Response to Referee #1

Dear Referee,

We appreciate your positive and constructive comments. We have read these comments carefully and made revisions accordingly. The responses to the comments are listed below.

Sincerely,

Naifu Shao, Chunsong Lu*, and all co-authors.

Main comments:

This manuscript presents a modelling study of two successive fog events in the Yantze River Delta region of China. It aims to show how the fog properties in the second event are influenced by the first. I find this a truly interesting topic and exciting approach. However, I struggled with the manuscript for the following reasons:

Response: Thank you for your valuable comments.

1. The central message is that fog properties are influenced by aerosol as well as other boundary-layer conditions. The latter may be modified by a preceding fog event, resulting in fog property differences between both events. (a) This simple -- and very interesting – finding is hidden behind the phrase "self-enhanced AFIs", and thus took me more time to understand than would have been necessary. I would suggest to focus on the changes to the fog rather than "AFIs", and to speak about "aerosol loading" or "polluted conditions" to clarify the meteorological context. (b) Also, "AFIs", which is modelled on the common abbreviation "ACI" for aerosol-cloud interactions should probably lose the "s" to make it consistent with ACI. (c) A change of the title could also

be considered to more close reflect the paper's focus, e.g. "Radiation fog properties in two consecutive events under clean and polluted conditions..." or similar.

Response: Thank you for your suggestion.

(a) We agree with the referee and have deleted the phrase "Self-enhanced AFI" in many places of the abstract and main text (e.g., Page 1 Line 25; Page 5 Lines 114-116). Instead, we focus more on the changes to the fog, as suggested by the referee. We also speak about "aerosol loading" or "polluted conditions" to clarify the meteorological context. For example:

- "Our simulations indicate that the PBL conditions conducive to Fog2 formation are affected by ACI with high aerosol loading in Fog1; subsequently, PBL promotes ACI in Fog2, resulting in a higher liquid water content, higher droplet number concentration, smaller droplet size, larger fog optical depth, wider fog distribution, and longer fog lifetime in Fog2 than in Fog1." (Page 1, Lines 21-25).

- "The two fog events provide an excellent opportunity to investigate ACI under polluted conditions as a chain. This involves analysing how high aerosol loading affects properties in the first fog event, how the properties in the first polluted fog event affect radiation and PBL structure, and finally, how radiation and PBL affect properties and ACI in the second fog event under polluted conditions" (Page 5, Lines 104-108).

- "Here, we study how radiation fog properties are affected by high aerosol loading and PBL meteorological conditions in two successive events in the YRD region" (Page 5, Lines 118-119).

- "Furthermore, compared with the difference in aerosol-induced changes in RH_{2m} and PBLH before fog formation, RH_{2m} increases by 6% and PBLH decreases by 92 m under polluted conditions, which is larger than those (RH_{2m}: 4% and PBLH: −59 m) under clean conditions" (Page 12, Lines 271-274).

(b) All the "AFIs" in this manuscript are revised to "ACI".

(c) According to your suggestion, we have revised the title to be "Radiation fog properties in two consecutive events under polluted and clean conditions in the Yangtze River Delta, China: A simulation study".

2. (a)The state of the art chapter does not seem complete. The central motivation, i.e. limited knowledge about AFI, is only briefly stated, and not explained (line 81). (b) The fundamental premise that an event may be influenced by a previous event does not follow from the literature review presented at all. (c) The focus, concepts and terminology of the first research question are neither derived from the literature, nor are they explained. (1) What is a "stronger" fog scenario? (2) What does "stronger AFIs" mean? (3) What would you expect? Why? And why does it matter?

Response: Thank you for your suggestion.

(a) Regarding limited knowledge about aerosol–cloud interaction (ACI) in fog, we meant that it is not clear how ACI and planetary boundary layer (PBL) interacts with each other and the evolution of ACI in successive fog scenarios remains unknown. To make the description clearer, we pointed out the questions directly (Page 4, Lines 98-101): "What are the physical mechanisms behind the property changes during two successive fog events? Furthermore, which fog event has macro- and microphysical properties that are more sensitive to aerosol loading, i.e., experiencing a stronger ACI? What are the mechanisms underlying the interactions between ACI and PBL?"

