Response to Referee #3

This study investigates the aerosol and meteorological parameters on warm clouds using satellite measurements. The authors focus on the period of 2008-2022 over the two contrasting regions over eastern China, i.e. Yangtze River Delta, a heavily polluted region in eastern China, and the East China Sea with a relatively clean atmosphere. The interaction between AOD and CER has been investigated by considering different AOD and LWP regimes in the both two different aerosol regimes. A new method (geographical detector method) was applied to explore the relative importance of AOD and meteorological parameters on cloud properties. The content of this manuscript is highly relevant to ACP readers. In general, the manuscript is well organized, and the analysis conducted is quite comprehensive. Based on the overall quality, it is recommended that the manuscript be considered for publication if the specific comments provided are addressed.

The authors thank Referee #3 for the valuable time spent on thorough reading our manuscript and providing expert views to guide us for improving the manuscript with the specific comments and a reference. We have taken notice of all comments, listed below in black, and made many changes to the manuscript to address these, together with the comments from the other referees. We address each of your comments below and refer to our responses in the revised manuscript and provide line numbers and copy text in "quotes".

To ensure that the data used only included single layer liquid clouds and nonprecipitating cases, the filtering criteria described by Saponaro et al. (2017) were applied. It is noted that all the figures have been updated throughout the revised manuscript.

Specific comments

1. Abstract: it would be beneficial if the authors emphasized the overall significance or implications of their study at the end of the abstract.

Answer: We have substantially revised the abstract and added to following sentence upfront, to provide the overall picture "The sensitivity (S) of cloud parameters to the influence of different aerosol and meteorological parameters has in most previous aerosol-cloud interaction (aci) studies been addressed using traditional statistical methods. In the current study, relationships between cloud droplet effective radius (CER) and aerosol optical depth (AOD, used as a proxy for cloud condensation nuclei, CCN), i.e. the sensitivity (S) of CER to AOD, is investigated with different constraints of AOD and cloud liquid water path (LWP). In addition to traditional statistical methods, the geographical detector method (GDM) has been applied to quantify the relative importance of the effects of aerosol and meteorological parameters, and their interaction, on S.". In addition, many other changes were made to the abstract in "track changes".

2. In order to provide a more comprehensive analysis, it would be beneficial for the authors to compare the results obtained in this study with findings from other regions around the world. By doing so, they can examine the unique aerosol effects on clouds in the specific target region.

Answer: In the revised text, the results are compared with many other findings. We have added the following text in the Sect 4.3 (lines 528 to 534): "The variation of S with changes in LWP indicates that the condition of constant LWP is not truly satisfied: if the data would be stratified according to smaller LWP intervals (quasi-constant LWP, Ma et al., 2018), S would likely vary more smoothly with LWP. As mentioned in the Introduction, LWP is not directly retrieved but calculated form CER and COT and thus also the calculation of S is to some extend affected by LWP. We further note the results by Ma et al. (2018), i.e. the slope of CER versus AI (comparable to S in this paper) varies little with LWP, with positive values over land and negative values over ocean and thus behaves similar to the data in Table 3 for YRD and ECS."

We have also added the following text in the Sect 4.3 (lines 647 to 666): "Tables 5 and 6 list q values for individual factors, together with p showing the absence of statistical significance in many cases, especially over the YRD, and often the explanatory power is not high when the significance is low. These data show that cloud parameters are dominated by aerosol effects over the ECS but meteorological influences on cloud parameters predominate over the YRD, as was also concluded from the analysis from "traditional" statistical methods presented in Section 4.5 and these conclusions are consistent with the results published by Andersen and Cermak (2015). Among the meteorological parameters, we also find that PVV (with highest q in the three meteorological parameters) predominantely influences cloud parameters over the ECS. Jones et al. (2009) and Jia et al. (2022) reported that stronger aerosol cloud interactions typically occur under higher updraft velocity conditions. In addition, we find that CTP is mainly affected by RH ($q = 0.74^{***}$) and PVV ($q = 0.56$) over the YRD, as suggested by Koren et al. (2010). Koren et al. reported that observed cloud top height correlates best with model pressure updraft velocity and relative humidity. To some extent, LTS influences CER ($q = 0.44^{***}$) and LWP ($q = 0.43^{***}$) over the ECS, while, in contrast, over the YRD LTS predominately influences CF ($q = 0.50^{***}$) and LWP ($q = 0.55^{***}$). Matsui et al. (2004) and Tan et al. (2017) reported that aerosol impact on CER is stronger in more dynamic environments that feature a lower LTS and argue that very high LTS environments dynamically suppress cloud droplet growth and reduce aci intensity. While strong correlations between AOD and cloud parameters have been previously observed, they are likely due to the swelling of aerosol particles in humid airmasses (Quaas et al, 2010), rather than an aerosol influence, which is in agreement with findings by, e.g., Myhre et al. (2007), Twohy et al. (2009) and Quaas et al. (2010)."

