First of all, we appreciate the editor's comment and suggestion. In response to them, we have made relevant revisions to the manuscript. Listed below are our answers and the changes made to the manuscript according to the question and suggestion given by the editor. The comment of the editor (in black) is listed and followed by our responses (in blue).

Dear Seoung Soo Lee and co-authors,

first of all, I apologize that it took so long to make the next step in the review of the paper. The reason is that referee #1 was not longer available to take care of the manuscript, and, because of the summer break, no new referee could be found. So, I have now looked at your answers to referee #1 and provide a new report which you find below.

Also, a new report from referee #2 is included at the end of this message.

Please consider the points from the new reports and submit a corresponding new version of the paper.

Best wishes, Martina Krämer

New report based on answers to Referee #1:
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Unfortunately, I have to say that I find the answers to the points raised by referee #1 not very satisfactory.

Major comments:

MC 1) Your answer is very long, but in the end I miss (or did not find in the lengthy text) a convincing, comprehensive short explanation/answer to the point (why the evaporation of cloud droplets and subsequent inefficient deposition of water vapour onto ice should be responsible for the lower LWP in mixed-phase compared to warm-phase clouds).

In the reviewer's comment that this editor's comment is about, we thought the reviewer strongly questioned how evaporation occurs with inefficient deposition. We believed that the occurrence of evaporation with inefficient deposition in our results is the main reason why the reviewer is not able to trust our finding that the evaporation and inefficient deposition are responsible for the lower water path (WP) in mixed-phase clouds compared to warm-phase clouds. This is why in our response to the reviewer's comment during the first review, we focused on explaining how evaporation occurs with inefficient deposition, as the reviewer phrases, in the mixed-phase clouds in the control run; here WP is the sum of liquid water path (LWP) and ice water path (IWP).

In our previous response to the reviewer's comment, we aim to convince the reviewer that deposition is not inefficient (when it comes to the control run itself) and is large enough to induce evaporation in the control run. In addition, we explained the theoretical background that even though deposition is inefficient, evaporation occurs based on Korolev and Mazin (2003; JAS) (see our response to this reviewer's first major comment during the first review for details of the occurrence of evaporation).

As explained in Section 4.1.1 in the manuscript, we hypothesized that the evaporation of droplets and low cloud ice number concentration (CINC) are the reason why WP is lower in the mixed-phase clouds in the control run than in the warm-phase clouds in the control-noice run. As described in Section 4.1.1 in the manuscript, the evaporation of droplets reduces cloud droplet number concentration (CDNC). This subsequently reduces condensation and thus LWP as compared to that in the control-noice run, considering that condensation occurs on the surface of droplets and microphysically, more integrated surface area of droplets favors more condensation. Note that lower CDNC tends to provide less integrated surface area of droplets, favoring less condensation. Deposition and thus IWP exist only in the control run but not in the control-noice run, hence, the presence of deposition and that of IWP compensate for the reduction in condensation and that in LWP, respectively, and thus compensate for the reduction in WP, as compared to WP in the control-noice run, due to the reduction in condensation and LWP in the control run. This compensation by deposition and IWP is not large enough to compensate for the reduction in condensation and LWP entirely, leading to lower WP in the control run than in the control-noice run (see Section 4.1.1 for details).

We hypothesized that the insufficient compensation by deposition and IWP is associated with low CINC, based on the fact that microphysically, the surface of ice crystals is where deposition occurs and more integrated surface area of ice crystals favors more deposition. Note that lower CINC tends to provide less integrated surface area of ice crystals, favoring less deposition. We hypothesized that due to low CINC, water vapor is not able to find enough integrated surface area of ice crystals, and this leads to a situation where deposition and IWP are not large enough to compensate for the reduction in condensation and LWP, respectively, entirely in the control run. This in turn leads to lower WP in the control run than in the control-noice run.

To prove the hypothesis about the insufficient compensation by deposition and IWP due to low CINC, we repeated the control run by increasing INP, as a way of increasing CINC, by a factor of 10 and 100. The repeated run with the increase in INP by a factor of 10 (100) is referred to as the INP-10 (INP-100) run as described in the manuscript.

