Response to Editor

Dear Editor, we appreciate your time and effort thoroughly reviewing our manuscript. We are truly grateful for your detailed comments and patient suggestions. We have revised the manuscript based on your comments. In the response below, your comments are in black text and our responses are in blue text.

After reading the revised manuscript, I found several unclear sentences, English mistakes, typos, and errors such as cross-referencing. Below is the list of my suggestions and questions. I don't think I found all mistakes and typos. Please do very careful reading and perform corrections and adjustments. Also, I found in some places the explanation of the physical processes mostly come from the existing studies and these explanations are not investigated by your analysis so there is no guarantee that these physical explanations hold for these IOPs. You seem to be making "sound reasonable" arguments without showing evidence. For these parts, please clearly make a separation from what your analysis shows to what other studies show and clearly state the arguments with other studies are reasonable/seems applicable but not necessarily true. I also suggest to use ACE-ENA Sum and ACE-ENA Win in the text.

Thank you for the suggestions. We have carefully and clearly made the relevant statements in the revised test to indicate the separations between what our current analysis shows and the possible hypotheses adopted from previous studies. Additionally, Dr. Tim Logan has thoroughly reviewed the manuscript and provided grammatical corrections and adjustments.

L13: are being examined => are examined

Corrected.

L16: larger number => larger number concentration

Corrected.

L17: cloud droplets => cloud droplet effective radius

Corrected.

L19: drizzle formation and growth due to => drizzle formation via droplet growth through

Corrected.

L23: sufficient water => sufficient water vapor (or moisture)

Corrected.

L24: You have not defined the aerosol-limited regime, yet. Maybe "ACE-ENA winter is in the aerosol-limited regime such that aerosols are more likely activated..." (L22-L24)

We have revised this to:

‘The ACE-ENA winter season features relatively fewer aerosols, which are more likely activated into cloud droplets under the conditions of sufficient water vapor availability and strong turbulence.’

L26: water-vapor-limit regime => water-vapor-limited regime

We have revised this to:

‘The enriched aerosol loading during ACE-ENA summer and SOCRATES generally leads to smaller cloud droplets competing for the limited water vapor and exhibiting a stronger ACI.’

L27: Please use more appropriate verb in stead of "pronounced" or describe how pronounced.

We have revised this to:

‘…the precipitation susceptibilities are stronger during the ACE-ENA…’

L51: "more and smaller cloud droplets not only extend cloud longevity and spatial coverage" I don't think this always holds. Please clarify it.

We have changed this to:

‘Furthermore, a larger number of small cloud droplets can sometimes extend cloud longevity and spatial coverage and modulate the precipitation processes in the MBL clouds, reflecting the cloud adjustments to aerosol disturbances (Albrecht, 1989; Bellouin et al., 2020)’

L57: "Aerosols have been found to suppress the precipitation frequency and strength by constantly buffering cloud droplet number concentrations via activation, hence increasing cloud

precipitation susceptibility" doesn't make sense. Buffering implies that multiple process work together to reduce the response to an aerosol perturbation but aerosol should increase cloud droplet number after it is activated. Also, how does this increase cloud precipitation susceptibility? Please clarify in plain language.

We have revised the statements to:

'Frequent aerosol intrusions in the MBL have been found to have to lower the efficiency of collision-coalescence-induced which results in the suppression of precipitation frequency and strength. Such phenomenon can be quantified and assessed via the cloud precipitation susceptibility.'

L67: cloud top => cloud-top

Corrected.

L80: CCN budgets also via => CCN budget via

Corrected.

L88: for such studies => for studying ACPIs / for studies of ACPIs

Corrected.

L94: were => was

Corrected.

L95: Remove "(ACE-ENA Sum)" and "(ACE-ENA Win)" since these are not used in other part of the text. Or use these names in stead of, e.g., ACE-ENA winter, ACE-ENA summer, winter ACE-ENA, and summer ACE-ENA in the text. The latter may be better so that you list like "SOCRATES, ACE-ENA Sum, and ACE-ENA Win" in stead of "SOCRATES, ACE-ENA winter and summer."

Throughout the manuscript, we have changed those terms to ACE-ENA Sum, and ACE-ENA Win where relevant.

L115: as well as => and

Corrected.

L117: aerosol, clouds and precipitation => aerosol, clouds, and precipitation

Corrected.

