First of all, we would like appreciate the reviewer’s comments and suggestions. In response to the reviewer 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 reviewers. Each comment of the reviewer is listed and followed by our responses (between dotted lines).

# Interactive comment on “Factors determining the effect of aerosols on cloud mass and the dependence of these factors on liquid-water path” by S. S. Lee and J. E. Penner

**Anonymous Referee #2**

Received and published: 26 October 2009

The submitted manuscript examines aerosol-cloud interactions in marine stratocumulus. Specifically, the work attempts to explain an apparent dichotomy between clouds of low and high liquid water path (LWP). Using the Goddard Cumulus Ensemble (GCE), the authors perform eight simulations generating mean LWPs ranging from 73.3 g m$_{-2}$ down to 36.2 g m$_{-2}$ by simply multiplying or dividing the latent heat flux from the surface by an arbitrary factor. It is noted that the clouds are considered to be “thin” when the LWP is less than about 50 g m$_{-2}$. A budget analysis of the production and loss terms (i.e., condensation, evaporation, autoconversion, accretion, and sedimentation) is performed to analyze the microphysical nature of each cloud. This analysis shows that condensation/evaporation is at least 1-2 orders of magnitude greater than the remaining processes for all cases, thus implying that the LWP is more-or-less controlled by the condensation/evaporation rate and not the autoconversion, accretion, or sedimentation rates.

The LWP is shown to increase in all simulations when run with present day (PD) aerosol concentrations in comparison to the runs performed with pre-industrial (PI) aerosols, except for when the latent heat flux is divided by 5 (LH-D5). The focus of the paper shifts towards explaining this occurrence. The authors show that the evaporation rate is higher under PI conditions (i.e., low aerosol concentration), leading to more cooling via latent heat released immediately below cloud base. This cooling creates a more unstable environment in comparison to the PD simulation, hence providing more available water vapor for condensation within the cloud. With that said, the paper does not address why the LWP decreases from PI to PD when the latent heat flux is divided by 5, but increases when the latent heat flux is divided by 10 (and thus resulting in an even lower LWP).

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As explained in Section 5.3, the smaller increase in the cloud-base rain evaporation in the low-aerosol run in LH-D10 than in LH-D5 cools cloud base less, leading to the smaller increase in cloud instability. The time- and area-averaged decrease in the cloud-base potential temperature in the low-aerosol run as compared to potential temperature in the high-aerosol run over the whole simulation period is 2.5 K and 1.7 K for LH-D5 and LH-D10, respectively. Hence, the increase in the instability is not large enough, resulting in smaller LWP at low aerosol in LH-D10, whereas the instability increase is large enough to increase LWP at low aerosol in LH-D5.

The following is added:

(LL490-493 in p17)

Due to this, the time- and area-averaged difference (high - low) in potential temperature at cloud base during the time integration between the high- and low-aerosol runs is 2.5 K in LH-D5, while the difference is 1.7 K in LH-D10.

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Major Comments:

A) Significance of Scientific Contribution

The manuscript lacks significant scientific advancement from previous works. In fact, much of the discussion found in the manuscript can be traced back to the authors' previous work in the paper entitled Aerosol Effects on Liquid-Water Path of Thin Stratocumulus Clouds (Lee et al., 2009). The previous study used the GCE to study aerosol effects on thin stratocumulus clouds (i.e., clouds with LWP smaller than about 50 g m_2) by initializing the simulations with different temperature and specific humidity profiles. The chosen profiles produce mean relative humidities at the top of the planetary boundary layer (PBL) ranging from 40% to 80% (dry to wet, respectively). Furthermore the LWP ranges from about 60 g m_2 for the high aerosol concentration and the wet case down to about 13 g m_2 for the low aerosol concentration and mid-wet run (Fig. 4, Lee et al.,2009). Moving to the study at hand, we find that the range of LWPs produced is in fact smaller than that of the previous work (i.e., 73.3 g m_2 down to 36.2 g m_2). Moreover, except for the high aerosol, increased latent heat flux case in the present study, the LWPs shown all fall within the range of those presented in the previous study.

