# Response to referee' comments on "Characterization of fog microphysics and their relationships with visibility at a mountain site in China"

**Reviewer 2**

**General comment:**

This manuscript presents an observational study of fog microphysics using measurements collected at a mountain site and tests several visibility estimation parameterizations based on in situ data. The results are clearly presented and could contribute meaningfully to short-term visibility forecasting during fog events. I believe the topic is appropriate for ACP. However, I have the following concerns that should be addressed before considering this work for publication.

[*Response*] We thank the reviewers for their thoughtful and constructive comments that help us improve the manuscript substantially. We have revised the manuscript accordingly. Listed below is our point-to-point response in blue to each comment that was offered by the reviewers. We hope that our revised manuscript will now be suitable for publication in ACP.

**Major**

1. Paper structure

By the end of the Introduction section, you should introduction the structure of the remaining of the manuscript.

Figures 4a-4c are methodology while the panel 4d is a result. You may consider to split this figure and move panels 4a-4c up to the method section.

Section 3.5.1: this section presents previous parameterizations of VIS. Part of the text should be moved to Introduction part and part of it should be moved to methodology. This part can also serve as your motivation of testing the parameterizations using measurements from the mountain site. The results and relevant discussion should remain in this section.

[*Response*] Thanks for pointing these out. We have added the relevant introduction of the structure for the remaining sections as followings:

"In this study, eight fog events are discussed in detail to illustrate the potential impacts of different aerosol concentration background on fog microphysical characteristics. Details on the observation site, instrumentation, sampling inlet system for fog interstitial particles and fog residual particles, and the SS estimation methods are described in the Measurement and methodology section. In the Results and discussions section, we first present general observations during this campaign in Section 3.1 and discuss the relationship between pre-fog aerosols and fog droplets in Section 3.2. Then, the variations of SS values derived by aerosol and fog measurements are presented in Section 3.3. The temporal evolution of fog DSD for two typical fog events is characterized and discussed in Section 3.4. Finally, the contributions of aerosols and droplets to visibility during different stages of fog evolution are presented in Section 3.5. The summaries are provided in the Conclusions and implications section."

For Fig. 4, we adopt your suggestions and move the Fig. 4a-4b to the Methods section (Section 2.2.5). Fig. 4c is the result of derived *SS* during E3 event. There are some introductions and discussions on it, therefore, we have retained the panel 4c in Fig. 4.

According to the suggestion of the referee, we move part of the content of Section 3.5.1 to the Introduction or Methods sections. Please see Lines 65-68 and Section 2.2.6-2.2.7.

2. Introduction:

This section needs more work. For example, there is no mentioning of aerosol extinction in the intro part until the very end. 'aerosol extinction' appears abruptly without any information on how it is related to VIS or microphysics. Second, the motivation of the study presented in this manuscript does not seem clear to me. You listed quite several past studies on fog microphysics and VIS, what are their disadvantages or limitations? What are the values of your work will add to the current understanding or parameterization in terms of VIS forecast? Why this work is necessary given the abundant of work have been done in the past?

[*Response*] Thanks for pointing these out. The calculations of aerosol extinction from particle number size distribution are similar with that of droplets. We added the relevant description in Section 2.2.6.

Regarding the motivation for this study, we acknowledge that numerous studies have explored the relationship between cloud microphysics and visibility. However, the parameterization schemes in those studies were derived from observations in relatively clean areas, where visibility degradation is predominantly caused by fog droplets. These schemes would induce in large uncertainties in visibility calculations in polluted areas, such as the North China Plain (Zhang et al., 2014), where aerosol concentration and extinction contribution can be much higher, especially in light fogs. Additionally, many previous studies have primarily focused either on the effects of haze particles on visibility under subsaturated conditions or on the effects of fog droplets on visibility under supersaturated conditions. However, studies on the contribution of hygroscopic growth of unactivated aerosol particles under supersaturated conditions to visibility are limited. This study conducted simultaneous measurements of aerosol particles and fog droplets to examine their contributions to visibility at different stages of fog evolution. These motivations for the study have been added to the Introduction. Please see Lines 68-74.

3. Incomplete descriptions of the presented figures and lack of discussions:

You seem to only described Figure 1a in Section 3.1, while there are ample information shown in Figures 1b-1e that should be described and discussed.

From my reading, only Figure 4, Figure 5 and Figure 6 are described in detail (while lacking specific reference to the panels in the main text). The rest of the figures deserve more detailed discussions.

