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 (black) and followed by our responses (blue).

Interactive comment on "Impact of solar radiation on aerosol-cloud interactions in thin stratocumulus clouds" by S. S. Lee and J. E. Penner

Anonymous Referee #1

Received and published: 20 November 2009

Summary: This paper provides nice support for current theory about the effect of aerosol, precipitation, and radiation on LWP, but suffers from a conceptual mistake early in the paper which causes problems throughout the entire analysis. It also doesn't seem that new, with most of the middle section coming almost directly from a previous paper by the same authors. For these reasons (explained in more detail below), I strongly urge that the paper be rejected. I think with more thought the existing model runs could be used in an interesting paper, even though they are not ideal (as noted below).

I quit reading in detail and only skimmed after 5.3.2 because everything seemed to depend on the flawed conceptual framework, so careful reading didn't seem worth my time. Perhaps I missed some original results by doing so.

I'm sorry I couldn't be more positive.

Major Issues:

1. I have a big problem with sections 5.2 and 5.3. First, they are almost identical to sections 5.2 and 5.3 of Lee et al, (2009; JGR) so they aren't original research. Second, I'm pretty sure their assertions are wrong.

In this study, our aim is to examine the effect of the intensity of solar radiation on aerosol-cloud interactions in "thin" stratocumulus clouds. Hence, we adopted the analysis method for "thin" stratocumulus clouds from Lee et al. (2009). Although the method in this study is adopted from Lee et al. (2009), it proves to be effective in understanding how solar radiation affects the aerosol-induced changes in cloud-liquid budget; the cloud-liquid budget can give us an insight not only into how aerosols affect the LWP but also into how the effect of aerosols on LWP varies with the intensity of solar radiation.

Despite similarity in discussions in 5.2 and 5.3 in this study to those in Lee et al. (2009), discussions in 5.2 and 5.3 are not only effective in explaining the effect of solar radiation on aerosol-cloud interactions in thin clouds but also necessary to lead to conclusions in this study. Hence, we put sections 5.3. and 5.3 in the new manuscript as well. However, similar expressions as compared to those in Lee et al. (2009) are re-written; however, the text describing Eq. (1)-(4) does not change much, since the description is mainly about their mathematical expressions.

We believe that using a similar analysis method does not mean that this study duplicated the study of Lee et al. (2009), since Lee et al. (2009) aims to understand the mechanism of aerosol-cloud interactions in thin clouds (per se) whereas this study aims to examine the dependence of these interactions on the intensity of the incident solar radiation. With varying incident solar radiation, the mechanisms controlling aerosol-cloud interactions and their effect on the LWP response to aerosols vary. This study showed that the intensity of the incident solar radiation could determine the presence of the surface precipitation, which in turn determines mechanisms for the LWP response to aerosols as described in the above response. The intensity of the incident solar radiation also affects how those mechanisms change for either cases with the surface precipitation or those with no surface precipitation. Those mechanisms are more effective in the increasing LWP with increasing aerosols in SW-D5 with higher LWP from less solar radiation causing less decoupling than in SW-D2 between cases with the surface precipitation. Between the cases with no surface precipitation, the effect of mechanisms associated with the cloud-base instability on the increasing LWP at low aerosol is stronger with higher LWP due to less decoupling (causing more conversion of cloud liquid to rain and thus rain evaporation around cloud base) from weaker incident solar radiation in CONTROL than in SW-M1.5.

Section 5.2 computes the domain- and time-averaged cloud liquid water budget and finds condensation and evaporation to be much larger than autoconversion and accretion. This is unsurprising in light of Fig. 2, which shows both cloud top and cloud base rising rapidly throughout all of the simulations. This graphic suggests several things. First, the difference between condensation and evaporation is probably a better measure than the individual components. Second, condensation/evaporation in these model runs is largely driven by entrainment, which determines the rate of PBL deepening. This means that even though sedimentation doesn't itself remove much liquid from the cloud, it could still be responsible for the observed LWP changes by altering the entrainment rate (and in fact, both cloud droplet and raindrop sedimentation are well known to have strong effects on entrainment). These sedimentation-induced entrainment changes are erroneously attributed to condensation in your analysis.

