We are again thankful to the editor and the reviewer for their time and effort they have dedicated to reviewing our manuscript. We agree with all the points that the reviewer has raised and have incorporated them in the revised manuscript. Our point-by-point replies to the comments are provided below. Referee comments are given in black and our replies are given in blue.

General Comments:

Thank you for authors's revision. Unfortunately, the authors response all question, but little resolved the problems I raised. Especially some important results are still missing, e.g. vertical distribution of CCN, uncertainty of dataset and day-night difference. I do not expect authors resolve all problems about lidar retrieval of CCN. But lidar is very sensitive to aerosol particle and enviromental conditions, the nessacery and enough diccusion about the limitationes and undertainties must been provided here. It is responsibility to consider or discuss all possible uncertainties if authors want publish a available dataset. Therefore, I suggest this manuscript should be further revised.

Reply: We appologize for the inconvenience. We have carefully incorporated all your suggestions in the revised manuscript and have revised the CCN data. We provide further details in the specific responses below.

Major Comments:

1. For previous Question 4: The CALIPSO track was change after September 2018. At least there is a difference in the observed area, which should be pointed out in the text.

Reply: We understand your point. We have now discussed it in Section 2.1 of the revised manuscript by adding the following sentences to lines 73-75 of the updated manuscript.

"Note that CALIPSO underwent an orbit adjustment in September 2018 to synchronize its path with that of the CloudSat satellite. Although this orbital shift resulted in a slight variation in the geographic region observed by CALIPSO, there are currently no known issues associated with CALIPSO's retrieval quality as a result of this transition."

2. For previous Question 9: For multiple layers of aerosols, the attenuation caused by the upper aerosol layer must influence the retrieval of CCN at lower layer. The author explains the LiDAR can penetrate most of aerosol layers, but how about heavy dust condition, which should be pointed out in the text? I know the CALIPSO data have been calibrated based on signal attenuation, but the related question is still existed. The effect of attenuation to CCN retrieval should been reminded in uncertainties discussion.

Reply: We agree with you. There can be instances where strong signal attenuation due to optically thick aerosol layer present above may lead to increased uncertainty in the retrieval below. Having said that, we do believe that a majority of these uncertain retrievals may be identified and filtered by the several quality control metrics included in the CALIPSO level 2 data, especially the extinction uncertainty metric. We have now discussed the uncertainty that may arise because of this issue in the updated manuscript by adding the following in lines 240-242 of the revised manuscript.

"Additionally, strong signal attenuation caused by optically thick aerosol layers located above may lead to increased uncertainties in the retrievals of layers below. Nevertheless, it is anticipated that these retrievals will be filtered out during the quality screening process."

3. For previous Question 11: I am very surprise author say “We also believe that it will not impact themean state of the CCN variations significantly”. The signal-to-noise of CALIPSO during daytime and nighttime even have the difference at one magnitude. The consideration about sample size is not reason why author not consider the difference of retrieval between daytime and nighttime. Addtionally, the day and night CCN retrieval uncertainty should be different due to the different signal-to-noise of CALIPSO. At least, authers should provide a figure and dissusion about CCN retrieval during daytime and nighttime, separately. This is important message for readers to use this dataset, which should be pointed out in the text.

Reply: We understand your point. We appologize for being not clear enough in our previous response. The low signal-to-noise ratio (SNR) of CALIPSO during daytime impacts on the aerosol extinction retrieval and therefore the CCN retrieval (Tackett et al., 2018; Mao et al., 2022). This may lead to weaker detection of aerosol features, especially the faint ones, which may be incorrectly classified as "clear air" by CALIPSO leading to an extinction coefficient (and CCN) underestimation. We tried to convey this information in Section 3.3 of the unmodified manuscript in lines 227-232 using the following:

"First, faint aerosol layers with extinction coefficient < 0.001 km^{-1} (optical depth < 0.01) may not exceed the signal-to-noise ratio required to be detected by CALIOP (Tackett et al., 2018; Mao et al., 2022). The background noise due to solar radiation further impacts the feature detection, especially for the daytime retrievals (Winker et al., 2009, 2013). Such layers may therefore be classified as clear air by CALIOP’s feature classification algorithm and assigned with a zero extinction coefficient. This may result in an underestimation of the average extinction and thus the n_{CCN}, particularly in grid cells comprising of clean environment (rural continental sites and higher altitudes)."