L134: numerous => many

Corrected.

L136: colder nature => colder weather/climate/atmospheric condition? near-freezing condition?

We have changed this to ‘colder climate’.

L137: "compositely speaking" sounds odd to me. "our composite analysis of ... shows that" is better

We have changed this to ‘our composite analysis of the synoptic pattern shows that the SOCRATES cloud…’

L139: The region of selected... => Because/Since the region of selected...

We have changed this to ‘Since the region of selected...’

L162: ...(Glienke and Mei, 2000). While... => ...(Glienke and Mei, 2000), while... Or remove "while" and start with "SOCRATES..." "the" in front of "SOCRATES" is unnecessary here. This should be generally applicable throughout the text.

We have changed this to ‘… (Glienke and Mei, 2000). SOCRATES used a…’. And we have corrected similar circumstances in the text.

L166: will be => are

Corrected.

L207: along with => , and

Corrected.

L208: cloud base heights (zt), cloud top heights (zb) and => cloud-base heights (zb), cloud-top heights (zt), and

Corrected.

L213: g/kg => g kg^-1 (superscript)

Corrected.

L224: g/kg => g kg^-1

Corrected.

L235: which counts => which count

Corrected.

L243: ACE-ENA is => ACE-ENA are

Corrected.

L262: "separated profiles" Please make it clear.

We have changed this to '… compared to profiles which aerosols and cloud layer are separated.'

L265: decreasing profile => decreasing aerosol profile

Corrected.

L266: during summertime, will induce => during summertime, induce

Corrected.

L266: What is the typical distance between the bottom of the elevated aerosol layer and the cloud top for both ACE-ENA and SOCRATES? Why is 200 m chosen in stead of 100 m which is used by the referenced study? Some clarification is necessary here.

The 100 m threshold in Gupta et al. (2021) was used in the ORACLES campaign analysis, which might be different from our study regions, and we have added the following discussion.
'Note that from previous studies on ACE-ENA and SOCRATES, the aerosol vertical profiles within ~200 m above the cloud layers are typically found to have less variation (Wang et al., 2020; Wang et al., 2021; McCoy et al., 2021; Zhang et al., 2023), hence representing the aerosol layers in contact with the cloud. Hence, the 200 m criterion used in this study provides a sufficient sample size population for statistical analysis.'

L268: SOCRATES will significantly => SOCRATES significantly
Corrected.

L268: aerosol budget, they would need => aerosol budget, and (or which?) they need
We have changed this to 'the aerosols would need…'

L310: Figure 1a reveals => Figures 1a and 1d reveal
Corrected.

L313: 1a&b => 1a and 1b
Corrected.

L314: 1b&c => 1b and 1c
Corrected.

L320: during SOCRATES => for SOCRATES
Corrected.

L321: 1e&f => 1e and 1f
Corrected.

L322: Section 3.1 => Section ? The paragraph is in Section 3.1.
We have changed this to '…will be further discussed in the following paragraphs.'

L343: entrained down => entrained

Corrected.

L369: Bulk cloud microphysical properties distribution => Distribution of bulk cloud microphysical properties

Corrected.

L372: "The results in Figure 1 have demonstrated that aerosol/CCN sources and concentrations, especially from the sub-cloud regime, play an important role in cloud droplet formation and evolution." I don't see any discussion regarding this point in Section 3.1. Are you mentioning about L318-L320? If you are mentioning the sentences following this sentence, then adjust the sentence appropriately.

This sentence was originally used to introduce the following context about the aerosols and cloud droplets differences between the three IOPs. We have removed the sentence to avoid further confusion.

L387: "Note that the NCCN0.35% and NC values are lower than NC values during the ACE-ENA winter IOP, which is also confirmed in previous studies" I don't get this. Which NCCN and NC are you comparing with NC of ACE-ENA winter?

We have changed this to 'Note that the $N_{CCN0.35\%}$ are lower than N_c values during the ACE-ENA Win, which is also confirmed in previous studies'

L406: "due to cloud-top entrainment" requires an immediate explanation. I think some text re-organization may be necessary to combine the sentences in the next paragraph. Or maybe just removing "due to cloud-top entrainment" from the sentence just work nicely, i.e., use the current paragraph to describe the general shape of the profile and use the next paragraph to give physical insights/interpretations.