(b) We have added the sentences to show that an event may be influenced by a previous event (Page 4, Lines 95-98): "Previous studies typically focused on either a single fog event or analysed multiple fog events statistically; however, several studies noted that LWC, N_d, and liquid water path (LWP) in a latter fog event exhibited larger values compared to those for the preceding fog event (Quan et al., 2011; Wærsted et al., 2017)."

(c) The focus, concepts and terminology are explained as follows.

(1) "Stronger fog scenario" means a fog event has larger macro- and microphysical

properties, such as fog droplet number concentration and liquid water content. To be more specific, we have improved the description (Page 4, Lines 96-97): "liquid water content, droplet number concentration and liquid water path in a latter fog event exhibited larger values compared to those for the preceding fog event."

(2) AFI is replaced by ACI. "Stronger ACI" means the more remarkable fog property response to changes in aerosol loading. For example, if aerosol-induced changes in fog optical depth is larger, ACI in fog is stronger. We have added the above explanation (Page 4, Lines 96-98): "which fog event has fog macro- and microphysical properties that are more sensitive to aerosol loading, i.e., experiencing stronger ACI?"

(3) The reason to analyze the evolution of ACI in two fog scenarios is that stronger ACI can affect fog development, for example, increasing droplet number concentration more significantly. Furthermore, we would like to examine the mechanisms responsible for the evolution of ACI and study how the interaction between ACI and PBL make fog properties change in the two successive fog events. We have revised the manuscript accordingly:

- "However, it is not clear how ACI in the first fog (Fog1) affects PBL, and subsequently affects ACI in the second fog (Fog2), which is important to understand the interaction between ACI and PBL as well as their effects on fog properties" (Page 1, Lines 16-19).
- "Our simulations indicate that the PBL conditions conducive to Fog2 formation are affected by ACI with high aerosol loading in Fog1; subsequently, PBL promotes ACI in Fog2, resulting in a higher liquid water content, higher droplet number concentration, smaller droplet size, larger fog optical depth, wider fog distribution, and longer fog lifetime in Fog2 than in Fog1" (Page 1, Lines 21-25).

3. In some places, aspects concerning methodology and interpretation remain unclear. (a)How precisely is the validation performed? (b)To what extent and under what

conditions can the findings of this study be generalized? (c)Instead of using "AFIs", in many places it would be more helpful to explicitly address the parameter of relevance, e.g. LWP, aerosol loading, droplet radius...

Response: Thank you for your suggestion.

(a) We add Table 3 to explain the elements a–d in the Heidke skill score (HSS). In our study, the HSS score are 0.34 and 0.36 in Fog1 and Fog2, respectively, which are close to previous reports (Mecikalski et al., 2008; Xu et al., 2020; Yamane et al., 2010). We have added the above description (Page 9, Lines 203-205).

Table 3. Elements a–d in the Heidke skill score calculation

	Fog observed	No fog observed
Fog simulated	a	b
No fog simulated	c	d

(b) “Our findings are generalised for the following reasons: First, the simulation design is reasonable. According to previous simulation studies, polluted and clean conditions are simulated by varying emission intensity. Second, the conclusions are robust, because they are derived from physical analyses. The interactions between aerosol loading, fog macro- and microphysical properties, and boundary layer meteorological conditions are understood physically. Third, fog events are typical and have large coverage. Therefore, the findings of this study are generalisable, at least for polluted fog events during winter.” The above discussions are added (Page 20, Lines 457-463).

(c) Thank you for your suggestion. AFI is replaced by parameters of relevance.

- “During the daytime before Fog2 formation, meteorological conditions in the PBL are affected by τ_c at the Fog1 dissipation stage. Compared with clean conditions, the larger τ_t (mainly due to larger τ_c) and delayed fog dissipation in polluted conditions reduce short-wave radiation reaching the ground (from −46 W m^{-2} to −121 W m^{-2}) during the Fog1 dissipation time, leading to a decrease in T_{2m} (from −0.2 °C to −1 °C) and PBLH (from −42 m to −118 m) (Fig. 7)” (Page 12, Lines 280-285).