We agree that the low SNR may also lead to an increased uncertainty in the retrieval. A part of this effect can be observed in the increase in extinction uncertainty metric given in level 2 CALIPSO aerosol profile data (Young et al., 2013). To constrain this limitation, we use the uncertainty metric (including other metrics like CAD score aimed at limiting the highly uncertain retrievals) in our data pre-processing stage and filter the CALIPSO profiles accordingly. The CCN climatology (similar to Figure 3 in manuscript) produced using daytime and nighttime CALIPSO retrievals separately is shown in Figure R1 of this document. As seen in the figure, the daytime retrievals show a higher average CCN value compare to night. This is expected over land as the anthropogenic activities are more pronounced during day light hours. This information can also be derived from the second row of Figure R1 in which the CCN concentrations from polluted continental aerosols have much higher magnitude during the day.

We do agree with the reviewer that the daytime retrievals are more susceptible to retrieval-related errors because of their relatively low SNR ratio and may occassionally result in significantly different "instantaneous" aerosol properties. However, if such occassional uncertain retrieval occur, they are expected to be suppressed over the period of a month (resolution used in our study) by the more frequent error free retrievals. This is what we wanted to convey in the previous response when we mentioned that the mean state of the CCN may not be affected significantly. Nevertheless, we believe that a detailed study is needed to better quantify the difference between daytime and nighttime aerosol properties at different time scales (instantaneous, month, season, and annual). We discuss this topic in Section 3.3 of the manuscript and keep the Figure R1 in the supplementary of the manuscript. Following texts are added to the revised manuscript (lines 243-251).

"As mentioned earlier in Section 3.2.1, we combine daytime and nighttime CCN retrievals to achieve an optimal sampling frequency. The daytime retrievals usually have a lower signal-to-noise ratio (SNR) compared to nighttime retrievals, which may result in higher retrieval uncertainty (Young et al., 2013; Tackett et al., 2018). By comparing the daytime and nighttime CCN climatology (refer to Fig. S1 in the supplementary material), we observe higher values over continents in the former. This observation is expected since anthropogenic emissions are more prominent during the day. The values over oceans are comparable in both cases. However, it is important to note that this concurrence may be attributed to long-term averaging used in computing the climatologies. Therefore, a more detailed comparison is required at various temporal scales (instantaneous, monthly, seasonal, and annual) to accurately quantify the effect of merging daytime and nighttime retrievals. Such an investigation is beyond the scope of the present study and will be a subject of future analysis."