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The reviewer here compared the maximum LWP and the minimum LWP during the time integration among WET, MID-WET, and DRY in Lee et al. (2009) to the time- and domain-averaged LWP in the present study. We think it is more reasonable to compare these maximum and minimum values of the LWP in Lee et al. (2009) to the maximum and minimum values simulated during the time integration in this study. Or it is also reasonable to compare the time- and domain-averaged LWPs in Lee et al. (2009) to those in this study. The maximum value of the LWP in Lee et al. (2009) is ~ 60 g $m^{-2}$, while it is ~ 320 g $m^{-2}$ in this study (compare Figure 4 in Lee et al. (2009) to Figure 6 in this study). Associated with this, all simulations have the time- and domain-averaged LWP of smaller than 50 g $m^{-2}$ in Lee et al. (2009), whereas two cases (i.e., CONTROL and LH-M5) have the time- and domain-averaged LWP of larger than 50 g $m^{-2}$. Based on the classification of Turner et al. (2008), generally, clouds with the LWP smaller than 50 g $m^{-2}$ can be considered thin. This indicates that clouds in Lee et al. (2009) are mostly thin clouds, whereas the significant portion of clouds simulated here is thick. In thick clouds in CONTROL and LH-M5, the conversion efficiency (the ratio of conversion to condensation) is 3 – 15 % which is ~ one order of magnitude larger than that in thin clouds in LH-D5 and LH-D10 and ~ one to two orders of magnitude larger than that in thin clouds in all of cases in Lee et al. (2009). This demonstrates the obvious differences between cloud type in LH-M5 and CONTROL and that in LH-D5, LH-D10, WET, MID-WET, and DRY, enabling us to examine how factors controlling aerosol-cloud interactions in warm clouds vary with transition of cloud type from thick clouds to thin clouds in this study. However, in Lee et al. (2009), only thin clouds with extremely low conversion efficiency are simulated, disabling us from the examination of the variation in factors with the transition. Also, want to point out that the averaged-LWP in LH-M5 is in the LWP range of one of the highest observation frequencies reported by McComisky et al. (2009) as discussed in the manuscript, enabling us to study aerosol-cloud interactions in most probable clouds, whereas none of the clouds have this LWP range in Lee et al. (2009).

In Lee et al. (2009), there are no consistencies in environmental conditions among the cases making it difficult to isolate the dependence of the conversion efficiency on condensation (determining the LWP or cloud thickness), leading to the varying role of the conversion and thus sedimentation (or precipitation) with the level of LWP or cloud thickness. Hence, Lee et al. (2009) dose not focus on the isolation of the dependence and, instead, they focus on the very low conversion efficiency in thin clouds, which is robust to various environmental conditions if these conditions are favorable for the formation of thin clouds. However, in this study, we controlled the environmental condition in a way that there is no variation of environmental conditions above the surface, enabling us to compare clouds with different LWPs by excluding the effect of the above-surface environment (such as humidity around cloud-top and large-scale subsidence known to affect clouds and aerosol-cloud interactions) on the comparison, enabling the isolation with better confidence.

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The manuscript also attempts to explain the effect of instability on LWP using the case in which the latent heat flux is divided by 5 (LH-D5). Table 2 in the present manuscript shows that this is the only case in which the LWP decreases with increased aerosol concentrations (from 40.9 g m$_{-2}$ to 39.9 g m$_{-2}$). The explanation (as described above) for this discrepancy is that the evaporation of rain is higher for the low aerosol (PI) case in comparison with the high aerosol case (PD). The latent heat released as result of the evaporation is higher in the PI case. Hence, the sub-cloud layer is more unstable and the updrafts are invigorated (Fig. 12). However, if we turn our attention back to Fig. 4 of Lee et al. (2009) we find that the LWP in the dry case is more or less the same for the low and high aerosol runs. The text claims that the time- and domain-averaged LWPs are 29.70 and 30.21 g m$_{-2}$ for the high and low aerosol runs, respectively. Again, we have a (slightly) higher LWP for the low aerosol scenario. This discrepancy is explained well by Fig. 11 in Lee et al. (2009), which is qualitatively the same as Fig. 12 in the present manuscript. The magnitudes of the evaporation, heating, and conversion rates may differ slightly between Fig. 11 of Lee et al. (2009) and Fig. 12 of the current work, but they are qualitatively identical and explain the exact same phenomenon, previously discussed in Feingold et al. (1996). The important factor here is that precipitation does not reach the ground for the corresponding cases in both the present manuscript and Lee et al. (2009).

