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

Review of "Mid-latitude mixed-phase stratocumulus clouds and their interactions with aerosols: how ice processes affect microphysical, dynamic and thermodynamic development in those clouds and interactions?" by Seoung Soo Lee et al.

The authors present LES simulations of a mixed-phase stratocumulus deck over the Korean Peninsula and investigate changes in water path resulting from temporal variations in CCN concentrations. They use a number of sensitivity experiments to investigate the impact of altered CCN and INP concentrations and the presence of ice crystals in these clouds. Alterations in water path between the simulations are largely explained by different efficiencies of condensation and evaporation and the Wegener-Bergeron-Findeisen process.

Overall the simulations and results are well presented. However, I have a few major issues with the scientific interpretation of the results and the hypothesised physical mechanisms, as outlined below. Also in places important details about the diagnostics shown are missing. Therefore I cannot recommend this paper being published before substantial revisions have been carried out by the authors.

Major comments

1. *Wegener-Bergeron-Findeisen process, condensation and evaporation rates*:
   The main hypothesis in the paper to explain lower LWP in mixed-phase compared to warm- phase only simulations is the evaporation cloud droplets and subsequent inefficient deposition of water vapour onto ice in the context of the WBF process. I find that not very convincing or indeed a logical argument.
   For WBF to operate deposition needs to be efficient enough to reduce in-cloud relative humidity below water saturation. All else being equal that would in itself imply an enhanced condensate content in the cloud (assuming we are starting from the same cloud base specific humidity). If deposition onto ice is very inefficient, relative humidity in clouds will remain at (or close to) water saturation and hence no evaporation of cloud droplets would be expected.

   As long as water-vapor pressure (WVP) is greater than water-vapor saturation pressure for ice particles (QIS), deposition occurs whether WVP is lower than the saturation pressure for liquid particles (QWS) or higher than QWS. When WVP is higher than QWS, there is competition between ice and liquid particles for water vapor needed for their growth and depending on how this competition evolves, the amount of deposition or deposition efficiency as the reviewer phrases is determined. Anyway, since QIS < QWS, although WVP is higher than QWS initially, the reduction of WVP due to condensation onto liquid particles and deposition onto ice particles eventually can lead to WVP lower than QWS but higher than QIS and this in turn can lead to a situation where deposition continuously occurs or efficient deposition occurs as the reviewer phrases but condensation stops and evaporation starts.

   Even though WVP is equal to QWS or WVP remains at QWS as the reviewer phrases, that does not mean that there is no evaporation. Even in this situation of WVP=QWS at the initial stage, since QIS < QWS, deposition can occur and this can lower WVP, leading to another situation where WVP < QWS and thus evaporation starts. This is supported by Korolev and Mazin (2003; JAS) showing that although initially WVP=QWS, due to WVP > QIS, deposition occurs, and this lowers WVP and makes WVP becomes "slightly" lower than (or close to) QWS, leading to droplet evaporation and the depletion of droplets.

   Based on the argument above, whether initial WVP = QWS or initial WVP > QWS, deposition can occur as long as WVP > QIS, then eventually WVP can be lower than QWS and evaporation occurs as shown in Figure 3c for the control run. If initially the WBF condition is there which is QIS<WVP<QWS, evaporation and deposition occur simultaneously at the very beginning. This evaporation reduces cloud droplet number concentration as a source of subsequent condensation as shown in Figure 3d. This provides lower cloud droplet number concentration for

condensation when the situation of WVP > QWS is recovered, and subsequently contributes to less condensation; note that unlike in parcel models, air parcels in the model adopted here experience various updraft, downdraft and microphysical conditions and feedbacks among them while those parcels move around three-dimensionally, hence, those parcels can repeatedly come back and forth between WVP>QWS and WVP$<$QWS. However, aided by the fact that QIS $<$ QWS, deposition is facilitated whether WVP at a grid point and a time step is higher than QWS or not as long as WVP is higher than QIS. This leads to greater deposition than condensation in the control run. The deposition is inefficient due to low CINC as a source of deposition. This inefficient deposition does not mean there is no deposition but mean that deposition is not large enough to make cloud mass in the mixed-phase clouds similar to that in the warm clouds due to the low CINC and the associated insufficient integrated surface area of ice crystals as demonstrated by the INP-10 and INP-100 runs. In the INP-10 and INP-100 runs, with increasing CINC, when WVP > QWS, ice particles can be more dominant in the competition between ice and liquid particles for their growth than in the control run. This enhances deposition and reduces condensation in the INP-10 and INP-100 runs as compared to those in the control run. When WVP $\leq$ QWS but WVP > QIS, more CINC makes deposition more efficient or significant, which is more favorable for maintaining WVP $<$ QWS and for more efficient evaporation (and thus subsequent less condensation) in the INP-10 and INP-100 runs than in the control run.

If we look at the control run only in Figure 3b, deposition occurs and its rate is generally greater than condensation rate. This means that if we restrict our argument only to the control run for the mixed-phase cloud, deposition occurs significantly as compared to condensation to explain cloud mass more than condensation. This in turn means that deposition enhances condensate content, as the reviewer phrases, in a way that this deposition-enhanced cloud mass is greater than condensation-related cloud mass. This significant deposition is considered inefficient, only when it comes to cloud mass in the control run for the mixed-phase cloud as compared to that in the control-noice run for the warm cloud. Here, it is notable that as seen in Figure 3c, evaporation occurs and this means that overall, the significant deposition involves evaporation in the control run. This in turn means that the statement that deposition is very inefficient, leading to no evaporation, as the reviewer phrases is not true when it comes only to the control run. Here, we see that deposition and evaporation interact with each other to induce the significant deposition in the control run, however, this deposition is not large enough, leading to lower WP in the control run than in the control-noice run.

We may think the sedimentation of ice particles and the PBL-top entrainment play a role in the lower WP in the control run than in the control-noice run. Regarding this, we repeated the control run with sedimentation turned off or by setting fall velocity of ice particles to zero as detailed in Section 4.1.3. In this repeated run, we can exclude the role of sedimentation of ice particles in the WP. Comparisons between the control run and this repeated run show that the qualitative nature of results does not vary with whether there is the ice-particle sedimentation or not. Also, as explained below, the entrainment at the PBL top is greater in the control-noice run than in the control run. Hence, the loss of ice particles and associated cloud mass via ice-particle sedimentation is not the reason why the control run has lower WP than the control-noice run, and entrainment tends to reduce cloud mass in the control-noice run more than in the control run. This means that ice-particle sedimentation and entrainment are not the reason why WP is lower in the control run than in the control-noice run.

2. *Loss of cloud condensate by sedimentation, changes in entrainment and cloud fraction*:
   A much more logical explanation (and indeed one that can be found in literature for explaining the behaviour of Arctic / Southern Ocean mixed-phase stratocumulus) is the change in sedimentation rates if ice crystals are present in the stratocumulus clouds. The authors do not consider loss processes due to sedimentation (or indeed altered cloud-top entrainment) in the presented results. This should be remedied in a future version of the manuscript.
   The authors also do not discuss changes in cloud fraction between the simulations, which are frequently reported to occurs for super-cooled stratus clouds in the Southern ocean as a function of the INP abundance.

   1. We obtained the time series of differences in the average entrainment rate between the control and low-aerosol runs as shown in Figure 9b. This figure shows that during the period between 12:50 and 13:20 LST on January 12th, there is no steady and rapid temporal increase in differences in the rate of entrainment at the PBL tops unlike the situation with CDNC differences between the control and low-aerosol runs. Hence, we believe that it is not likely that the jump in differences in evaporation between the runs is induced by the entrainment rate. However, we believe that entrainment together with the WBF mechanism plays a role in

the reduction in the temporal decrease in evaporation and contributes to the lower temporal reduction in evaporation than that in condensation after 13:30 LST on January 12th in each of the control and low-aerosol runs. Regarding this, the following is added:

(LL869-872 on p29)

For the period between 12:50 and 13:20 LST, there is no steady and rapid temporal increase in differences in the entrainment rate at the PBL tops unlike the situation with CDNC differences between the ice runs (Figure 9b). Hence, the greater jump in differences in evaporation between the ice runs is not likely to be induced by entrainment.

