First of all, we appreciate the reviewer's comments. In response to the reviewer's comments, we have made relevant revisions in the manuscript. Listed below are our answers and the changes made to the manuscript according to the questions and suggestions given by the reviewer. Each comment of the reviewer (in black) is listed and followed by our response (in blue).

Interactive comment on "Effects of model resolution and parameterizations on the simulations of clouds, precipitation, and their interactions with aerosols" by Seoung Soo Lee et al.

Anonymous Referee #2

Received and published: 29 June 2017

This paper nicely demonstrates the role of spatial resolution and microphysics in determining differences between a model with high resolution and bin representation of microphysics compared to low resolution and bulk representation of microphysics. It should be published after clarification of the following and/or improvement in wording.

Many places use "resolutions" where I would have thought "resolution" was best English usages.

We went through text and replaced "resolutions" with "resolution" when needed.

Line 71: Change "These" to This

Done.

Line 136: change "less than" to "above"

Following the other reviewer's comment, "less than" is replaced with "At pressures less than"

Lines 118 – 126: this cannot be the full description of ammonium sulfate sources and sinks, since it only describes the interaction of aerosol with clouds. What about nucleation from the gas phase production of sulfate? How is gas phase sulfate produced? Do you represent condensation onto existing aerosols? What about dry deposition loss?

In this study, we focus on interactions among aerosol, clouds, and precipitation but not on aerosol physics and chemistry. Stated differently, this study aims to examine errors and mechanisms that govern those errors in the simulations of aerosol-cloud-precipitation interactions themselves by the NWP models as stated in "introduction". Thus, the examination of errors and associated mechanisms in the simulations of aerosol physics and chemistry by the NWP models is out of scope of this study. Based on this, we do not explicitly simulate aerosol physics and chemistry and we prescribe aerosol physical and chemical properties. To clarify the points here, the following is added:

(LL123-130 on p7)

As stated in introduction, this study focuses on the uncertainties or errors in the simulations of clouds, precipitation, and CAPI themselves. This means that the examination of the uncertainties in the simulations of aerosol physics and chemistry is out of scope of this study. Hence, in this study, instead of simulating aerosol physics and chemistry explicitly, initial aerosol physical and chemical properties (i.e., aerosol chemical composition and size distribution) are prescribed. Then, aerosol size distribution (or aerosol number concentration in each size bin) evolves only through cloud processes but not through aerosol physical and chemical processes. During the evolution, the prescribed aerosol composition is assumed not to vary.

Fig 1a,b: please increase size of rectangle, similar to 1c, d.

Done.

Model set up: What is used for boundary conditions for the CSRM? How do these boundary conditions compare to the incoming air in the GFS simulations?

For the ARW simulations (including the CSRM simulations), we use open lateral boundary conditions and hence, the synoptic conditions are advected into and out of the domain by air through the boundary of the domain. This emulates the situation in the GFS simulations where the synoptic conditions are advected into and out of an area (corresponding to the domain in the ARW simulations) by air through the border between the area and places outside the area. In the ARW simulations, the synoptic conditions are derived from the National Centers for Environmental Prediction GFS final (FNL) analysis. The FNL analysis is based on environmental conditions that are produced by GFS and thus there are basically no differences in the synoptic conditions between those advected into and out of the domain in the ARW simulations by air and those advected into and out of the area (corresponding to the domain in the ARW simulations) in the GFS simulations by air.

In summary, the domain in the ARW simulations and the area (corresponding to the domain in the ARW simulations) in the GFS simulations experience an identical synoptic condition. The advection of the synoptic condition into and out of the domain by air in the ARW simulations is through the boundary of the domain, which is enabled by the use of the open boundary conditions and emulates the advection of the synoptic condition into and out of the area in the GFS simulations through the border between the area and places outside the area.

To clarify the point here, the following is added:

(LL198-205 on p10-11)

Initial and boundary conditions, which represent the synoptic features, for the control run are derived from the National Centers for Environmental Prediction GFS final (FNL) analysis. Since the FNL analysis is based on environmental conditions that are produced by the GFS model and thus for each of the cases, there are basically no differences in the synoptic condition between the CSRM simulations and the GFS simulations that are described in the following Section 4.2. The open lateral boundary condition is adopted in the control run. This enables the advection of the synoptic condition into and out of a domain in the CSRM simulations to occur through the boundary of the domain, which emulates the advection in the GFS simulations.

Line 294: what are the deposition rates shown in Fig 9? This is not surface deposition, since the units are wrong.