- “Larger τ_c and delayed dissipation result in lower temperature, higher relative humidity, and higher stability by affecting solar radiation during the daytime” (Page 13, Lines 301-302).

- “The cold centre is related to lower temperature under polluted conditions due to larger τ_c and longer duration in Fog1” (Page 13, Lines 306-307).

4. While the paper is both legible and intelligible, it would profit from a linguistic revision.

Response: Thank you for your comment. We have revised the sentences according to Editor’s suggestion. We also hope this manuscript has been improved after a linguistic revision supported by Wiley Editing Services (https://editingservices.wiley.cn/).

DETAILS

(1) 15 - "pivotal" is unclear here

Reply: The word "pivotal" is replaced by "critical" (Page 1, Line 16).

(2) 15 - what is "the fog cycle"?

Reply: We mean the fog life cycle. We have revised the sentence: “Aerosol–cloud interaction (ACI) in fog and planetary boundary layer (PBL) conditions play critical roles in the fog life cycle” (Page 1, Lines 15-16).

(3) 16: Why should they focus on these differences? What is special about successive events?

(4) 17: What knowledge gap exactly?

Reply: We would like to reply to the two comments together, because they are closely related to each other. The difference between two successive events is important to understand the interaction between Aerosol–cloud interaction (ACI) and planetary boundary layer (PBL) as well as their effects on fog properties. That is why we are interested in the difference between two fog events. However, it is not clear how ACI in the first fog affects PBL and then ACI in the second fog. This is the knowledge gap. We have revised the abstract accordingly (Page 1, Lines 16-19).

(5) 19: "AFIs ... promote..." -- Do you mean high/low aerosol loadings? Or the interaction (mechanisms) specifically?

Reply: We mean the interaction (mechanisms) specifically. We have revised the sentence (Page 1, Lines 21-25): "Our simulations indicate that the PBL conditions conducive to Fog2 formation are affected by ACI with high aerosol loading in Fog1; subsequently, PBL promotes ACI in Fog2, resulting in a higher liquid water content, higher droplet number concentration, smaller droplet size, larger fog optical depth, wider fog distribution, and longer fog lifetime in Fog2 than in Fog1."

(6) 22: "is defined as" -- you mean that you define it as, or is this taken from elsewhere?

Reply: We mean that we define it as. This phrase is deleted because self-enhanced AFI is deleted, according to the referee's other comments.

(7) 38: fog does not lead "to environmental pollution" - please clarify this statement

Reply: We agree with the referee and have deleted this phrase (Page 2, Lines 41-43): "This results in low visibility, affecting human health, transportation, and power system (Niu et al., 2010)."

(8) 40: You state that the "physical processes of fog remain unclear". What exactly do you refer to? Can you provide a reference, please? I would think that the processes are pretty well understood.

Reply: We have reorganized the sentences to describe the unclear physical processes of fog and have added references (Page 2, Lines 43-47): “An important reason is that the physical processes of fog remain unclear because many processes (aerosol activation, condensation, radiation, and turbulence) occur simultaneously and interact with each other nonlinearly (Haeffelin et al., 2010), which affects fog properties (Mazoyer et al., 2022) and impedes related parameterisation (Poku et al., 2021).”

(9) 47: First sentence is a repetition of statement in line 36.

Reply: We have revised the sentence (Page 3, Lines 54-56): “Since fog is a special type of cloud (Guo et al., 2021; Kim and Yum, 2010, 2013; Wang et al., 2023), aerosol–fog interaction is expected to share similarities with aerosol–cloud interaction (ACI).”

(10) 52: What do you mean by "fog number concentration"? droplet number concentration in fog?

Reply: Yes, we mean fog droplet number concentration. The phrase is revised accordingly (Page 3, Line 63).

(11) 53: Can these numbers be generalized? How would they be expected to change given different environmental conditions? Is this continental radiation fog, sea fog, advection fog over land, ...?