Thanks for the suggestion, we have removed this statement from the sentence.

L429: Define DSD here.

Corrected.

L435: "In addition, the cloud adiabaticity is defined as ..." is not connected well to the previous sentence. Please elaborate it.

We have elaborated on this: 'Cloud adiabaticity is a key parameter as it provides insight into the degree of mixing and microphysical processes occurring within clouds. The sub-adiabatic conditions indicate that the LWC_c is less than what would be expected in an adiabatic scenario, often due to processes such as in-cloud collision-coalescence and entrainment mixing (Hill et al., 2009; Braun et al., 2018; Gao et al., 2020; Wu et al., 2020b). In addition, the cloud adiabaticity is defined as $f_{ad} = LWC_c/LWC_{ad}$, where the LWC_{ad} denotes adiabatic LWC (Wu et al., 2020b).'

L450: cloud top => cloud-top

Corrected.

L455: "generally weaker cloud-top inversions" In L461, the temperature jumps are listed, which should be listed here for clarity. Or move "Within the above-cloud inversion layer, the temperature (water vapor mixing ratio) differences ΔT (Δq) are 1.76 K (-1.75 g kg-1), 1.54 K (-1.66 g kg-1) and 1.48 K (-1.09 g kg-1) for SOCRATES, ACE-ENA summer and winter, respectively." right after the sentence.

We have modified the narrative structure as suggested.

L455: "stronger near-cloud top turbulence" In Fig. 5, TKE near the cloud top for ACE-ENA Win is strongest. So add a cross-reference of (Figure 5).

Cross-reference is added.

L457: cloud top => cloud-top

Corrected.

L460: How about influence on the water vapor jump? ACE-ENA Win is lowest and SOCRATES is strongest so entrained air could be dryer? It is better to use virtual potential temperature.

We have elaborated this to:

'Within the above-cloud inversion layer, the temperature (water vapor mixing ratio) differences ΔT (Δq) are 1.76 K (-1.75 g kg^{-1}), 1.54 K (-1.66 g kg^{-1}) and 1.48 K (-1.09 g kg^{-1}) for SOCRATES, ACE-ENA Sum, and ACE-ENA Win, respectively. The virtual potential temperature differences $\Delta\theta_V$ are 4.90 K, 5.16 K, and 3.82 K, for SOCRATES, ACE-ENA Sum, and ACE-ENA Win, respectively, indicating relatively dryer entrained airmasses during SOCRATES and ACE-ENA Sum.'

L462: Remove "Therefore".

Done.

L465: exhibited => exhibit

Corrected.

L490: droplet size distributions (DSD) => DSDs. DSD should be defined at L429.

Corrected.

L515: Move "For the four cloud portions from cloud base to cloud top, the skewness of summertime (wintertime) cloud DSDs are 0.627 (0.271), 0.358 (0.175), 0.098 (-0.063), and -0.362 (-0.554), respectively." to L508 before "Notably, the cloud DSDs..." and adjust both sentences.

We have modified the narrative structure as suggested.

L520: Make new paragraph starting with "Note that in the upper region..." and adjust the sentence.

Done. We have added the new paragraph starting with 'In the upper region of the cloud (Fig. 4a)…'

L541: m/s => m s^-1

Corrected.

L546: 5c & d => 5c and 5d

Corrected.

L554: might be slightly => is

Corrected.

L578: are elongated => would become longer (a time scale does not have width)

Corrected.

L578: growth can be => growth could be

Corrected.

L581: which disturb => which would disturb

Corrected.

L583: "As a result, the ACE-ENA..." The discussion above the sentence is all hypothesis/speculations based on past studies and there is no guarantee that these occur in ACE-ENA. Please correct it.

We have modified the discussion to 'The physical hypotheses from previous studies could potentially serve as the explanation for the phenomena that the ACE-ENA Win drizzle DSD is sufficiently broadened, and the D_{mmd} is enlarged toward the cloud base.'

L630: higher => higher than ACE-ENA

Corrected.

L632: "relatively less Nccn,0.35% condition for SOCRATES" In Fig. 1f, Nccn,0.35% is largest for SOCRATES. Please clarify this.

The ‘relatively less’ was a typo, should be ‘relatively more’.

