drops and could water.

3.2 Sensitivity study of the initial aerosol

Furthermore, three model runs were performed as part of the sensitivity study of the initial dry aerosol particles spectrum and their impact on the previous results. The control was initialized with mean polluted continental background aerosol concentration (CON-3) and other two runs with multiplied background concentration in which one (CON-2) of them is with more aerosols, radii larger than 0.1μm ($r_{AP} > 0.1\mu m$) and the second one (CON-1) with strong polluted background aerosol concentration as shown in Figure 3.

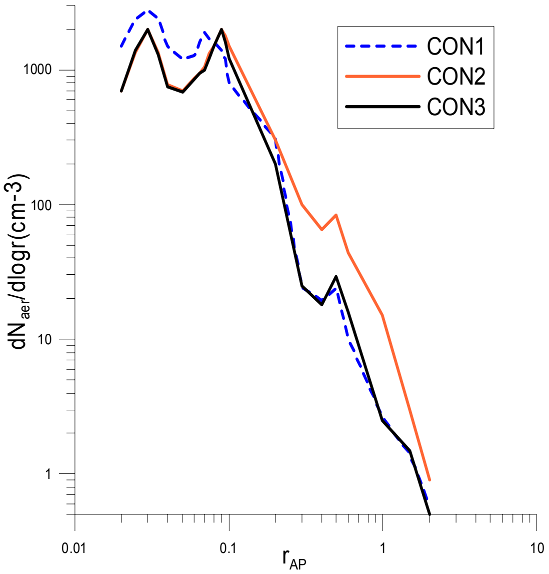

Fig.3. Aerosol spectra for sensitivity studies

Decrease in rain water content is observed in the case of CON-2 accompanied with higher cloud water content. These results as shown in Figure 4 illustrate the reduction of precipitation due to the increases of concentration of aerosols within a certain range ($0.1\mu m < r_{AP} < 1\mu m$), which intends to increase the CCN and decrease the mean droplet size with the negative effects on the onset of

Table-1 Comparison between Observed and Simulated Fields.

	Qc(g/kg)	LWC(g/kg)	N_{cdn} (cm^{-3})	Naer (cm-3)
	Simulated	Observed	Simulated	Observed
Case-1 (8 August 2003)	0.27	0.12	1.1×10^3	1.0×10^3
Case-2 (21 August 2003)	0.41	0.24	5.7×10^2	2.0×10^2

microphysical processes of collision coalescence. Aerosols with radii smaller than 0.01μm ($r_{AP} < 0.01\mu m$) are not activated and do not influence the cloud microphysical structure. An increase in the concentration of aerosols with intermediate size ($0.1\mu m < r_{AP} < 1\mu m$) may increase in the droplet concentration and lead to a delay in raindrop formation. The total water content in the air does not show much difference from simulation to simulation and is not sensitive to aerosol concentration.

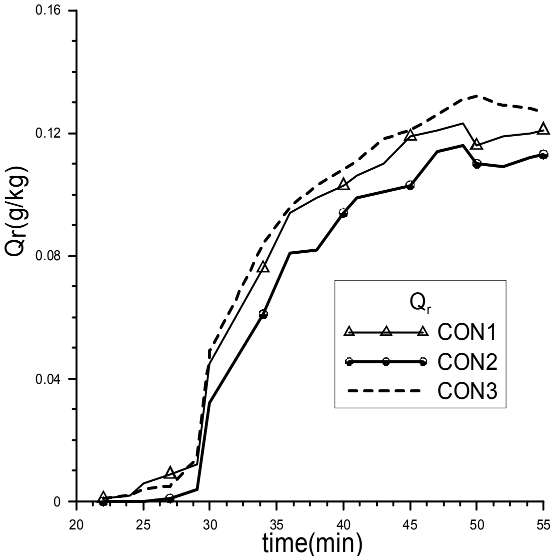

Fig.4. Time series of domain average rain water content

3.3 Sensitivity of precipitation formation to concentration of giant nuclei

In this section the sensitivity of precipitation formation to the concentration of giant nuclei (large aerosol particles with radii $r_{AP} > 0.1\mu m$) is considered. The concentration of giant nuclei was assumed to be zero in the case of CON3-OFF compared with the CON3-ON case with giant nuclei. The size distribution of aerosols is same as that for the CON3 case in the section 3.2.