Reply: The referee’s concern is reasonable. Here we take the two fog field campaigns as examples representing polluted and clean conditions, respectively. Although the field campaign in the North China Plain cannot fully stand for all polluted conditions and the field campaign in Xishuangbanna, China, cannot fully stand for all clean conditions, the comparison between the two examples does show the difference of fog properties between polluted and clean conditions, i.e., fog droplet number concentration is higher and effective radius is smaller in polluted conditions than in the clean one. Examples above are both continental radiation fog.

We have revised the sentences as follow (Page 3, Lines 60-66): "Various continental fog observation projects showed that fog microphysical properties were significantly affected by aerosol loading (Mazoyer et al., 2019; Niu et al., 2011; Quan et al., 2011; Wang et al., 2021). For instance, in polluted fog observations, Quan et al. (2011) found that the fog droplet number concentration (N_d) was higher than 1,000 cm^{-3} and effective radius (R_e) was approximately 7 μm in the North China Plain. In clean fog observations, Wang et al. (2021) showed that N_d was smaller than 100 cm^{-3} and R_e was approximately 9 μm in the tropical rainforest in Xishuangbanna, China."

(12) 70: That radiative cooling "is an important factor for temperature inversion, providing stable conditions for fog formation" is not a finding of the cited studies in the 2010s, but can be derived from very basic textbook knowledge.

Reply: We agree with the referee and have revised the sentence (Page 4, Lines 79-81): "Previous studies showed that radiative cooling was an important factor in temperature inversion that provided stable conditions for fog formation (Fitzjarrald and Lala, 1989; Holets and Swanson, 1981; Roach et al., 1976)."

(13) 81: In what respect is this knowledge limited? What is lacking?

(14) 83: Why do you think successive fog events are worth considering?

Reply: The two comments are replied together. The understanding of ACI in fog remains limited because the mechanism behind the interaction between aerosol, fog and PBL is not fully studied, especially in two successive fog events. We have reorganized the sentences to make a clearer description (Page 4, Lines 95-101): "Previous studies typically focused on either a single fog event or analysed multiple fog events statistically; however, several studies noted that LWC, N_d, and liquid water path (LWP) in a latter fog event exhibited larger values compared to those for the preceding fog event (Quan et al., 2011; Wærsted et al., 2017). What are the physical mechanisms behind the property changes during two successive fog events? Furthermore, which fog event has macro- and microphysical properties that are more sensitive to aerosol loading, i.e., experiencing a stronger ACI? What are the mechanisms underlying the interactions between ACI and PBL?"

(15) 84/5: Why?

Reply: The reason is that fog is a special cloud near ground. We have revised the sentence (Page 5, Lines 108-111): "Additionally, since fog is a special type of cloud near the ground, studying the evolution of ACI in fog aids in examining the progression of ACI in cloud, which is critical for climate prediction (Boutle et al., 2018; Vautard et al., 2009)."

(16) 89: How do you define "stronger AFIs", what do you mean by this and why does it matter?

Reply: According to editor's comments, AFI is revised to ACI. "Stronger ACI" in fog is defined as the more remarkable fog property response to changes in aerosol concentration. For example, if aerosol-induced change in fog optical depth is larger, ACI in fog is stronger. The reason for comparing ACI strength in two fog scenarios is that stronger ACI promotes fog development, for example, increasing droplet number concentration more significantly. Furthermore, we would like to examine the mechanisms responsible for the evolution of ACI and study how the interaction between ACI and PBL make fog properties change in the two successive fog events. We have revised the manuscript accordingly (Page 4, Lines 99-101, Page 5, Lines 104-108).

(17) 101: What aerosol species?

(18) 101: What is "massive"? Please be more specific.

Reply: We would like to reply two comments together. It is $PM_{2.5}$ and the $PM_{2.5}$ mass concentration is over 100 μg m^{-3}.

We have revised the sentence (Page 5, Lines 119-121): "Before fog events in the YRD, the $PM_{2.5}$ mass concentration was over 100 μg m^{-3} due to anthropogenic emissions (Zhu et al., 2019)."

(19) 140: What does this experiment consist of, and what sensitivities are tested for?