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Although mechanisms explained for the effect of aerosols on clouds with no surface precipitation in this study are similar to those in Lee et al. (2009), we do not believe that the study here is identical to that in Lee et al. (2009). This is because the main purpose of this study is to examine the dependence of factors controlling aerosol-cloud interactions in stratocumulus clouds on the cloud thickness represented by the LWP level, whereas the purpose of the study of Lee et al. (2009) is to examine aerosol-cloud interactions only in thin clouds with the LWP < 50 g m$^{-2}$; this study simulates clouds with the LWP > 50 g m$^{-2}$ as well as those with the LWP < 50 g m$^{-2}$ to examine the dependence.

We also want to emphasize that LH-D5 is compared to LH-D10 in this study to show that varying difference in the cloud-base precipitation between the high- and low-aerosol runs with varying cloud thickness can result in the different sign of the effect of aerosols on the LWP in the absence of the surface precipitation. However, the previous study only investigates the case with the decreased LWP with the increased aerosols in the absence of the surface precipitation.

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B) Language and Understandability

First and foremost, entire paragraphs have been taken verbatim from Lee et al. (2009). For example, paragraph 17 of Lee et al. (2009,) is duplicated in section 3 of the current manuscript, paragraph 38 and the first half of paragraph 39 of Lee et al. (2009) is replicated at the beginning of section 5.3, and paragraph 41 of Lee et al. (2009) is used in section 5.3 (pg. 19326), just to name a few. If a difference exists between the two works, it merely lies in the naming convention, figure number, and/or LWP value; there is absolutely no difference in the verbiage used in the explanations. This is entirely unacceptable.

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We revised the parts pointed out here as follows. Also, the other parts from Lee et al. (2009) in the old manuscript are re-written.

"Reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) provide initial conditions and large-scale forcings. The 6-hourly analyses were applied to the model as a large-scale advection for potential temperature and specific humidity at every time step by interpolation. Temperature and humidity were nudged toward the large-scale fields from the ECMWF using the large-scale advection. The horizontally averaged wind from the GCE model was also nudged toward the interpolated wind field from ECMWF at every time step with a relaxation time of one hour, following Xu et al. (2002). The model domain is considered to be small compared to large-scale disturbances. Hence, the large-scale advection is approximated to be uniform over the model domain and large-scale terms are defined to be functions of height and time only, following Krueger et al. (1999). Identical observed surface fluxes of heat and moisture were prescribed in both the high- and low-aerosol runs. This method of modeling cloud systems was used for the CSRM comparison study by Xu et al. (2002). The details of the procedure for applying large-scale forcing are described in Donner et al. (1999) and are similar to the method proposed by Grabowski et al. (1996)."

is replaced with

(LL154-156 in p6 in the new manuscript)

"Initial conditions and large-scale forcings are provided by the reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF). These data are applied in the same mannter as in Lee et al. (2009a)."

We think the text associated with the description of Eqs.(3) and (4) needs to remain instead of asking readers to refer to Lee et al. (2009), since the description is very important in understanding the interactions between CDNC and supersaturation.

"Among the variables associated with the condensational growth of droplets in Eq. (3), differences in the supersaturation and CDNC contribute most to the differences in condensation between the high- and low-aerosol runs. Percentage differences in the other variables are found to be ~ two orders of magnitude smaller than those in supersaturation and CDNC throughout the simulations. Figure 8 shows the time series of CDNC and Figure 9 the time series of supersaturation, conditionally averaged over areas where the condensation rate > 0, for the cases in this study."

is replaced with

(LL381-386 in p13 in the new manuscript)

"Differences in condensation between the high- and low-aerosol runs are mostly accounted for by those in supersaturation and CDNC. The other variables in Eq. (3) show percentage differences which are ~ two orders of magnitude smaller than those in supersaturation and CDNC throughout the simulations. Figures 9 and 10 show the time series of CDNC and supersaturation, respectively, conditionally averaged over areas where condensation rate > 0, for the cases in this study."

"The intensified interactions between condensation and updrafts due to increased CDNC in LH-D5 lead to larger condensation and, thereby, LWP in the high-aerosol run than in the low-aerosol run prior to 02 LST on July 15th by compensating for the lower supersaturation (Figure 10). The domain-averaged LWPs are 40.1 and 39.8 g $m^{-2}$ in the high- and low-aerosol runs, respectively, prior to 02 LST on July 15th. However, Figure 10 shows that condensation rate (indicated by the slope of cumulative condensation) begins to increase more rapidly around 00 LST on July 15th in the low-aerosol case than in the high-aerosol case. As a result of this, the cumulative condensation begins to be larger around 02 LST on July 15th in the low-aerosol run than in the high-aerosol run in LH-D5. This leads to larger averaged LWP over the entire domain and simulation period at low aerosol than at high aerosol. This indicates that there is a mechanism compensating for the decreased interactions among CDNC, condensation, and dynamics in the low-aerosol run in LH-D5."