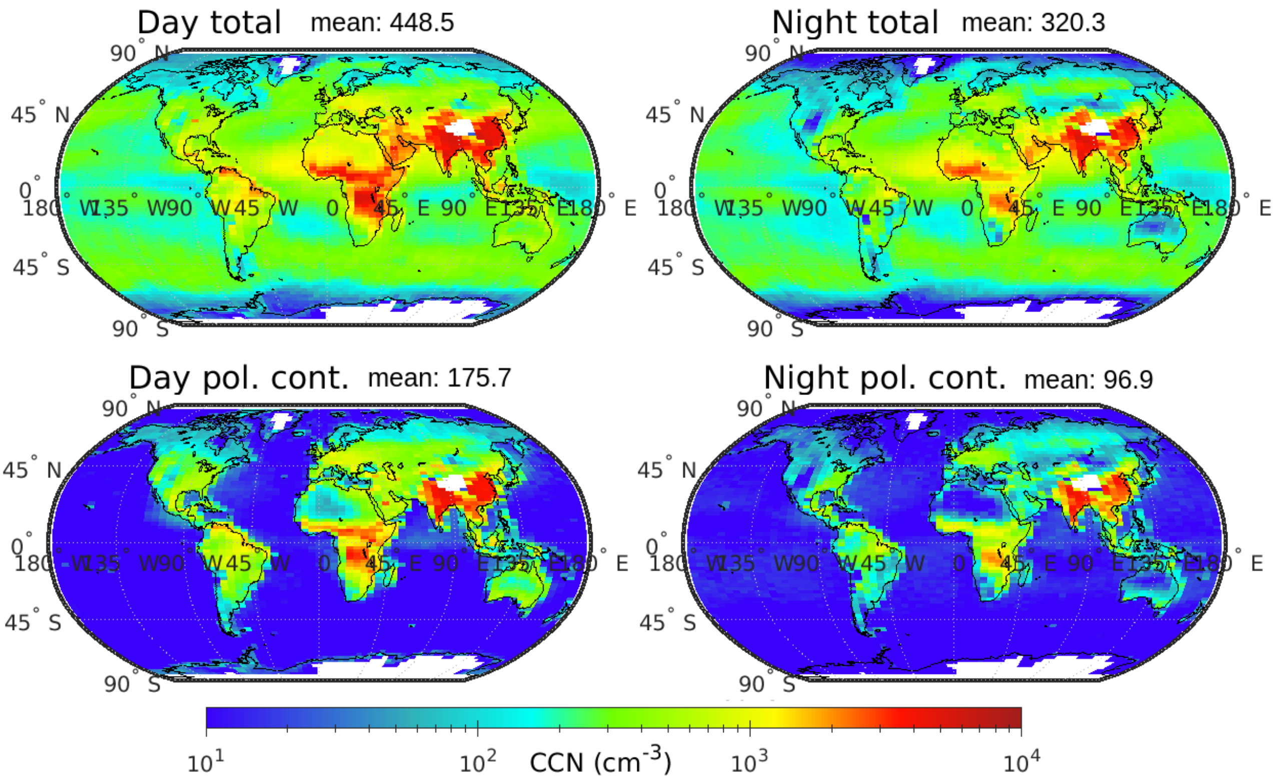

Figure R1: CCN daytime (left column) and nighttime (right column) climatology estimated using more than 15 years of CALIPSO level 2 aerosol profile product (June 2006 to December 2021). The top and bottom row represents the total CCN and polluted continental CCN concentrations, respectively.

4. For previous Question 14: Line 208. The uncertainty indicators are so important. For monthly average data, the authors do not need to provide many percentiles data, but at least the standard deviation for each pixel also can provide some information for using data.

Reply: We agree with you. We have now revised the monthly CCN data by adding standard deviations for mean total CCN concentrations and mean aerosol type-specific CCN concentrations. We have updated Table 2 of the manuscript accordingly. The following variables are added to the updated data set: CCN_std, CCN_cc_std, CCN_pc_std, CCN_d_std, CCN_m_std, and CCN_es_std.

5. For previous Question 16: If the authors emphasize height resolved or 3D, it is necessary to provide a profile of CCN distribution or global CCN at some typical altitude levels. I do not understand authors annoucement the dataset is vertical, but not provide the vertical information. Maybe, authors remove the “height-resolved” from title.

Reply: We apologize for not presenting the vertical profiles of CCN concentrations. We have now updated Figures 3 and 4 of the manuscript by adding an additional sub-panel to each panel showing the CCN profiles. In the CCN climatology shown in Figure 3, we now include the global mean CCN profile and also separate profiles for CCN over land and ocean for each aerosol type. Further, in the CCN seasonal climatology (Figure 4), we show the CCN profile for different aerosol type for four (boreal) seasons. We further discuss the CCN profiles in Section 4.2 of the manuscript. The following texts are added to the revised manuscript.

"When considering the vertical distribution of n_{CCN}, the highest values are observed near the surface, and these values decrease exponentially as the altitude increases. The majority of marine CCN (97 %) and continental CCN (78 %) are predominantly located at altitudes below 2 km. On the other hand, smoke and dust CCN extend into the free troposphere, with approximately 60 % and 33 % located above 2 km altitude, respectively. Interestingly, smoke CCN exhibit an opposite trend, with concentrations increasing with height and reaching a maximum between 2 and 3 km before decreasing at higher altitudes. Land-based aerosols make up the majority of free tropospheric CCN, with 68 % located above 2 km, compared to 32 % for aerosols over oceans. They exhibit a relatively higher contribution to the global CCN across all altitude levels. It is important to note that this variation may not be observed in localized regions over oceans that are more frequently affected by dust and smoke transported from nearby continents, for instance in regions close to the west coast of African continents."

"Furthermore, seasonality in the n_{CCN} profiles is observed for all the aerosol types, except for marine aerosols. During boreal winter, CCN concentrations are predominantly limited to altitudes below 2-3 km (84-94 %), with the highest near-surface concentrations compared to other seasons. The vertical distribution of CCN for all the aerosol types gradually expands to higher altitudes with the transition to warmer spring and summer seasons. Although near-surface n_{CCN} are at their lowest during summer, they contribute the most to the free-tropospheric CCN, accounting for 35 % of CCN at altitudes higher than 2 km. This is followed by spring (29 %), autumn (24 %), and winter (16 %), highlighting the substantial impact of boundary layer depth in modulating the vertical extent of CCN throughout all seasons."

Other modifications:

As mentioned in the response to comment 3, we have now added Figure R1 to the supplementary (as Fig. S1). We have further updated the MATLAB scripts in the supplementary.

References:

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