First of all, we appreciate the reviewer's comments 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 questions and suggestions given by the reviewer. The comment of the reviewer (in black) is listed and followed by our responses (in blue).

This study examines the impact of ICNC and CDNC on the properties of mixed-phase clouds using large-eddy simulations. However, I do not see new and exciting findings in this study, and some results are not convincing. Therefore, I recommend rejecting this paper in the current format.

Major comments:

1. The authors seem to be not familiar with the literature in the field. The impact of ICNC and CDNC on the properties of mixed-phase clouds, which arises from the efficiency of INP and CCN, has been explored extensively in the past. Key conclusions of this study are very similar to some previous studies, e.g, by Solomon et al. 2018 (doi: 10.5194/acp-18-17047-2018). I do not see any new or exciting results out of this study.

This study talks about impacts of INP and CCN on latent-heat processes such as condensation and deposition thorough INP- and CCN-induced changes in ICNC and CDNC as sources of deposition and condensation, respectively. These impacts of INP and CCN on condensation and deposition eventually have a significant impact on the response of LWP and IWP to changing INP and CCN concentrations. In contrast to this, Soloman et al. (2018) have focused on CCN and INP impacts on cloud-top radiative cooling via aerosol-induced changes in droplet sizes. They have focused on the fact that these impacts on radiative cooling eventually alter dynamics and then LWP and IWP. This study focuses only on aerosol-induced changes in deposition and condensation excluding those changes on radiative cooling. In other words, the main driver of results in this study is aerosol-induced changes in deposition and condensation themselves but not aerosol-induced changes in radiative cooling. Hence, we believe that this study can be distinguished from Soloman et al. (2018). Regarding this, we repeated all of the previous simulations in the old manuscript by turning off radiative processes and comparisons between these repeated simulations and the previous simulations have shown that the qualitative nature of results in this study is robust to whether radiative processes, which include cloud-top radiative cooling, are considered for the simulations or not. This confirms that aerosol impacts on radiative cooling are not a main thrust for results in this study and the main thrust is aerosol-induced changes in ICNC, CDNC and associated deposition and condensation.

Also, want to mention that most of the previous studies of mixed-phase stratocumulus clouds have raised entrainment, detrainment, and hydrometeor sedimentation as important factors that control cloud mass and aerosol impacts on it (e.g., Albrecht, 1989; Ackerman, 2004: Ovchinnikov et al., 2011; Possner et al., 2017); cloud mass is represented by IWP and LWP. However, this study finds that entrainment, detrainment, and sedimentation are not important factors that control cloud mass, aerosol-induced changes in cloud mass, and their variation between different cloud systems at different locations. This study finds that CDNC, ICNC and then condensation and deposition are important factors for cloud mass, aerosol impacts on it and their variation between different cloud systems. Hence, this study can be distinguished even from other previous studies focusing on entrainment, detrainment, and hydrometeor sedimentation.

Regarding the argument here, the following is added:

(LL828-837 on p28)

Previous studies on mixed-phase stratocumulus clouds (e.g., Ovchinnikov et al., 2011; Possner et al., 2017; Solomon et al., 2018) have primarily focused on investigating the impacts of cloud-top radiative cooling, entrainment, and sedimentation of ice particles on these clouds, as well as their interactions with aerosols. However, there are a scarcity of studies that specifically examine the role of microphysical interactions, involving processes such as condensation and deposition, as well as factors like cloud-particle concentrations, between ice and liquid particles in mixed-phase stratocumulus clouds, and their interactions with aerosols as performed in this study. Therefore, our study contributes to a more comprehensive understanding of mixed-phase clouds and their intricate interplay with aerosols.

Regarding the simulations with radiation turned off, Section 3.3 is added.

To better put this study in the context of the previous studies of mixed-phase stratocumulus clouds, the following is added in introduction:

(LL136-141 on p5)

Choi et al. (2010 and 2014) and Zhang et al. (2019) have shown that as temperature lowers, IWC/LWC or IWP/LWP tends to increase and indicated that temperature is a primary environmental condition to explain the differences in IWC/LWC among different regions or clouds. However, Choi et al. (2010 and 2014) and Zhang et al. (2019) have not discussed process-level mechanisms that govern the role of temperature in those differences.