is replaced with

(LL415-427 in p14-15 in the new manuscript)

"Despite lower supersaturation, stronger interactions between condensation and updrafts induced by larger CDNC enable larger condensation and, thus, LWP in the high-aerosol run than in the low-aerosol run prior to 02 LST on July 15th in LH-D5 (Figure 10). The domain-averaged LWPs are 40.1 and 39.8 g $m^{-2}$ in the high- and low-aerosol runs, respectively, prior to 02 LST on July 15th. However, an increase in condensation rate (indicated by the slope of cumulative condensation) starts to be significantly larger around 00 LST on July 15th in the low-aerosol case than in the high-aerosol case. Condensation rate here represents the rate of the domain-averaged change of air-column cloud-liquid mass due to condensation. This leads to cumulative condensation starting to be larger around 02 LST on July 15th. This results in larger averaged LWP over the entire domain and simulation period at low aerosol than at high aerosol in LH-D5. A mechanism is likely to exist to compensate for the weakened interactions among CDNC, condensation, and dynamics in the low-aerosol run in LH-D5."

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I found the manuscript very difficult to understand. The use of adjectives like increase and decrease are used in excess. Many sentences attempt to explain too much information, e.g., the first sentence of Sect. 4.

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“increase” and “decrease” are replaced with synonyms or removed when they are not necessary.

Sentences with too much information are revised as shown in the following selected sentences among the revised ones:

(LL23- LL1 in p19319-19320 in the old manuscript)

To isolate the dependence of the role of the conversion of droplets to rain and the sedimentation of hydrometeors in the response of cloud mass to aerosols on the level of LWP, it is ideal to compare the role among clouds with a difference only in the LWP level and with no differences in any other environmental conditions in which the clouds embed.

is replaced with

(LL197-201 in p7 in the new manuscript)

This study aims to isolate the varying role of the conversion of droplets to rain and the sedimentation of hydrometeors in the cloud-mass response to aerosols with the varying LWP. It is ideal to compare the role among clouds with a difference only in the LWP level. For the ideal comparison, differences in any other environmental conditions, in which the clouds embed, need to be removed.

(LL6-9 in p19314 in the old manuscript)

However, a recent study showed that this mechanism played a negligible role in the determination of the cloud mass as compared to aerosol-induced feedbacks between microphysics and dynamics in thin stratocumulus clouds with LWP of ~ 50 g $m^{-2}$ or less.

is replaced with

(LL34-38 in p2 in the new manuscript)

However, a recent study showed that this mechanism played a negligible role in the determination of the cloud mass in thin stratocumulus clouds with LWP of ~ 50 g $m^{-2}$ or less. Instead, aerosol-induced feedbacks between microphysics and dynamics predominantly determined cloud mass in these thin clouds.

(LL22-24 in p19314 in the old manuscript)

The results of this study indicate that the traditional approach to the understanding of the aerosol-cloud interactions and its application to the parameterization of these interactions in climate models can be misleading.

is replaced with

(LL48-51 in p2 in the new manuscript)

The results of this study indicate that the traditional approach to the understanding of the aerosol-cloud interactions can be misleading. Hence, the application of this traditional approach to the parameterization of these interactions in climate models can cause errors in the assessment of the effect of aerosols on climate.

(LL12-15 in p19315 in the old manuscript)

Increasing aerosols decrease the collection efficiency among droplets and this slows down the droplet growth to a critical size (generally ~ 20 – 40 μm in radius) for active collections and thereby the formation of rain, leading to decreased surface precipitation.

is replaced with

(LL70-73 in p3 in the new manuscript)

Increasing aerosols reduce the collection efficiency among droplets, which slows down the droplet growth to a critical size (generally ~ 20 – 40 μm in radius) for active collections. This in turn slows down the formation of rain, leading to suppressed surface precipitation.

