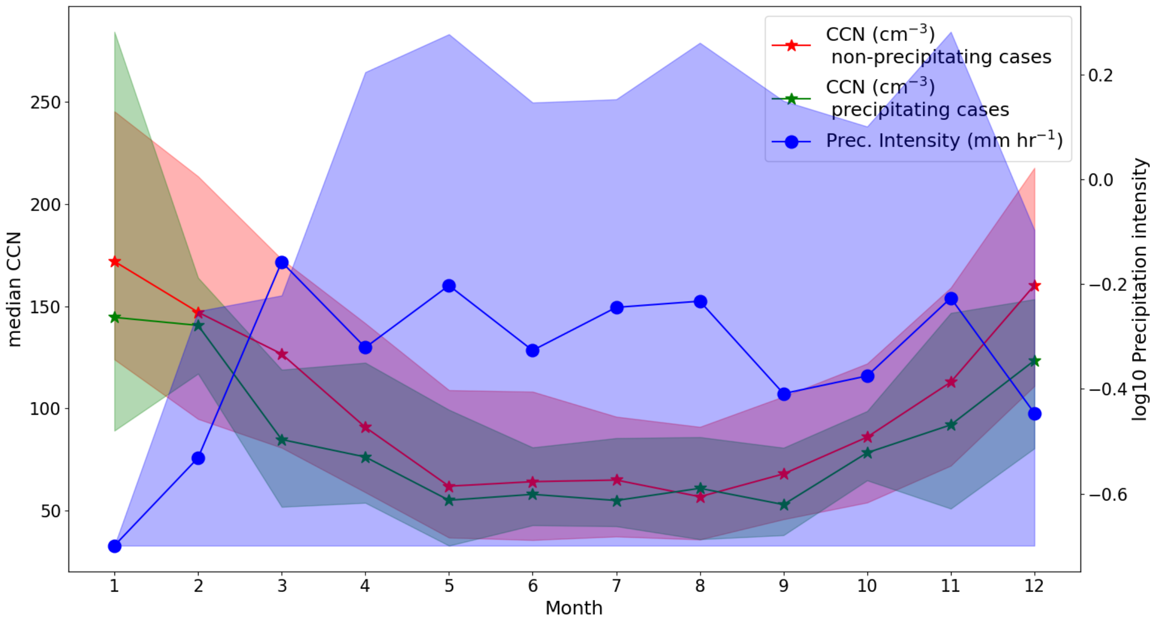
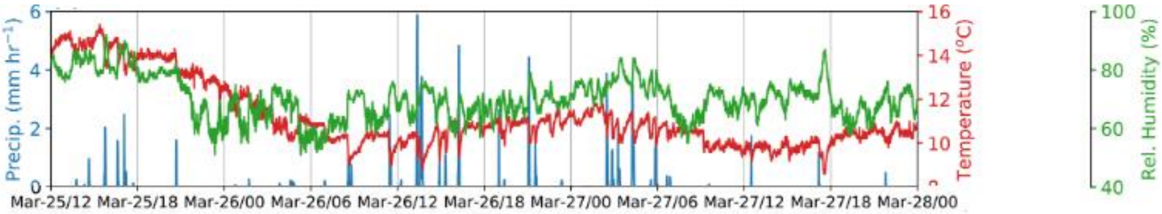
Major comment:

Line 227-240, Figure 6: A negative correlation was found between precipitation and CCN. However, the seasonality of CCN also reflects the effect of seasonal variations in sources (e.g., biogenic aerosols are higher in the austral summer and lower in winter). I'm curious if the authors can further isolate the effects of the source and sink by filtering the CCN data based on precipitation rates. For example, what would the CCN in the current Figure 6 look like for non-precipitating and precipitating cases, respectively? For the non-precipitating cases, the seasonality of CCN would mainly be due to sources. On the other hand, the seasonality of precipitating cases would include the effect of both source and sink. I suspect the seasonality of CCN for non-precipitating cases would resemble that in the current Figure 6 (but with higher values). It is also likely that CCN for non-precipitating cases would negatively correlate with precipitation due to coincidental lows and highs. Moreover, the ratio of the CCN values between precipitating and non-precipitating cases might be indicative of the role of precipitation in controlling the seasonality of CCN.

We appreciate your suggestion to further isolate the effects of source and sink processes by filtering the CCN data based on precipitation rates. Following your recommendation, we analyzed CCN concentrations for both precipitating and non-precipitating cases. As you correctly anticipated, the seasonality in CCN concentrations during non-precipitating events (red star-line in the attached figure) are slightly higher (median of 161 for summer (DJF) and 62 for winter (JJA)). Conversely, CCN values are lower during precipitating conditions (the green star-line in the attached figure) (median of 134 for DJF and 57 for JJA), which we attribute to aerosol washout from precipitation.

