First of all, we would like appreciate the reviewer's comments and suggestions. Listed below are our answers to the questions and suggestions given by the reviewer. Each comment of the reviewer (black) is listed and followed by our responses (blue).

Review of "Thunderstorm and stratocumulus: how does their contrasting morphology affect their interactions with aerosols?" by Lee et al.

This paper shows that the different morphologies of these two cloud types lead to different aerosol-cloud interactions. Increasing aerosols increases droplets and then leads to intensify downdrafts because of stronger evaporative cooling (as the authors claimed). The acceleration of the intensity of downdrafts is larger in convective clouds due to their larger cloud depths (providing longer paths for downdrafts to follow to the surface) than in stratiform clouds, leading to significantly increased updrafts and an enhancement of precipitation with increased aerosols in convective clouds. The motivation and the goal of the study are good but some of the methods and analyses are questionable. The precipitation from the GCE bulk scheme is not reliable since many thresholds or parameters for auto-conversion are fixed.

Saleeby and Cotton's (2004) double-moment microphysics used in this study adopts an autoconversion scheme with no reliance on thresholds as described in Section 3 in the manuscript. Stochastic collection equations are solved explicitly for collection processes in this study as in bin models. The only difference (regarding collection processes) between the double-moment microphysics in this study and the bin microphysics is that this study assumes gamma size distribution for hydrometeors (see Eq. (1) in the manuscript) but the bin microphysics does not assume a specific size distribution. Many observational studies indicate that cloud hydrometeors can be fit into the gamma size distribution reasonably well. Hence, the gamma size distribution used here is expected to represent the hydrometeor distribution reasonably well.

To test the robustness of results here to the size distribution assumed here, we repeated simulations by varying the shape parameter (ν) in Eq. (1) from 1 to 10 (see Walko et al. (1995, Atmos. Res.) for the gamma distributions corresponding to the shape parameter from 1 to 10); for $\nu = 1$, the gamma distribution reduces to the exponential or Marshall-Palmer distribution. We found that the qualitative results here are robust to the shape parameter. This is supported by Seifert et al. (2006, Atmos. Res) indicating that the exact shape of size distribution of hydrometeors is not of importance to the reasonable simulation of precipitation. Hence, it can be said that results here do not depend on the assumption of size distribution.

Li et al 2009a, b (JAS, v66) have indicated the overestimation of evaporative cooling in the squall lines for the GCE bulk scheme compared with the size-resolved cloud microphysical scheme, through overpredicting the intensity of rain and underpredicting the stratiform ice formation. Therefore, the results of the paper is questionable since the authors built their points upon the evaporative cooling for deep convective clouds, which was proven to be much overpredicted by the bulk schemes in the studies of Li 2009a,b and Khain et al 2009a, b (JGR, D22203 and D19209).

The bulk microphysics used in Li et al. (2009a,b) adopts a saturation adjustment scheme for condensation and evaporation; also, note that the bulk microphysics used in Li et al. 2009a,b) is a single-moment microphysics (predicting only mass of hydrometeors) based on Lin et al. (1983). However, in this study, we adopted a double-moment scheme predicting supersaturation as well as mass and number of hydrometeors explicitly as in bin microphysics the reviewer mentioned here. Our other studies (Lee, Penner, Wang (2009, ACP) and Lee,Penner (2009,ACPD)) showed that the saturation adjustment overestimated the condensation and evaporation as compared to the scheme predicting supersaturation as pointed out by the reviewer here. In these our other studies, we compared the supersaturation-prediction scheme used in this study with a saturation adjustment scheme used in a GCM and found similar tendency of overestimation of evaporation to that simulated in Li et al. (2009a,b) by the saturation adjustment scheme; this smaller evaporation by the supersaturation scheme led to better agreement with observation as compared to evaporation by the saturation adjustment. Hence, we believe the supersatuation-prediction scheme used here predict the evaporation reasonably and smaller as compared to a type of saturation adjustment used in Li et al. (2009a,b).

A cause of overestimation of total evaporation can be the overestimation of rain evaporation as proposed by Li et al. (2009b). Li et al. (2009b) pointed out over-predicted rain evaporation as the cause of overestimation of evaporation and of the non-optimal structure of a squall line (having convective elements in the trailing stratiform clouds and thus having unclear trailing regions) simulated by the single bulk microphysics in their study. However, the double-moment microphysics of Morrison et al. (2009, MWR, p991-1007) resulted in smaller rain evaporation than a single-moment microphysics (in their comparison between the double-moment and the single-moment microphysics) and this leads to an optimal structure of a squall line with a much more well-defined trailing region of stratiform clouds than that in the single-moment microphysics; our study submitted here also simulated well-defined trailing region of stratocumulus clouds. This indicates that the double-moment microphysics used here is able to simulate deep convective clouds with a fairly good performance and confirms the finding of Li et al. (2009b) that the single-moment microphysics is not able to capture the structure of deep convective clouds reasonably. In this study, the sedimentation of all hydrometeors (known to affect evaporation of precipitable hydrometeors significantly) including rain is simulated by emulating a full-bin model with 36 bins (see section 2.2 in the manuscript for details). This simulates the sedimentation with better confidence than previous treatments of sedimentation that use a mass-weighted fall speed, which is adopted in the Lin style microphysics in Li et al. (2009a,b). Using this sedimentation method in addition to the use of supersaturation prediction enables a better simulation of evaporation than a single-moment microphysics.