We have corrected the discussion to ‘Recall that the sub-cloud $N_{CCN,0.35\%}$ during SOCRATES is generally higher than ACE-ENA and is constituted by more small-sized aerosols (as indicated in Fig. 2b). Consequently, after activation, the lower part of the cloud exhibits a higher number of smaller cloud droplets for SOCRATES, as shown in Fig. 4d.’

L636: According to Fig.1 "under the relatively more CCN condition" is not true for ACE-ENA compared with SOCRATES. Please clarify this.
We have corrected this to ‘…under the relatively less CCN condition …’

L640: add appropriate references for VOCALS, CSET, ORACLES, ACTIVATE
The following references are added:
‘VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS; Wood et al., 2011), the Cloud System Evolution over the Trades (CSET; Albrecht et al., 2019), the ObseRvations of CLouds above Aerosols and their intEractionS (ORACLES; Redemann et al., 2021), and the Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE; Sorooshian et al., 2019)’

L645: Move "The AI indices from three IOPs are ..." between "...the cloud base)." and "Note that the availability..." in L607 or move it to a better place before discussing these indices
We have modified the narrative structure as suggested.

L648: Include Fig. S5 into Fig. 6. Also state that the LWC near cloud top for the three IOPs are not comparable each other.
We have added Fig. S5 into Fig. 6, and adjusted the discussions accordingly.
‘To investigate the ACI indices at the upper level of the cloud, the N_c and r_c at the upper cloud ($z_i > 0.8$) are plotted against the above-cloud $N_{CCN,0.35\%}$ in Figures 6c and 6d…’
and
‘Note that the LWC_c near the cloud top for the three IOPs are not comparable to each other, which might also induce uncertainty in the near-cloud-top ACI assessment.’

L682: near the cloud base => near the cloud base in ACE-ENA winter

Corrected.

L682: "the ACE-ENA winter featured enhanced collision-coalescence and drizzle-recirculating processes" has not been shown by data analysis. Or are you mentioning L617-L621? But it still lacks drizzle-recirculating process. Please clarify it.

We have modified the discussion to:

'As previously discussed, the ACE-ENA Win featured enhanced collision-coalescence suggested by the stronger in-cloud turbulence, and a possible drizzle-recirculating process as indicated by the previous study. And such mechanisms might explain the low N_c conditions with more large drizzle drops, leading to the increase of S_o values ACE-ENA Win.'

L684: "the higher ambient aerosol and CCN concentrations ... may induce effective aerosol buffering effects" is unclear. Are you saying that aerosol of SOCRATES is mainly composed of fine Aitken mode aerosol (I think you mentioned somewhere in the text), which results in smaller cloud droplets, thus collision-coalescence is not effective, which means that the warm-rain processes are suppressed? Please explain clearly.

We have modified the discussion to:

'In comparison, the aerosol of SOCRATES is largely composed of fine Aitken mode aerosol, which results in smaller cloud droplets. Thus, collision-coalescence is ineffective during SOCRATES, which leads to the relatively narrower drizzle DSDs, where the warm-rain processes are suppressed, and in turn, diminishing the sensitivity of R_{CB} to N_c'

L695: Do you really think the difference of R^2 between 0.165 and 0.295 for SOCRATES is significant and think SOCRATES are more related to Nc? These numbers as well as correlation coefficients for S0 (L672) are generally small and I am not sure if these are statistically meaningful. How reliable are these values with uncertainty of observed data?

We have clarified the discussions to:

‘The S_0 values are 0.979, 1.229, and 1.638, with the absolute values of correlation coefficients being 0.33, 0.29, and 0.45 for SOCRATES, ACE-ENA Sum, and ACE-ENA Win, respectively. The regression relationships are statistically significant with $p<0.05$ for all three IOPs.’

and

‘The statistical coefficient of determination (R^2) values of R_{CB} against H_c (N_c) are 0.696 (0.177), 0.419 (0.212) and 0.165 (0.295), for the ACE-ENA Sum, winter and SOCRATES, respectively, suggesting that the R_{CB} in ACE-ENA clouds may be more determined by H_c, while the R_{CB} in SOCRATES clouds could be less dependent on both H_c and N_c.’

L754: Sentences below this line are unclear and need elaboration. "Hence ..." This is unclear and need better explanation. "the time needed, ..." is also unclear to me. What budget are you talking about? The sub-cloud CCN budget? "restore the sub-cloud CCN to the budget" sounds strange since these units are different.