We have also added the following text in the Discussion (lines 747 to 756): "It is noticed that in recent papers (e.g., Gryspeerdt et al., 2023; Arola et al., 2022) the usefulness of correlating aerosol and cloud parameters has been seriously challenged because cloud variability and retrieval errors are such that correlations between AOD and cloud properties (N_d, CER, LWP) can be spurious. Gryspeerdt et al. (2023) discussed aci in terms of the susceptibility β of Nd to aerosol rather than the sensitivity S of CER to aerosol (see the discussion in the Introduction on the use of N_d vs CER), and the problem arises with low aerosol conditions due to larger aerosol retrieval uncertainty due to surface correction (larger surface effect on the radiance at the top of the atmosphere), which applies equally to β and S. In the current study we did not consider the lowest aerosol conditions by limiting the data to situations with AOD ≥ 0.1, as discussed in Section 4.2. Furthermore, we stratified the analysis for moderate ($0.1 \leq$ AOD < 0.3) and high ($0.3 \geq$ AOD) aerosol regimes, based on the data."

This text is followed by the discussion of the implications of the findings of Arola et al (2022) for our results (lines 757-777): "Arola et al. (2022) addressed the susceptibility of N_d to changes in aerosol and the adjustment of LWP (using satellite observations), and confounding factors, in particular co-variability of N_d and LWP induced by meteorological effects. They show how errors in the retrieved CER and COT or spatial heterogeneity in cloud fields influence the N_d -LWP relation. However, both N_d and LWP are not retrieved but derived from CER and COT. Using Eq. 1 and Eq. 2 in Arola et al. (2022), the N_d -LWP relationship can be shown to have a highly non-linear dependence on CER and thus it is no surprise that any error in CER strongly affects the relation between N_d and LWP. Their experiments, i.e. using smaller scales (5° x 5°) to reduce spatial meteorological variability, or using snapshots to remove meteorological variability in time, did not lead to a conclusion whether the N_d - LWP variability is due to spatial heterogeneity in the cloud fields or due to retrieval errors. The main message from this part of the study (using satellite data) by Arola et al. (2022) is "the spatial variability of CER introduces a bias which moreover becomes stronger in conditions where the CER values are lower on average". Experiments with simulated measurements show that "the main cause of the negative LWP vs N_d slopes is the error in CER". Arola et al. emphasize that the spatial cloud variability and retrieval errors in CER and COT are similar sources for negative bias in LWP adjustment and that these sources could not be separately assessed in their simulations. The implication of the findings of Arola et al. (2022) on the adjustment of LWP for the results of the current study on the sensitivity of CER to aerosol (or CCN, using AOD as proxy) is that the assumption of constant LWP may be violated. This would affect the results presented in Section 4.3 where LWP was stratified and S was found to vary with LWP. In view of the LWP adjustment to changes in aerosol, the variation of CER sensitivity with LWP may be somewhat different from that reported in section 4.3."

3. Page 5，line 146：add "." in the end.

Thank you: done

4. Page 6，line 150：change "Eastern China Sea (ECS) area (20°N-28°N, 126°E-134°E)" to "Eastern China Sea area (ECS, 20°N-28°N, 126°E-134°E)"

Thank you: done

5. Page 7，line 191：change "(cloud optical thickness, cloud droplet effective radius, etc.)" to "(COT, CER, etc.)".

Thank you: done

6. Page 8, line 202: change "Where re represents the cloud droplet effective radius (CER)" to "Where re represents the CER".

Thank you: done

7. Page 11, line 276: it suggests to define the acronyms about "NW" and "SW".

Thank you. We feel that the use of wind directions is common in geographical descriptions of spatial variation and since we refer here to the maps in Fig. 4, it is not necessary to define the abbreviations for the wind directions. However, after reading the relevant text again, we noticed that we have used the full names for other wind directions (like south) and therefore decided to write them in full throughout the manuscript, i.e. we replace NW with northwest etc.

8. Page 14, line 344: remove right parenthesis.

Thank you: done

9. Page 15, line 365: replace "for the YRD" with "over the YRD".

Thank you: done

10. Page 21, line 501: add right parenthesis after “by Liu et al., (2017”.

Thank you: done

11. Page 22, line 516: change “for three different LWP intervals” to “for five different LWP intervals”.

Thank you: done

12. Page 16, line 377-380: The statistically significance is used through the manuscript, so it suggests to describe at the first place in the manuscript.

Answer: We have added the following text in the Sect 3.1 (lines 307 to 310): “The significance of these relations is determined by using the student’s t test, i.e. the results are statistically significant when the p value is smaller than 0.01, where p is defined as the probability of obtaining a result equal to or “more extreme” than what was actually observed.”.

References

Ma, X., Jia, H., Yu, F., & Quaas, J. (2018). Opposite aerosol index-cloud droplet effective radius correlations over major industrial regions and their adjacent oceans. Geophysical Research Letters, 45, 5771–5778. https://doi.org/10.1029/2018GL077562