[*Response*] Thanks for pointing these out. We add the descriptions and discussions for these figures. For example, the relevant information for Figure 1 has been added as follows:

Lines 201-205: “The visibility variations at this site exhibited distinct characteristics, with values predominantly concentrated in high and low ranges (Fig. 1b), without the gradual increase or decrease typically observed in urban areas (Qiang et al., 2015; Wang et al., 2015). Moreover, When RH < 75%, the visibility remained above 10 km, whereas it declined below 1 km when RH > 95%. This indicated that low-visibility events at the site were predominantly driven by fog processes during the observation period."

Lines 210-213: "The variations of $N_d$ and *LWC* showed a consistent trend during fog formation and dissipation stages. However, after fog formation, the trends of the two variables may diverge (Fig. 1c), which is closely related to the variations in $D_{eff}$ (Fig. 1d). The relationship between $N_d$ and *LWC* during the 8 available fog events is presented in Fig. S4 to further illustrate their correlation."

Lines 219-224: "Although there were few anthropogenic sources near the site, the observed aerosol concentrations varied dramatically. As shown in Fig. 1e, the $N_a$ ranged from 230 to 15620 $cm^{-3}$, with a median of 2750 $cm^{-3}$. Episodes with $N_a$ exceeding 8000 $cm^{-3}$ were typically associated with a pronounced increase in the concentration of small particles within a range of 10-100 nm (Fig. 1e), which were likely driven by new particle formation (Shen et al., 2022). In the subsequent discussion, the pre-fog aerosol concentration below and above this median were defined as low and high aerosol loading backgrounds, respectively."

4. Grammar errors

I found many grammar errors in the abstract. I tried to capture some of them in my minor comments, but they are by no means a complete list. I did not list any grammar errors in the main text. The authors should do a thorough proof reading before resubmitting.

[*Response*] Thanks for pointing these out. We have carefully checked the entire manuscript and corrected the grammar errors.

**Minor**

Line 17: Clarify whether the elevation of 1483 m is above ground level or mean sea level.

[*Response*] Above mean sea level

Line 18: Consider rephrasing to, "In this study, eight fog events were investigated during the campaign, ..."

[*Response*] Revised.

Line 23: Add "and collision-coalescence mechanisms."

[*Response*] Revised.

Line 24: Rephrase as, "Peaks were observed at around ..."

[*Response*] Suggestion adopted.

Citation Format: When citing a reference at the beginning of a sentence (e.g., "Song et al. (2019) found that ..."), you do not need to cite it again in parentheses at the end of the sentence.

[*Response*] Revised. We remove the repetitive citation at the end of the sentence.

Line 164-167, and Equation 1-3: The linear relationship between LWC and Nd within a specific Deff bin seems expected based on equations 1–3. Since D_eff is the ratio of the third to second moments, it can be treated as particle size, meaning that LWC should increase with higher Nd. Can you clarify or further discuss this?

[*Response*] As pointed out by the referee, these three parameters in Fig. 2 are derived from the observed droplets size distribution and Equations 1-3. Their relationship should be the outcome of Equations 1-3. The purpose of this figure is to highlight that $N_d$ generally decreases as $D_{eff}$ increases within a given range of $LWC$ values. This negative correlation between them is ubiquitous in fog, as the presence of more droplets competes for available water vapor, thereby inhibiting their growth (Li et al., 2017). This serves as a foundation to the subsequent discussion on the evolution of fog droplets size distribution. We have moved it to the supplementary material (Fig. S4).

Lines 183-184: Could the difference in findings between this study and the previous one be due to the different elevations of the measurement sites?

[*Response*] The slope of the linear relationship between peak $N_d$ and pre-fog $N_a$ can represent the bulk activation rate of aerosol particles, which is depended on aerosol physicochemical properties and ambient water vapor supersaturation (*SS*) conditions. As the discussion in Section 3.3, compared with previous studies, the estimated *SS* in various observation environments seems to be positively correlated with altitude. This can be partly attributed to the lower aerosol number concentration and temperature at high altitudes (Liu et al., 2020), which reduce excess water vapor consumption in clouds and fog, as well as the equilibrium vapor pressure (Baccarini et al., 2020; Shen et al., 2018), thereby promoting supersaturation. Therefore, the difference in the slope between this study and the previous one can be attributed to both different aerosol properties and *SS* conditions in the studies. We add the relevant discussion in the revised manuscript. Please see Lines 269-272.

Line 198: When you mention the second approach, do you mean $N_d$ is equivalent to $N_{CCN}$? Please clarify.

[*Response*] Thanks for pointing this out. In the second approach, the $N_d$ in the fog is considered to be consistent with the activated CCN number concentration ($N_{CCN}$). Therefore, the $SS_{CCN}$ was determined as the $N_d$ is equivalent to $N_{CCN}$ by using linear interpolation of the pre-fog *SS*-resolved $N_{CCN}$ measurements. We have clarified it in the revised manuscript, please see Lines 169-170.