To investigate the role of interactions among CDNC, supersaturation, and dynamics and those between rain evaporation and cloud-base instability and the role of sedimentation of hydrometeors in the LWP difference between the high- and low-aerosol runs, additional simulations are performed and described in Section 5.4 in the new manuscript as follows:

(LL565-632 in p19-22)

A pair of additional simulations, which is composed of the high- and low-aerosol runs, in each of the four cases in this study is performed. This pair of simulations adopts the identical N_d only for condensation in each of the four cases; N_d in Eq. (3) is fixed at a constant value and forced to be the same for the high- and low-aerosol runs, though predicted N_d is allowed to be used in the other processes. The budget numbers of Eq. (2) for these additional simulations are shown in Table 3. This pair of simulations is referred to as the high-aerosol run (N_d-high fixed) and low-aerosol run

(N_d-high fixed) in each of the four cases. The high-aerosol run (N_d-high fixed) and low-aerosol run (N_d-high fixed) in each of SW-M1.5, CONTROL, SW-D2, and SW-D5 adopt an averaged N_d in the high-aerosol run in each of SW-M1.5, CONTROL, SW-D2, and SW-D5 as a fixed value only for condensation as described in Table 1.

The LWPs in the low-aerosol runs (N_d-high fixed) increase significantly as compared to LWPs in the low-aerosol runs, resulting in negligible differences in LWP between the high-aerosol run (N_d-high fixed) and low-aerosol run (N_d-high fixed) in each of SW-D2 and SW-D5. This is mainly due to larger N_d in the low-aerosol runs (N_d-high fixed) than average N_d in the low-aerosol runs, leading to increased condensation as compared to that in the low-aerosol runs (Table 3). These additional simulations indicate that the LWP responses to aerosols can be nearly the same for the high- and low-aerosol runs only by making N_d for condensation identical. This demonstrates the most crucial role of N_d impacts on condensation in the LWP responses to aerosols in SW-D2 and SW-D5. This also demonstrates that the impacts of aerosols and thus N_d on the other processes such as the sedimentation of cloud liquid, the conversion of cloud liquid to rain, thus, the sedimentation and evaporation of rain do not play an important role in the LWP responses in thin clouds with the surface precipitation here.

Time- and domain-averaged LWPs in the high-aerosol run (N_d-high fixed) and low-aerosol run (N_d-high fixed) are 10.8 and 14.6 g m^{-2}, respectively, in SW-M1.5. In CONTROL, the LWPs are 13.0 and 19.5 g m^{-2} in the high-aerosol run (N_d-high fixed) and low-aerosol run (N_d-high fixed), respectively (Table 3). These additional simulations for SW-M1.5 and CONTROL with the absence of the surface precipitation show a larger increase in LWP in the low-aerosol run (N_d-high fixed) than that in the low-aerosol run. This is due to the near absence of increased interactions between N_d and supersaturation in the high-aerosol run (N_d-high fixed) as compared to those in the low-aerosol run (N_d-high fixed). This is caused by the increase in the intensity of these interactions in the low-aerosol run (N_d-high fixed) as compared to that in the low-aerosol run. Due to the increase in N_d in the low-aerosol run (N_d-high fixed) as compared to N_d in the low-aerosol run, the intensity of the interactions increases in the low-aerosol run (N_d-high fixed) as compared to that in the low-aerosol run. This increase in the intensity of the interactions acts to increase condensation together with the increased cloud-base instability in the low-aerosol run (N_d-high fixed), leading to the larger increase in LWP in the low-aerosol run (N_d-high fixed) than in the low-aerosol run.

