Reply on RC1

RC1: The authors have addressed most of my comments. However, I still quite puzzled about the total lack of CWC to the SIP mechanism choices despite orders of magnitude changes in the ice crystal concentration. The authors provided some speculation about this, but none of their reasons would explain why there is no CWC sensitivity with SIP mechanism tests but substantial CWC sensitivity when the CCN concentration is varied. In Figure 6 (CCN tests), only the top middle panel shows a near lack of CWC sensitivity to CCN, but in this case the ice crystal number concentration is likewise not sensitive to CCN. The CWC analysis to me strongly suggests that there is an error in the data processing code. The authors state (Lines 454-55) that "As soon as one SIP process is activated, all mean vertical profiles of CWC are merged in the WARM and MID-WARM cases." What does this mean exactly? Is this merging the reason why the CWC profiles are so similar?

We understand the comment regarding the insensitivity of the cloud water content (CWC) to the secondary ice processes (SIP). The data processing scripts have been double-checked and no errors in the code have been found. Additionally, we have plotted the cloud droplet mixing ratio directly from the model outputs, and it shows the same tendencies as CWC. The same code is used to plot the ice crystal number concentrations (Figures 4 and 12) and it results in significantly different profiles for this variable for all sensitivity tests. Consequently, we are sure that this behavior cannot be attributed to an error in the processing code. Therefore, it must be related to the model itself, and in particular to the microphysics scheme, to the configuration of the sensitivity tests, and/or to the way the diagnostics is performed.

We first examined the sensitivity of CWC to the way the diagnostics is performed. In Figures 5 and 12, we plotted the mean vertical profiles of CWC in the convective region during the early cloud electrification. As stated in the manuscript "the initial stage of cloud electrification is defined as the first 10 min during which the absolute value of the non-inductive charging rate integrated over the volume of the convective region is greater than 0.1 C s^{-1}". It corresponds approximately to the period around 20-25 min of simulation. We have investigated more thoroughly the sensitivity of CWC to N_{CCN}, N_{INP} and SIP without the constraint of the electrification period defined in the manuscript.
Figure R1 shows the mean vertical profiles of cloud droplet mixing ratio in the convective region, for the 3 storms and at different times of the simulation, for sensitivity tests on SIP. At 22 min (first column of Fig. R1), quasi-identical vertical profiles of cloud droplet mixing ratio are found for each simulation and each idealized storm. However, at a later stage in the storm, small differences are found in all storms when SIP processes are activated, creating a sink of cloud droplets. For example, at 52 minutes in the COLD storm, differences of 0.05 g kg^{-1} are observed between the ALLSIP (0.25 g kg^{-1}) and HM simulation (0.30 g kg^{-1}) around 5 km altitude. This outcome arises from a complex balance between competing processes, notably autoconversion, riming and depositional growth.
The same figures as Figure R1 have been plotted for sensitivity tests on N_{INP} (Figure R2) and N_{CCN} (Figure R3). High N_{INP} tends to reduce cloud droplet mixing ratio in altitude in the WARM and MID-WARM storms at 22 minutes (Figure R2a and R2d) by accelerating the formation of ice crystals, and precipitation ice particles (aggregates and graupel) and

consuming cloud droplets. This effect is not observed in the COLD storm at 22 min because the development of the ice phase occurs sooner. Later in the storm life, the vertical profiles appear almost indistinguishable, except at 52 minutes in the WARM storm where high N_{INP} leads to higher cloud droplet mixing ratio.
Increasing N_{CCN} leads to a clear enhancement of cloud droplets mixing ratio during the whole lifecycle of the cloud, but with a higher impact at the development stage of the storms (22 min). Cloud droplet mixing ratio is reduced during the storm life mostly by riming resulting in similar vertical profiles regardless of N_{CCN} in the WARM and MID-WARM storms at 52 minutes (Figures R3c and R3f).
N_{CCN} directly impacts the formation and evolution of cloud droplets and it has naturally the highest impact on cloud droplet mixing ratio during the cloud development. On the contrary, N_{INP} and SIP processes have an indirect effect on cloud droplet mixing ratio and CWC through depositional growth and riming, and thus have a negligible impact during the early cloud electrification period compared to CCN. These figures also clearly show that the impact of N_{CCN}, N_{INP} and SIP on CWC depends on the period of the storm during which the diagnostics are computed.