Lines 213-215: Are the studies you compare your results to all focused on fog events, or do any deal with clouds, such as the Gong et al. paper?

[*Response*] We have confirmed it again. The studies we used to compare the *SS* in different environments all focused on fog events except Gong et al. (2023). The *SS* in Gong et al. (2023) was derived from aircraft measurements of clouds. We have rewritten the sentence to make it clear. Please see Lines 265-268.

Line 225: The VIS during the development stage of the 04/12 event does not appear to decrease at a slower rate compared to the formation stage. Did you apply specific thresholds for the rate of change of VIS to define these stages? If so, please justify how these thresholds were determined.

[*Response*] According to previous studies (Mazoyer et al., 2022; Niu et al., 2010; Pilie et al., 1975), the stages during fog event were mainly determined by the thresholds of *VIS* value. As it shown in Fig. R1, there are 12 data points with the *VIS* decreasing from 967 m to 100 m in the formation stage, but 20 data points with the *VIS* decreasing from 95 m to 23 m in the development stage. Although there is no specific threshold for the rate of change of *VIS*, the decrease rate of *VIS* in the development stage (~4 m $min^{-1}$) was much slower than that in the formation stage (~72 m $min^{-1}$) during the 04/12 event.

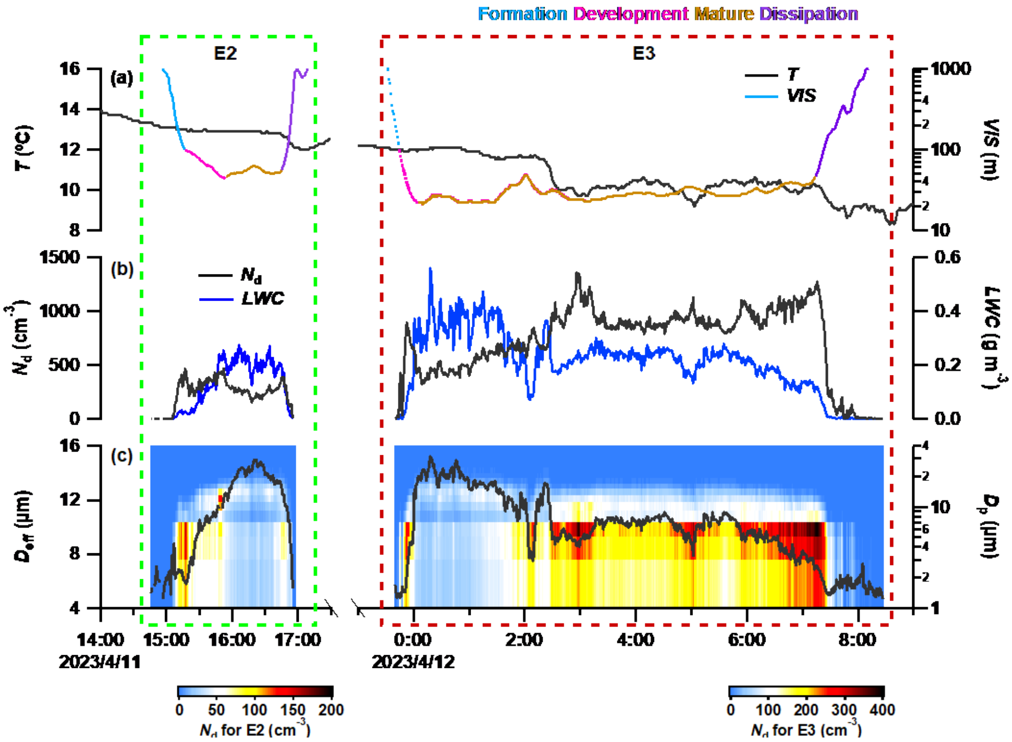


Fig. R1 Temporal evolution of meteorological parameters and fog microphysical characteristics for two typical fog events, including (a) temperature ($T$) and visibility ($VIS$), (b) fog droplet number concentration ($N_d$) and liquid water content ($LWC$), (c) fog droplets size distribution and effective diameter ($D_{eff}$). E2 represents fog occurring under low pre-fog Na background, while E3 represents fog occurring under high pre-fog $N_a$ background. The colored lines separate each fog event into four stages based on the evolution of visibility.

Lines 230-244: It would be helpful to include specific figure and panel numbers after each discussion sentence, particularly when referring to DSD descriptions, to make it easier for readers to follow along. This is especially important in the case of the E3 event.

[*Response*] Thanks for pointing this out. We have added the specific figure and panel numbers after the corresponding discussions in the revised manuscript.

## References

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