As described in Section 4.1.2 in the manuscript, increasing INP and associated 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 feedback in turn enables cloud-top height in the INP-100 run to be similar to that in the control-noice run by making air parcels with stronger updrafts go up more in the INP-100 run as compared to air parcels in the control run. The stronger updrafts and associated feedback between updrafts and deposition enable deposition and IWP to increase further in the INP-100 run as compared to those in the control run and this results in the similar WP between the INP-100 and control-noice runs (see Section 4.1.2 for details).

By analyzing results from the simulations (i.e., the control, INP-10 and INP-100 runs), it is found that low CINC in the control run leads to insufficient deposition, in turn leading to its weaker feedbacks with updrafts and 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.

I also miss a clear statement about whether, what and where
something has been changed in the paper?

Authors' argument here particularly about the role of CINC in deposition and feedbacks between deposition and updrafts was already made to address the other reviewer's comments and accordingly, text was revised and added as follows during the first review:

(LL697-718 on p23-24)

As seen in Figure 9a, the enhanced average WP in the INP-100 (INP-10) run reaches 91% (53%) of that in the control-noice run, while the average WP in the control run accounts for only ~30% of that in the control-noice run. Associated with the enhanced average WP, the average cloud fraction over time steps with non-zero cloud fraction increases from 0.92 in the control run to 0.97 (0.94) in the INP-100 (INP-10) run. 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, while the average updraft mass flux in the control run accounts for only ~50% 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 (i.e., updrafts). This eventually enables air parcels in the INP-100 run to have stronger updrafts than those in the control run and thus to go up nearly as high as those in the control-noice run. Through the positive feedbacks between the increasing deposition and dynamics, increasing dynamic intensity with the increasing vertical extent of air parcels or clouds in turn enables deposition and IWP to further increase, resulting in the similar WP and cloud fraction between the INP-100 and control-noice runs. Here, comparisons among the control, INP-10 and INP-100 runs confirm the hypothesis that ascribes much lower WP in the control run than in the control-noice run to the CINC-related inefficient deposition in the control run.

MC 2) Again your answer is very long, and you write a lot about the role of entrainment, but the question was if changes in sedimentation rates in the presence of ice crystals or changes in cloud fraction could be responsible for the for the lower LWP in mixed-phase compared to warm-phase clouds.

To examine the role played by the sedimentation of ice particles (i.e., ice crystals, snow aggregates, graupel and hail) in the lower WP in the mixed-phase clouds in the control run than that in warm-phase clouds in the control-noice run, the control run is repeated by setting the fall velocity of ice particles to zero; this is also motivated by the other reviewer's comments during the first review. The repeated run is the control-no-sedim run. The time- and domain-averaged IWP, LWP and WP are 11 (14), 7 (5) and 18 (19) g m^{-2}, respectively, in the control (control-no-sedim) run. The presence of the sedimentation of ice particles decreases IWP and increases LWP as compared to the situation with no sedimentation of ice particles as seen in comparisons between the control and control-no-sedim runs. However, the average WP in the control-no-sedim run is still much lower than WP, which is 55 g m^{-2}, in the control-noice run. Hence, the lower WP in the control run than in the control-noice run does not depend on whether the sedimentation of ice particles (including ice crystals) is present in the mixed-phase clouds in the control run. This indicates that the sedimentation of ice particles (including ice crystals) is not a factor that causes the lower WP in the control run than in the control-noice run.