To investigate the role of a possible overestimation of rain evaporation in this study, we decreased rain evaporation (for both high- and low-aerosol runs for all of cases) by applying a reduction factor which is adopted from Li et al.(2009b) but found no changes in the qualitative nature of results; the reduction factors (which is denoted by "r" in Li et al. (2009b)) applied in this investigation are 0.8, 0.5 and 0.25 as in Li et al. (2009b). This is because the aerosol-induced differences in feedbacks among downdrafts, convergence and condensation in cases of convective clouds are set up by differences in droplet evaporation but not by rain evaporation. DEEP shows this important role droplet evaporation plays in feedbacks clearly. As shown in Figure 5 and explained in the associated text, before these feedbacks set up, rain evaporation in the high-aerosol run is smaller than that in the low-aerosol run in DEEP. This is due to less conversion of cloud liquid to rain (through collections among droplets or between droplets and rain) and thus less rain precipitated to unsaturated areas in the high-aerosol run at the initial stage of cloud development, which is caused by increased aerosols. Hence, rain evaporation counters the development of more intense downdrafts and low-level convergence in the high-aerosol run. Less conversion of cloud liquid to rain increases cloud liquid suspended in the air and thus cloud-liquid evaporation in the high-aerosol run and this is the cause of more intense downdrafts, low-level convergence and subsequent stronger updrafts, condensation and more precipitation in the high-aerosol run in DEEP by setting up those feedbacks.

Another problem is that the authors never tried to establish robust base runs for the cases from the recent field campaigns and compare with many observational data available in their series publications on aerosol-cloud interactions. This is probably their fourth or fifth paper that the same cases observed in 1997 are used. I noticed that this work was supported by the DOE ARM program and the PIs are very aware of the many aerosol, cloud and precipitation data available from many recent field campaigns (after 2003). Those data are so crucial to look into aerosol-cloud interactions. I am very surprised that authors kept using the old case without detailed aerosol and cloud measurements all these years and did not bother to use the latest available observational data to obtain more solid simulations of clouds and precipitation. Many instruments for in-situ measuring aerosol and cloud data have been developed or updated/corrected and many retrieved algorithms have been developed and updated for radar and lidar measurements in the recent years. Those recent data have been very useful for many modelers to constrain/validate simulations. It is known that great progress has been made on measuring cloud microphysical properties and precipitation, and probably nobody is still using a cloud case in nineties without much constraint/validation of cloud properties and precipitation to look at the aerosol-cloud interactions. The essential thing for a good publication is to use the latest available data that accommodate the recent scientific progress to do research, especially for publications in ACP. Back to 7-8 year ago, the case could be fine since rare in-situ cloud measurements were available and the retrieved algorithms were very limited. For this study, validation of precipitation from the simulation with the measured CCN size distribution is especially necessary. At the SGP site where the cases that used in the paper are located, more instruments measuring precipitation in the recent field campaigns provide reliable precipitation data for modelers to use.

Although it is an old case, we evaluated the model performance in terms of observed precipitation and LWP. This evaluation shows that microphysical processes work reasonably well to produce macrophysical variables (i.e., precipitation and LWP) in good agreement with observation. The good agreement in precipitation and LWP between simulation and observation supports that overall model performance is good. We want to point out that results here are closely linked to cloud-liquid amount or LWP (playing very important role in the aerosol-induced changes in precipitation by determining cloud-liquid evaporation) and that the purpose of this study is to examine how aerosols affect precipitation in deep convection. Thus, the good agreement between simulated and observed LWP and precipitation indicates that the model used here produced cloud-liquid evaporation and thus feedbacks between cloud-liquid evaporation and precipitation reasonably. The good agreement also indicates that aerosols are well represented by the imposed aerosol profiles from AM2 GCM (to produce reasonable LWP and precipitation).

It is true that this old case dose not have observed microphysical variables (such as those associated with aerosols) as many as recent cases. However, it is also true that observational advancement for microphysical processes (e.g., collision and collection among hydrometeors) except for aerosol properties has not been done much over the last decade. Also, observation systems associated with dynamics for looking into aerosol-induced changes in evaporation, downdrafts and gust front are not established well yet. Hence, still, it is hard to elucidate mechanisms elaborated in this study by using observational data. This is one of most important motivations of this study. Difficulty in elucidating mechanisms associated with aerosol-cloud interactions in deep convection by using observation leads us to use a model framework to examine these mechanisms.

