Role of Aerosols in Ice Nucleation in Cirrus Clouds

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1. Introduction

The role of clouds in climate change is very uncertain. Especially, the role of cirrus clouds, which may contribute to a net heating of the underlying troposphere, is not yet completely understood. Our knowledge of cirrus properties results from several intensive experiments (e.g., CRYSTAL-FACE (Jensen et al., 2004)) and modeling studies carried out to explore the different microphysical processes of formation of cirrus cloud (Jensen et al., 2006). Previous studies emphasized the importance of aerosol in ice nucleation in cirrus cloud (Ström et al., 1997). However, it is difficult to establish the link between the number of aerosols and the ice crystal concentration in cirrus clouds. Very little is known about the relative importance of the indirect aerosol effect and changes in the dynamical forcing patterns on cirrus clouds in a future climate.

Objectives :

- To study the formation and evolution of aerosols and ice crystal under the Upper Tropospheric condition.
- To investigate the role of sulfur dioxide (SO_2) concentration and updraft speed (w) that govern aerosol concentration and ice nucleation respectively, on final ice crystal number distribution and its surface area.

2. Model Overview

In present study, we used a modified version of a fast $H_2SO_4 - H_2O$ liquid aerosol microphysical model (hereafter known as MSAMM) (Tripathi et al., 2004; Kanawade and Tripathi, 2006; Modgil et al., 2005), which is further extended to include two recently developed homogeneous ice nucleation parameterization schemes (Karcher et al., 2002; Ren et al., 2004). The condensation and coagulation processes of ice crystals are modeled after Jacobson (2003). Hereafter this model will be referred to as Cirrus Cloud Microphysical Model (CCMM). The processes implemented in CCMM exactly conserve mass between gas and solid phase in all size bins. Mass balance equations, for ice crystals, are solved in a semi-implicit manner. The saturation ratio with respect to ice is calculated assuming only Kelvin effect as many studies revealed that solute effects are not important in case of ice. The different components of CCMM are schematically shown in Fig. 1.

Flow chart for the CCMM

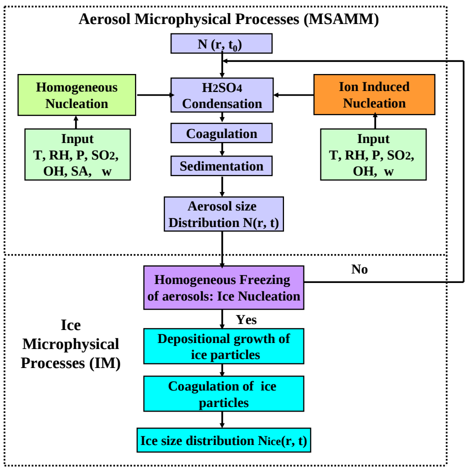

Fig. 1 The different components of CCMM.

The sulfuric acid (H_2SO_4) is known to be an extremely efficient aerosol-producing agent in UT owing to its extremely low equilibrium vapor pressure (Karcher, 2003). We assumed that change in pre-existing aerosol distribution in UT is predominantly due to convective transport of boundary layer trace gases such as SO_2. This change in pre-existing aerosol distribution in UT has been incorporated in our model by varying SO_2 concentration and updraft speed (w).

3. Result and Discussion

Based on the magnitude of updraft speed we have simulated two different convective regimes (viz. no convection and high convection), which account for change in SO_2 concentration for four different combinations of nucleation schemes of aerosol (homogeneous / ion induced nucleation) and ice crystal (Karcher's / Ren's nucleation scheme). The fraction of aerosols frozen after ice nucleation event for all the four combinations is quantified. The model simulated ice crystal number distribution and its surface area are compared with in situ measurements made during CRYSTAL-FACE mission (23 July 2002 WB-57 aircraft data).