(LL878-883 on p29)

The presence of the WBF mechanism and entrainment facilitates evaporation and this acts against the temporal decrease in evaporation with time over the period in each of the ice runs. This counteraction by the WBF mechanism and entrainment reduces the temporal decrease in evaporation and enables evaporation to reduce temporally to a less extent as compared to condensation in each of the ice runs for the period (Supplementary Figure 1).

2. Regarding the role of entrainment in the noice runs, the following is added:

(LL954-966 on p32)

The average entrainment rate over all grid points at the PBL tops and over the whole simulation period is 0.71 and 0.60 cm s^{-1} in the control-noice and low-aerosol-noice runs, respectively. The average entrainment rate over all grid points at the PBL tops and over the whole simulation period is 0.13 and 0.15 cm s^{-1} in the control and low-aerosol runs. There are aerosol-induced decreases in the average entrainment over the whole simulation period between the ice runs. The boost of evaporation by the WBF mechanism in each of the ice runs leads to greater evaporation efficiency by outweighing the lower entrainment rate in the control run than in the control-noice run and in the low-aerosol run than in the low-aerosol-noice run. Aerosol-induced increases in the boost lead to aerosol-induced greater increases in evaporation efficiency between the ice runs than between the noice runs despite aerosol-induced decreases (increases) in the entrainment rate between the ice (noice) runs for the whole simulation period.

3. Regarding the role of entrainment between the control and control-noice runs, the corresponding text is revised as follows:

(LL543-554 on p18-19)

Associated with the more evaporation and difficulty in droplet activation, droplets disappear more and form less, leading to a situation where cloud droplet number concentration (CDNC) starts to be lower in the control run during the initial stage (Figure 3d). This is despite the higher entrainment rate at the PBL tops and associated more evaporation in the control-noice run than in the control run. The average entrainment rate over all grid points at the PBL tops and over the initial stage is 0.18 and 0.08 cm s_{-1} in the control-noice and control runs, respectively. In this study, the entrainment rate is calculated as follows:

The entrainment rate = $dz_i/dt - w_{sub}$

Here, z_i is the PBL height and w_{sub} is the large-scale subsidence rate at the PBL top.

4. Regarding the role of entrainment between the control and INP-reduced runs, the corresponding text is revised as follows:

(LL1050-1061 on p35)

Also, more entrainment contributes to the more evaporation in the control run (Figure 9b). Between the INP-reduced and control runs, with no increases in the concentration of background aerosols acting as CCN, increases in the surface-to-volume ratio of droplets and the associated enhancement in the WBF-mechanism-related efficiency of evaporation are negligible as compared to those between the control and low-aerosol runs. Note that there are overall larger increases in entrainment and associated evaporation between the control and INP-reduced runs than between the control and low-aerosol runs (Figure 9b). The negligible enhancement in the WBF-mechanism-related efficiency of evaporation overshadows the overall larger increases in entrainment and associated evaporation between the control and INP-reduced runs. This leads to aerosol-induced overall smaller increases in evaporation between the control and INP-reduced runs than between the control and low-aerosol runs (Figures 9a and 9d).

5. Regarding the role of the sedimentation of ice crystals, sensitivity tests are performed. Sections 4.1.3 and 4.2.3 describe those tests and their results.

6. Regarding the cloud fraction, the following is added:

(LL464-467 on p16)

This higher WP in the control-noice run accompanies the higher average cloud fraction over time steps with non-zero cloud fraction. The average cloud fraction is 0.98 and 0.92 in the control-noice and control runs, respectively.

(LL736-738 on p25)

This involves aerosol-induced decreases in the average cloud fraction over time steps with non-zero cloud fraction from 0.93 in the low-aerosol run to 0.92 in the control run.

(LL748-750 on p25)

This involves aerosol-induced increases in the average cloud fraction over time steps with non-zero cloud fraction from 0.96 in the low-aerosol-noice run to 0.98 in the control-noice run.

(LL1092-1096 on p36)

This greater increase in IWP dominates over the smaller decrease in LWP between the control and INP-reduced runs, leading to an increase in WP in the control run as compared to that in the INP-reduced run with an increase in the average cloud fraction over time steps with non-zero cloud fraction from 0.89 in the INP-reduced run to 0.92 in the control run.

Specific comments

1. In the introduction (l. 104 ff.) the WBF process is introduced. The discussion is relatively superficial and for example ignores that the occurrence of WBF dependence on the balance in timescales between supersaturation generation and its depletion by condensation and deposition on the existing cloud particle population. As so much of the paper rests on the WBF process are more detailed discussion is required here (if the focus on WBF is to remain in future versions of the manuscript).

The following is added:

(LL121-128 on p5)

The occurrence of the WBF mechanism depends on updrafts, humidity, associated supersaturation and microphysical factors such as cloud-particle concentrations and sizes (Korolev, 2007). Also, it needs to be pointed out that when the WBF mechanism starts and how long it lasts depend on how a timescale for updrafts and associated supersaturation is compared to that for phase-transition processes as a part of microphysical processes (Pruppacher and Klett, 1978). Korolev (2007) have utilized a parcel-model concept to come up with conditions of updrafts and microphysical factors where the WBF mechanism is operative.

To give more detailed explanation of the methodology to examine the interplay between ice and liquid particles including the WBF mechanism, the following is added:

(LL160-179 on p6-7)

To fulfill the aim, this study focuses on effects of the interplay between ice crystals and droplets on those clouds, and interactions of these effects with aerosols using a large-eddy simulation (LES) Eulerian framework. The LES framework reasonably resolves microphysical and dynamic processes at turbulence scales and thus we can obtain process-level understanding of those effects and interactions. Note that with the Eulerian framework, instead of tracking down individual air parcels, which can be pursued with the Lagrangian framework, this study looks at updrafts, microphysical factors, phase-transition processes and their evolution, which are averaged over grid points in a domain, to examine the overall interplay between ice and liquid particles over the whole domain. Also, in the LES framework, air parcels go through various updrafts, microphysical factors and feedbacks between them. Thus, unlike in Korolev (2007), an air parcel in the LES framework can repeatedly experience conditions where the WBF mechanism does not work and those where the mechanism works as it moves around three-dimensionally. Hence, chasing down air parcels in terms of conditions (e.g., updrafts and microphysical factors) for processes such as the WBF mechanism is enormous task and not that viable. This motivates us to embrace the approach that adopts the averaged updrafts, microphysical factors and phase-transition processes to examine the overall interplay between ice and liquid particles which includes the WBF mechanism. To help this approach to identify the overall interplay between ice and liquid particles clearly, this study utilizes sensitivity simulations.

2. Figure 2: It is unclear what the data shown is. Observations somehow regridded? Some model output? You need to state this in the text and the caption.

Observed and measured PM data by ground stations are shown in Figures 2a, 2b and 2c. For Figures 2b and 2c, observed and measured PM data are interpolated into grid points in the domain. To make this point clear, corresponding text and caption are revised and the following is added:

(LL201-202 on p7)

These stations observe and measure PM10 and PM2.5 using the beta-ray attenuation method (Eun et al., 2016; Ha et al., 2019).

(LL215-217 on p8)

To construct Figures 2b and 2c, observed and measured aerosol mass concentrations by the ground stations are interpolated into equidistant points in the rectangle.