The high- and low-aerosol runs are repeated for all of the four cases again by turning off sedimentation and evaporation of rain and sedimentation of droplets to investigate the role of rain evaporation and hydrometeor sedimentation in thin clouds and their responses to aerosols and referred to as the high-aerosol run (sed-off) and the low-aerosol run (sed-off). As shown in Table 4, the qualitative nature of the results described for the high- and low-aerosol runs does not change with whether rain evaporation and hydrometeor sedimentation operate in SW-D2 and SW-D5 with the surface precipitation. However, condensation and LWP increase in the high-aerosol run (sed-off) in SW-M1.5 and COTROL (with no surface precipitation) due to the absence of cloud-base evaporation and its effect on the cloud-system instability, contrary to their decrease in the high-aerosol run.

Table 5 shows the budget numbers for repeated simulations for the high- and low-aerosol runs both with the fixed N_d (adopting an averaged N_d in the high-aerosol run) only for condensation and with rain evaporation and hydrometeor sedimentation turned off. This pair of simulations is referred to as the high-aerosol run (N_d-high fixed and sed-off) and low-aerosol run (N_d-high fixed and sed-off) in each of the four cases. Over all of the four cases, the LWP difference between the high- and low-aerosol runs is negligible as compared to that between the high- and low-aerosol runs. This demonstrates that interplay between interactions among N_d, supersaturation, and dynamics and those between rain evaporation and cloud-base instability predominantly determines the LWP response to aerosols in SW-M1.5 and CONTROL. That both the pair of the high- and low-aerosol runs (N_d-high fixed) and the pair of high- and low-aerosol runs (N_d-high fixed and sed-off) show negligible differences in LWP between the high- and low-aerosol cases demonstrates that interactions among N_d, supersaturation, and dynamics play the most important role in the determination of the LWP response to aerosols in SW-D2 and SW-D5; whether rain evaporation and hydrometeor sedimentation are included does not affect the negligible LWP differences in these two pairs of simulations in each of SW-D2 and SW-D5.

Section 5.3 builds off of the faulty logic in 5.2 by trying to identify why aerosols have such a strong impact on sedimentation through the use of the vapor diffusion equation. This is misguided because vapor diffusion is just a vehicle for converting supersaturated vapor to liquid and is unrelated to the underlying *source* of the supersaturation. The source of that supersaturation is aerosol-induced change in moisture fluxes, entrainment, etc. as noted above.

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 (only including cloud liquid, excluding rain)), 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 aerosols. Note that there are only four terms controlling LWC and LWP, which are condensation, evaporation, autoconversion, and accretion. The LWC sink in Albrecht's argument is about the depletion of cloud-liquid mass via autoconversion and accretion (forming rain). Albrecht argued that decreasing autoconversion and accretion with increasing aerosols led to increasing LWC and LWP.

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 variations in cumulative condensation and evaporation are the main controls among the four microphysical terms determining the variation in the time- and domain-averaged LWP and that the cumulative conversion of cloud liquid to rain by autoconversion and the accretion of cloud liquid by rain play a minor role in controlling the variations in the time- and domain-averaged LWP as compared to condensation and evaporation of cloud liquid. Hence, Albrecht's autoconversion and accretion do not play an important role in the response of the time- and domain-averaged LWP to aerosol changes in simulations here.