We have also tested the impact of the region over which the diagnostics are made. In the manuscript, the mean vertical profiles are computed in the convective region where the cloud electrification is supposed to mainly occur. We have computed the mean vertical profiles of CWC during the early electrification period in the stratiform region and in the whole cloud for the sensitivity tests on SIP processes (not shown). We clearly observe different CWC profiles between the NOSIP simulation and the simulations where at least one SIP process is activated in the WARM and MID-WARM storms. The cloud region over which the average is calculated can also influence the effect of N_{CCN}, N_{INP} and SIP on CWC.

Part of the behavior of CWC could also be attributed to the configuration of sensitivity tests on SIP processes. Indeed, all sensitivity tests on SIP have been performed with fixed N_{CCN} (1000 cm^{-3}) and N_{INP} (10 L^{-1}). We performed additional simulations to investigate whether changing these values would modify the behavior of CWC profiles. N_{CCN} and N_{INP} have been set to 5000 cm^{-3} and 100 L^{-1}, and two simulations with none SIP and all SIP activated have been performed for the WARM case. Figure R4 shows the mean vertical profiles of cloud droplet mixing ratio for these simulations. There is almost no impact of the SIP processes on the cloud droplet mean vertical profile for the WARM case. The impact of SIP processes when N_{INP} and N_{CCN} are increased is even less pronounced at 52 min than in the original set of experiments (1st line of Figure R1). We also tested lower aerosol concentrations: N_{CCN} and N_{INP} have been set to 500 cm^{-3} and 10 L^{-1}, respectively. Results are shown in Figure R5. As in other cases, differences in the mean vertical profiles of cloud droplet mixing ratio widen over time. But as soon as 37 minutes, slight differences are observed. The maximum difference is reached at 52 min between the NOSIP and ALLSIP simulations (0.02 g kg^{-1}). The sensitivity of CWC to SIP processes seems to increase at lower N_{CCN}.

Finally, and as stated in the first review, some microphysical treatment in LIMA v1.0 (Vié et al., 2016) could affect the insensitivity of CWC to ice particles. Four additional simulations of the WARM storm have been performed using the full two-moment version of the LIMA microphysics scheme (LIMA v2.0; Taufour et al., 2024). In all these simulations, N_{CCN} and N_{INP} are set to 1000 cm^{-3} and 10 L^{-1}, respectively. The SIP processes are enabled or disabled in turn. Figure R6 shows the mean vertical profiles of the cloud droplet mixing ratio at 22, 37 and 52 min for the four sensitivity tests using LIMA v2.0. At 22 min, there is almost no impact of activating or not the SIP processes. However, at 37 and 52 min, the impact of the SIP processes is much more important when using LIMA v2.0 than when using LIMA v1.0. As stated in the manuscript, “snow and graupel number concentrations are not prognostic, potentially accelerating their formation and depleting liquid and small ice species in comparison with a full two-moment version of LIMA”. In LIMA v2.0 the formation of snow/aggregates and graupel is more gradual.

To summarize, additional simulations enable to conclude that:

- Increasing the initial N_{CCN} and N_{INP} does not change the effect of SIP processes on the CWC vertical profile during the early cloud electrification period. It even diminishes the long-term effect. But, reducing the initial N_{CCN} enhances the effect of SIP processes on CWC, though this remains limited to the mature stage of the storm.
- Using the full two-moment version of the LIMA scheme does not change the CWC results during the early electrification period. However, a contrasted behavior of CWC when SIP processes are activated is observed as soon as the storm reaches its mature stage.