(In caption for Figure 2)

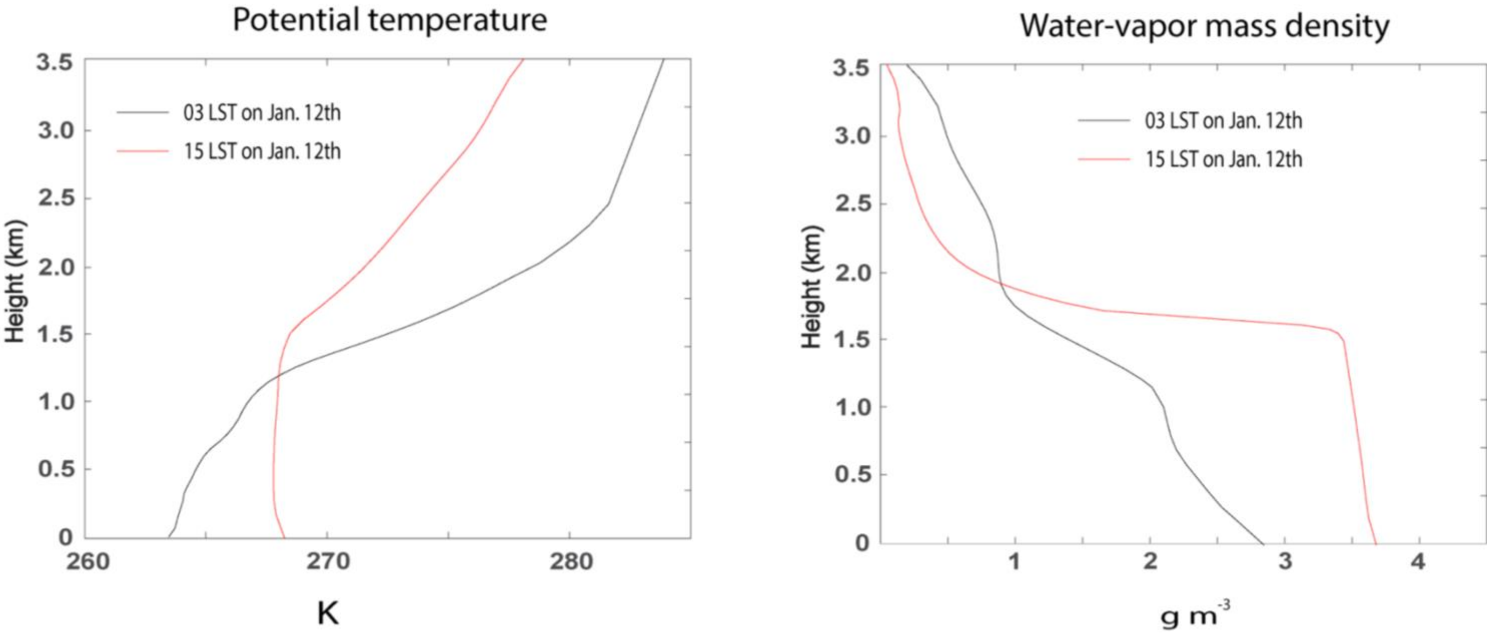
The spatial distribution of PM2.5, which is observed and measured by the ground stations and interpolated into grid point over the rectangle in Figure 1, at (b) 05:00 LST and (c) 18:00 LST on January 12th in 2013.

3. Section 2: You discuss changes in ambient aerosol concentrations in this section due to advection. Changes in airmass as implied by the large increase in aerosol concentrations shown in the timeseries likely also imply changes in meteorology (e.g. moisture content or vertical temperature structure). Are there any data available to check how large these changes are and what the impact of these changes on the cloud deck would be?

Yes, there are changes in meteorology accompanying changes in aerosol concentrations in the domain.

This paper focuses only on impacts of advected aerosols on clouds and does not focus on impacts of advected meteorological conditions on those clouds. Hence, impacts of advected meteorological conditions are out of scope of this study. That's why we repeated the control run only by changing aerosol concentrations but not by changing meteorological conditions. Then, we compared the control run to the repeated run (i.e., the low-aerosol run) to isolate impacts of advected aerosols.

Although impacts of advected meteorological conditions are out of scope, we obtained the vertical distribution of the radiosonde-observed potential temperature and humidity at 03:00 and 15:00 LST on Jan. 12th as shown in the following figure. At 03:00 LST on Jan. 12th just before when aerosol concentrations start to increase due to the aerosol advection in the Seoul area, there is a stable layer in the PBL whose top is around 1.0 km. This stable layer is not favorable for the formation of a deck of stratiform clouds. However, after 03:00 LST, the PBL becomes a well-mixed layer and its top height increases to 1.5 km as seen in comparisons between 03:00 and 15:00 LST in the figure. Hence, with advection-induced increases in aerosol concentrations in the Seoul area, meteorological conditions become favorable for the formation of a deck of stratocumulus clouds. Regarding this, if we had repeated the control run with an assumption that meteorological conditions after 03 LST on January 12th do not evolve and are fixed at 03 LST on January 12th, there would have been no or nearly no formation of stratocumulus clouds in the repeated run.



4. Section 3.2 (l. 247): Are observations at this spatial resolution also available over the ocean area of your domain? How is the horizontal interpolation done and how potential domain-filling required in areas with fewer stations? Also could you use the AERONET data to justify your assumption about constant modal radius and standard deviation?

Aerosol data are not available over the ocean area. Using the inverse distance weighting (IDW) method for interpolation or extrapolation, aerosol observed data on the land are extrapolated to the ocean area. Simply speaking, distances between a grid point of interest over the ocean and grid points over the land are obtained and based on these distances, an aerosol concentration for the grid point over the ocean is obtained. Here, IDW adopts an assumption that things that are close to one another or have shorter distances among them are more alike than those that are farther apart or have longer distances among them.

Only ~20% of the simulation domain is occupied by the ocean area and thus, we believe that the ocean area does not occupy a significant portion of the domain. So, we think that ocean does not affect the conclusions in this study. As a way of testing this thought and a way of removing the uncertainty associated with the ocean, we performed analyses of observation and simulation results here only over the land area (without the extrapolation of observation in the land area to the ocean area). These analyses give us the same conclusions that are already given in the old manuscript. Hence, whether we include the ocean and associated uncertainty in analyses or not does not affect the qualitative nature of conclusions in this study.

According to the AERONET data, the shape of aerosol size distribution and aerosol composition do not show a significant variation during the simulation period. Hence, we assume that the shape and composition do not vary during the period. The shape and composition described in the old manuscript are the average shape and composition over the simulation period.

To indicate the shape of aerosol size distribution and aerosol composition in the AERONET data do not show a significant variation during the simulation period, the following is added:

(LL299-302 on p10-11)

Aerosol chemical composition in this study is assumed to be represented by this mixture in all parts of the domain during the whole simulation period, based on the fact that aerosol composition does not vary significantly over the domain during the whole period with the observed clouds.

(LL315-317 on p11)

Since the AERONET observation shows that the shape of the size distribution does not vary significantly over the domain during the simulation period, we believe that this assumption is reasonable.

5. Figure 3 (and several other figures): It is unclear whether the averages shown are average over the entire domain or in-cloud areas only. The former would / could potentially include a large number of small values in cloud-free areas and include potential changes in cloud cover into the shown metrics / diagnostics.

By "definition", the domain average means that all grid points are used for the average whether they have non-zero values of a variable of interest or not. For example, the domain-averaged condensation rate is "the sum of condensation rate over all grid points in the domain whether they have the zero value of condensation rate or not" divided by "the number of all grid points in the domain". When "the domain average" is used, that is indicated in figure captions and text.

When the average is performed over grid points only with non-zero values of a variable of interest but not with zero values, that is indicated in figure captions and text. For example, CDNC averaged over grid points only with non-zero values of CDNC for the whole domain is "the sum of CDNC over grid points with non-zero CDNC excluding those with zero CDNC in the domain" divided by "the number of grid points with non-zero CDNC excluding those with zero CDNC in the domain"

Most of variables in this paper are averaged with "the domain average". However, it is conventional to show the values of variables, such as CINC, CDNC, cloud-particle radius, and cloud-top and -bottom heights, averaged over grid points with the non-zero values of those variables, since in this way, readers can make comparisons of those variables between different studies most of which perform the average of those variables over grid points with the non-zero values of those variables but not over all grid points including both the non-zero and zero values. In the case of cloud-particle radius, it is conventional that it can also be averaged over grid points with non-zero cloud-particle concentration.