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 (cumulative) condensation controls (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 not significant. Larger (smaller) cumulative condensation induces larger (smaller) cloud liquid, contributing to 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 those in condensation when CDNC is fixed for the condensation term only; experiments with the fixed CDNC are described in our responses to one of the comments above. Differences in evaporation and condensation are only ~ 25 (17) and ~ 28 (17) % of those in the standard high- and low-aerosol runs where the CDNC is predicted for all processes including condensation in SW-D2 (SW-D5). 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 in SW-D2 and SW-D5; in CONTROL and SW-M1.5, when both CDNC is fixed for condensation and rain evaporation and hydrometeor sedimentation are turned off, differences in the cloud-liquid mass become negligible 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. This confirms the above argument that cumulative condensation not only controls the time- and domain-averaged cloud-liquid mass variations (and therefore the time- and domain-averaged LWP variations) but also controls the variations in 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 cumulative evaporation of cloud liquid and the variation in the cumulative evaporation of cloud liquid are 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 an insignificant 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 (and no hydrometeor sedimentation and rain evaporation for cases with no surface precipitation) 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 LWP and its variation due to aerosol changes or the cumulative evaporation and its variation due to aerosol changes. It is also possible to say that evaporation plays much more important roles in the response of the LWP to aerosol changes than the conversion. However, increasing evaporation with the variation in aerosols is not able to explain increasing LWP with the aerosol variation. The increase in the cumulative condensation best explains the increase in the time- and domain-averaged LWP 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. Hence, we analyzed the terms determining the condensation rate in section 5.3 and found that the CDNC and supersaturation variations dominate the condensation variation. Supersaturation represents the dynamical and thermodynamical impacts (e.g., moisture fluxes and entrainment) on condensation, since it is affected by the updraft intensity, temperature and moisture in air parcels. The analysis in section 5.3 showed that the impact of changes in microphysical factors (i.e.,CDNC) on condensation can offset that in dynamical and thermodynamical factors, represented by supersaturation, by changing the surface areas of droplets. Here, we want to stress that it is obvious that condensation is controlled by variables in Eq. (3) and, as expected, the ventilation coefficient and the saturation water vapor mixing ratio showed negligible differences between the high- and low-aerosol runs as compared to those in supersaturation and CDNC. Thus, the supersaturation and CDNC changes explain the cause of the larger condensation resulting in larger LWC and LWP at high aerosol in SW-D2 and SW-D5 as shown in the budget analysis in section 5.2; as explained in our response to one of comments above, the aerosol-induced changes in CDNC control the change in interactions between CDNC and supersaturation and their effect on the aerosol-induced change in condensation based on additional simulations with CDNC fixed. The CDNC and supersaturation effects on condensation offset each other as explained in the text and the CDNC effects are larger than the supersaturation effects, leading to more condensation and LWC (and thus LWP) at high aerosol in SW-D2 and SW-D5. As explained in the text, in SW-M1.5 and CONTROL, the interactions between cloud-base rain evaporation and cloud-base instability interplay with those between CDNC and supersaturation due to the absence of the surface precipitation, resulting in larger LWP at low aerosol in SW-M1.5 and CONTROL.

Vapor deposition *could* be the limiting step preventing condensation from occurring, but if that was the case supersaturation would build up over the course of your simulations as supersaturation created by other processes fails to be converted into liquid. This doesn't happen because liquid drop nucleation and vapor deposition are extremely fast (almost instantaneous) processes. This is why your peak supersaturation is always less than 0.1% in Fig. 7. I am not surprised that increasing Nd decreases supersaturation, but I'm pretty sure this just constitutes a repartitioning of how supersaturation generated by other processes is converted to liquid without actually affecting the rate at which this occurs.

Obviously, equation (3) indicates that the deposition rate depends on Nd and supersaturation defined in the text (LL347 in 12) below equation (3). In other words, Equation (3) indicates that the supersaturation defined this way is one of the factors which control the rate of change of cloud-liquid mass by vapor diffusion. At each time step, the predicted supersaturation and Nd (affected by microphysical and dynamical processes in the previous time steps) are put into equation (3) to determine the rate of cloud-liquid mass change by vapor diffusion. Then, supersaturation changes by this vapor diffusion and other processes and this changed supersaturation is used for the calculation of the rate of cloud-liquid mass change in the next time step through the equation (3). In the text, we intend to talk about the supersaturation which interacts with Nd for the determination of the rate of cloud-liquid mass change at each time step.

2. I am concerned that you are nudging moisture and temperature towards the ECMWF reanalysis at all model heights. This will tend to lock your model into having the same PBL height and structure as ECMWF. It also introduces aphysical forcing tendencies into the model. Both of these problems make it difficult to ascribe model behavior to physical mechanisms.