Regarding the use of “merge” in lines 454-55, it is done to describe the visual appearance of the curves rather than a technical process. This term has been changed to “almost indistinguishable” to avoid confusion in the new version of the manuscript.

Therefore the paragraph discussing the insensitivity of CWC to SIP processes in Section 4.2.4 has been modified to better explain the potential origins of such a behavior.
“The weak sensitivity of CWC to SIP processes may result from several factors: data sampling, configuration of the sensitivity tests, and configuration of the microphysics scheme. First, data sampling during the electrification period limits the detection of differences which occur more significantly during the storm's mature stage (not shown). While N_{CCN} directly impacts the formation of cloud droplets, N_{INP} and SIP processes have a more indirect effect on cloud droplets. They impact the cloud water content through depositional growth and riming. Thus their effect is delayed in time compared to N_{CCN} and is negligible during the early cloud electrification period investigated in this study. Secondly, additional simulations for the WARM case have been performed in which N_{CCN} and N_{INP} were varied, and the SIP processes were enabled or disabled. Increasing the initial N_{CCN} and N_{INP} does not change the effect of SIP processes on the CWC vertical profile during the early cloud electrification period. It even diminishes the long-term effect. But, reducing the initial N_{CCN} enhances the effect of SIP processes on CWC, though this remains limited to the mature stage of the storm. Finally, in the version of LIMA used in this study, snow and graupel number concentrations are not prognostic, potentially accelerating their formation and depleting liquid and small ice species in comparison with a full two-moment version of LIMA (Taufour et al., 2024). Using the full two-moment version of the LIMA scheme in the WARM simulation and enabling or disabling the SIP processes does not change the CWC results during the early electrification period. However, a contrasted behavior of CWC when SIP processes are activated is observed as soon as the storm reaches its mature stage.”

Minor Comments:

1. Line 88: Rather than "..." it would be better to use "etc." to end the sentence.

Done.

2. Line 125: "rimmed" → "rimed"

Done.