In this study, we are interested in how the total amount of cloud variables (e.g., LWP, IWP, WP, condensation, evaporation and deposition) vary over the whole domain with varying aerosol conditions or cloud conditions (e.g., mixed-phase or warm clouds). Based on the interest, we summed up each of those variables over the whole grid points whether they have the non-zero values of each of those variables or not. Then, following the convention which shows the normalized sum of each of those cloud variables as a way of showing the total amount of each of those cloud variables, we normalized the sum by dividing it by the total number of all grid points over the whole domain in all of simulations, which is equivalent to "the domain average", so that readers can compare the normalized sum to that in other studies most of which also perform "the domain average" for those cloud variables.

We find that whether we perform the domain average for each of variables, such as CINC, CDNC, cloud-particle radius, cloud-top and -bottom heights, and compare each of these domain averages to each of the domain-averaged cloud variables (e.g., LWP, IWP, WP, condensation, evaporation and deposition) or we perform the average of each of those cloud variables (e.g., LWP, IWP, WP, condensation, evaporation and deposition) only over grid points where it has non-zero values and compare each of these averages to the average of each of variables, such as CINC, CDNC, cloud-particle radius, cloud-top and -bottom heights, only over grid points where it has non-zero values, the qualitative nature of conclusions in this study does not vary.

Technical corrections

- Throughout the text IN is used to refer to aerosols able to initiate ice. In recent literature this term is not standard anymore, instead "ice nucleating particles" (INP) is used. The authors should consider switching to this nomenclature.

Done.

- l. 57: interactions with what?

Replaced with the following:

(LL58-59 on p3)

This study examines the roles of ice processes in those clouds and their interactions with aerosols using a large-eddy simulation (LES) framework.

- l. 62: I do not understand what you want to say with the sub-sentence starting with "whose"

The sub-sentence is removed.

- l. 102: Make sure you make clear that “level“ refers to an altitude, at which homogeneous freezing would be expected based on an average temperature profile. The current formulation is somewhat confusing.

The word “level” pointed out here is replaced with “altitude”

- l. 104: “The ~~level of~~ water-vapour equilibrium saturation **pressure** is lower …“

Done.

- l. 111: “… differences in water-vapour equilibrium saturation **pressure over** ice and liquid …“

We put “pressure” in the corresponding sentence. However, we believe that “between” is a better word than “over”, since the corresponding sentence wants to express that the saturation pressure is “different” between ice and liquid particles.

- l. 118 ff: I am not sure the sentence starting with “hence“ is logical or I do not understand what you are trying to say. Please rephrase.

The corresponding sentences are replaced with the following:

(LL129-135 on p5)

The evolution of cloud particles as well as their interactions with aerosols is strongly dependent on thermodynamic and dynamic conditions such as humidity, temperature and updraft intensity (Pruppacher and Klett, 1978; Khain et al., 2008). Interactions between ice and liquid particles in mixed-phase clouds, which include the WBF mechanism, change thermodynamic and dynamic conditions where cloud particles grow. Impacts of these changes on the development of mixed-phase clouds and their interactions with aerosols have not been understood well.

- l. 177: Please indicate the location of these stations (also the Seoul one) on Figure 1.

Done.

- l. 179: Not sure I would agree with 03 LST based on the plot. It more looks like 10 LST.

We looked at data and it is 05 LST. We marked the time points with arrows and the following is added to the corresponding caption, accordingly:

The blue (red) arrow marks time when aerosol mass starts to increase in BN (SL) due to the advection of aerosols from East Asia to the Seoul area.

- l. 227: Please rephrase this sentence. It sounds very strange. Also state whether you use equi-distant vertical levels or a stretched coordinate system.

Replaced with the following:

(LL261-263 on p9)

In the vertical domain, the resolution coarsens with height. The resolution in the vertical domain is 20 m just above the surface and 100 m at the model top that is at ~ 5 km in altitude.

- l. 280: “… aerosols **acting** as IN …“ (missing also at various other instances throughout the text, please carefully review)

Done.

- l. 338: Interplay between what?

The corresponding text is revised as follows:

(LL431-437 on p15)

Via comparisons between the control and control-noice runs, we aim to identify effects of the interplay between ice crystals and droplets on the adopted system. Via comparisons between a pair of the control and low-aerosol runs and that of the control-noice and low-aerosol-noice runs, we aim to identify effects of the interplay between ice crystals and droplets on interactions between the system and aerosols. Henceforth, the pair of the control and low-aerosol runs is referred to as the ice runs, while the pair of the control-noice and low-aerosol-noice runs is referred to as the noice runs.

- l. 388: Is this refering to MTSAT or ground based observations? How is averaging done?

The corresponding text is revised as follows:

(LL485-500 on p17)

Multifunctional Transport Satellites (MTSAT), which are geostationary satellites and available in the East Asia, do not provide reliable data of LWP and IWP, although they provide comparatively reliable data of cloud fraction and cloud-top height throughout the whole simulation period (Faller, 2005). Ground observations provide data of cloud fraction and cloud-bottom height throughout the whole simulation period. Here, the simulated cloud fraction and cloud-bottom height are compared to those from ground observations, while the simulated cloud-top height is compared to that from the MTSAT. The average cloud fraction over time steps with non-zero cloud fraction is 0.92 and 0.86 in the control run and observation, respectively. The average cloud-bottom height over grid columns and time steps with non-zero cloud-bottom height is 230 (250) m in the control run (observation). The average cloud-top height over grid columns and time steps with non-zero cloud-top height is 2.2 (2.0) km in the control run (observation). For this comparison between the control run and observation, observation data are interpolated into grid points and time steps in the control run. The percentage difference in each of cloud fraction, cloud-bottom and -top heights between the control run and observations is ~ 10% and thus the control run is considered performed reasonably well for these variables.

- l. 621 ff: I do not get this sentence, please rephrase.

As seen in supplementary Figure 1 and described in text, evaporation and condensation jump in each of the ice runs (i.e., the control and low-aerosol runs) in a time period between 12:50 and 13:20 LST. As seen in supplementary Figure 1 and described in text, the jump (or the surge or the rapid increase) in evaporation is higher than that in condensation in each of the ice runs. This accompanies a situation where the jump in differences in condensation between the ice runs is not as high as that in differences in evaporation between the ice runs as seen in supplementary Figure 1 and described in text. As seen in supplementary Figure 1 and described in text, associated with this, differences in the jump between evaporation and condensation are greater in the control run than in the low-aerosol run.

It is well-known that evaporation tends to make droplets disappear and condensation counteracts this disappearance of droplets. Hence, more evaporation tends to make more droplet disappear, while more condensation counteracts the disappearance of droplets more as described in text. The jump (or the surge or the rapid increase) in evaporation leads to the jump (or the surge or the rapid increase) in the disappearance of droplets, while the jump in condensation leads to the jump in the counteraction against the disappearance of droplets. Since the jump in evaporation is higher than that in condensation in each of the ice runs, evaporation-induced disappearance of droplets outweighs condensation-induced counteraction against the disappearance of droplets. Hence, for each of the ice runs, this induces the decreasing trend of cloud droplet number concentration (CDNC) starting at 13:30 LST. If the rate of this decrease in CDNC with time is equal between the runs, there won't be any decreasing trend in "differences" in CDNC between the runs. However, remember that differences in the jump between evaporation and condensation are greater in the control run than in the low-aerosol run. Hence, evaporation-induced disappearance of droplets is counteracted by condensation "less" in the control run than in the low-aerosol run. This induces the rate of the decrease in CDNC with time to be greater in the control run than in the low-aerosol run, which in turn induces differences in CDNC between the runs to reduce with time starting at 13:30 LST.