The large-scale forcings are imposed as large-scale advective tendencies. The CSRM domain is considered to be small compared to large-scale disturbances. Hence, the large-scale forcing is assumed to be uniform over the model domain and the large-scale terms are defined to be functions of height and time only. For example, the large-scale advective tendency of water vapor mixing ratio is $\left(\partial\overline{q} / dt\right)_{LS} = -\overline{\vec{V}} \bullet \nabla\overline{q} - \overline{w}(\partial\overline{q} / \partial z)$. Here, bars indicate observed large-scale values. This tendency term is included in the water-vapor prediction equation. This inclusion of the tendency term enables the model to take into account the effects of large-scale disturbances on the predicted water-vapor field. This inclusion also acts to make differences between the predicted water-vapor field and the large-scale water-vapor field smaller than when the tendency is not applied, hence, to nudge the predicted field to the large-scale field. The imposition of the large-scale temperature tendency term follows the same methodology as that of the water vapor mixing ratio term and, thus, acts to nudge the predicted temperature field to the large-scale temperature field.

The details of the application of the forcing can be found in Krueger et al. (1996: GEWEX Cloud Systems Study Working Group 4: First Cloud-Resolving Model Intercomparison Porject CASE 2).

The forcing is used to maintain the horizontally-averaged fields in simulations close to the ECMWF fields. But it is not to remove the differences in cloud-scale circulations between high- and low-aerosol runs. The large-scale forcing does not entirely control the amount of LWC the model produces; it only determines the net total water supplied to or removed from the domain. We do in fact see LWC and PBL-height differences between the high- and low-aerosol cases. Although feedbacks from these differences onto the large-scale flow cannot be captured by this design, the controlled large-scale forcing isolates the effects of microphysics in an imposed large-scale flow. Contrary to the concern raised by the reviewer here (about the results dictated by the imposed forcing), this actually enables one to see more clearly the particular effects of the aerosol changes on microphysics. While this approach cannot simulate interactions between the modeled cloud system and larger-scale flows, it isolates interactions among aerosols, microphysics, and local thermodynamics (e.g., updrafts and instability) and enables the identification of microphysics-aerosol interactions on the scale of cloud systems

My feeling is that your results are still useful because all of your model runs are being nudged towards the same background state, so differences between runs can still be unambiguously attributed to aerosol/solar forcing differences. I think the results we see are probably damped/distorted by your nudging choice though. At the very least, I think you should show that the nudging tendencies in/near the PBL are always much smaller than other terms in the relevant budgets.

As can be seen in the comparison between Figures 3a and 3b, the temperature and humidity tendency by cloud motion is much larger than that by large-scale forcing. Also, want to point out that although the tendency by large-scale forcing were larger than that by cloud motion, still, the difference among runs would made only by cloud motion (see our responses above) and thus we think it is hard to say that the difference in results is distorted by our nudging choice.

The following is added:

(LL 149-156 in 5-6)

Figures 3a and 3b compare the averaged large-scale forcings of temperature and humidity with the time- and area-averaged simulated cloud-scale temperature and humidity tendencies below the maximum cloud-top height during simulations in CONTROL, respectively. To obtain the cloud-scale tendency in Figure 3, all of the magnitudes of tendencies from cloud-scale processes are summed. This comparison shows that the cloud-scale tendencies are generally ~ 3 times to ~ one order of magnitude larger than the large-scale tendencies. This indicates that results here are mostly controlled by cloud-scale motions but not by the imposed large-scale forcings.
3. I don't like your MODIS validation. First, more explanation is needed - are we looking at MODIS data for a single overpass? What time(s) are involved?

The following is added:

(LL232-234 in p8)

The MODIS-observation is provided as the averaged values over one-day period (for the 10:30 AM and 10:30 PM crossing times on July 1st in 2002).

What is the spatial resolution of the MODIS data (ie are you comparing boxes of similar spatial scale)?

The spatial resolution of the MODIS data is 1 km and the MODIS data are compared to the model results at the location of simulations for similar spatial scale.

What is the observational uncertainties?
Are there any relevant known biases?

The following is added to indicate the uncertainties:

(LL 234-239 in p8)

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.