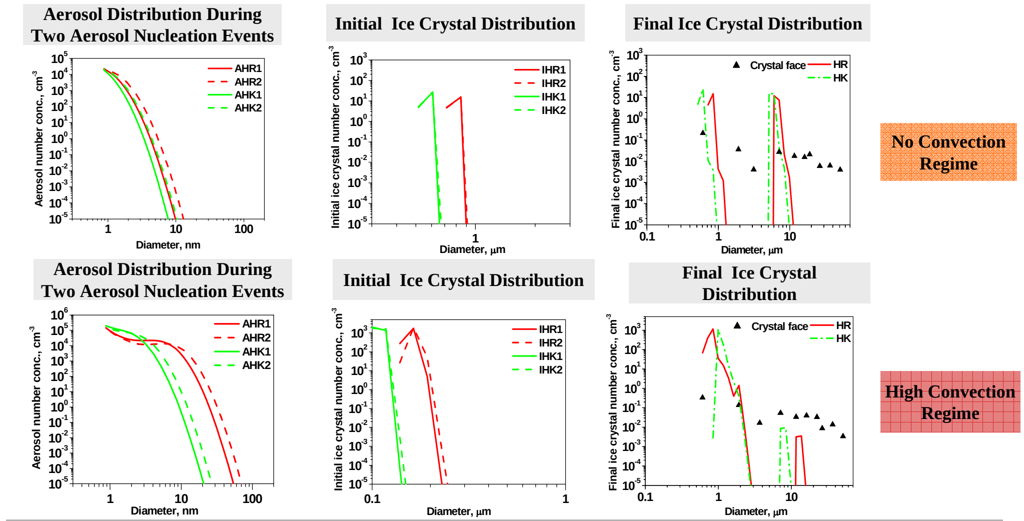

Fig. 2 The aerosol size distribution during two aerosol nucleation events, initial and final ice crystal number distributions for no convection regime and high convection regime.

4. Conclusions

- Cirrus ice crystal number distribution is sensitive to the aerosol size distributions predicted by MSAMM for different convection regimes and total number of aerosols available for freezing.
- The model produces bimodal or trimodal number distributions of cirrus ice crystal depending on the degree of convection.
- The model over predicts ice crystal surface area by factor of 3-12 depending upon the combinations of aerosol and ice nucleation schemes chosen and the intensity of convection.
- The sensitivity studies indicate that influence of updraft on ice number distribution and surface area (a strong and positive relationship) is more than that of SO_2.
- Ice crystals of size less than 20 µm have been found in both the no convection and high convection regimes which is in agreement with previous studies.
- As updraft speed is increased more small size ice crystals are generated.

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References

Jacobson, M. Z., (2003) , Development of mixed-phase clouds from multiple aerosol size distributions and the effect of the clouds on aerosol removal, J. Geophys. Res., 108(D8), 4245, doi:10.1029/2002JD002691

Jensen, E. J., D. Starr, and O. B. Toon, (2004), CRYSTAL-FACE mission, Eos Trans. AGU, 85, 45–50.

Jensen E.J., and A.S. Ackerman (2006), Homogeneous aerosol freezing in the tops of high altitude tropical cumulonimbus clouds, Geophys. Res. Lett., 33, L08802, doi: 10.1029/2005GL024928.

Karcher, B., and U. Lohmann, (2002), A Parameterization of cirrus cloud formation: Homogeneous freezing including effects of aerosol size, J. Geophys. Res., 107(D23), 4698, doi:10.1029/2001JD000470

Kanawade, V., and S.N. Tripathi, (2006), Evidence for the role of ion-induced particle formation during an atmospheric nucleation event observed in Tropospheric Ozone Production about the Spring Equinox (TOPSE), J. Geophys. Res., 111, D02209, doi:10.1029/2005JD006366

Modgil, M. S., S. Kumar, S. N. Tripathi, and E. R. Lovejoy (2005), A parameterization of ion-induced nucleation of sulphuric acid and water for atmospheric conditions, J. Geophys. Res., 110, D19205, doi:10.1029/2004JD005475

Ren, C., and A. R. MacKenzie, (2005), Cirrus parameterisation and the role of ice nuclei, Quart. J. Roy. Meteorol. Soc., 131, 1585-1605

Ström, J., B. Strauss, T. Anderson, F. Schršoder, J. Heintzenberg, and P. Wendling, (1997), In situ observations of the microphysical properties of young cirrus clouds, J. Atmos. Sci., 54, 2542-2553

Tripathi, S. N., X. P. Vancassel, R. G. Grainger, and H. L. Rogers, (2004), A fast Stratospheric Aerosol Microphysical Model (SAMM): $H_2SO_4 - H_2O$ aerosol development and validation, AOPP Memo. 2004.1, Dep. of Phys., Univ. of Oxford, Oxford, UK.