We have modified the discussions to:

‘Hence, the retrospective period used here might quickly exceed the actual time of cloud-processing to become effective on aerosol and CCN. In other words, the actual time needed to trace back to the sub-cloud CCN concentration before they were cloud-processed, is shorter than the retrospective time tested here in Figure 8.’

L756: Thus, => This

Corrected.

L775: "Physical processing like in-cloud Brownian capture can reduce Aitken mode aerosols, while the chemical processes transform Aitken mode aerosols to larger sizes, moving them toward the accumulation mode. In addition, the in-cloud coalescence processes shift sub-cloud aerosol residuals to larger sizes, as multiple aerosols combine into a single aerosol core inside the cloud droplet during collision-coalescence" These are not shown from your analysis. These from the existing studies are used so that "the observed increase in the tail-end of the aerosol distribution for all IOPs" is somehow explained. So, these statements are speculation or can be hypothesis for future research. Please distinguish the existing studies from your findings.

We have modified the discussions to:

‘According to previous studies, physical processing like in-cloud Brownian capture can reduce Aitken mode aerosols, while the chemical processes transform Aitken mode aerosols to larger sizes, moving them toward the accumulation mode. In addition, the in-cloud coalescence processes could also shift sub-cloud aerosol residuals to larger sizes, as multiple aerosols combine into a single aerosol core inside the cloud droplet during collision-coalescence. Those physical mechanisms could potentially explain the observed increase in the tail of the aerosol size distribution for all IOPs, and it will be of interest for future research to prove such hypotheses.’

L794: "which substantially enhances the collision-coalescence and the drizzle re-circulating processes" is not demonstrated by your analysis and this is another speculation.

We have modified the discussions to:

‘The ACE-ENA Win clouds feature more prominent drizzle formation and evolution owing to the combined effects of relatively cleaner environment, deeper cloud layer, and slightly stronger in-cloud vertical turbulence, which is speculated to substantially enhance the collision-coalescence and the drizzle re-circulating processes, compared to the other two IOPs.’

L802: cloud base => cloud-base

Corrected.

L807: "a result of turbulence-driven in-cloud droplet interactions, especially under low NC condition" is not shown by your analysis and this is a speculation/hypothesis.

We have modified the discussions to:

‘This could be possibly hypothesized as the result of turbulence-driven in-cloud droplet interactions, which could result in much higher R_{CB} induced by larger drizzle drops near the cloud base for ACE-ENA, especially under low N_c condition.’

L809: "The relationships established in this study indicate that ACE-ENA clouds, are largely determined by Hc, while SOCRATES clouds are more influenced by the Nc." This needs to be corrected because of small R2.

We have modified the discussions to:

'The relationships established in this study indicate that the S_o in ACE-ENA clouds can be partially determined by H_c, while in SOCRATES clouds the S_o is less influenced by H_c and N_c.'

L810: "The combination of a deeper cloud layer and relatively lower ambient aerosol concentration, eventually leading to stronger drizzle production and evolution during ACE-ENA, especially during the winter season, results in more robust precipitation susceptibility" Even this is a sort of speculation. This has not been demonstrated by your analysis. A sound reasonable explanation doesn't mean that that is true or happening without evidence.

We have modified the discussions to:

'Based on the physical mechanisms found in the previous study, a possible hypothesis can be leveraged to explain the observed results. That is, the combination of a deeper cloud layer and relatively lower ambient aerosol concentration, eventually leading to stronger drizzle production and evolution during ACE-ENA, especially during the winter season, results in more robust precipitation susceptibility. And further numerical simulations and experiments are warranted to prove this hypothesis.'

Fig. 1: "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"

Corrected.

Fig. 2: "Accumulation mode, Aitken mode and Coarse mode" => "Accumulation mode, Aitken mode, and Coarse mode"; "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"

Corrected.

Fig. 3: "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"

Corrected.

Fig. 4: "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"
Corrected.

Fig. 5: "u'2 (c) and v'2" => "u'2 (c), and v'2": "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"
Corrected.

Fig. 6: Add label (a) and (b). Include Fig. S5 here; "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"
Corrected.

Fig. 7: "ACE-ENA summer, winter and SOCRATES" => "ACE-ENA Sum, ACE-ENA Win, and SOCRATES"; "pink, purple and green" => "pink, purple, and green"
Corrected.