(LL 245-249 in p9)

Figure 6 demonstrates that the simulated potential temperature and humidity are also in good agreement with the MODIS observations. However, a high uncertainty exists in the retrieval of the profile as discussed in Menzel and Gumley (1998). Hence, this agreement should be considered as a rough assessment of model performance.

Second, it's easy to get the time-averaged mean state right for the wrong reasons. In fact, perhaps your agreement with MODIS comes from nudging to the ECMWF data and doesn't reflect your model's ability to respond to forcing changes at all! I would have much more faith in your analysis if I knew that you were getting the evolution of PBL height right, since entrainment plays such a critical role in PBL structure/ evolution/response to forcings. The fact that your PBL depth almost doubles over 12 hrs (Fig. 2) makes me worry that you *aren't* getting entrainment right. I would feel much better if you could show me that your model captures the BL evolution for that day, or even that it matches the climatological diurnal cycle.

The ECMWF data showed that the PBL depth doubles over 12 hours and this indicates that the model used here responds reasonably to the large-scale forcings. The averaged PBL growth rate for the simulation time (1LST – 14 LST) and location (42 N, 60 W) in this study over one month (July, 2002) also showed the PBL depth doubling over 12-hr period. Hence, the simulated PBL-depth evolution is not unusual.

Figure 14 in Guo et al. (2007, JGR) shows that the PBL depth can be doubled even over 5 hours and the model used in Guo et al. produced results in a good agreement with observations. Also, Jiang et al. (2002, JGR) showed the PBL-top growth from 900m to 1200m in 8 hours, which implies the growth from 900m to 1350m in 12 hours. The PBL growth (~ 50% growth) in Jiang et al. (2002, JGR) is comparable to that (~ 70-80% growth) in this study. These indicate that the PBL-depth growth simulated here is not extremely high.

Wood and Bretherton (2004, Journal of Climate) averaged the PBL growth rate over 2 months collected over 30000 sites and found the averaged growth rate of ~ 4-7 mm/s in mid-latitude area. The growth rate simulated here is included in the range of the growth rate calculated by Wood and Bretherton.

Minor Issues:

1. p. 23795 l. 2: You use CDNC in text to mean the same thing as Nd in equations. I'd suggest using Nd throughout.

CDNC is replaced with Nd throughout.

2. p. 23795 l. 5: Can you defend why do you choose this location/time? It would be much easier to show that your model is behaving reasonably if you ran one of the standard cases from a Sc campaign.

The area off the coast of the Maine is found to have a persistent development of stratocumulus clouds based on our analysis on the MODIS observation. We selected this area and the chosen time period to simulate stratocumulus clouds, which are not contaminated by other types of clouds.

The GCE has been tested against Sc campaigns such as the ASTEX observation and has showed a good agreement with observed cloud properties.

3. p. 23796, l. 11: Is there added value in using aerosol from the CAM-IMPACT model, or would your conclusions be the same if you just fixed the droplet concentrations at high and low values (or if your model can't handle that, fixing the aerosol to be high and low)?

We imported aerosols from the CAM-IMPACT model to use the PD and PI aerosols (comparatively) realistically predicted by the CAM-IMPACT model, instead of using arbitrarily determined aerosols.

As described above in one of our responses, when the CDNC is fixed, the LWP difference nearly disappears in the cases with the surface precipitation; for the cases with no surface precipitation, when the CDNC is fixed and hydrometeor sedimentation and rain evaporation are turned off, the LWP difference also nearly disappears. This indicates that the most critical role of interactions between CDNC, supersaturation, and dynamics in making differences in the LWP between the high- and low-aerosol runs in the cases with the surface precipitation. This also indicates that the most critical role of the interplay between these interactions and interactions between rain evaporation and cloud-base instability in making the LWP differences in the cases with no surface precipitation.