(LL13-17 in 19316 in the old manuscript)

Small cloud droplets grow to the critical size by condensation as well as turbulent collisions; for particles smaller than the critical size, condensational growth is as important as the growth through these turbulent collisions, though, after the critical size, the role of condensation in the growth is negligible as compared to collection (Rogers and Yau, 1991).

is replaced with

(LL105-109 in p4 in the new manuscript)

Small cloud droplets grow to the critical size by condensation as well as turbulent collisions. For particles smaller than the critical size, condensational growth is as important as the growth through these turbulent collisions. However, after the critical size, the role of condensation in the growth is negligible as compared to collection (Rogers and Yau, 1991).

(LL4-7 in p19317 in the old manuscript)

The aim is to understand how the validity of the traditional concept of the second AIE and its application to the parameterization of the aerosol-cloud interactions in climate models varies with the thickness of clouds (represented by the LWP).

is replaced with

(LL124-126 in p5 in the new manuscript)

The aim is to understand how the validity of the traditional concept of the second AIE varies with the thickness of clouds (represented by the LWP).

(LL3-6 in p19323 in the old manuscript)

The storage of hydrometeors is zero (no suspended hydrometeors in the air) at the end of simulation, and, therefore, the domain-averaged cumulative tendency, which is the term on the left hand side of Eq. (2), is zero for all of simulations except for simulations in LH-M5 (Figure 5).

is replaced with

(LL307-310 in p11 in the new manuscript)

The storage of hydrometeors is zero (no suspended hydrometeors in the air) at the end of simulation. Therefore, the domain-averaged cumulative tendency, which is the term on the left hand side of Eq. (2), is zero for all of simulations except for simulations in LH-M5 (Figure 5).

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The use of “in other words” is not necessary. The clarifying statements that follow “in other words” are no clearer than the preceding statement. Moreover the article “the” is also used excessively and in places where it is not necessary, e.g., the two sentences beginning on line 6 of pg. 19320.

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Unnecessary “In other words” is removed or replaced with “Hence”
The article “the” is checked and add or removed depending on whether it is necessary or not.

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Eq. 1 represents the production equation for liquid integrated over the domain and the duration of the simulations. The units of < A > are given as mm in Table 2. However from Eq. 1 itself, I do not see how one arrives at units of length only. Using units of kg kg$_{-1}$ s$_{-1}$ (or simply mass over mass times time) for Q$_j$ where j represents one of the microphysical processes in the GCE model, < Q$_j$ > has units of mass over length squared. Whereas in the present manuscript, the values of < Q$_j$ > are given in mm (i.e., some unit of length).

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It is correct that < Q$_j$ > has units of mass over length squared, which is “kg m$^{-2}$”. Considering the water density, the area-averaged cumulative surface precipitation of “1mm” over the unit area (1 m-$^{2}$) is equivalent to 1 kg of water over that unit area (i.e., 1 kg m$^{-2}$). Using this fact, for expediency, “mm” replaced “kg m$^{-2}$” for the unit of budget terms. This enables the reader to compare budget terms to precipitation, which in turn enables the reader to visualize the magnitude of budget terms easily.

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It appears that a density factor is missing from Eq. 1. Along the same lines, Eq. 3 and Eq. 4 are given without explaining what each variable means. Specifically, the variables $D_n$, u, and G(u) are not defined. Furthermore, it is not mentioned that $f_{gam}(D)$ represents a gamma distribution.

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In Eq. 1, the air density is already included. The definitions of variables pointed out here are added.

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C) Basis for Analysis Using Eq. 1

Eq. 1 is used to produce the quantities reported in Table 2. Ignoring the units discrepancy for the time being (discussed above), and instead focusing on comparing the magnitude of the budget terms themselves, I find the discussion comparing the condensation rate to that of the conversion (autoconversion plus accretion) troubling. The reason for this is that the manuscript states numerous times that condensation outweighs the effects of autoconversion and accretion (by 1 to 2 orders of magnitude) in all cases. However, this may be comparing apples and oranges. Condensation is a change of phase while autoconversion and accretion are simply the conversion of liquid from one category to another. I think it would make more sense to compare net condensation (condensation minus evaporation) to that of autoconversion and accretion. Averaged over the domain, using Table 2 for guidance, one finds that the net condensation is 0.44 (LH-M5, PD), 0.63 (LH-M5, PD), 0.04 (CONTROL, PD), 0.08 (CONTROL, PI), 0.01 (LH-D5, PD), 0.01 (LH-D5, PI), 0.0 (LH-D10, PD) and 0.0 (LH-D10, PI). Then, given the values of autoconversion plus accretion, i.e., 0.38, 0.57, 0.04, 0.08, 0.006, 0.011, 0.003, and 0.004, respectively, it is clear that the net condensation is of the same order of magnitude as that of the conversion rate. This should be addressed in the manuscript.