However, we believe that analyzing CCN based on hourly precipitation data may not provide a fully accurate representation, given the highly intermittent nature of precipitation in our study area as discussed in Alinejadtabrizi et al., (2024). Specifically, open MCCs often produce intermittent precipitation in one hour, followed by non-precipitating periods in the subsequent hours. Following figure from Lang et al., (2021), show a time series of the precipitation based on the CAPRICORN 2016 Field Campaign, which illustrate the nature of the precipitation over our study area. This discontinuity could obscure the impact of precipitation on CCN, as the washout effect may still be present even when the event is categorized as non-precipitating. To avoid potential misinterpretations, we have opted to retain our original approach in this section, which we believe offers a more consistent analysis of the relationship between CCN and precipitation.





Time series of surface level precipitation, temperature, and relative humidity during a case study within the CAPRICORN 2016 field campaign (Lang et al., 2021 (their figure 2d))

Lang, F., Huang, Y., Protat, A., Truong, S. C. H., Siems, S. T., & Manton, M. J. (2021). Shallow convection and precipitation over the Southern Ocean: A case study during the CAPRICORN 2016 field campaign. Journal of Geophysical Research: Atmospheres, 126(9), e2020JD034088.

Section 4.2: This subsection focuses on free tropospheric entrainment and the backward trajectories were run at 2500m. If the focus is on the contribution from the free troposphere to the boundary layer (where CGO CCN measurements were made), why weren't the backward trajectories initialized from the boundary layer instead? In addition, the trajectory analysis in this study mostly focuses on the spatial distribution of the trajectories. How do the trajectories vary vertically?

To address this, we ran additional analyses at the boundary layer level and found that the results are largely consistent with those from the 2500 m analysis. Air parcels in summer more frequently originate from lower latitudes, while in winter, they primarily come from higher latitudes. We have included these boundary layer results alongside the original analysis to further support our discussion (Figure 6a in revised manuscript).

Additionally, we plotted the frequency distribution of the vertical heights of the back trajectories which demonstrate the subsidence in large scale. However, it is important to note that ERA5 does not explicitly resolve entrainment processes, as they occur at sub-grid scales. Despite this limitation, we have included the vertical height distribution plot in the supplementary materials (Figure A1) for reference.

Section 3: To improve the flow and readability of this section, it might be helpful to introduce the patterns of the clusters (Figure 3) before discussing their frequency (Figure 1).

We appreciate your suggestion to improve the flow and readability of Section 3. In response, we have relabelled Figure 3 as Figure 1 in the revised manuscript to present the cluster patterns earlier. Additionally, we combined the original Figures 1 and 2 to better illustrate the consistency of the observed seasonality in our clusters with the STR, as advised by another reviewer. We hope these changes will make the manuscript clearer and easier to follow.

Minor comments:

• *Line 64. In this paper, the word "pristine" was used multiple times here and elsewhere. The meaning of pristine needs to be clarified (e.g. in Hamilton et al., 2014). Here, it referred to the Southern Ocean as pristine, while in other places, it seemed to suggest that pristine means low aerosol concentration. Hamilton, D. S., Lee, L. A., Pringle, K. J., Reddington, C. L., Spracklen, D. V., & Carslaw, K. S. (2014). Occurrence of pristine aerosol environments on a polluted planet. Proceedings of the National Academy of Sciences, 111(52), 18466–18471.* We have added a general note in line 31 to clarify this.

• *Line 130, Figure 1: Please consider adding the full names for each cluster in the caption.* The full names of each cluster have been added to the caption of the revised Figure 1 for clarity, as requested.

• *Line 133, Figure 2: The circles in the figure are not labeled in the legend and are not mentioned in the main text.* They are the outliers. We added this to the new figure 2 caption.

• *Line 204 & Line 196. Why was a different test used for mean precipitation (Student's t-test), while the Whitney U test was used for CCN?*
Due to the nature of precipitation over our study area as discussed before, the median precipitation is 0, which makes the mean more appropriate for capturing the range of precipitation events. In contrast, the median was used for CCN data to mitigate the influence of outliers (this has been clarified in lines 113-116). Subsequently, we used the two-tailed Student's t-test for precipitation as it is appropriate for comparing means between two groups. For CCN and radon in contrast, the Mann-Whitney U test was used as it is more suitable for medians. I have added a note in this regard in lines 226 and 212 respectively.

• *Line 230. What does it mean by "combine the two baseline clusters together"? Please clarify in the text.* Done (line 256).

• *Line 234 & Figure 6: To make understanding the orders of magnitude of rain rate more intuitive, please consider using a base-10 logarithmic scale (log10) for the precipitation rate instead of a natural logarithmic scale.* Done.
• *Line 259 & Figure 7: It might be helpful to show the back trajectories for S-base and W-base alongside their differences.* We already have shown the differences in their back trajectories at 500 m in figure 4.