(LL175-187 on p6-7)

This comparison is based on Choi et al. (2010 and 2014) and Zhang et al. (2019) which have shown that temperature is an important factor which explains the differences in IWC/LWC among regions or clouds. Due to significant differences in latitudes, noticeable differences in the temperature of air are between the polar and midlatitude cases. Hence, through this comparison, this study looks at the role of temperature in those differences in IWC/LWC and associated aerosol-cloud interactions. More importantly than that, as a way of identifying process-level mechanisms that control the role of temperature, this study tests how ICNC/CDNC as the general factor is linked to the role of temperature, using the LES framework. Through this test, this study also identifies process-level mechanisms that control how ICNC/CDNC affects roles of ice processes in the differentiation between mixed-phase and warm clouds in terms of cloud development and its interactions with aerosols, and causes the variation of the differentiation between the cases of mixed-phase stratiform clouds.

2. The authors stated “ICNC/CDNC can be a simplified general factor that contributes to a more general understanding of mixed-phase clouds”. If the authors can establish "a general principle" for the mixed-phase cloud, I think it would be very useful and this study would be worth for a publication. However, this argument is not convincing for the following reasons:

2.1. The author conducted nine idealized simulations of the mixed-phase clouds. It is not convincing to me how results from nine idealized simulations can be helpful to establish a general principle or a general parameterization for the mixed-phase cloud.

Just want to emphasize that as described in text, this study is only about an “attempt” to test a factor that can help us with the development of the general principle but not about the establishment of a perfect, complete general principle. To clarify this, the following is added:

(LL161-168 on p6)

Here, we want to emphasize that this study does not aim to gain a fully established general principle, but aims to test the factor that can be useful to move ahead on our path to a more complete general principle. Hence, this study should be regarded a steppingstone to the established principle, and should not be considered a perfect study that get us the fully established principle. Taking into account the fact that even attempts to provide general factors for the general principle have been rare, the fulfilment of the aim is likely to provide us with valuable preliminary information that streamlines the development of a more established general principle.

Just want to add that this study focuses on a factor, explaining differences in IWC/LWC among different clouds, as a steppingstone to the general principle, motivated by the fact that IWC/LWC plays an important role in cloud radiative properties and thus their climate feedbacks as discussed in Choi et al. (2010 and 2014). Choi et al. (2010 and 2014) and Zhang et al. (2019) have shown that temperature is an important factor which explains the differences in IWC/LWC among different clouds. However, Choi et al. (2010 and 2014) and Zhang et al. (2019) have not discussed process-level mechanisms that govern the role of temperature in those differences. Motivated by this, this study aims to find process-level mechanisms controlling the role of temperature in those differences by using the LES framework and to fulfill the aim, this study tests ICNC/CDNC which potentially can act as the factor or a general factor, explain the differences in IWC/LWC among different clouds and thus contribute to the development of the general principle in connection to the role of temperature. Regarding this, the following is added:

(LL132-141 on p5)

Mixed-phase stratocumulus clouds in different regions are known to have different IWC/LWC or IWP/LWP and aerosol-cloud interactions (e.g., Choi et al., 2010 and 2014; Zhang et al., 2019). Lots of factors such as environmental conditions, which can be represented by variables such as temperature, humidity and wind shear, can explain those differences. Choi et al. (2010 and 2014) and Zhang et al. (2019) have shown that as temperature lowers, IWC/LWC or IWP/LWP tends to increase and indicated that temperature is a primary environmental condition to explain the differences in IWC/LWC among different regions or clouds. However, Choi et al. (2010 and 2014) and Zhang et al. (2019) have not discussed process-level mechanisms that govern the role of temperature in those differences.

(LL169-187 on p6-7)

For the attempt, this study investigates a case of mixed-phase stratiform clouds in the polar region. Via the investigation, this study aims to identify process-level mechanisms that control the development of those clouds and their interactions with aerosols, and the impact of ice processes on the development and interactions using a large-eddy simulation (LES) framework. Then, this study compares the mechanisms in the case of polar clouds to those in a case of midlatitude clouds which have been examined by Lee et al. (2022). This comparison is based on Choi et al. (2010 and 2014) and Zhang et al. (2019) which have shown that temperature is an important factor which explains the differences in IWC/LWC among regions or clouds. Due to significant differences in latitudes, noticeable differences in the temperature of air are between the polar and midlatitude cases. Hence, through this comparison, this study looks at the role of temperature in those differences in IWC/LWC and associated aerosol-cloud interactions. More importantly than that, as a way of identifying process-level mechanisms that control the role of temperature, this study tests how ICNC/CDNC as the general factor is linked to the role of temperature, using the LES framework. Through this test, this study also identifies process-level mechanisms that control how ICNC/CDNC affects roles of ice processes in the differentiation between mixed-phase and warm clouds in terms of cloud development and its interactions with aerosols, and causes the variation of the differentiation between the cases of mixed-phase stratiform clouds.