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The budget analysis in this study was carried out to find out which microphysical terms dominate in determining the liquid-water content (LWC). Although the budget analysis does not enable us to find the cause of the higher LWP (the vertical integration of LWC, excluding the rain content), it is at least able to find the dominant microphysical terms determining the rate of change of the LWC and thereby the LWP variation due to the aerosol variation. Since we are interested in explaining the variation in time- and domain-averaged LWP with varying aerosols, all of the cumulative microphysical terms in the LWC tendency, which are averaged over the domain, are obtained. The budget analysis shown in Table 2 demonstrates that condensation and evaporation variations are the main controls among the microphysical terms determining the variation in the time- and domain-averaged LWP and that the conversion of cloud liquid to rain by autoconversion and the collection of cloud liquid by rain play a minor role in controlling the variation in the time- and domain-averaged LWP as compared to condensation and evaporation of cloud liquid.

Cloud liquid formed by condensation eventually disappears via evaporation and very small portion of cloud liquid converts to rain via autoconversion and accretion before its disappearance in this study. This indicates that the cumulative condensation controls the cumulative evaporation by determining the amount of source (i.e., cloud liquid) of evaporation; the role of autoconversion, accretion, and sedimentation in the determination of the source is negligible. Larger (smaller) condensation induces larger (smaller) cloud liquid, contributing to the larger (smaller) time- and domain-averaged LWP. Larger (smaller) cloud liquid eventually disappears and this disappearance should involve larger (smaller) cumulative evaporation for larger (smaller) cloud liquid (produced by larger (smaller) condensation).

Differences in evaporation between the high- and low-aerosol runs decrease substantially as does the condensation rate when CDNC is fixed for the condensation term only in LH-M5 and CONTROL; experiments with the fixed CDNC are described in our responses to the comment 2 of the reviewer 1 and in Section 5.4. In the standard high- and low-aerosol runs where the CDNC is predicted for all processes including condensation, larger cloud-liquid mass eventually contributes to larger evaporation when the cloud liquid is detrained from the updrafts into the sub-saturated areas (as can be seen from the budget analysis using cumulative values at the end of time integration). When CDNC is fixed for condensation, differences in the cloud-liquid mass decrease due to the reduced differences in the production of cloud liquid by condensation between the high- and low-aerosol runs. This leads to reduced differences in the detrained mass of cloud-liquid into the sub-saturated areas and thereby to reduced differences in evaporation of cloud liquid in LH-M5 and CONTROL. The experiments with the fixed CDNC only for condensation in LH-D5 show larger condensation difference due to the absence of increased interactions among CDNC, supersaturation, and dynamics in the high-aerosol run than condensation difference in the standard experiments in LH-D5 (see Section 5.4 for more detail). This larger difference in condensation leads to larger difference in cloud liquid transported to unsaturated areas, in turn leading to larger difference in evaporation than those in the standard experiments. This confirms the above argument that the cumulative condensation not only controls the cloud-liquid mass variations (and therefore the variations in the time- and domain-averaged LWP) but also controls the variations in the cumulative evaporation due to aerosols.

In summary, the variation in the time- and domain-averaged LWP is mostly controlled by the variations in the cumulative condensation and the variation in the cumulative evaporation of cloud liquid is controlled by the variation in the cumulative condensation which provides the source for the evaporation of cloud liquid; here, we want to stress that the time series of the domain-averaged differences in condensation and evaporation between the high- and low-aerosol runs showed much larger values than those from autoconversion and the collection of cloud liquid by rain throughout simulation periods, indicating that the cumulative values of these processes at the end of time integration can represent situations during the time integration reasonably well. From the budget analysis (using the cumulative values), we can see condensation and evaporation are two major terms controlling the cloud-liquid mass and autoconversion and accretion play a negligible role in the determination of the cloud-liquid mass. It is the cumulative condensation (evaporation) which increases (decreases) the time- and domain-averaged LWP and our additional simulations with the fixed CDNC demonstrate that the cumulative evaporation is controlled by the cumulative condensation. Hence, we can say that the LWP which is averaged over time and domain is determined by the cumulative condensation which eventually affects the cumulative evaporation and, thus, we can only use the cumulative condensation to explain the time- and domain-averaged LWP and its variation due to aerosol changes or the cumulative evaporation and its variation due to aerosol changes.