The corresponding paragraph is revised as follows:

(LL801-817 on p27)

The jump in differences in condensation between the ice runs is not as high as that in differences in evaporation between the ice runs (Figure 9a). This situation accompanies the fact that in each of the ice runs, the jump in evaporation is higher than that in condensation (Supplementary Figure 1). This means that differences in the jump between evaporation and condensation are greater in the control run than in the low-aerosol run (Supplementary Figure 1). Hence, evaporation-driven jump in the disappearance of droplets outweighs condensation-driven jump in counteraction against the disappearance in each of the ice runs. Due to this, the increasing temporal trend of CDNC turns to its decreasing trend in each of the ice runs around 13:30 LST on January 12th. If the rate of this decrease in CDNC with time is equal between the ice runs, there is no decreasing trend in differences in CDNC between the runs. However, remember that differences in the jump between evaporation and condensation are greater in the control run than in the low-aerosol run. Hence, when the jumps occur, evaporation-induced disappearance of droplets is counteracted by condensation "less" in the control run than in the low-aerosol run. This induces the rate of the CDNC decrease to be greater in the control run than in the low-aerosol run. This in turn turns the increasing temporal trend of the CDNC differences between the ice runs to their decreasing trend around 13:30 LST on January 12th (Figure 9a).

- Fig. 2a: Make clear the x-axis is in days!

Done by adding "January" and replacing "dates" with "days"

- Fig. 9a, 9c: Consider changing the scaling. The temporal evolution of most variables is very hard to discern in the current versions of these plots.

Done.

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

The paper reports on the sensitivity analysis of a supercooled stratus cloud to changes in cloud condensation nucleation and ice nucleating particles.

The authors frame the analysis as an investigation of changes to condensation and evaporation rate. Unfortunately I think that misses out what is going on in this cloud. We are also lacking process rates that could help to clarify the situation. The authors claim that the changes in WP are simply due to changes in condensation and evaporation. What it looks like is happening is that dehydration of the layer at which the cloud forms is being controlled by hydrometeor number concentration that ultimately controls the particle mean size and the flux of mass out of the cloud.

While the simulations seem to be fine, the interpretation needs to be revisited and additional plots included.

Main point.

The authors seek to explain the changes in WP by changes in condensation and evaporation rate. This is not the complete water budget for the cloud. There is also sedimentation that needs to be taken into account. My impression from looking at the results is that the WP changes can all be explained by the role of sedimentation dehydrating the cloud layer. The authors discuss increased surface area leading to more efficient condensation, but to first order the amount condensed is governed by how high a parcel ascends (if the timescale for condensation/deposition is shorter than eddy overturning timescale). The particle number concentration then leads to smaller particles for higher concentrations that fall slower and are therefore less efficient at dehydrating the cloud layer.

This can be demonstrated by:

i) showing precipitation rate at cloud base for the different simulations (precip rate will decrease with increasing concentration).

Precipitation rates at cloud base are shown in Section 4.1.3

ii) setting the sedimentation speed of ice particles to zero – this would then mean that the control and 100x IN simulations develop similar WP.

We repeated the standard simulations (the control, INP-10 and INP-100 runs) with sedimentation of ice particles turned off or by setting fall velocity of ice particles to zero. In these repeated runs, we can exclude the role of sedimentation of ice particles in WP between the standard runs (e.g., the control, INP-10 and INP-100 runs). We find that the qualitative nature of results in the standard runs does not depend on the sedimentation of ice particles and associated cloud-base precipitation as detailed in Section 4.1.3.

iii) for evaporation rate to be important thre would need to be a large change in cloud top evaporation rate (converted to Wm-2) compared to any change in longwave cooling rate between simulations.

From the control run to the control-noice run, the cloud-top cooling (evaporative + sublimation+radiative cooling) increases. This is found to be due to increasing WP and associated cloud mass around the cloud tops from the control run to the control-noice run. Due to inefficient deposition in the control run, WP is lower (and then cloud-top cooling is lower) in the control run than in the control-noice run as demonstrated by comparisons between the control, INP-10 and INP-100 runs. As detailed in our responses below, the control, INP-10 and INP-100 runs show that increasing CINC and efficiency of deposition intensify positive feedbacks between deposition and updrafts and this intensification of feedbacks enables WP in the INP-100 run to be similar to that in the control-noice run. Associated with this, cloud mass and associated cooling at cloud tops increase from the control run to the INP-100 run through the INP-10 run, leading to a situation where cloud mass and cooling at cloud tops in the INP-100 run are much closer to those in the control-noice run than those in the control run are. Hence, increasing cloud-top cooling is a by-product of increasing deposition efficiency and associated intensified feedbacks between deposition and updrafts with increasing CINC among the control, INP-10 and INP-100 runs. This means that changes in cloud-top cooling do not drive changes in WP among the control, INP-10 and INP-100 runs but changes in in-cloud deposition (but not cloud-top deposition) drive those changes in WP and associated changes in cloud-top cooling.

I think the authors should carry out these suggestions

Other points.

Line 146 there are several high resolution studies of mixed-phase stratiform cloud that could usefully be reviewed and compared to. Here are some examples.

Possner et al. GRL 2017. https://doi.org/10.1002/2016GL071358

Ovchinnikov et al. JGR 2011. https://doi.org/10.1029/2011JD015888

Regarding Possner et al. (2017) and Ovchinnikov et al. (2011), the following is added:

(LL1213-1221 on p40)

Note that many of the previous studies of mixed-phase stratocumulus clouds (e.g., Ovchinnikov et al., 2011; Possner et al., 2017) have focused on roles of cloud-top radiative cooling, entrainment and sedimentation of ice particles in mixed-phase stratocumulus clouds and their interactions with aerosols. However, there have not been many studies that focus on roles of microphysical interactions, which involve microphysical processes (e.g., evaporation, condensation and deposition) and factors (e.g., cloud-particle concentrations and sizes), between ice and liquid particles in those clouds and their interplay with aerosols. Hence, we believe that this study contributes to the more general understanding of mixed-phase clouds and their interactions with aerosols.

Young et al. ACP 2017. https://acp.copernicus.org/articles/17/4209/2017/

Regarding Young et al. (2017), the following is added:

(LL152-154 on p6)

Young et al. (2017) have reported that the parametrization of ice-crystal nucleation can be a key reason for the misrepresentation of mixed-phase clouds in models.

It would also be worth looking at Ackerman et al.

https://pubs.giss.nasa.gov/docs/2004/2004_Ackerman_ac07000g.pdf

Regarding Ackerman et al. (2004), the follow is added:

(LL94-97 on p4)

These aerosol effects strongly depend on how increasing aerosols affect entrainment at the tops of the planetary boundary layer (PBL) (Ackerman et al., 2004) and disrupt global hydrologic and energy circulations.

Line 152. Need to slightly rewrite - there have always been aerosols affecting clouds.

The corresponding sentence is revised as follows:

(LL180-187 on p7)

Mixed-phase stratiform clouds have been formed frequently over the Korean Peninsula in midlatitudes. These clouds have been affected by the advection of aerosols from East Asia (e.g., Lee et al., 2013; Oh et al., 2015; Eun et al., 2016; Ha et al., 2019). However, we do not have a clear understanding of those clouds and impacts of those aerosols, which are particularly associated with the industrialization of East Asia, on them in the Peninsula (Eun et al., 2016). Motivated by this, we examine those clouds and effects of the advected aerosols from East Asia on them over an area in the Korean Peninsula as a way of better understanding those clouds and aerosol-cloud interactions in them.

Line 221. Some more metrological information would be useful. What temperature is cloud base and cloud top at?

The following is added:

(LL269-271 on p9-10)

When clouds start to form around 08:00 LST on January 12th, the average temperature over all grid points at cloud tops and bottoms is 252.0 and 263.9 K, respectively.

Line 242. Is representing this variability within the domain important? How does it compare to just using averaged values over the domain?

To deal with this comment, we obtained the domain-averaged background aerosol concentration at each time step in each of the control, low-aerosol, control-noice and low-aerosol-noice runs. Then, we repeat the control run by applying the average background aerosol concentration to all grid points at each time step. This process is repeated for each of the other simulations. In these repeated runs, background aerosol concentration does not vary in the domain but vary with time.

The repeated simulations show that the qualitative nature of results in the control, low-aerosol, control-noice and low-aerosol-noice runs does not depend on whether background aerosol concentration varies spatially or not.

