Atmos. Chem. Phys. Discuss., 9, C9680–C9683, 2010
www.atmos-chem-phys-discuss.net/9/C9680/2010/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effect of hygroscopic seeding on warm rain clouds – numerical study using a hybrid cloud microphysical model" *by* N. Kuba and M. Murakami

N. Kuba and M. Murakami

kuba@jamstec.go.jp

Received and published: 14 January 2010

We appreciate the profitable comments of Anonymous Referee #2.

Referee Comment 1. The kinematic framework used by Szumowski et al. (1998) was developed based on measurements of marine clouds over Hawaii. Does the thermodynamic and dynamic structure of that cloud type represent the warm clouds developed over other geographic locations?

Reply: This model takes the effect of updraft velocity, but can not take the effect of geography location into account. These effects can not be neglected and will be studied by installing our hybrid cloud microphysical model into a non-hydrostatic cloud model in next paper.

Referee Comment 2. Both stochastic and continuous coalescence schemes are considered in the same model. Does this scheme overestimate the efficiency of collision-coalescence?

Reply: To properly estimate multi-coalescence in one time step even if the time step is not extremely short, two schemes are used. One is a general stochastic coalescence scheme for rare lucky coalescence between droplets, and the other is a continuous coalescence scheme for frequent coalescence of a large drop and numerous small droplets (numerous small droplets are evenly shared by large drops). We distinguish rare lucky coalescence and frequent coalescence by predicted frequency of collision in one time step. If predicted frequency of collision of one particle in i-th bin and smaller particles in j-th bin in one time step is 1 or less, a general stochastic coalescence scheme is used to calculate the growth of particles in i-th bin by coalescence with particles in j-th bin. If predicted frequency of collision of one particle in i-th bin and smaller particles in j-th bin in one time step is larger than 1, a continuous coalescence scheme is used to calculate the growth of particles in i-th bin by coalescence with particles in j-th bin. This method using both continuous scheme and stochastic scheme with time step of 0.5 sec leads to the same results with ones from the method using only stochastic scheme with time step of 0.01 sec as shown in Appendix (Fig A1). This scheme does not overestimate the efficiency of collision-coalescence and can also avoid the underestimate of the multi-coalescence in one time step.

Referee Comment 3. Feingold et al. (1989) scheme was a numerical solution to stochastic collision breakup of drops. How the breakup of drops formed by continuous coalescence process is treated in this model?

Reply: Collision-coalescence and collision-breakup are calculated separately. In calculation of breakup, all collisions are treated as stochastic coalescence. It is obviously contradictory to the treatment in calculation of coalescence (continuous scheme and

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stochastic scheme are used). In calculation of coalescence growth, this method using both continuous scheme and stochastic scheme with time step of 0.5 sec leads to the same results with ones from the method using only stochastic scheme with time step of 0.01 sec as shown in Appendix (Fig A1). In calculation of breakup, to use only stochastic scheme seems to cause some underestimation of the efficiency of breakup following the multi-coalescence in one time step. However the probability of the break up following the collision between a large drop and numerous small droplets is very small. Therefore the method in this study can provide quite accurate results.

Referee Comment 4. The seeding effect is also very much dependent on the time and location of the seeding practice. Are the conclusions of this study sensitive to changes in these parameters?

Reply: Our preliminary numerical experiments using our hybrid microphysical cloud model suggest that later timing of seeding leads to the smaller effect of seeding on precipitation. Therefore, hygroscopic seeding is assumed to begin 5 min after cloud initiation. We have never test the effect of location of the seeding practice. Seeding is assumed to be carried out by airplane under the cloud base in this study. Other method (at cloud top or in cloud) will be considered in future study.

Referee Comment 5. In previous field experiments, seeding materials are generally more water soluble than natural aerosol particles. For example, KCl is the main chemical component of South African flares. NaCl is assumed for both the natural and seeding particles in this study. Will the conclusions be different if KCl is assumed for seeding material and ammonium sulfate for natural aerosol?

Reply: We will assume ammonium sulfate for natural aerosol for confirmation. However, size distribution of CCN is more important to estimate the cloud droplet size distribution than the difference in chemical constituent if constituent is water soluble as NaCl and ammonium sulfate, as shown in Takeda and Kuba (1982, Numerical study of the effect of CCN on the size distribution of cloud droplets. Part I. Cloud droplets in the stage of condensation growth. J. Meteor. Soc. Japan, 60, 4, 978-993). For seeding particles we assumed real material which we are using in field experiments to compare the results. NaCl is assumed for micro-powder, and CaCl2 is assumed for seeding particles from “ICE 70% flare” produced by Ice Crystal Engineering in this study. We will assume KCL as seeding particles from flare in future.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 24145, 2009.