In this paper, condensation, evaporation, and deposition occur on the surface of hydrometeors. Condensation and evaporation occur on the surface of drops, while deposition occurs on the surface of solid hydrometeors such as ice crystals; deposition is, by definition in microphysics, the diffusion of water vapor onto solid hydrometeors such as ice crystals in clouds. In this paper, condensation rate and evaporation rate are defined as the rates of changes in drop mass (or liquid mass) in a unit volume of air and for a unit time due to condensation and evaporation, respectively, following the conventional definition of condensation and evaporation rates in cloud community. Deposition rate is defined as the rate of changes in the mass of solid hydrometeors (or ice mass) in a unit volume of air and for a unit time due to deposition, following the conventional definition of deposition rate in cloud community. To clarify this, the following is added:

(LL331-333 on p17)

Here, condensation and deposition rates are defined as the rates of changes in liquid mass and ice mass in a unit volume of air and for a unit time due to condensation and deposition on the surface of hydrometeors, respectively.

(LL414-416 on p21)

Here, evaporation rate is defined as the rate of changes in liquid mass in a unit volume of air and for a unit time due to evaporation on the surface of hydrometeors.

Line 298-300: why do updraft mass fluxes increase with higher aerosol?

As stated in text (LL331-335) in the old manuscript, aerosol-induced invigoration of convection through aerosol-induced increases in freezing or aerosol-induced intensification of gust fronts is the main mechanism behind aerosol-induced increases in updraft mass fluxes or the intensity of updrafts. To provide more detailed information on aerosol-induced invigoration of convection, the following is added:

(LL336-349 on p17-18)

Increasing aerosol concentrations alter cloud microphysical properties such as drop size and autoconversion. Aerosol-induced changes in autoconversion in turn increase cloud-liquid mass as a source of evaporation and freezing. Numerous studies (e.g., Khain et al., 2005; Seifert and Beheng, 2006; Tao et al., 2007, 2012; van den Heever and Cotton, 2007; Storer et al., 2010; Lee et al., 2013, 2017) have shown that aerosol-induced increases in cloud-liquid mass and associated increases in freezing of cloud liquid enhance the freezing-related latent heating and thus parcel buoyancy, and this invigorates convection or increases updraft mass fluxes. Those studies have also shown that the aerosol-induced increases in cloud-liquid mass and associated increases in the evaporation of cloud liquid enhance the evaporation-related latent cooling and thus negative buoyancy. This intensifies downdrafts and after reaching the surface, the intensified downdrafts spread out toward the surrounding warm air to form intensified gust fronts and then, to uplift the warm air more strongly. More strongly uplifted warm air leads to invigorated convection or increased updraft mass fluxes. These freezing- and evaporation-related invigoration mechanisms are operative to induce the aerosol-induced enhancement of updraft mass fluxes, condensation, and deposition in this study.

Line 526: what are “high-level” updrafts? At high altitude? Similar comment for lowlevel updrafts. You did not discuss this in the paper. (also only updraft mass flux is in figures).

Discussion in the paragraph related to this comment is based on Figure 7 that shows the vertical distributions of the time- and domain-averaged updraft mass fluxes in the ARW simulations. Just want to note that updraft mass fluxes are obtained by multiplying the predicted updraft speed (or updrafts) with air density. Since there are negligible differences in air density among simulations at different resolutions, differences in updraft mass fluxes among those simulations are mostly caused by differences in the updraft speed or updrafts. This means that the qualitative nature of discussion about the differences in updraft mass fluxes among simulations is not different from that of discussion about the differences in the updraft speed or updrafts. Hence, discussion in paragraphs using the word “updrafts” can be replaced with discussion using the word “updraft mass fluxes”. In the paragraph, high-level and low-level simply mean high-value and low-value, respectively.

To clarify our points here, the following is added:

(LL324-329 on p17)

Updraft mass fluxes are obtained by multiplying the predicted updraft speed by air density. Since there are negligible differences in air density among the ARW simulations, most of differences in updraft mass fluxes among the simulations are caused by differences in the updraft speed or updrafts. Those differences in air density are in general ~ two orders of magnitude smaller than those in the updraft speed or updrafts.

Based on our points here, the corresponding text is revised as follows:

(LL585-588 on p30)

When they are resolved with the use of high-resolution models, there are high-value averaged updrafts and associated variables, and their strong sensitivity but when they are not resolved in low-resolution models, there are low-value averaged updrafts and associated variables, and their weak sensitivity.