It is well known that the basic properties of mesoscale cloud system are driven by temperature and humidity forcings. These forcings determine basic cloud-system structure and macrophysical properties of cloud system. We used forcings produced by a constrained variational objective analysis of Zhang and Lin (1997) and Zhang et al. (2001). This analysis produces the forcing data obeying energy and mass conservation and, thus, is known to constrain simulated cloud system toward observed cloud system well. This contributes to the good agreement in LWP and precipitation between simulation and observation.

As discussed in Lee et al. (2008a,b), aerosols (whose observation improved over the last decade most among microphysical variables) only trigger feedbacks among downdrafts, gust front and condensation at the very beginning stage of simulations. These feedbacks are associated more with macrophysical processes (e.g., gust front, updrafts and downdrafts) than microphysical processes and microphysical details such as aerosol distributions don’t have strong impact on these feedbacks and precipitation increase with increasing aerosols. After the feedbacks are triggered, those feedbacks themselves determine the response of precipitation to aerosol changes and the direct impact of aerosols on feedbacks and precipitation is nearly absent. In other words, it is mostly the interactions among evaporation, downdarfts and gust front which determine the precipitation response to aerosols and aerosols are not involved in these interactions after the feedbacks are set up. This indicates that detailed aerosol data are not needed to simulate the precipitation-increase mechanism. Just the reasonable simulation of the aerosol-induced change in autoconversion (leading to changes in cloud-liquid amount as a source of evaporation) and evaporative cooling of droplets at the beginning stage of simulation is needed for the simulation of the feedbacks; the good agreement in precipitation with observation indicates that autoconversion (determining basic division between cloud liquid and precipitation) works well. This is why even a single-moment microphysics (where CDNC acts as a proxy for aerosols and there is no explicit aerosol involvement for nucleation) simulates these feedbacks (see brief description for the single-moment experiments in summary and discussion in Lee et al. (2008, JGR)) and thus we found that the qualitative results here were robust to whether a double-moment microphysics or a single-moment microphysics was used (Lee et al. (2008b, JGR)). This is also why bulk microphysics (with less detailed microphysical processes as compared to bin microphysics) is able to simulate these feedbacks as bin microphysics. Hence, although observed aerosol data are not used, the precipitation variation with aerosols is likely to be robust to what the original aerosol input is; also, as mentioned above, want to note that the good agreement between simulation and observation indicates that aerosol input used in this study is not that unreasonable. To confirm this, we repeated the high-aerosol run in MID and DEEP with different aerosols. These different aerosols are also from AM2 and correspond to the minimum and the maximum aerosol number for the period between June 28th and 30th 1997. We compared these repeated high-aerosol runs with the maximum and minimum aerosols (with different aerosol size distributions) to the low-aerosol run in each of MID and DEEP. From this comparison, we found no changes in the qualitative nature of results; the minimum aerosol number is larger than the aerosol in the low-aerosol run and, thus, these repeated simulations with the minimum and maximum aerosol numbers both act as a high-aerosol run relative to the low-aerosol run and aerosol number varies between the minimum and the maximum by a factor of ~ 6.

We agree that better observational campaign can provide us with more detailed observation to restrain and evaluate simulations. However, we think this does not mean that we should use most recent observational data. We want to note that most important findings of cloud physics and dynamics are from CSRM studies in 70s and 80s. These studies in 70s and 80s used necessary observed data to evaluate what was simulated, though these data were sparse as compared to those in recent years. These studies utilized observed data just fitting into their research purposes. In the same context, we think the purpose of this study does not require very detailed microphysical and aerosol data. Large-scale temperature and humidity forcings driving cloud system (especially cloud macrophysical properties (e.g., evaporation and downdrafts) mainly controlling precipitation-increase mechanisms) are most essential for the simulation of aerosol effect on precipitation and these forcings constrained by objective analysis of Zhang and Lin (1997) and Zhang et al. (2001) are good enough to drive cloud system in a reasonable way.

Also, we want to point out that there are still many studies using data from old campaign due to reasons explained above. For example, a recent study by Tao et al. (2007, JGR) used data from TOGA COARE (done in 1993) and PRESTORM (done in 1985) (older than our ARM case here) and were able to simulate the interactions between cold pool and precipitation (i.e., interactions between evaporative cooling, downdrafts and precipitation) and their variation with aerosols with a good agreement between simulation and observation. Also, Khain et al. (2009, D22203,JGR), Li et al. (2009a, JAS, Part I) and (2009b,JAS, Part II) (these are the very papers cited by the reviewer here) simulated PRESTORM case for the comparison between bin microphysics and bulk microphysics. Even data from older campaigns CCOPE and GATE done in 1981 and 1974, respectively, are used in the recent studies of Cui et al. (2006, JGR), Phillips, Pokrovsky and Khain (2007, JAS), Khian, Cohen, and Pokrovsky (2008, JAS) and Khain, Benmoshe and Pokrovsky (2008, JAS); these studies made a significant contribution to the understanding of aerosol-cloud interactions in deep convection. This indicates that using the 1997 ARM case is not that outdated.