To further examine the role played by the sedimentation of hydrometeors in the lower WP in the mixed-phase clouds in the control run than that in warm-phase clouds in the control-noice run, the control run is repeated again by setting the fall velocity of both of ice and liquid particles (i.e., droplets and rain drops) to zero. The repeated run is the control-no-sedim-ice-liq run. The time- and domain-averaged IWP, LWP and WP are 11 (15), 7 (9) and 18 (24) g m^{-2}, respectively, in the control (control-no-sedim-ice-liq) run. The presence of the sedimentation of both of ice and liquid particles decreases both of IWP and LWP as compared to the situation with no sedimentation of both of ice and liquid particles as seen in comparisons between the control and control-no-sedim-ice-liq runs. However, the average WP in the control-no-sedim-ice-liq run is still much lower than WP, which is 55 g m^{-2}, in the control-noice run. Hence, the lower WP in the control run than in the control-noice run does not depend on whether the sedimentation of both of ice and liquid particles is present in the mixed-phase clouds in the control run. This indicates that the sedimentation of both of ice and liquid particles is not a factor that causes the lower WP in the control run than in the control-noice run.

Here, we want to clarify that cloud fraction is a byproduct of cloud processes such as microphysical, dynamic and thermodynamic processes, but not a factor that controls those processes. Keeping this in mind, as explained in our response to the first comment by the editor here, due to insufficient deposition, updrafts are much weaker in the control run than in the control-noice run. Associated with this, the amount of cloud mass, which is produced by updrafts and represented by WP, is much lower in the control run than in the control-noice run. We believe this greater amount of cloud mass leads to higher cloud fraction in the control-noice run than in the control run, but not the other way around. Stated differently, weaker updrafts due to insufficient deposition, as detailed in our response to the first comment above, are the cause of lower cloud fraction in the control run, but lower cloud fraction is not the cause of weaker updrafts and associated insufficient deposition in the control run.

Also here I miss a clear statement about whether, what and and where something has been changed in the paper?

The simulations with no sedimentation of ice particles were already described in Section 4.1.3 which was added to respond to the other reviewer's comment during the first review. To respond to the editor's comment here, the above-described control-no-sedim-ice-liq run is additionally performed and its description is added to Section 4.1.3 as follows:

(LL769-781 on p26)

To further examine the role played by the sedimentation of hydrometeors particularly in the lower WP in the control run than that in the control-noice run, the control run is repeated again by setting the fall velocity of both of ice and liquid particles to zero. The repeated run is the control-no-sedim-ice-liq run. The time- and domain-averaged IWP, LWP and WP are 11 (15), 7 (9) and 18 (24) g m^{-2}, respectively, in the control (control-no-sedim-ice-liq) run. The presence of the sedimentation of both of ice and liquid particles decreases both of IWP and LWP as compared to the situation with no sedimentation of both of ice and liquid particles. However, the average WP in the control-no-sedim-ice-liq run is still much lower than that in the control-noice run. Hence, the lower WP in the control run than that in the control-noice run does not depend on whether the sedimentation of both of ice and liquid particles is present in the control run. This indicates that the sedimentation of both of ice and liquid particles is not a factor that causes the lower WP in the control run than in the control-noice run.

The lower cloud fraction due to weaker updrafts in the control run than in the control-noice run is indicated as follows:

(LL 613-615 on p21)

The much stronger updrafts produce much larger WP and associated larger cloud fraction in the control-noice run than in the control run after the initial stage (Figure 5a).

Cloud fractions in the control, INP-10 and INP-100 runs are mentioned as follows to indicate the increasing cloud fraction with the increasing updrafts and WP:

(LL700-702 on p24)

Associated with the enhanced average WP, the average cloud fraction over time steps with non-zero cloud fraction increases from 0.92 in the control run to 0.97 (0.94) in the INP-100 (INP-10) run.

(LL712-715 on p24)

Through the positive feedbacks between the increasing deposition and dynamics, increasing dynamic intensity with the increasing vertical extent of air parcels or clouds in turn enables deposition and IWP to further increase, resulting in the similar WP and cloud fraction between the INP-100 and control-noice runs.

Specific Comments:

SC 3) This is a point that you might mention in the paper, but I miss a statement about whether, what and where something has been changed?

