Aerosol effects on ice clouds: Can the traditional concept of aerosol indirect effects be applied to aerosol-cloud interactions in cirrus clouds?

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1. Introduction

Cirrus clouds regularly cover 20-25 % of the globe and as much as 70 % over the tropics and, thus, can act as one of major modulators of the global radiation budget (Liou, 1986, 2005). Hence, the effect of aerosols on cirrus clouds may have contributed to changing global radiation budget and to climate change since industrialization. In this study, the effect of aerosols on cirrus clouds developing with the large-scale low vertical motion is examined using a cloud-system resolving model.

2. Model Description

This study uses the Goddard Cumulus Ensemble (GCE) model coupled with Saleeby and Cotton's (2004) double-moment microphysics. The GCE is used in a 3-D framework (12 km^2 x 20 km). Δx = 100 m and Δz = 50 m above 10 km. ECMWF reanalysis data provide initial sounding, large-scale forcing and surface fluxes for simulations.

3. Simulations

	CONTROL
Location	20 º N, 30 º W
Period	6 LST to 18 LST on July 1st in 2002
Average aerosol number (cm^{-3}) above 10 km	○High (present-day)aerosol : ~ 23 ○Low (preindustrial)aerosol: ~ 13

Table 1. Description of simulations

The high-aerosol (with present-day aerosols) and low-aerosol (with preindustrial aerosols) runs for a case of tropical cirrus clouds (CONTROL) are performed above 10 km to examine the mechanisms which control the response of ice water path (IWP) to aerosols.

4. Results

4.1 Ice-water budget

	High-aerosol	Low-aerosol	High minus Low
IWP (g m^{-2})	2.68	2.11	0.57
$<Q_{depo}>$ Deposition (μm)	5.42	4.66	0.76
$<Q_{subl}>$ Sublimation (μm)	1.06	0.46	0.60
$<Q_{auto}>$ Autoconversion of cloud ice to aggregates + $<Q_{accr}>$ Accretion of cloud ice by aggregates (μm)	0.021	0.023	-0.002
$<\|Q_{ased}\|>$ Sedimentation of aggregates above the cloud base (μm)	0.050	0.051	-0.001
$<\|Q_{ised}\|>$ Sedimentation of cloud ice above the cloud base (μm)	0.71	0.73	-0.02
$(<Q_{auto}>+<Q_{accr}>)/<Q_{depo}>$; $\|\Delta(<Q_{auto}>+<Q_{accr}>)\|/\|\Delta<Q_{depo}>\|$ for "High minus Low"	0.004	0.005	0.003
$<\|Q_{ased}\|>/<Q_{depo}>$; $\|\Delta<\|Q_{ased}\|>\|/\|\Delta<Q_{depo}>\|$ for "High minus Low"	0.009	0.011	0.001
$<\|Q_{ised}\|>/<Q_{depo}>$; $\|\Delta<\|Q_{ised}\|>\|/\|\Delta<Q_{depo}>\|$ for "High minus Low"	0.13	0.16	0.03

Table 2. IWP and domain-averaged budget terms of cloud ice

4.2. Feedbacks

- Domain-averaged aerosol-induced cloud mass changes due to the conversion of cloud ice to aggregates and in-cloud sedimentation of cloud ice are less than ~ 3% of changes due to deposition (Table 2). Hence, the conversion and sedimentation play a minor role in the response of cloud mass to aerosols as compared to deposition
- Instead, it was found that feedbacks among cloud ice number concentration (CINC), deposition and dynamics (controlling deposition) play the most important role in the cloud-mass response to aerosols (Figure 1)
- Homogeneous freezing of haze particles predominantly determined CINC and its response to aerosols. Heterogeneous nucleation processes played a negligible role in the determination of CINC (Figure 2)

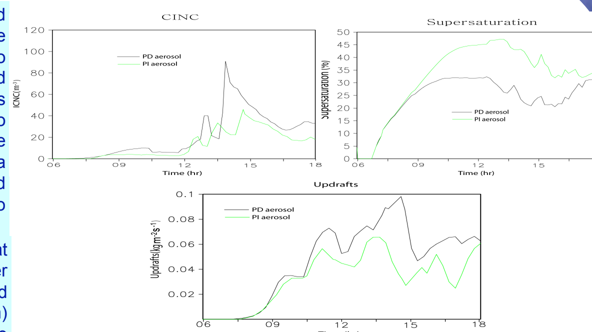

Fig. 1. Time series of CINC, supersaturation and updraft mass flux

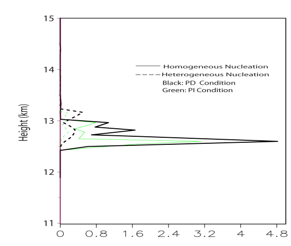

Fig. 2. Vertical distribution of the time- and area-averaged homogeneous and heterogeneous nucleation rates.

6. Summary and Conclusion

■The role of conversion of cloud ice to snow (autoconversion+accretion) and sedimentation of hydrometeors in the IWP response to aerosols is negligible in cirrus clouds simulated here. Instead, feedbacks among CINC, supersaturation and dynamics determine the IWP response.

■The ICNC variation with aerosols is controlled by homogeneous freezing of haze particles and the role of heterogeneous freezing in the variation is negligible. Hence, cloud condensation nuclei (CCN) play a much more important role than ice nuclei (IN) in aerosol-cloud interactions in cirrus clouds.

■The traditional understanding of aerosol-cloud interactions proposed by Albrecht (1989) based on the observation of warm stratocumulus clouds indicates that the response of the liquid-water path (LWP) to aerosol changes is controlled by the conversion of cloud liquid to rain and sedimentation of rain. Cloud ice (or ice crystal) and aggregates in ice clouds above the level of homogeneous freezing is equivalent to cloud liquid (or cloud droplets) and rain, respectively, in warm clouds. This is because cloud ice and cloud liquid both are considered to form from nucleation while rain and aggregates form from autoconversion. Adopting this equivalence, it can be said that the traditional understanding of aerosol-cloud interactions is not applicable to the ice clouds simulated here. This is because the conversion of ice crystals to aggregates through autoconversion and accretion played a negligible role in the IWP responses to aerosols, as did the sedimentation of aggregates.

Reference:

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