Last, we want to emphasize that the main purpose of this study is not to evaluate model using observation as in the above-mentioned studies (e.g., Tao et al. (2007, JGR), Khain et al. (2009, JGR), Li et al. (2009a, JAS, Part I) and (2009b,JAS, Part II), Cui et al. (2006, JGR), Phillips, Pokrovsky and Khain (2007, JAS), Khian, Cohen, and Pokrovsky (2008, JAS) and Khain, Benmoshe and Pokrovsky (2008, JAS)) but to elucidate mechanisms (which are hard to be elucidated by observation) by using idealized model frameworks as utilized in MID and SHALLOW. We believe the mechanisms about the relative role of evaporation to that of freezing for aerosol-induced precipitation enhancement (elucidated by model results here) are not investigated in previous studies and hence are unique and merit publication.

I generally agree that stronger downdrafts will occur in the deep convective clouds than the stratiform clouds, but it could be mainly due to the enhanced updraft from the increased latent heat release (condensational growth) in the polluted case.

Note that latent heat release from condensational growth increases in both deep convective clouds and stratiform clouds. Our one of other studies (Lee,Penner,Saleeby (2009,JGR)) showed that this increase in condensation in stratiform clouds lead to larger LWP in a polluted case as shown in this study. However, this does not lead to larger precipitation in a polluted case in Lee,Penner, Saleeby (2009, JGR) as in SHALLOW here, since downdrafts do not have a long enough path to the surface as they descend to the surface in SHALLOW as described in the text. Hence, the increased intensity of downdrafts at the level of evaporation is not magnified enough to induce much stronger convergence around the surface with increased aerosols. This prevented additional increases in updrafts, condensation and accretion of cloud liquid by rain (in addition to increases in updrafts and condensation only from microphysical causes pointed out by the reviewer here), leading to smaller precipitation in a polluted case in SHALLOW. However, in DEEP, the intensified downdrafts can be magnified as they descend due to the longer path to the surface as compared to that in SHALLOW (see Figure 8 in Lee,Donner,Phillips,Ming (2008, QJRMS) for the acceleration of downdrafts in deep convective clouds). This increases the intensity of convergence around the surface in a polluted case, leading to an additional increase in updrafts. This additional increase in updrafts enables additionally and substantially increased condensation and accretion of cloud liquid by rain, leading to more precipitation in a polluted case in DEEP.

Just aerosol increase (per se) can increase condensation by providing increased total surface area of droplets where water vapor deposit as described in Lee,Penner,Saleeby (2009,JGR). Hence, condensational heating increases with increasing aerosols in any type of clouds. However, this (microphysical cause) alone cannot increase precipitation in a polluted case. There should be a subsequent intensification of low-level convergence through that of downdrafts for the precipitation enhancement in deep convective clouds based on the fact that the absence of strong intensification of downdrafts and low-level convergence (due to shallow cloud depth) leads to smaller precipitation despite increased condensation in a polluted case in a case of stratocumulus clouds.

We carried out additional simulations for DEEP by reducing evaporative cooling of droplets in the high-aerosol run following a method similar to that of Li et al. (2009b). We multiplied the droplet evaporation in the high-aerosol run by a reduction factor to make cumulative evaporation in the high-aerosol run to be identical to that in the low-aerosol run; the reduction factor is calculated based on the difference in the cumulative evaporation shown in Table 2. With reduction only in the droplet evaporation in the high-aerosol run in DEEP, precipitation increases in the low-aerosol run (despite more condensation in the high-aerosol run) whether ice physics is included or not. This demonstrates that the critical role of increase in droplet evaporation in the intensification of low-level convergence and precipitation enhancement with increasing aerosols.

Evaporative cooling would contribute to the increased downdraft, but obviously the model with the bulk scheme overestimates it's contribution (see 1st paragraph) and thus the results built on that would not be valid.

We did not use a saturation adjustment but we used a scheme predicting supersaturation explicitly for evaporation of all species of hydrometeors. This prevents the overestimation of evaporation as explained above. Li et al. (2009b) indicated the bulk representation of rain evaporation can lead to overestimation of evaporative cooling. However, our additional simulations with reduction factors for rain evaporation show that results here are robust to how rain evaporation is parameterized due to reasons explained in one of our above comments (see our second comment above for details). Also, as explained above, the sedimentation of all hydrometeors including rain (known to affect evaporation of precipitable hydrometeors significantly) is simulated by emulating a full-bin model with 36 bins (see section 2.2 in the manuscript for details). The use of the supersaturation prediction and this sedimentation method leads to a better simulation of rain evaporation than single-moment microphysics, which is demonstrated by a well-defined trailing region of stratiform clouds in this study.

Based on many past studies on the cases with bulk schemes and the size-resolved scheme (e.g., Seifert et al. 2006, Atmos. Res.,v80, Khain et al 2009a, b, and Li et al 2009a, b), bulk microphysical schemes have big problems in simulating precipitation, therefore, the results of the paper built on that could be wrong.