The effect of the giant nuclei on precipitation formation shows the time evolution of the relative difference in the domain maximum rain water content between the CON3-ON and CON3-OFF, both cases illustrated in Figure 5. Slight differences between the two cases were found only for the simulation after 25min of integration. The effect of the giant nuclei initiates the precipitation earlier and also slightly enhances the amount of precipitation at the initial stage of cloud evolution. These changes are likely due to the rapid drop growth by collection caused by the wider distribution of CCN particles. The rapid development of larger drops forms precipitation size drops at lower altitudes and starts the rain process earlier. There were no significant effects of giant nuclei on precipitation in the subsequent stage which indicates that the presence of giant nuclei ($r_{AP} > 0.1\mu m$) was only important in the earlier stages of cloud evolution.

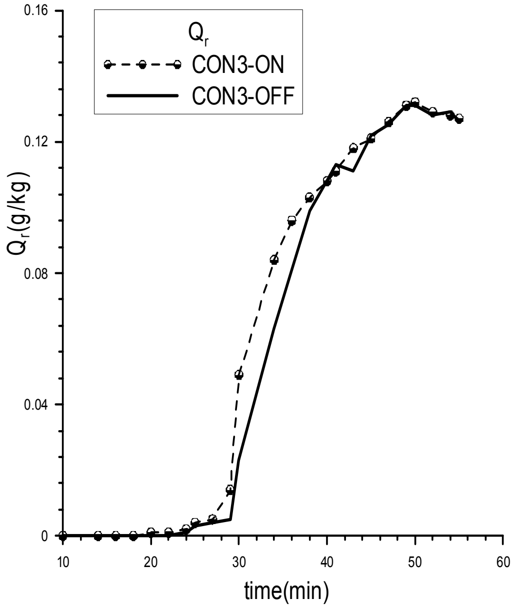

Fig.5 Time evolution of the domain maximum rain water contents of simulations for the CON3-ON and CON3-OFF cases.

4. Summary

This study investigated the characteristics of aerosol particles affecting the microphysical processes of warm cloud. The detailed microphysical mode was incorporated with CAMS Model to simulate the evolution of water drops from aerosol particles. In essence, the effect of aerosols on the clouds is highly complex. Normally, increasing the concentration of small aerosol particles with intermediate size ($0.1\mu m < r_{AP} < 1\mu m$) increases the CCN and droplets concentration, therefore delays the initiation of rain and slightly reducing the rainfall amount. An increase in large aerosol particles may lead to enhanced precipitation and amount of rain water content at the initial stages of cloud evolution.

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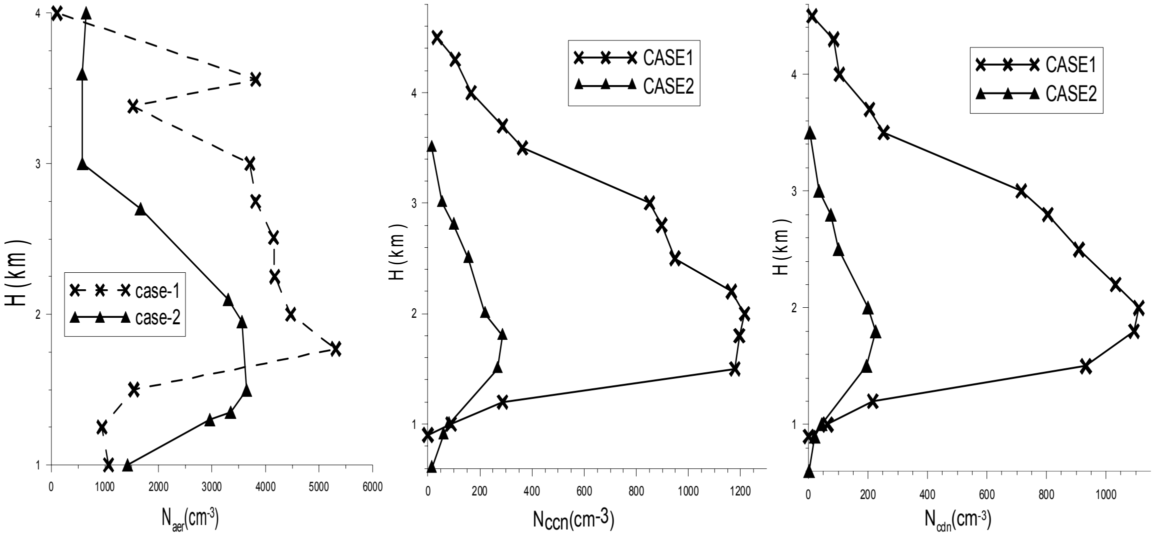

(a) Concentration of AP (Observed)

(b) Concentration of CCN (Simulated)

(c) Concentration of could droplet (Simulated)

Fig.2. Vertical distribution of aerosol particles, CCN and could droplets concentration for 8 August (case-1) and 21 August (case-2) cases.

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