Line 291-298. So the microphysics uses up the aerosol ?

Yes, “only in clouds”, microphysics consumes aerosol particles via aerosol activation.

And then the aerosol is nudged back to a background concentration? What is the timescale to do this? Why isn't advection of aerosol from the boundary sufficient?

Immediately after clouds disappear completely at any grid points, aerosol size distributions and number concentrations at those points recover to background properties that background aerosols at those points have before those points are included in clouds. In this method, there is no time interval between the cloud disappearance and the aerosol recovery. Here, when the sum of mass of all types of hydrometeors (i.e., water drops, ice crystals, snow aggregates, graupel and hail) is not zero at a grid point, that grid point is considered to be in clouds. When this sum becomes zero, clouds are considered to disappear. Note that background number concentrations, based on observed PM data and the assumption on aerosol size distribution and composition, are interpolated or extrapolated to grid points immediately above the surface and time steps in the simulation; background aerosol concentrations are assumed not to vary with height from immediately above the surface to the PBL top, however, above the PBL, they are assumed to reduce exponentially with height; aerosol size distribution and composition do not vary with height; once background aerosol properties (i.e., aerosol number concentrations, size distribution and composition) are put into each grid point and time step, those properties at each grid point and time step do not change during the course of the simulation. In this way, background aerosol concentrations (or background aerosols or aerosols outside clouds) in the simulation are exactly identical to those observed, in case we neglect possible errors from the assumption on aerosol size distribution and composition, and interpolation or extrapolation of observed data to grid points and time steps in the simulation.

Background aerosols, which are observed and in the simulations, are different among grid points and time steps, although background aerosols at “each” grid point and time step do not change during the course of the simulation. This means that background aerosols vary with time and space over grid points and time steps. One of processes that control this variation of background aerosols is the observed advection of aerosols. This variation of background aerosols induced by the advection of aerosols is captured in and represented by the spatiotemporal variability of background aerosols in both observation and the simulations over gird points and time steps within the boundary of the domain without the need to simulate influx of aerosols into the domain through the boundary as a way of simulating the advection of aerosols.

Reasonably well, seems vague. In what way is it reasonable? And to what level of accuracy?

Morrison and Grabowski (2011), Lebo and Morrison (2014), Lee et al. (2016) and Lee et al. (2018) and other studies have demonstrated that simulations using the method described in

Section 3.2 and involving the prescription of background aerosols show a good consistency in cloud and precipitation properties between observation and simulations. These properties include cloud fraction, cloud-top height, cloud-bottom height, cumulative precipitation, precipitation frequency distribution, mean precipitation rate, cloud-system organization and precipitation spatiotemporal distributions, etc. The good consistency here means that the percentage difference in those properties between simulations and corresponding observation is ~10% to 20% or less.

The following is added:

(LL365-370 on p13)

These properties include cloud fraction, cloud-top height, cloud-bottom height, cumulative precipitation, precipitation frequency distribution, mean precipitation rate, cloud-system organization and precipitation spatiotemporal distributions. These studies have shown that there is good consistency between those simulated properties and observed counterparts. The good consistency means that the percentage difference in those properties between simulations and corresponding observation is ~ 10 to 20% or less.

Line 297-298. so the aerosols are not used by the clouds?

As mentioned in our response above, aerosols are used by clouds when aerosols are "in clouds." Once clouds form and background aerosols start to be in clouds, those aerosols are not background aerosols anymore and the size distribution and concentrations of those aerosols begin to evolve through aerosol sinks and sources. These sinks and sources include advection and aerosol activation (Fan et al., 2009). For example, activated particles are emptied in the corresponding bins of the aerosol spectra. Remember that as mentioned above, immediately after clouds disappear completely at any grid points, aerosol size distributions and number concentrations at those points recover to background properties that background aerosols at those points have before those points are included in clouds.

Line 301 the simulations are run such that the microphysics see the aerosol and can activate it to form cloud but does not remove it?

"In clouds", as described in text, aerosol mass included in hydrometeors, after activation, is moved to different classes and sizes of hydrometeors through collision-coalescence and removed from the atmosphere once hydrometeors that contain aerosols reach the surface. Here, grid points in clouds are defined by those having the non-zero mass of hydrometeors. When the sum of mass of all types of hydrometeors (i.e., water drops (droplets and raindrops), ice crystals or cloud ice (plate, columnar and branch types), snow aggregates, graupel and hail) is not zero at a grid point, that grid point is considered to be in clouds.

I think this section (3.2) needs to be rewritten to clarify how the aerosol is being used in the microphysics.

Here, we want to say that the recovery of aerosols to their background counterparts is mainly to keep aerosol concentrations outside clouds in the simulations at observed aerosol concentrations. Maybe, the WRF-Chem can be used for the simulation of aerosol evolution by considering aerosol chemical and physical processes, and cloud impacts on aerosols without using the aerosol recovery method or with no recovery of aerosol concentrations to their background counterparts when clouds disappear. Hence, in the WRF-Chem, technically, aerosols evolve in a more realistic way than in the WRF or ARW used in study. Here, it is notable that in clouds, regarding aerosol-cloud interactions via aerosol activation, which is nucleation scavenging, and aerosol transportation by wind and turbulence, there are nearly no differences between the WRF used here and the WRF-Chem, although when those clouds disappear, in the WRF-Chem, without nudging aerosols to observed background ones, aerosols just evolve based on the parameterization of aerosol chemical and physical processes, aerosol transportation and so on, however, in the WRF used here, aerosols are forced to be nudged into observed background aerosols.

Although the way to simulate aerosols is more realistic in the WRF-Chem than in the WRF used here, WRF-Chem has its weaknesses. One of those weaknesses is that it is not viable that the predicted aerosol spatial distribution and its evolution with time in the WRF-Chem are identical to those observed according to previous studies. In many cases, there are significant differences in the aerosol distribution and evolution between the WRF-Chem and observation particularly outside clouds. This is mainly because there are uncertainties in the representation of aerosol chemical and physical processes in the WRF-Chem.

For this study, particularly to simulate the variation of aerosol concentrations over grid points and time steps induced by the aerosol advection as observed, instead of using the WRF-Chem, we just apply observed aerosol concentrations to the simulations directly in association with the aerosol recovery method. In this way, background aerosols in the simulations are exactly identical to those observed, in case we neglect possible errors from the assumption on aerosol size distribution and composition, and the interpolation or extrapolation of observed data to grid points and time steps in the simulations. Also, we have to say that generally there are ~ 5-10 times more computational resources and time involved in the WRF-Chem than in the WRF. Moreover, the WRF-Chem with the bin microphysical scheme is computationally too expensive and this study, using the high horizontal resolution of 100 m, involves ~20 sensitivity tests over the 2-day period. Hence, in addition to above-described reason, as a way of releasing the computational burden, we adopt the aerosol recovery method.

The aerosol recovery method looks unrealistic, since once clouds disappear, it forces aerosol concentrations at grid points, which were in clouds immediately before their disappearance, to follow their background counterparts with no physical consideration. Here, it should be remembered that the background aerosols in the simulations are identical to those observed, in case we neglect possible errors from the assumption on aerosol size distribution and composition, and the interpolation or extrapolation of observed data to grid points and time steps in the simulations. In addition, those background aerosols from observation are results of processes related to aerosols in real nature (e.g., aerosol emissions, cloud impacts on aerosols via scavenging processes, aerosol chemical and physical processes and aerosol transportation by wind and turbulence). Hence, by adopting background aerosols, as they are in observation, for the simulation, not only we are able to consider the transportation of background aerosols by wind (or aerosol advection) and associated aerosol evolutions as observed but also we are able to consider the evolution of background aerosols induced by the other aerosol-related processes as observed in the simulation. We believe that this balances out the weakness of the aerosol recovery method to result in the reasonable simulation of the selected case, as is evidently shown by the fact that simulated cloud properties are in a good agreement with observed counterparts as described in text.

Based on our responses to the comment here and those above related to Section 3.2, it is revised. See text for details.