We want to reiterate that the bulk microphysics used here is different from generally used bulk microphysics, since the bulk microphysics used here considers the size spectral information for collection processes and does not use a threshold mixing ratio and constant or average collection efficiencies. Lee,Penner,Wang(2009,ACP) and Lee,Penner(2010,ACPD) showed that the use of size spectral information for collection processes led to much better agreement between simulation and observation than the use of threshold value for autoconversion and constant collection efficiency for collection between precipitable hydrometeors and cloud liquid or cloud ice.

As stated above, the only difference between the bulk scheme used here and the bin scheme (regarding collection processes) is the assumption of size distribution for hydrometeors; the bulk scheme here assumes a gamma distribution while bin scheme assumes no specific distribution. It is well known that hydrometeors follow the gamma distribution and, thus, bulk scheme with the gamma distribution has been used in numerous case studies and showed good agreement with observation (e.g., Wang and Feingold (2009,3237-3256,JAS), Wang and Feingold (2009,3257-3275,JAS), Lee,Donner,Penner (2010,ACPD), Walko et al. (1995, Atmos. Res.), Meyers et al. (1995, Atmos. Res.) and Saleeby and Cotton (2004, JAM)); this is also supported by Seifert et al. (2006, Atmos. Res) indicating that the exact shape of size distribution of hydrometeors is not of importance to the reasonable simulation of precipitation.

We also want to reiterate that Khain et al.(2009a,b) and Li et al. (2009a,b) used a single-moment microphysics while this study used a double-moment microphysics. As explained above, Morrison et al. (2009, MWR) showed that a double-moment microphysics simulated a much more realistic squall line, evaporation and precipitation in it than a single-moment microphysics.

We want to note that bin microphysics also has problems. There are still unresolved issues related to application of bin schemes to CSRMs with relatively low spatial resolutions (on the order of 100m) used for mesoscale studies (like this study) (e.g., droplet nucleation, cf., Saleeby and Cotton, 2004, and the impact of entrainment and mixing on cloud droplet spectra, cf., Grabowski, 2006, J. Climate). Also, most of bin schemes (including Khain's HUCM model) still do not adopt ice nucleation schemes considering aerosol effect explicitly. They just rely on temperature or supersaturaion to calculate the number of ice crystals nucleated. They also do not consider the haze-particle homogeneous freezing, playing an important role in the aerosol-induced changes in anvil clouds and cloud radiative forcing (Lee,Donner,Phillips (2009, ACP)). However, ice nucleation scheme considers the impact of aerosol properties on ice nucleation and haze particle freezing is considered in this study. Most of bin schemes (including Khain's HUCM model) do not consider aerosol size distribution, aerosol chemical composition, and supersaturation explicitly for droplet nucleation. Supersaturation here indicates the peak of supersaturaion around cloud base occurring in a 10-m layer; hence, this supersaturation can't be resolved in the CSRM simulations with a vertical resolution of ~ 100m. This supersaturation should be calculated for accurate droplet nucleation as is done in this study. However, most of bin models (including Khain's HUCM model) just assume that supersaturation resolved by the CSRM grid can be used for nucleation and, based on this assumption, use the following formulation for droplet nucleation:

$$\mathrm{Nccn} = \mathrm{C}s^{k}$$

Here, Nccn is number of CCN activated, s supersaturation (%), C and k parameters that depend on the airmass type; here, s is supersaturation resolved by grids. This is just an empirical formulation with no explicit consideration of aerosol properties and no parameterization of sub-grid supersaturation. However, this study used Abdul-Razzak and Ghan's (2000,2002,JGR) scheme considering those properties and sub-grid supersaturation.

Seifert et al. (2006) indicated that the most important ingredient to achieve a good agreement of the bulk scheme with the spectral bin method is an accurate representation of the warm phase autoconversion process. Seifert et al. (2006) pointed out that the use of threshold for autoconversion can be problem. Hence, they developed an autoconversion scheme (for a double-moment microphysics) less relying on the threshold by using stochastic collection equation as in this study. However, their scheme is not as sophisticated as the one used here, since their scheme used a function-form collection kernels while the scheme in this study used realistic collection kernels. Using their autoconversion scheme, Seifert et al. (2006) indicated that both approaches (i.e., bin model and double-moment model) predict a similar evolution of the important microphysical and dynamical variables, e.g. surface precipitation and maximum updraft velocities, when applied to cloud resolving simulations of mixed-phase deep convection.

Also, as pointed out by Seifert et al. (2006), for the bin approach, a very large number of model variables has to be handled which is currently and in near future too expensive for mesoscale models. At present, double-moment schemes are the most promising microphysical compromise (between computational cost and realistic simulations) to be used in models for mesoscale cloud-resolving simulations since they show a forecast skill superior to commonly used single-moment cloud microphysical schemes (as used in Li et al. (2009a,b)) and comparable to bin microphysics (Seifert et al., 2006, Atmos. Res. and Morrison et al., 2009, MWR). These schemes are computationally efficient, since the number of variables is generally increased only by a factor of two compared to a single-moment mixed-phase scheme.

