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Interactive comment on “Development of a cloud microphysical model and parameterizations to describe the effect of CCN on warm cloud” *by* N. Kuba and Y. Fujiyoshi

N. Kuba and Y. Fujiyoshi

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We would like to thank Referee #3 for the close comments. We are revising our manuscript according to the comments.

Replies to the general scientific comments and questions

The wind field used in this study is given by Szumowski et al. (1998). The flow pattern shows low level convergence, upper level divergence, and a narrow updraft located in the center of the domain. The magnitude, vertical structure, width and tilt of the flow through the central updraft are all prescribed using simple analytical functions. The updraft is held constant at 1ms-1 for the first 15 min of the simulation. The updraft intensifies to a peak value of 8 ms-1 at 25 min and subsequently decays to a value of 2 ms-1 at 40 min. During the 10-min rain out time at the end of the 50-min simulation, the updraft is held constant at 2 ms-1 (Szumowski et al. 1998). This dynamical framework predicts updraft velocity, water vapor, and potential temperature explicitly. The bulk microphysical scheme imbedded in original Szumowski's model was replaced with our hybrid microphysical model in this study. Updraft velocity and water vapor determine the liquid water content, aerosol properties and updraft velocity determine the number of cloud droplets, liquid water content and cloud droplet number determine the cloud droplet size distribution. Therefore primary factors determining the cloud properties are water vapor and updraft velocity. In addition, aerosol properties determine cloud microstructure.

The parameterization of activated CDNC developed in this study is based on Kuba et al. (2003) and Kuba and Iwabuchi (2003). The numerous numerical experiments using parcel model and many kinds of CCN spectrum derived the most correlative factor Nc(S) with cloud droplet number. S in Nc(S) is not necessarily Smax realized in the simulation. In many studies, Twomey's (1959) relationship is used to estimate the number of activated CCN. This method tends to overestimate the number of activated CCN, or the number of cloud droplets. In our previous studies, it is shown that even after growing beyond their critical radii, some CCN revert to being inactivated after supersaturation has reached its maximum value. It is because that supersaturation does not keep its maximum value and decreases rapidly. Chuang et al. (1997) and Yun and Hudson (2002) also noted this overestimation, which is caused by assuming that the cloud droplet concentration is equal to the concentration of CCN for which critical supersaturation is lower than the maximum supersaturation in the cloud. Our parameterization takes this effect into account. In this parameterization, Nc(S) includes all aerosol particles. Therefore competition of water vapor among aerosol species are taken into account under the assumption that aerosol particles with the same critical supersaturation behave in the same way except some aerosol particles made of special substance with unusual Koehler curve.

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Replies to the specific comments and questions

1) We would like to adopt your suggestion.

2) We would like to adopt your suggestion.

3) In this study, parcel model is only used to produce the initial cloud droplet size distribution for bin method and to estimate the inflow of cloud droplets from the windward with no cloud water. We used 0.05 seconds as the time step of time integration. Because droplets approach their equilibrium radius and do not exceed it before they reach their critical radius, short time step of time integration is needed. In case 0.05 seconds is not short enough, condensation growth is limited so that the radius of each droplet does not exceed its equilibrium radius for environment.

4) Yes. Water condensed on activated CCN is reduced from inflow of vapor.

5) We are adding some sentences as mentioned in Replies to the general scientific comments and questions.

6) In the dynamical framework used in this study, the magnitude, vertical structure, width and tilt of the flow through the central updraft are prescribed using simple analytical functions. Therefore, latent heat does not induce turbulence in this study unfortunately. We are installing our cloud microphysical model into a three-dimensional non-hydrostatic cloud model to estimate the effect of CCN on cloud dynamical field.

7) Sorry, it is a mistake. "Szumowski et al. (1998)" is correct.

8) Combination of alpha, beta and Qc0 is determined based on trial and error simulations considering CCN properties.

9) This hybrid cloud-microphysical model is used to validate the results of a bulk parameterization in this study.

10) We would like to show the new figures of the time change of rainfall rate for cases of A, C, D, E, F, and H to see the beginning of precipitation. We can find that the

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formation of rain is accelerated with increased giant particle CCN only when there are a large number of small CCN.

11) This parameterization is valid for soluble constitutes of aerosol particle which have usual Koehler curves.

12) Aerosol particle size distributions are assumed as log-normal. Determination of parameters of log-normal distribution for sea salt particles, sulfate particles, and organic carbon particles are mentioned in Takemura et al. (2000) and Takemura et al. (2005). Sensitivity of parameterized CDNC to the CCN distribution type has not tested yet.

13) We would like to adopt your suggestion.

14) We would like to add sentences as follows; Dynamical factors primarily determine the precipitation properties, nevertheless aerosol properties as CCN can modify the precipitation.

References

Chuang, P. Y., R. J. Charlson and J. H. Seinfeld: Kinetic limitations on droplet formation in clouds. Nature, 390, 11, 595-596, 1997.

Yun, S. S. and J. Hudson: Maritime/continental microphysical contrasts in stratus. Tellus, 54B, 61-73, 2002.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 1413, 2006.