Line 350 section 4, 4.1

I am afraid I disagree with the interpretation presented here. The modelling results need to be reassessed and text rewritten.

Line 408-409. i would assume this is simply because cloud parcels have ascended higher (fig 3d shows the cloud top is ~1km higher for the noice simulation). In the ice simulations the water will be efficiently removed (due to deposition, riming and sedimentation) stopping the parcels reaching saturation as they ascend.

As mentioned above, we repeated the standard simulations (the control, INP-10 and INP-100 runs) with sedimentation of ice particles turned off or by setting fall velocity of ice particles to zero. In these repeated runs, we can exclude the role of sedimentation of ice particles in the WP between the standard runs (e.g., the control, INP-10 and INP-100 runs). Via comparisons between the standard and repeated runs, we find that the qualitative nature of results in the standard runs does not depend on the sedimentation of ice particles and associated cloud-base precipitation as detailed in Section 4.1.3.

As described in Section 4.1.2, increasing INP and CINC lead to increasing deposition in the INP-10 and INP-100 runs as compared to those in the control run. This increasing deposition in turn induces increasing updraft intensity, which establishes a positive feedback between deposition and updrafts. This in turn enables cloud-top height in the INP-100 run to be similar to that in the control-noice run (see Section 4.1.2 for details).

By analyzing results from the standard and repeated simulations (i.e., the control, INP-10 and INP-100 runs, and the repeated control, INP-10 and INP-100 runs with no ice-particle sedimentation), it is found that low CINC in the control run leads to insufficient deposition, in turn leading to weaker updrafts involving lower cloud-top height in the control run as compared to those in the control-noice run. This induces much lower WP in the control run than in the control-noice run and the repeated simulations show that the role of ice-particle sedimentation in the lower WP in the control run is negligible as compared to that of CINC and associated deposition.

To indicate the relation between condensation and cloud-top height in the control-noice run, the following is added:

(LL560-562 on p19)

It should be noted that as seen in Figures 3c and 3d, air parcels go up higher, which also contribute to more condensation in the control-noice run than in the control run.

To indicate changes in updrafts and cloud-top height in the INP-10 and INP-100 runs, the following is added:

(LL667-674 on p22-23)

Accompanying this is that the time and domain-averaged updraft mass flux in the INP-100 (INP-10) run over the whole simulation period reaches 95% (78%) of that in the control-noice run. The average cloud-top height over grid columns and time steps with non-zero cloud-top height in the INP-100 (INP-10) run, particularly over the initial stage between 00:00 LST and 20:00 LST on January 12th, reaches 92% (80%) of that in the control-noice run. Hence, the increasing deposition in the INP-10 and INP-100 runs involves its positive feedbacks with dynamics and this eventually enables air parcels in the INP-100 run to go up nearly as high as in the control-noice run.

Assuming similar updraft speeds and modest supersaturations if this microphysics supports it,, then the condensation rate just represents how much water has been removed from the parcel.

As described above, with increasing CINC and deposition in the INP-10 and INP-100 runs, updrafts also intensify, involving the increasing cloud-top height. Hence, updraft speeds are not fixed but vary with increasing CINC among the control, INP-10 and INP100 runs. The increasing updraft intensity and cloud-top height in turn alter supersaturation for ice particles whether the water-vapor pressure (WVP) is higher than water-vapor saturation pressure for liquid particles (QWS) or not at each grid point. This changing supersaturation with increasing updraft intensity and cloud-top height in the INP-10 and INP-100 runs works in a way to make WP in the INP-100 run similar to that in the control-noice run.

Its not the condensation rate alone, but the sink of moisture from the ascending cloud parcels that controls the lwp, iwp.

As found by the standard and repeated simulations (i.e., the control, INP-10, INP-100 runs, and the repeated control, INP-10 and INP-100 runs with no ice-particle sedimentation), the role of sedimentation of ice particles and associated precipitation in LWP and IWP is not significant as compared to that of deposition and condensation. This is why the LWP and IWP evolutions are highly correlated with the condensation and deposition evolutions, respectively, and we use this correlation to understand the LWP and IWP evolutions in terms of the condensation and deposition evolutions, respectively. Ovchinnikov et al. (2011) have also shown high-degree correlations between LWP and condensation or between IWP and deposition when precipitation is weak, supporting findings in this study.

line 433-434. is this just because there is coexisting ice that is competing for water. This will make it harder to activate new droplets.

We agree with this point raised by the reviewer. To reflect it, the corresponding text is revised as follows:

(LL540-546 on p18)

In addition, it should be noted that ice crystals consume water vapor that is needed for droplet nucleation. This makes it difficult for droplets to be activated in the control run as compared to a situation in the control-noice run. Associated with the more evaporation and difficulty in droplet activation, droplets disappear more and form less, leading to a situation where cloud droplet number concentration (CDNC) starts to be lower in the control run during the initial stage (Figure 3d).

1 per cc ice particles is extremely high concentrations for these temperatures.

In observations it should be more like 1-10 litre. 100litre if secondary production of ice is occurring

We checked codes and it should be in the unit of liter^{-1}. Also, the unit in Figures 6a, 9a and 9d should be liter^{-1} as well. Accordingly, Figure labels are corrected.

Line 441-444. No. the lower wp is because moisture has been removed from the column by sedimentation

To isolate the effect of sedimentation on IWP and WP and their variation among the control, IN-10 and IN-100 runs, the control, INP-10 and INP-100 runs are repeated by setting the fall velocity of ice particles to zero. These repeated runs demonstrate that the qualitative nature of the varying WP does not depend on varying sedimentation of ice particles among the control, INP-10 and INP-100 runs. These repeated runs also demonstrate that the lower WP in the control run than in the control-noice run is not caused by ice-particle sedimentation and associated cloud-base precipitation in the control run. The details of these repeated simulations are found in Section 4.1.3.

Line 455-470. Deposition is occurring because the vapour pressure over ice is lower than the environmental vapour pressure (in this case at water saturation). This will be a sink of water vapour leading to droplets evaporating and maintaining the vapour pressure at water saturation.

Deposition occurs whether the water-vapor pressure (WVP) is higher than water-vapor saturation pressure for liquid particles (QWS) or not as long as WVP is higher than water-vapor saturation pressure for ice particles (QIS). Whether WVP > QWS or QIS < WVP ≤ QWS, this study finds that the amount of deposition, associated updraft and their feedbacks are strongly dependent on CINC. With increasing CINC, there are increases in the updraft intensity and the intensification of feedbacks between updrafts and deposition as explained above. Mainly due to this intensification of these feedbacks, deposition and associated WP increases with increasing CINC.

In the case of WVP > QWS, more CINC and associated greater integrated surface area of ice crystals enable water vapor to find more integrated surface area of ice crystals for its deposition and in turn enable more deposition, stronger updrafts and stronger feedbacks between deposition and updrafts. Due to this more deposition, there is less condensation, and it is found that these stronger feedbacks enable more deposition to overcome less condensation, leading to increasing WP with increasing CINC.

In the case of QIS < WVP ≤ QWS, more CINC and associated greater integrated surface area of ice crystals enable water vapor to find more integrated surface area of ice crystals for its deposition and in turn enable more deposition, more evaporation of droplets and lower CDNC as sources of condensation. This provides lower CDNC for condensation when the situation of WVP > QWS is recovered, and subsequently contributes to less condensation; note that unlike in parcel models, air parcels in the model adopted here experience various updraft, downdraft and microphysical conditions and feedbacks among them while those parcels move around three-dimensionally, hence, WVP in those parcels can repeatedly come back and forth between WVP>QWS and WVP<QWS. The control, INP-10 and INP-100 runs in this study show that more deposition and associated stronger updrafts with more CINC lead to a situation where increasing deposition leads to increasing WP by outweighing subsequently decreasing condensation with increasing CINC among those runs.

In the old manuscript, the situation with QIS < WVP ≤ QWS is mainly discussed in the corresponding text. To reflect both of the conditions, which are WVP > QWS and QIS < WVP ≤ QWS, the corresponding text and other associated text are revised.