For a simulation with ice physics in this study, we used 64 cpus; we used NERSC supercomputing system for simulations in this study. It took ~ 15 days to complete a simulation in this study. Considering a bin microphysics which uses ~ 30-40 times more variables than a double-moment microphysics, it will take ~ 2 months to complete simulations (even though we use ~ 640 cpus). This time frame and use of cpus are not practical at this point. This and the studies of Seifert et al. (2006, Atmos. Res.) and Morrison et al. (2009, MWR) indicate that the use of double-moment microphysics is a best compromise between realistic cloud simulation and available computational cost.

Thomson's scheme used in the comparison study by Khain et al. (2009a,b) is also a type of single-moment microphysics relying on the threshold for autoconversion with no consideration of spectral information of hydrometeor size distribution. Also, Thomson's scheme is coupled with a saturation adjustment. As described in Li et al. (2009b), this type of microphysics can overestimate evaporation. Khain et al. (2009a) also find this overestimation of evaporation as well as that of updrafts and thus condensation. This is also shown by our comparison studies (e.g., Lee,Penner,Wang (2009,ACP), and Lee,Penner (2010,ACPD)). Khain et al. (2009a) indicated differences in squall-line structure between bin-model and bulk-model simulations and Li et al. (2009b) pointed out that they can be caused by too much evaporation and high hail speed. As explained above, this study predicts supersaturation explicitly preventing overestimation of evaporation (not by eliminating subsaturation at one time step as shown by Lee,Penner,Wang (2009,ACP) and Lee,Penner (2010,ACPD)) and bin method is applied to the calculation of hail speed and hail sedimentation. For each size of hail in each bin of size distribution, experimental data constructing a power-law relation between fall speed and mass for hail are applied. Also, the sedimentation is simulated by emulating a full-bin model with 36 bins (see section 2.2 in the manuscript for details). As mentioned above, this simulates the sedimentation with better confidence than previous treatments of sedimentation that use a mass-weighted fall speed used in Thompson's scheme and the Lin style microphysics in Li et al. (2009a,b). The following is brief description of how sedimentation is treated in the scheme used here in the manuscript:

"The philosophy of bin representation of collection is adopted for calculations of drop sedimentation. Bin sedimentation is simulated by dividing the gamma distribution into discrete bins and then building lookup tables to calculate how much mass and number in a given grid cell falls into each cell beneath a given level in a given time step. 36 bins are used for collection and sedimentation. This is because Feingold et al. [1999] reported that the closest agreement between a full bin-resolving microphysics model in a large eddy simulation (LES) of marine stratocumulus cloud and the bulk microphysics representation was obtained when collection and sedimentation were simulated by emulating a full-bin model with 36 bins."

Khain et al. (2009a,b) pointed out the deficiency of bulk microphysics associated with aerosol nucleation scavenging; note that the impaction scavenging plays a minor role in aerosol scavenging as compared to the nucleation scavenging. However, we want to note that the nucleation scavenging with clouds is considered in this study, although background aerosols are fixed. Within clouds, aerosol number varies due to nucleation scavenging, advection, and diffusion. We repeated simulations for DEEP with background aerosols not fixed as well as varying aerosols within clouds and found no qualitative differences from the original simulations.

Khain et al. (2009a,b) and Li et al. (2009a,b) also pointed out the non-optimal structure of squall line (having irregular convective elements in the trailing stratiform clouds and thus having unclear trailing regions) simulated by a bulk scheme (i.e., single-moment scheme); they explained that this was due to the overestimation of evaporation. We did not carry out simulations for squall lines using the microphysics used in this study. However, we were able to simulate clear convective areas and following anvil cirrus and stratiform clouds with no convective areas; we think the elimination of convective structures in anvil and stratiform cloud regions is due to the use of the prediction of supersaturation preventing over-condensation and evaporation. Also, as simulated with bin microphysics in Li et al. (2009a), this study shows that the stratiform region simulated contributes to about 25% of the total surface rainfall in DEEP, compared with a narrow stratiform region that contributes to only 7% of the total rainfall in the single-moment bulk simulation used in Li et al. (2009a,b). Hence, evaporation simulated in this study can be considered reasonably represented by the double-moment microphysics used here. Li et al. (2009b) pointed out more rain evaporation (in the bulk scheme) as a cause of overestimation of evaporation and thus of differences in results between the bin scheme and the double-moment scheme. We decreased rain evaporation (following the method of Li et al. (2009b)) but found no changes in the qualitative nature of results (e.g., precipitation and the structure of convective system) as described above. This is because the aerosol-induced differences in feedbacks among downdrafts, convergence and condensation are set up by differences in droplet evaporation and the non-optimal structure does not occur due to the use of the supersaturation prediction.