The following is added:

(LL219-234 on p8)

With the advection of aerosols, there is the advection of meteorological conditions. To identify this advection of meteorological conditions in the Seoul area, the vertical distributions of the radiosonde-observed potential temperature and humidity at 03:00 and 15:00 LST on January 12th in the Seoul area are obtained and shown in Figure 3. At 03:00 LST on January 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 (Figure 3a). This stable layer is not favorable for the formation of a deck of stratiform clouds. However, after 03:00 LST on January 12th, the PBL becomes a well-mixed layer and its top height increases to 1.5 km as seen in comparisons between 03:00 LST and 15:00 LST on January 12th in the Seoul area (Figures 3a and 3b). Hence, with advection-induced increases in aerosol concentrations and the associated advection of meteorological conditions, meteorological conditions become favorable for the formation of a deck of stratocumulus clouds in the Seoul area. In this study, we examine how the advection of aerosols affects the observed mixed-phase stratocumulus clouds in the Seoul area and impacts of the advection of meteorological conditions on those clouds are out of scope of this study.

(LL434-450 on p15)

As mentioned above, impacts of the advection of meteorological conditions, which accompanies the advection of aerosols and associated increases in aerosol concentrations, on the stratocumulus clouds in the Seoul area are out of scope of this study. Hence, there are no differences in synoptic-scale environment or meteorological conditions between the control and low-aerosol runs. This enables the isolation of impacts of the aerosol advection through comparisons between the runs. If impacts of the advection of meteorological conditions were investigated by repeating the control run, with an assumption that meteorological conditions after 03:00 LST on January 12th do not evolve and are fixed at 03:00 LST on January 12th, for the purpose of comparing the control run to this repeated run, there would be no or nearly no formation of stratocumulus clouds in this repeated run; this is because there is a stable layer at

03:00 LST on January 12th, which is just before the advection of aerosols affects aerosol concentrations in the Seoul area and not favorable for the formation of clouds as described in Section 2. As mentioned in Section 2, the advection of meteorological conditions, which are with advection-induced increases in aerosol concentrations, enables the formation of the stratocumulus clouds in the Seoul area. This study examines impacts of the aerosol advection on those clouds for this given advection of meteorological conditions.

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

The authors responded to my requests to look at the sedimentation and clearly demonstrated that it is negligible.
The authors also responded in full to my other comments.

I am still unclear about the ice concentrations. The INP concentration is the 0.01 x ccn concentration for the INP base state and equal to the ccn concentration (~100 per cm3 ?) for the INP-100 case. Given cloud temperatures of -10C to -20C and looking at Lohmann and Diehl suggests that ice crystal concentrations should be of order >1 cm-3. I see that the concentrations in the plot have been changed to per litre but that would mean that only 1 in 1e6 INP have been turned to ice for the INP-100 case.
If the ice concentrations were high (order of several per cm3) i can see how that would mean the sedimentation rate was low. Also, high ice concentrations of several per cm3 (higher than typically observed ice concentrations at -15C) would need to be mentioned in the abstract and conclusions.
I think the authors should just discuss why the ice concentrations are so low relative to the abundance of INP when using Lohmann and Diehl compared to what that paper shows.

I think if the authors can clear up the ice number concentrations then it should be fine to go ahead and publish with the caveats mentioned.

We double-checked model codes, model data and codes for a post-processor analyzing model data. We found errors in the post-processor regarding the unit. We corrected those errors, and based on this correction, the unit for CINC is corrected in Figures 6b, 8a, 11a and 11d.

Yes, in the control run (referred to as "CTL") in Lohmann and Diehl (2006), for observed and simulated CDNC of ~50-100 cm^{-3} in the temperature between -10 and -20C, CINC can be on the order of magnitude of ~1 cm^{-3} as shown in Figure 6 in Lohmann and Diehl (2006). Here, we want to emphasize that CINC on the order of magnitude of ~1 cm^{-3} in CTL in Lohmann and Diehl (2006) is with the INP concentrations, which are dependent only on temperature, with no consideration of the spatiotemporal variation of the INP concentrations. Lohmann and Diehl (2006) have shown that using the INP concentrations, which are empirically obtained based only on temperature, for the INP activation can increase CINC by a factor of ~10 as compared to that when the spatiotemporal variation of the INP concentration, as a result of processes related to aerosols (e.g., aerosol emissions, cloud impacts on aerosols via scavenging processes, aerosol chemical and physical processes and aerosol transportation by wind and turbulence), is considered for the activation, as seen in comparisons between CTL, KAO and MON for CDNC of ~50-100 cm^{-3} in temperature between -10 and -20C in Figure 6 in Lohmann and Diehl (2006); KAO and MON represent simulations that consider the spatiotemporal variation of the INP concentration in Lohmann and Diehl (2006) (see Lohmann and Diehl (2006) for details of KAO and MON).