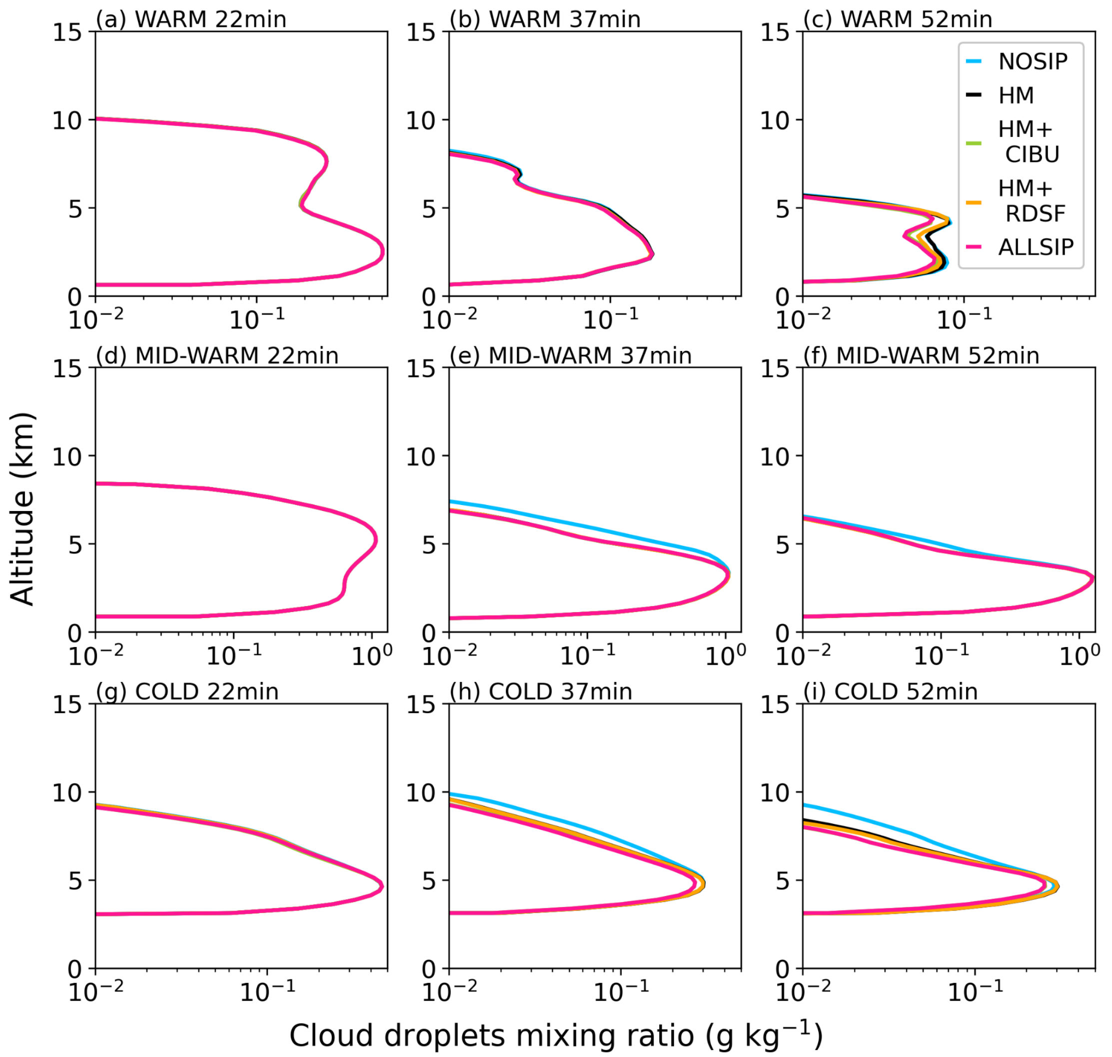

Figure R1: Effect of time and SIP processes. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (left column), 37 min (middle column) and 52 min (right column) of the WARM (first line), MID-WARM (second line), and COLD (third line) simulations. In each panel, the blue, black, green, orange and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for the NOSIP, HM, HM+CIBU, HM+RDSF and ALLSIP simulations, respectively. In all these simulations, N_{CCN} and N_{INP} are set to 1000 cm^{-3} and 10 L^{-1}, respectively.