Reply: The control run is tested for polluted conditions with emission intensity directly from the MEIC database. The sensitive experiment is tested for clean conditions with the emission intensity multiplied by 0.05. The design of the control run and sensitivity test is the same as those in Jia et al. (2019) and Yan et al. (2020). We have revised the sentences (Page 7, Lines 159-164).

(20) 160: How do you compare observations and model? How do you define "consistent" in this regard?

Reply: We use ground-based fog observations and cloud optical depth from Himawari-8 to evaluate simulations (Fig. 4). "consistent" is defined as similarity of the simulated fog spatial distributions and magnitude of optical depth between simulations and observations. We add "generally" before "consistent" and revised the sentences to be more objective (Page 8, Lines 188-192): "Qualitatively, the spatial distribution and magnitude of the simulated fog are generally consistent with satellite and ground-based observations. Similarly, Lee et al. (2016) evaluated fog distribution simulations against satellite-derived cloud optical depth from satellite and concluded that the distributions of simulations and observations were generally comparable to each other.”

Besides the qualitative evaluation, we also use Heidke skill score (HSS) to quantitatively evaluate the simulations. Please see the response to the next comment.

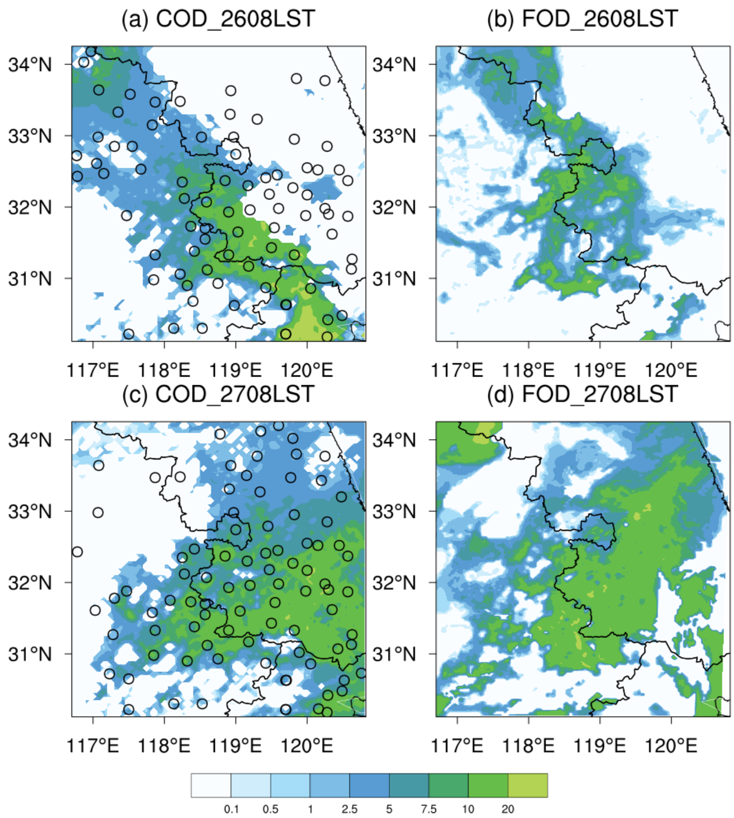

Figure 4. (a, c) Distributions of ground-based fog observations (the circular points) and cloud optical depth from Himawari-8 products at 08:00 LST on 26 and 27 November 2018. (b, d) Simulated fog optical depth distributions in domain 03 at the corresponding time of observations. Time ‘2608LST’ indicates 08:00 local standard time (LST) (LST = Universal Time Coordinated + 8 h) on 26 November 2018. The other time expressions follow the same logic.

(21) 161: Based on which parameters is HSS calculated?

Reply: Table 3 is added to more clearly show how HSS is calculated. The description of HSS score is also revised (Page 9, Lines 196-202): “Elements *a*–*d* are the numbers of “hits”, “false alarms”, “misses”, and “correct negatives”, respectively, which are determined by observations and simulations as shown in Table 3. To identify observed fog at a station, two criteria are used: visibility less than 1 km and relative humidity larger than 90% (Yan et al., 2020). Simulated foggy grids are classified based on three criteria (Jia et al., 2019; Zhao et al., 2013): fog water mixing ratio over 0.01 g kg^{-1}, N_d greater than 1 cm^{-3}, and fog base touching the ground. Elements *a–d* are calculated based on the fog occurrence at the observation stations and the closest model grids."