If you see equation (2), The cumulative condensation minus the cumulative evaporation should be equal to the cumulative conversion in case of no suspended cloud liquid at the end of simulations; in LH-D5 and LH-D10, we showed budget numbers rounded up and if we consider numbers not rounded up, the cumulative condensation minus the cumulative evaporation is equal to the cumulative conversion as in CONTROL. In LH-M5, the condensation minus evaporation is equal to the conversion plus cloud liquid amount suspended at the end of time integration (represented by the storage term on the left hand side of equation (2)); if we insert $\frac{\partial q_c}{\partial t}$ in (1), we can see the meaning of the domain-averaged cumulative value of $\frac{\partial q_c}{\partial t}$ more clearly; $< \frac{\partial q_c}{\partial t} >$ is just the averaged LWP of suspended cloud liquid at the end of the simulations. Hence, condensation minus evaporation does not give us any information about the relative importance of terms associated with cloud liquid. The traditional concept proposed by Albrecht stated that the conversion controlled the response of LWP to aerosol changes. This study indicates that the source of LWP (i.e., condensation) plays much more important roles in this response than the conversion. It is also possible to say that evaporation plays much more important roles in this response than the conversion. However, increasing evaporation with the variation in aerosols is not able to explain increasing LWP with the aerosol variation. Condensation increase best explains the LWP increase with the negligible conversion in this study. This is why this study performed comparison between condensation and conversion but not between evaporation and conversion. Also, by showing much larger condensation and its variation with aerosols than the conversion and its variation, we can simultaneously explain larger evaporation and its variation with aerosols than the conversion and its variation due to the connections between condensation and evaporation as explained above.

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Minor Comments

A) Why Mexico? Why July 14 and 15, 2002? Why 14:00 LST on the 14th to 14:00 LST on the 15th?

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The area off the coast of the western Mexico is well-known for persistent development of stratocumulus clouds as reported in Schubert et al. (1979, JAS, pp1286-1307); this persistent development has been confirmed by the satellite observation. We selected this area to simulate stratocumulus clouds, which are not contaminated by other types of clouds.

The following is added to indicate the persistent stratocumulus off the coast of the western Mexico:

(LL148-149 in p5 in the new manuscript)
where the persistent development of stratocumulus clouds has been observed

We found that thick clouds with the LWP > 50 g $m^{-2}$ developed during the time period chosen in this study. We performed test-simulations by varying the surface LH for these clouds and found that the LWP varies (from thick clouds with LWP > 50 g $m^{-2}$ whose LWP range corresponds to most frequently observed LWP range in McComiskey et al. (2009) to thin clouds with LWP < 50 g $m^{-2}$) as we intended with the surface LH multiplied and divided as described in the manuscript by error and trial.

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B) The aerosol concentrations given in the text (Sect. 3) do not correspond to those given in Fig. 4.

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The sentence pointed out here is replaced with:

(LL179-180 in p6)

Generally, the aerosol number varies between ~ 300 (150) and ~ 400 (180) for the high-aerosol (low-aerosol) run.

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C) Why do you not multiple the latent heat flux by 10 also?

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In LH-M5, the maximum LH is ~ 450 W $m^{-2}$ which is around the observed maximum LH over the ocean in July. When the multiplication by 10 is applied, the maximum LH is ~ 900 W $m^{-2}$ which is way above the observed maximum LH and hence is not realistic.

Through the multiplication and division of LH by trial and error, we were able to capture the typical observed range of LWP according to McComiskey et al. (2009).

When we multiply LH by a factor of 10, deepening-warming decoupling (described in Bretherton and Wyant (1997, JAS)) occurs to change cloud types from stracocumulus clouds to cumulus clouds at the early stage of cloud development. This disables us from examining the effect of aerosols on stratocumulus clouds which are of main interest to us.

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D) Section 5.1.1 mentions that the cloud fraction is larger than 0.8 except for the first and last 30 minutes of cloud evolution. Is there a figure to support this? The previous work (i.e., Lee et al., 2009) provides a figure showing the cloud fraction as a function of time.

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Figure 6 is added to depict the time evolution of cloud fraction.

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E) It is mentioned that the difference between MODIS retrieved LWP and model output LWP is less than 10%. What about retrieval errors? Furthermore, what is meant by “good” agreement in line 18 on pg. 19321.