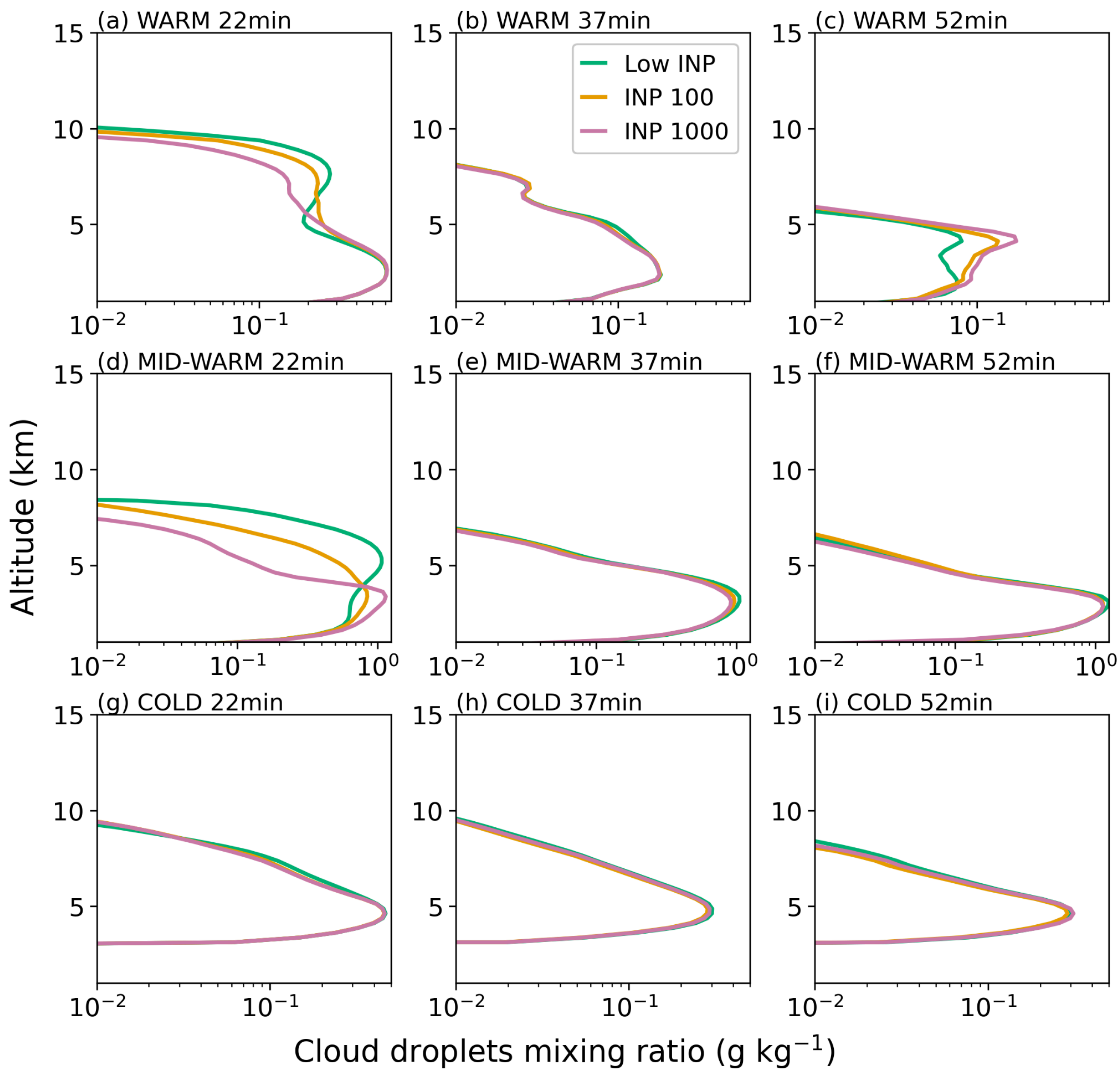

Figure R2: Effect of time and N_{INP}. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (left column), 37 min (middle column) and 52 min (right column) of the WARM (first line), MID-WARM (second line), and COLD (third line) simulations. In each panel, the green, orange and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for N_{INP} = 10, 100 and 1000 L^{-1}, respectively. In all these simulations, N_{CCN} is set to 1000 cm^{-3} and only the HM process is activated.