Here, regarding "maintaining the vapour pressure at water saturation" as the reviewer phrases in the comment here and the reviewer's another comment on the phase relaxation timescale below, according to Figure 7 in Korolev and Mazin (2003, JAS), we want to add that even though the relaxation timescale is controlled by liquid particles when liquid and ice particles coexist and the WBF mechanism works, water pressure is not exactly at water saturation but slightly lower than water saturation but higher than ice saturation, in association with deposition of ice particles and evaporation of liquid particles. Based on this, we believe that water pressure exactly at water saturation while the WBF mechanism works is likely to be rare.

If the cloud parcel is not fully glaciated then the water should be condensed out by the time the top of the parcel ascent is reached with perhaps a few seconds lag if there is substantial supersaturation.

When QIS < WVP < QWS, the evaporation of droplets increases water vapor which is a source of deposition. Sometimes, this increase in water vapor can make water-vapor pressure recover to QWS or its saturation pressure for liquid particles as pointed out by the reviewer here. However, even after this recovery, due to QIS< QWS, for given WVP, deposition and evaporation can restart. According to the control, INP-10 and INP-100 runs, deposition or the amount of water vapor deposited out, which involves droplet evaporation, potential recovery to QWS and subsequent droplet evaporation, increases with increasing CINC.

When WVP > QWS, droplets and ice crystals grow together via condensation and deposition, respectively. In this case, droplets and ice crystals compete for available water vapor needed for their condensation and depositional growth, respectively. Even in this case, according to the control, INP-10 and INP-100 runs, more ice crystals or higher CINC enables more deposition by providing more integrated surface area of ice crystals and this enables the relative importance of deposition regarding WP as compared to that of condensation to enhance. Hence, with decreasing INP and CINC, in the competition between condensation and deposition, the portion of water vapor condensed out on droplets increases and that deposited out on ice crystals decreases.

Due to above-mentioned intensified feedbacks between deposition and updrafts with increasing CINC, the total amount of water vapor condensed and deposited out increases, leading to increasing WP with increasing CINC, although the portion of water vapor condensed out accounts for the total amount of water vapor, condensed and deposited out, "less" with higher CINC.

The reason that the wp is larger for higher cinc is that the parcel has not been dehydrated. The total water is unchanged because the particles are much smaller and are not sedimenting out in the timescale of the parcel ascent.

The role of sedimentation of ice particles and associated dehydration in the WP changes among the control, INP-10 and INP-100 runs is found to be negligible as compared to that of deposition, according to simulations with the ice-particle sedimentation turned off. The details are given in Section 4.1.3.

In fact, if an even higher concentration were used the wp should exceed the control noice as the vapour can be brought to ice saturation.

We also think that higher CINC can make the WP exceed that in the control-noice run. However, we believe that based on the INP-10 and INP-100 runs, this can occur not through reduced sedimentation and precipitation but through the feedbacks between deposition and updrafts.

You can assess this by looking at the precipitation rate at cloud base.

The assessment of the cloud-base precipitation rate, associated sedimentation of ice particles and their roles in the WP variation among the control, INP-10 and INP-100 runs is shown in Section 4.1.3.

Changing the concentration will change the sink rate of moisture to ice, but you can estimate that timescale (e.g. Korolev and Mazin, JAS, 2003). The concentrations used here are high, so the timescales will be short - approaching what you typically see for liquid. For control even though concentrations are 100x less than droplets, the ice particle size is probably 10x the size of the droplets and it is the integrated number x size that controls the phase relaxation timescale. For the 10x and 100x IN concentrations - the phase relaxation will likely be similar to the control noice case.

As shown in Korolev and Mazin (2003), the phase relaxation timescale in mixed-phase clouds is inversely proportional to not only <NiRi> but also <NwRw>. Here, Ni and Ri are CINC and the radius of ice crystals, respectively, while Nw and Rw are CDNC and the radius of droplets, respectively. <A> indicates the average of A as an arbitrary variable.

In the control run, although <Ri> is ~7 times greater than <Rw>, <NwRw> is much greater than <NiRi>, since <Ni> is much lower than <Nw>. Hence, the relaxation time is considered to be controlled by <NwRw> more than <NiRi> in the control run.

It is found that the phase relaxation timescale is much greater in the control run than in the control-noice run. This is mainly due to the fact that both of <Rw> and <Nw> are greater in the control-noice run than in the control run.

<NiRi> increases from the control run to the INP-100 run through the INP-10 run and this is mainly due to increasing <Ni> from the control run to the INP-100 run through the INP-10 run. However, <Ni> even in the INP-100 run is still much lower than <Nw> in the control-noice run. Hence, this increase in <NiRi> and associated decrease in the relaxation timescale is not large enough and thus, the relaxation timescale is still much smaller in the control-noice run than in the INP-10 and INP-100 runs.

Line 474. i assume this is a histogram of all of the columns in the domain for the final timestep? Fig 5 does not look like a cumulative frequency plot. It is not constantly increasing or decreasing as wp changes

The corresponding figure shows the sum of occurrence of IWP, LWP or WP over the whole domain and simulation period at each bin of IWP, LWP or WP. We classify the value of each of IWP, LWP and WP at each time step and grid point in the whole domain and during the whole simulation period. The classified values of each of IWP, LWP and WP are put into corresponding bins of those values. Then, we count the number of those values in each bin and the number in each bin is shown in the figure.

For example, let us assume that the minimum and maximum non-zero values of WP over the whole domain and simulation period are 1 and 12, respectively, and we use a bin interval of 3. In this assumed situation, there are three bins. The first bin is between the WP value of 1 and that of 4, the second bin between 5 and 8 and the third bin between 9 and 12. Then, let us assume that there are 2 time steps during the whole simulation period and 2 grid points over the whole domain, and non-zero WP value occurs at all time steps and grid points. Then, there are 2 WP values over the whole domain at each time step. Let us assume these values are as follows:

At the first time step:

The first grid point: 1

The second grid point: 7

At the second time step:

The first grid point: 6

The second grid point: 12

Then, there is “one count” of WP whose value is 1 for the first bin between 1 and 4, “two counts” of WPs whose values are 6 and 7 for the second bin between 5 and 8, “one count” of WP whose value is 12 for the third bin between 9 and 12. Here, we see that as we move from the first to third bin, the number of the count increases and then decreases but not constantly increases or decreases. This exemplifies why LWP, IWP or WP frequency does not increase or decrease constantly as the LWP, IWP or WP values change in Figure 5 and the other figures showing the frequency.

Line 497. In this section, what has been tested indirectly is the role of sedimentation in dehydrating parcels.

You could demonstrate this by turning off sedimentation for ice and seeing that the control wp was the same as the 100x IN wp.

The role of sedimentation and associated dehydration in the WP changes among the control, INP-10 and INP-100 runs is found to be negligible as compared to that of deposition, according to simulations with the ice-particle sedimentation turned off. The details are given in Section 4.1.3.

Line 577 ,For the control noice runs there is also sedimentation. Decreasing aerosol leads to formation of larger droplets that fall faster - more rainout means lower wp. We need to see the cloud base rainrates.

The following is added:

(LL992-1002 on p33)

Also, with higher CDNC and associated smaller sizes of droplets, there is suppressed autoconversion in the control-noice run as compared to that in the low-aerosol-noice run. Here, autoconversion is the process of droplets colliding with and coalescing each other to grow into raindrops. Due to this, the time- and domain-averaged precipitation rate at cloud bases is lower in the control-noice run. The average cloud-base precipitation rate is ?? and ??? g m-2 s-1 in the control-noice and low-aerosol-noice runs, respectively. The difference in this average precipitation rate is ?? and this difference is ~ ??% of that in the average condensation rate. Hence, while aerosol-induced precipitation suppression contributes to higher WP in the control-noice run, this contribution is smaller than that of aerosol-enhanced condensation.

We also examined effects of ice-particle sedimentation on results between the control and low-aerosol runs as detailed in Section 4.2.3.

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