Li et al. (2009b) pointed out another uncertainties of bulk microphysics associated with ice physics. In this study, full stochastic collection solutions for self-collection is applied among ice crystals (or cloud ice) and for the collection of cloud droplets and ice crystals by precipitable hydrometeors based on Feingold et al. (1988, JAS) as among liquid particles. The bin representation of collection is adopted for the calculations of hydrometeor sedimentation for solid particles as for liquid particles. Each species of solid particles (cloud ice, snow, aggregates, graupel, and hail) has its own terminal velocity. The terminal velocity of each species is expressed as power law relations (see Eq. (7) in Walko et al. (1995, Atmos. Res.)). A Lagrangian scheme is used to transport the mixing ratio and number concentration of each species from any given grid cell to a lower height in the vertical column, following Walko et al. (1995). Also, to account for the variability of crystal type under different environmental conditions, the capacitance and mass-dimensional relations of pristine ice crystals and snow are allowed to vary. Since the model does not keep track of the history of all crystals, a simple diagnostic check of the ambient temperature and saturation conditions at each grid location is performed during each time-step to determine the crystal habit; see Table 1 in Meyers et al. (1997. Atmos. Res.) for the habit diagnosis adopted here. The habit diagnosis impacts the model in several ways. The capacitance is dependent on crystal type (Harrington et al., 1995) and may change the growth characteristics of the crystals. Different types of crystals fall at different speed which is determined by the power law relation, affecting sublimation differently. Hence, we believe ice physics used here is advanced enough to minimize uncertainties associated with ice physics.

We think the double-moment microphysics used here is able to overcome shortcomings (pointed out the papers cited by the reviewer here) in the previous bulk schemes reasonably well. This is based on comparison studies (Lee,Penner, Wang (2009, ACP), Lee, Penner (2009, ACPD), Seifert et al. (2006,Atmos. Res.) and Morrison et al. (2009, MWR)) and additional sensitivity tests descried above. The assumption of hydrometeor distribution in the bulk model used here can be justified by Seifert et al. (2006, Atmos. Res) and simulations with various distributions showing that the model results are robust to the assumed distributions. Hence, we believe the bulk scheme used here gives us results fairly reliable, also considering more reasonable treatment of nucleation than bin models and sophisticated ice physics adopted in this study.

We want to note that Li et al. (2009a,b) used 500m horizontal resolution with 2D domain and Khain et al. (2009a) used 2km horizontal resolution with 3D domain. Khain et al. (2009b) used 1 km resolution with 2D domain; these papers are cited by the reviewer here to indicate the shortcomings of the single-moment microphysics. We used 3D domain with 200m horizontal resolution. Studies show coarse resolution or 2D domain can contribute to unrealistically high updrafts, evaporation and precipitation (Phillips and Donner (2007,QJRMS), Lee,Penner,Wang (2009, ACP), and Lee and Penner (2009,ACPD)). In addition to the use of the single-moment microphysics coupled with the saturation adjustment, the use of rather coarse resolution and/or the use of 2D domain may have contributed to the simulated larger updrafts, evaporation and precipitation with the single bulk scheme than with the bin scheme in Li et al. (2009a,b) and Khain et al. (2009a,b). The use of higher resolution (than the studies cited by the reviewer here) and 3D domain acts to minimize the possibility of occurrence of unrealistically high updrafts, evaporation and precipitation and, thus, indicates that this possibility (associated with resolution and domain setup) is likely to be much lower in this study than that in the studies cited by the reviewer here.

Even if it is not, the results can not be generalized because evaporative cooling highly depends on dynamic and thermodynamic conditions (e.g., wind shear and RH). A recent work has indicated the increase of the condensational heating could easily exceed the increase of evaporative cooling by CCN under the weak wind shear conditions (Fan et al 2009, JGR).

First of all, we want to say that we used a strong wind-shear condition for all of cases according to the criterion set by Fan et al. (2009).

Note that Fan et al. (2009) simulated an isolated deep convective cloud, while this study simulated a mesoscale cloud ensemble. Hence, Fan et al. (2009) was not able to see the effect of aerosols on the subsequent development of secondary clouds over large domain through aerosol effects on downdrafts and low-level convergence which is simulated in this study. This is why Fan et al. (2009) simulated suppressed convection due to increased evaporation with increasing aerosols in a strong wind-shear condition, whereas this study simulated invigorated convection (in terms of averaged intensity of convection over the mesoscale domain) with the strong wind-shear condition. Increased evaporation only affects the isolated one single cloud in Fan et al. (2009) and this suppresses convection. However, in this study and Lee et al. (2008, QJRMS), the increased evaporation with increased aerosols affects subsequent numerous clouds over the mesoscale domain, leading to overall intensification of mesoscale cloud system. This is also pointed out by Fan et al. (2009). Fan et al. (2009) cited one of our studies (i.e., Lee et al. (2008, JGR)) and indicated as follows:

"Wind shear was found to have another role in regulating aerosol effects on deep convective clouds for squall lines [Tao et al., 2007] and cloud ensembles [Lee et al., 2008]. The evaporative cooling enhanced by wind shear could enhance precipitation by secondary cloud formation through a stronger cold pool. This dynamic feedback can contribute to increased total convective area and precipitation [Tao et al., 2007; Khain, 2009]. Therefore, we stress that our results may only be applicable to isolated storms."