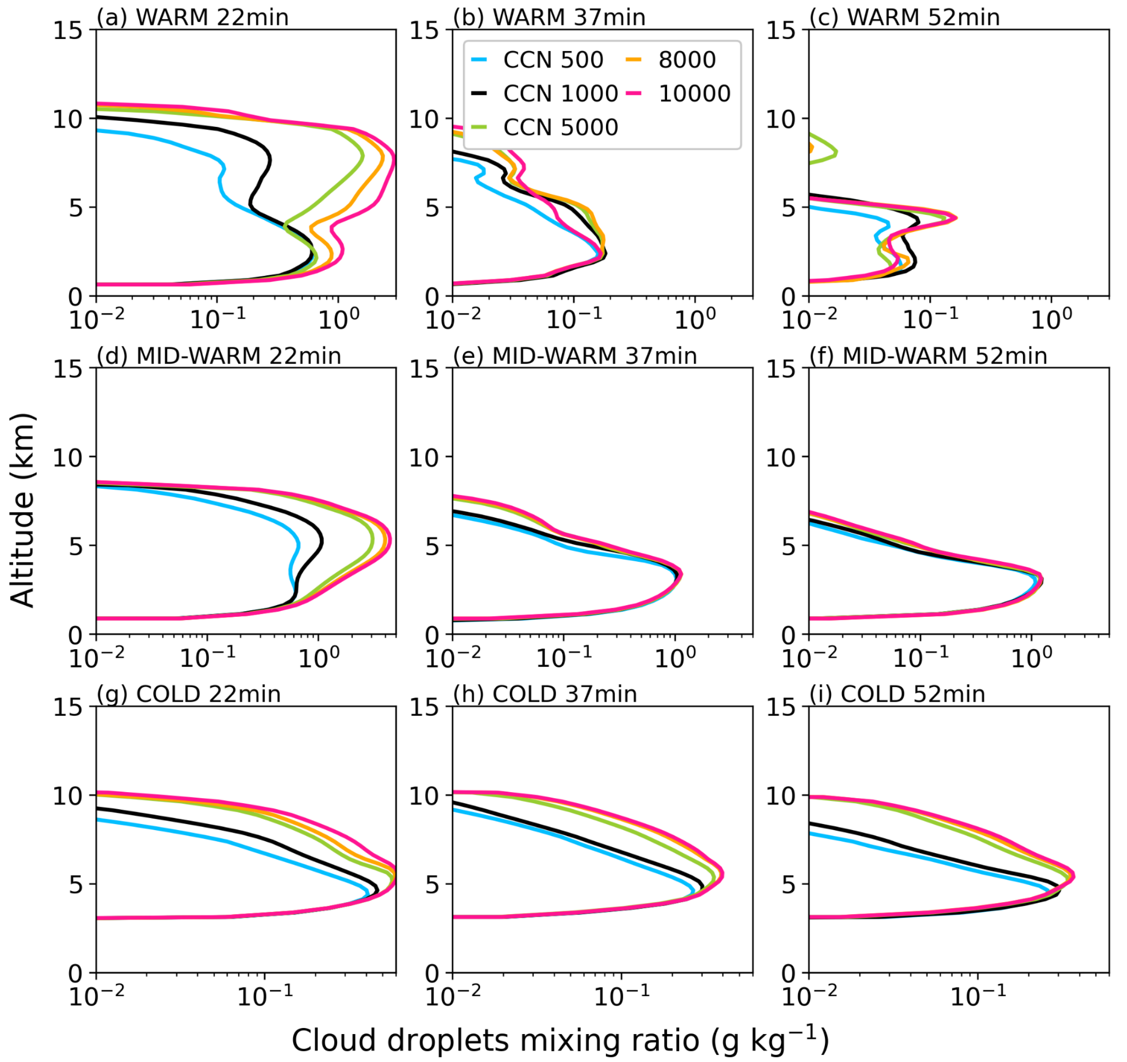

Figure R3: Effect of time and N_{CCN}. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (left column), 37 min (middle column) and 52 min (right column) of the WARM (first line), MID-WARM (second line), and COLD (third line) simulations. In each panel, the blue, black, green, orange and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for N_{CCN} = 500, 1000, 5000, 8000 and 10000 cm^{-3}, respectively. In all these simulations, N_{INP} is set to 10 L^{-1} and only the HM process is activated.