In addition, based on comments from both the reviewers, to improve the generality of findings of this study and thus to better streamline the establishment of the general principle, more simulations are performed as described in Sections 3.3, 4.1 and 4.2.

2.2. Observations are missing to justify the model setup and evaluate simulation results. For example, it said that "a system of mixed-phase stratocumulus clouds was observed to exist over a period between 02:00 local solar time (LST) and 20:00 LST on March 29th, 2017. On average, the bottom and top of these clouds are at ~400 m and ~3 km in altitude, respectively." Is there any ground-based observations to support this statement? See Fig. 1 in Solomon's paper as a good example.

The following is added:

(LL235-243 on p8-9)

In the Svalbard area, Norway, a system of mixed-phase stratocumulus clouds existed over the horizontal domain marked by a red rectangle in Figure 1 and a period between ~02:00 local solar time (LST) and 10:00 LST on March 29th, 2017. These clouds are observed by ground radar and lidar and these radar and lidar are a part of the Cloudnet ground observation that is deployed at a location in the red rectangle. The Cloudnet ground observation is composed of a suite of instruments such as lidar, radar and radiometer and described in Hogan et al. (2006). On average, the bottom and top of these clouds are at ~400 m and ~3 km in altitude, respectively, according to observation by those radar and lidar.

(LL343-358 on p12)

This study adopts the Cloudnet ground observation to evaluate the 200_2 run. Observed LWP is provided by radiometer. The retrieval of IWP is performed by using radar reflectivity and lidar backscatter as described in Donovan et al. (2001), Donovan (2003) and Tinel et al. (2005). As mentioned above, observed cloud-bottom and -top heights are obtained from radar and lidar measurements. Simulated LWP and IWP, as shown in Figure 4 and Table 2, are compared to the observed LWP and retrieved IWP, respectively. The average LWP over all time steps and grid columns is 1.23 in the 200_2 run and 1.12 in observation. The average IWP over all time steps and grid columns is 31.94 in the 200_2 run and 29.10 in retrieval. Cloud-bottom height, which is averaged over grid columns and time steps with non-zero cloud-bottom height, is 420 and 440 m in the 200_2 run and observation, respectively. Cloud-top height, which is averaged over grid columns and time steps with non-zero cloud-top height, is 3.5 and 3.3 km in the 200_2 run and observation, respectively. Each of LWP, cloud-bottom and -top heights shows an ~10% difference between the 200_2 run and observation. IWP also shows an ~10% difference between the 200_2 run and retrieval. Thus, the 200_2 run is considered performed reasonably well for these variables.

Following the comment by the other reviewer, among the observed variables, the time series of the observed cloud-top height is compared to that of the simulated height as follows:

(LL359-366 on p12-13)

To provide additional or supplementary information of cloud development, the time evolution of the simulated and observed cloud-top height is shown together with the simulated evolution of the surface sensible and latent-heat fluxes in Supplementary Figure 1. This is based on the fact that the cloud-top height is considered a good indicative of cloud development and the surface fluxes are considered important parameters controlling the overall development of clouds. Simulated evolutions in Supplementary Figure 1 are from the 200_2 run. The cloud-top height increases between 02:00 and ~05:00 LST and after ~05:00 LST, it reduces gradually.

2.3. Model setup for the initial CCN and INP measurements is also not convincing. One weird result is the extremely high IWC for the control run. As far as I know, IWC in the mixed-phase stratocumulus cloud is usually much smaller than LWC. However, in the control run, IWC/LWC is 26.28, which is extremely high. Do you have any observations to support this result? Can you find any literature to support such high ratio exist in the mixed-phase cloud? If you cannot find observations to support such high IWC/LWC value, it means that the control run might not be setup correctly, and the goal to establish “a general principle” from those simulation results is not convincing.

First of all, as described above in our response to the reviewer’s comment 2.2, the Cloudnet observation is used to evaluate the 200_2 run. As described in the response, the Cloudnet observation shows that the average observed/retrieved IWP is 29.10 and the average observed LWP is 1.12. Hence, the Cloudnet-based IWP/LWP is 25.98.