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The following is added:

(LL243-249 in p9 in the new manuscript)

The difference between the domain-averaged LWP in the high-aerosol run and the MODIS-observed LWP is less than 10 % relative to LWP observed by the MODIS. It should be noted that there is an uncertainty associated with the retrieval of the MODIS LWP. Generally, retrieval errors are ~ 10 % for LWP according to Juárez et al. (2009). Considering this error range, the possible range of the difference between the simulated LWP and the true LWP is ~ 2 % - 22 %. This demonstrates that LWP is simulated reasonably well.

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F) The conversion efficiencies reported in the text on line 23 of pg. 19324 do not correspond to those reported in Table 2. The table leads the reader to believe that the efficiencies should be about 0.68% and 0.91%, not _1% and _3%.

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(LL22-25 in p19324 in the old manuscript)
However, as the conversion efficiency lowers with the decreasing LWP, sedimentation is lowered to only ~ 1% of condensation and ~ 3% of condensation difference in LH-D10.

is replaced with

(LL355-358 in p12 in the new manuscript)
However, as the conversion efficiency lowers with the decreasing LWP, sedimentation is lowered to only 0.68-0.91% of condensation and the sedimentation difference to 2.5% of the condensation difference between the high- and low-aerosol runs in LH-D10.

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G) Line 1 on pg. 19327 is unclear. The slope of the cumulative condensation has units of length per time while the condensation rate, according to Table 2 has units of simply length. If one uses the condensation rate before applying Eq. 1, the units are simply per time, again not matching those derived from the slope of Fig. 10.

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Condensation in Table 2 is cumulative condensation (with the unit of “mm” equivalent to “kg m$^{-2}$” as explained above) but not condensation rate.

The slope of the time variation of cumulative condensation (representing condensation rate) is in kg m$^{-2}$ s$^{-1}$ or equivalently mm s$^{-1}$. Hence, condensation rate in the sentence pointed out here is defined as the rate of the domain-averaged change of air-column cloud-liquid mass due to condensation. To avoid confusion, the sentence (LL1-3 in 19323 in the old manuscript) is revised as follows:

(LL304-306 in p11 in new manuscript)

Here, $q_c$ is cloud-liquid mixing ratio. $Q_{cond}$, $Q_{evap}$, $Q_{auto}$, and $Q_{accr}$ refer to the rate of changes in cloud-liquid mixing ratio due to condensation, evaporation, autoconversion of cloud liquid to rain, and accretion of cloud liquid by rain, respectively.

Also, the following sentence is added:

(LL422-423 in p15 in the new manuscript)

Condensation rate here represents the rate of the domain-averaged change of air-column cloud-liquid mass due to condensation.

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H) The phrase “reduced increase” is used in lines 28 and 29 on pg. 19328. The sentence should be reworded so that the authors’ intention is clear.

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The sentence pointed out here is reworded as follows:

(LL487-489 in p17 in the new manuscript)

This leads to a smaller increase of rain precipitated to the cloud base and a smaller increase of the cloud-base evaporative cooling at low aerosol in LH-D10 than those in LH-D5.

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Summary

A) There is very little in the present manuscript that is not already described in the authors’ earlier work (Lee et al., 2009).

B) A large fraction of the present manuscript has been taken verbatim from the authors’ earlier work (i.e., Lee et al., 2009). Moreover, the original portion of the text is filled with poorly explained material and bad grammar.

C) Recently, I noticed an additional paper (i.e., Lee and Penner, 2009) that follows in the footsteps of the current manuscript by again using text verbatim from the Lee et al. (2009).

D) I do not recommend that his paper be published in ACP.

Feingold, G., B. Stevens, W. R. Cotton, and A. S. Frisch, 1996: The Relationship between Drop Incloud Residence Time and Drizzle Production in Numerically Simulated Stratocumulus Clouds. J. Atmos. Sci., 53, 1108-1122.

Lee, S. S., J. E. Penner, and S. M. Saleeby, 2009: Aerosol Effects on Liquid-Water Path of Thin Stratocumulus Clouds. J. Geophys. Res., 114, D07204, doi:10.1029/2008JD010513.

Lee, S. S. and J. E. Penner, 2009: Comparison of a Global-Climate Model to a Cloud-System Resolving Model for the Long-Term Response of Thin Stratocumulus Clouds to Preindustrial and Present-Day Aerosol Conditions. Atmos. Chem. Phys. Discuss., 9, 21317-21369.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 19313, 2009.