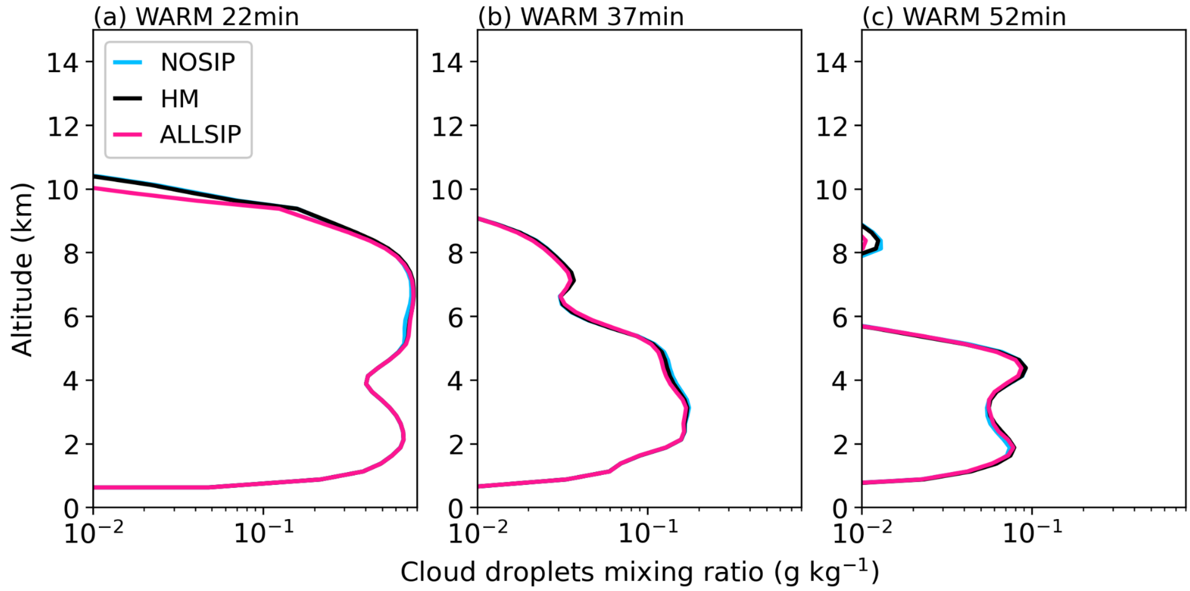

Figure R4: Effect of the initial aerosol concentration. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (a), 37 min (b) and 52 min (c) of the WARM simulations. In each panel, the blue, black and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for the NOSIP, HM and ALLSIP sensitivity tests, respectively. In all these simulations, N_{CCN} and N_{INP} are set to 5000 cm^{-3} and 100 L^{-1}, respectively.