IWP/LWP in the 200_2 run is 25.96. This demonstrates that the simulated high IWP/LWP is well supported by the Cloudnet observation.

Moreover, Choi et al. (2014) have done work on the supercoold cloud fraction (SCF), which is equivalent to LWP/(LWP+IWP), using satellite-observed data collected over the period of ~5 years. As seen in Figure 1 in Choi et al. (2014), their work has shown that SCF can be lower than 0.05 and as low as 0.01 for the temperature range between -16 and -33 ºC. Regarding the temperature, as stated in the manuscript, the average air temperature immediately below the cloud base over the simulation period is -16 ºC and the average air temperature immediately above the cloud top is -33 ºC in the 200_2 run. Note that SCF in the 200_2 run in this study is 0.04. Zhang et al. (2019) have also shown that for the temperature range between -16 and -33 ºC, SCF can be as low as ~0.03, though clouds with SCF below 0.05 are rare, based on ground observations in the Arctic area over a one-year period; for details, see Figure 7 in Zhang et al. (2019).

In association with Choi et al. (2014) and Zhang et al. (2019), the following is added:

(LL381-391 on p13)

Choi et al. (2014) and Zhang et al. (2019) have obtained the supercooled cloud fraction (SCF), which is basically the ratio of LWC to the sum of LWC and IWC and denoted by LWC/(LWC+IWC), using satellite- and ground-observed data collected over the period of ~5 years and ~1 year, respectively. Choi et al. (2014) have shown that SCF is as low as ~0.01 for the temperature range between -16 and -33 ºC. Zhang et al. (2019) have also shown that SCF is as low as ~0.03 for the same temperature range, although the occurrence of SCF of ~0.03 or lower is rare. Note that the average air temperature immediately below the cloud base and above the cloud top over the simulation period is -16 and -33 ºC, respectively, in the 200_2 run, and SCF in the 200_2 run is 0.04. Hence, based on Choi et al. (2014) and Zhang et al. (2019), we believe that SCF in the 200_2 run is observable and thus not that unrealistic, although it may not occur frequently.

In summary and conclusion, to explain reasoning behind the choice of the possibly rare polar case with SCF of 0.04, the following is added:

(LL774-777 on p26)

To gain the understanding efficiently, the polar case is chosen in a way to make stark contrast with the midlatitude case in terms of ICNC/CDNC and IWC/LWC. Although such polar cases may be uncommon, the stark contrast provides an opportunity to elucidate mechanisms that control the above-mentioned role of different ICNC/CDNC.

Here is one suggestion to improve the paper quality: whenever you refer to the observation (cloud, CCN, INP, LWP, IWP...), you should either cite a reference if the results are published or add it in the paper to support your statement. If you don't have those observations, you should provide reasonable assumptions. If results are quite different from previous studies (e.g., extremely high IWC/LWC), you should provide strong justifications.

As stated in our response above, observed LWP and observed/retrieved IWP are obtained from the Cloundnet observation and these LWP and IWP are compared to simulated counterparts as a way of evaluating the simulation. As stated in our response above, these observed LWP and observed/retrieved IWP also justify the simulated extremely high IWC/LWC. Associated text is added in the new manuscript as described above. Moreover, as stated in our response above, important cloud variables such as cloud-top and cloud-bottom heights are compared between observations and the 200_2 run. As stated above, this comparison demonstrates that the simulation of these cloud variables is performed reasonably well, and text about this is added in the new manuscript.

With respect to the observation of CCN and the associated assumption on INP, the following is added with associated text:

(LL263-271 on p9-10)

The properties of cloud condensation nuclei (CCN) such as the number concentration, size distribution and composition are measured in the domain (Tunved et al., 2013; Jung et al., 2018). The measurement indicates that on average, aerosol particles are an internal mixture of 70 % ammonium sulfate and 30 % organic compound. This mixture is assumed to represent aerosol chemical composition over the whole domain and simulation period for this study. The observed and averaged concentration of aerosols acting as CCN is ~200 cm^{-3} over the simulation period. Based on this, 200 cm^{-3} as an averaged concentration of aerosols acting as CCN is interpolated into all of grid points immediately above the surface at the first time step.

(LL285-288 on p10)

It is assumed that the properties of INP and CCN are not different except for concentrations. The concentration of aerosols acting as CCN is assumed to be 100 times higher than that acting as INP over grid points at the first time step based on a general difference in concentrations between CCN and INP (Pruppacher and Klett, 1978).