In the same context, for the single isolated cloud, in a weak wind-shear condition, the magnitude of increase in evaporation can be smaller than that in condensation with increasing aerosols due to no impact of evaporation on subsequent secondary clouds in mesoscale domain; in a weak wind-shear condition, the transportation of cloud liquid to unsaturated areas and thus cloud-liquid evaporation reduces. However, for mesoscale cloud ensemble in a weak wind-shear condition, the effect of evaporation on subsequent cloud through the intensification of low-level convergence can be weakened and thus the subsequent increase in condensation in subsequent clouds can be smaller than the increase in evaporation as shown in LOW CAPE case in Lee et al. (2008, JGR).

For the mesoscale cloud ensemble, when environmental humidity is high, increase in evaporative cooling with increasing aerosols can decrease (efficiency of evaporation can be lowered when droplets are detrained into environment), leading to decreased intensification of low-level convergence and suppression of mesocale cloud ensemble with increasing aerosols. But, the drying effect of entrained air into cloud will be lower with high humidity (Khain et al. (2007)). However, when environmental humidity is low, the evaporation efficiency and thus increase in evaporation with increasing aerosols (thus increase in the intensity of low-level convergence and condensation) will be larger, which can lead to the intensification of subsequent cloud and thus of mesoscale cloud ensemble. But, dry humidity increases the drying effect of entrained air into cloud and this can oppose the effect of evaporation on low-level convergence and condensation. Hence, there is a competition between entrainment and the effect of evaporation on low-level convergence and subsequent condensation (with increasing aerosols) to determine the sign of the effect of aerosols on the intensity of cloud ensemble for a given humidity condition. The investigation of this competition between entrainment and interactions between evaporation and low-level convergence and its variation with humidity will merit future study. Also, we want to add that since one of our papers (Lee et al. (2008,JGR)) already examined the dependence of the effect of aerosols on clouds on environmental conditions such as wind shear and CAPE, we did not pursue the understanding of the dependence on wind shear and CAPE in this submitted study.

We want to emphasize that the purpose of this study is to examine the relative role of freezing (associated with parcel buoyancy) to that of evaporation (associated with low-level convergence) in the aerosol-induced intensification of convection and to isolate the dependence of the relative role on cloud morphology represented by cloud-top height and depth (but not on environmental conditions). Hence, for the better isolation of the dependence on cloud morphology, we applied nearly identical environmental conditions (e.g.., RH and wind shear) for all cases in this study. Thus, contrary to the concern raised by the reviewer here, the near identical environment can give us an insight into cloud morphology controlling the dependence with better confidence. However, we will remove statement associated with generalization of results here and add statement to discuss about the effect of humidity and differences between this study and study with an isolated cloud.

Based on the problems that I concerned above, I cannot recommend the paper for publication in ACP. The authors either need to carry out this study based on a well constrained recent case (especially in aerosol and cloud properties and precipitation, or need to constrain their cases with the results from a size-resolved cloud microphysics under the same CCN inputs, with the focus on precipitation and evaporative cooling.

We believe double-moment microphysics used here can get over shortcomings of bulk microphysics pointed out by the reviewer here (see our responses above for details). We also believe that the case we used here can give fairly enough information for the investigation of the aerosol-triggered variation of feedbacks between dynamics and precipitation. (see our responses above for details).

There are some other problems regarding the results and the reasoning throughout the paper. For example, the authors examined the convergence instead of the droplet evaporation rate directly in terms of the role of evaporative cooling, which I do not understand because convergence can be affected by many factors and evaporative cooling is only one of them.

We carried out additional simulations by reducing the evaporative cooling of droplets in the high-aerosol run for DEEP and MID, respectively, following the methodology similar to that of Li et al. (2009b) (for rain evaporation). We multiplied the droplet evaporation in the high-aerosol run by a reduction factor to make cumulative evaporation in the high-aerosol run to be identical to that in the low-aerosol run; the reduction factor is calculated based on the difference in the cumulative evaporation shown in Table 2. With a reduction only in the droplet evaporation in the high-aerosol run in DEEP, precipitation decreases in the high-aerosol run whether ice physics is included or not in these additional simulations. This demonstrates the critical role of increase in droplet evaporation in the intensification of low-level convergence and precipitation enhancement with increasing aerosols. In MID, due to reduced droplet evaporation (leading to the reduced intensity of low-level convergence), precipitation decreases in the high-aerosol run in these additional simulations as compared to precipitation in the standard high-aerosol run in each of cases with and without ice physics. However, the sign of precipitation response to aerosols for each of cases with and without ice physics in MID does not change in these additional simulations as compared to that in the standard simulations. In other words, in these additional simulations with no ice for MID, less intensified low-level convergence in the high-aerosol run as compared to that in the standard high-aerosol run leads to more decreased precipitation in the high-aerosol run as compared to that in the standard high-aerosol run. With ice for MID in these additional simulations, though the intensity of low-level convergence decreases in the high-aerosol run (as compared to that in the standard high-aerosol run), the ice physics still enables more precipitation in the high-aerosol run.