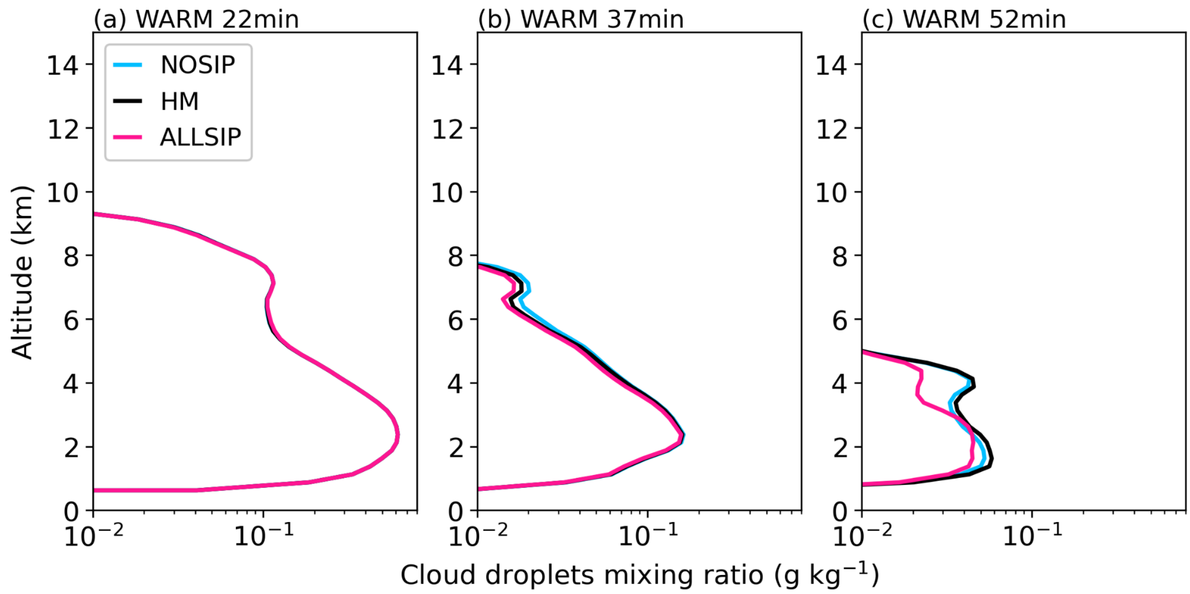

Figure R5: Effect of the initial aerosol concentration. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (a), 37 min (b) and 52 min (c) of the WARM simulations. In each panel, the blue, black and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for the NOSIP, HM and ALLSIP sensitivity tests, respectively. In all these simulations, N_{CCN} and N_{INP} are set to 500 cm^{-3} and 10 L^{-1}, respectively.

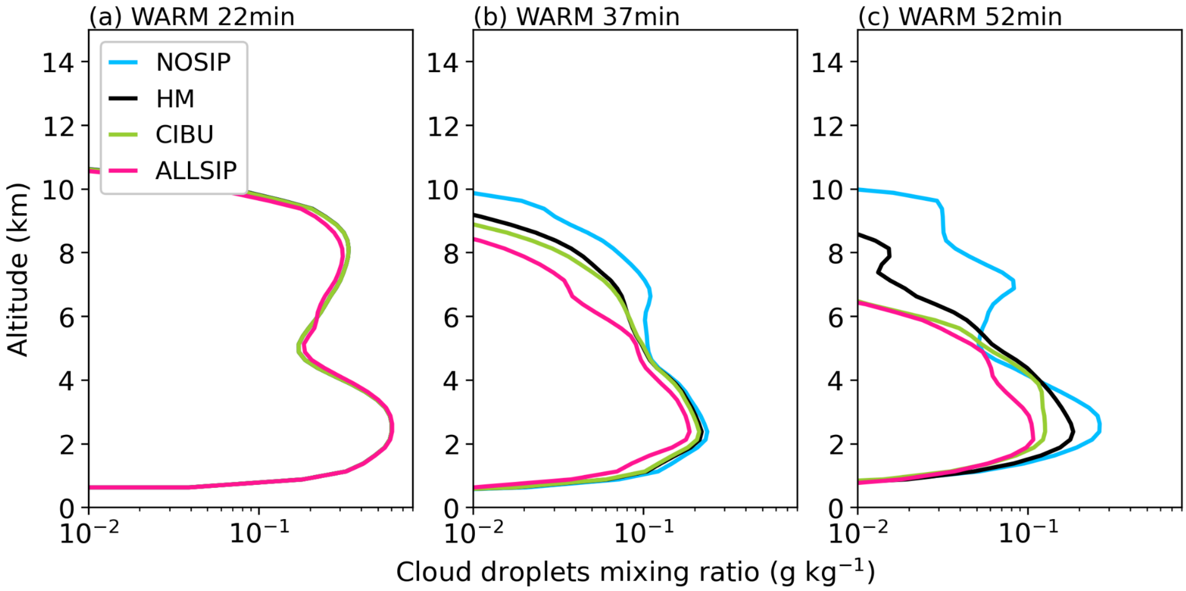

Figure R6: Effect of the microphysics scheme. Mean vertical profiles of cloud droplet mixing ratio (g kg^{-1}) in the convective region at 22 min (a), 37 min (b) and 52 min (c) of the WARM simulations. In each panel, the blue, black, green and pink curves correspond to the mean vertical profiles of cloud droplet mixing ratio for the NOSIP, HM, CIBU and ALLSIP sensitivity tests, respectively. In all these simulations, N_{CCN} and N_{INP} are set to 1000 cm^{-3} and 10 L^{-1}, respectively, and the full two moment scheme described in Taufour et al. (2024) is used.