Note that in this study, the average CDNC is around 70 cm^{-3} in the control run, and this CDNC of ~70 cm^{-3} is within or near the CDNC range for the temperature range between -10 and -20C in Figure 6 in Lohmann and Diehl (2006). For the similar CDNC in the similar temperature range between the control run in this study and CTL as shown in Figure 6 in Lohmann and Diehl (2006), in the control run in this study, as seen in Figures 6b and 8a, CINC is on the order of magnitude of ~0.1 cm^{-3}, while in CTL as shown in Figure 6 in Lohmann and Diehl (2006), CINC is on the order of magnitude of ~1 cm^{-3}. In the control run in this study, as described in the manuscript, the observed spatiotemporal variation of the INP concentration, as a product of processes related to aerosols, is considered for the INP activation. Based on findings in Lohmann and Diehl (2006), described in the second paragraph above, and the similar CDNC in the similar temperature range between the control run in this study and CTL as shown in Figure 6 in Lohmann and Diehl (2006), discrepancy between CINC on the order of the magnitude of ~0.1 cm^{-3} in the control run in this study and that on the order of the magnitude of ~1 cm^{-3} in CTL as shown in Figure 6 in Lohmann and Diehl (2006) can be explained by the fact that the control run in this study considers the observed spatiotemporal variation of the INP concentration for the INP activation, while CTL in Lohmann and Diehl (2006) only uses the empirical relation between the INP concentration and temperature for the activation.

CINC on the order of magnitude of ~0.1 cm^{-3} for CDNC of ~50-100 cm^{-3} is also simulated in Gilgen et al. (2018) considering the spatiotemporal variation of the INP concentration, as a result of processes related to aerosols (e.g., aerosol emissions, cloud impacts on aerosols via scavenging processes, aerosol chemical and physical processes and aerosol transportation by wind and turbulence), for the INP activation with no reliance on the empirical dependence of INP concentrations on temperature.

Points here are summarized as follows in summary and conclusions:

(LL1270-1284 on p42-43)

The average CINC in the control run in this study is on the order of magnitude of ~0.1 cm^{-3} and this is an order of magnitude lower than that in the control run in Lohmann and Diehl (2006) for similar temperature and CDNC ranges between the runs. Remember that this study uses parameterizations by Lohmann and Diehl (2006) for the heterogeneous INP activation. In the control run in Lohmann and Diehl (2006), the INP concentrations, which are dependent only on temperature, are used for the INP activation. However, in the control run in this study, instead of obtaining the INP concentrations empirically using the temperature as in Lohmann and Diehl (2006), the observed spatiotemporal variation of the INP concentration is considered for the INP activation. Lohmann and Diehl (2006) have shown that using the INP concentrations, which are empirically obtained based only on temperature, for the INP activation can increase CINC by a factor of ~10 as compared to that when the spatiotemporal variation of the INP concentration, as a result of above-mentioned processes related to aerosols, is considered for the activation. It is believed that this explains the discrepancy in CINC between the control in this study and that in Lohmann and Diehl (2006).

Points here are briefly mentioned as follows in abstract:

(LL60-63 on p3)

Note that the INP concentration in this study is based on the observed spatiotemporal variability of aerosols. This results in the lower CINC as compared to that with empirical dependence of the INP concentrations on temperature in a previous study.

Reference:

Gilgen, A., Huang, W. T. K., Ickes, L., Neubauer, D., Lohmann, U., How important are future marine and shipping aerosol emissions in a warming Arctic summer and autumn?, Atmos. Chem. Phys., 18, 10521–10555, 2018