Lee et al. (2009) examined the competition between the interactions among CDNC, supersaturation, and dynamics and those between cloud-base rain evaporation and instability (in a case with no surface precipitation) by varying aerosols in Section 5.6. They showed that as aerosol increases significantly the interactions among CDNC, supersaturation, and dynamics become dominant over those between cloud-base rain evaporation and instability leading to increasing condensation and LWP with increasing aerosols. They also showed that when aerosol increase is not significant, the increasing interactions among CDNC, supersaturation, and dynamics is not large enough to be dominant over those between cloud-base rain evaporation and instability, leading to decreasing condensation and LWP with increasing aerosols (as simulated here). Hence, if we fix the aerosol level which is higher than that in the high aerosol run in the cases with no surface precipitation, it is possible that the increased intensity of interactions among CDNC, supersaturation, and dynamics can be dominant over the intensity of interactions between rain evaporation and cloud-base instability, leading to increasing LWP with increasing aerosols contrary to decreasing LWP in the low-aerosol run in the cases with no surface precipitation (i.e., SW-M1.5 and CONTROL).

4. p 23797, l. 6: Why do you need to include the stratosphere to simulate stratocumulus?

We wanted to simulate atmospheric conditions above the boundary layer realistically with no need to impose (or prescribe) those conditions above the boundary layer; if we limit our vertical domain to the top of the boundary layer, we have to impose atmospheric conditions above it, which is not realistic. With imposed conditions, we can't consider the effect of the cloud-scale dynamics and thermodynamics on the layers above the MBL through propagating mechanisms such as the cloud-induced gravity wave. Also, we want to stress that with the prediction of those above-boundary-layer conditions, we can calculate the top-of-the-atmosphere radiative fluxes with better confidence; thermodynamic conditions (above the MBL) which is likely to be affected by the MBL clouds through mechanisms such as the wave affect radiative fluxes.

5. I'm unclear why increasing/decreasing the solar constant is relevant. Are you trying to simulate stratus in different seasons? Or are you just using solar forcing to push the model into different regimes (precip reaching surface or not). Some explanation of your motivation would be helpful on p. 23797.

Our intention was to examine the variation of the aerosol-cloud interactions in thin stratocumulus clouds with the variation of the incident solar radiation whose magnitude nearly corresponds to that of latitudinal variation of the incident solar radiation in July, if only the variation among CONTROL, SW-D2, and SW-D5 (excluding SW-M1.5) is considered. The incident solar radiation in SW-M1.5 is an idealized one, since it is larger than the observed maximum incident solar radiation in July. SW-M1.5 is generated to examine how mechanisms which control aerosol-cloud interactions with no surface precipitation vary with solar radiation with the comparison to CONTROL.

The following is added:

(LL195-200 in p7)

The range of the averaged SW among CONTROL, SW-D2, and SW-D5 in Table 1 nearly corresponds to the magnitude of the latitudinal variation of the averaged SW over the daytime in July. The averaged SW in SW-M1.5 which is larger than that in CONTROL enables the examination of the aerosol-cloud interactions in shallower clouds than those in CONTROL. This is because the decoupling in the MBL generally increases with increasing incident solar radiation.

6. p. 23803 l. 20: Increased updrafts are probably what causes the condensation, not the othe way around (as noted in major pt #1).

The sentence pointed out here is replaced with:

(LL380-382 in p13)

The larger number of cloud droplets, initiating the intensified feedbacks between condensation and updrafts, plays a critical role in the increased condensation in cases where the LWP is higher at high aerosol.

7. Fig 2 really displays the evolution of cloud base and cloud top, but its labels make it look like a contour plot, which is confusing.

The text describing Figure 3 in the old manuscript is revised as follows:

(LL212-218 in p8)

Figure 4 depicts the time-height cross section of cloud-liquid mixing ratio at 0.01 g kg^{-1} for the high-aerosol run (with the PD aerosol) and low-aerosol run (with the PI aerosol) from 30 minutes after the cloud formation to the end of simulation; in this paper, all the figures, depicting the time evolution of any variables, are over the period from 30 minutes after the cloud formation to the end of simulation. The contour line of 0.01 g kg^{-1} is chosen to represent cloud boundary in Figure 4. Hence, the upper (lower) two lines represent cloud-top (-base) height in Figure 4.