Table 3. Elements a–d in the Heidke skill score calculation

	Fog observed	No fog observed
Fog simulated	a	b
No fog simulated	c	d

(22) 172: Why this threshold?

Reply: "We also test other thresholds, 1%, 2.5%, 7.5%, and 10% (Fig. S3). The results are similar to those based on the threshold of 5%." We have added the above description (Page 9, Lines 211-213). Figure 3 is added in the supplement.

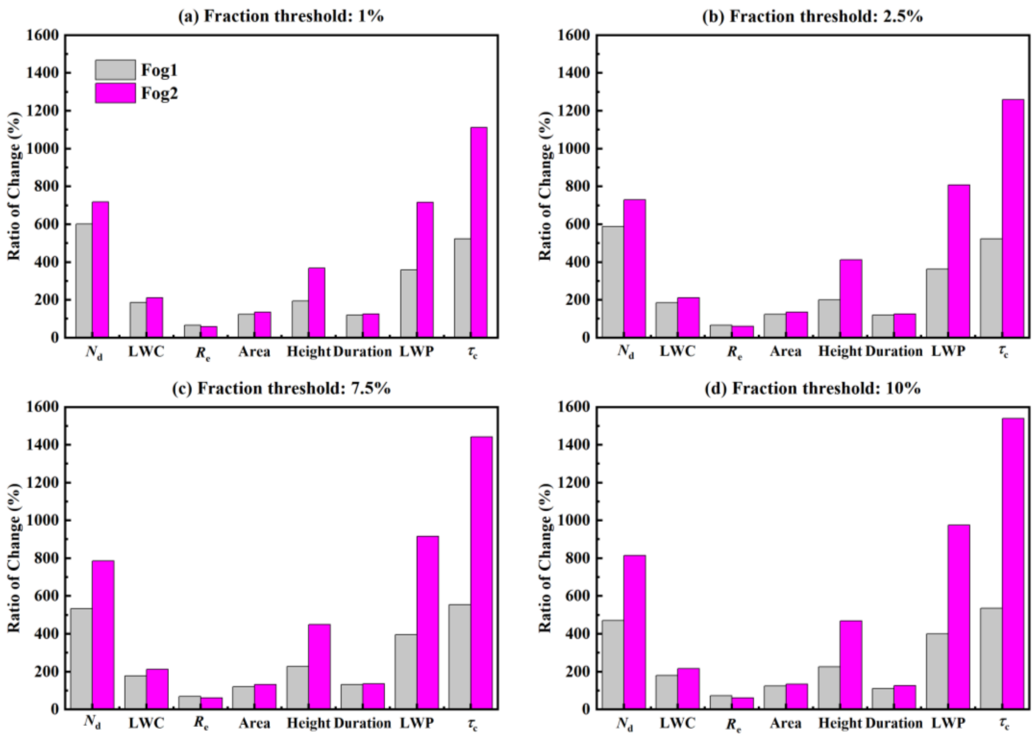

Figure S3. Aerosol effect on relative changes in macro- and microphysical properties during the first fog (Fog1) and the second fog (Fog2). Figure S3 a–d are the results with fog fraction area thresholds 1%, 2.5%, 7.5%, and 10% respectively. N_d, LWC, R_e, Area, Height, Duration, LWP, and τ_c indicate fog number droplet concentration, liquid water content, effective radius, fog area fraction, fog-top height, liquid water path, and fog optical depth, respectively. The ratio of changes is calculated as Polluted/Clean.

(23) Figure 5: I find it slightly confusing that the reference case is shown with 100% bars in all cases. I suggest leaving this out and only showing the polluted (a,b) or fog2 (c) situations.

Reply: We agree with the referee and have deleted the 100% bars. As suggested, we only show figure (a, b) and deleted figure c.

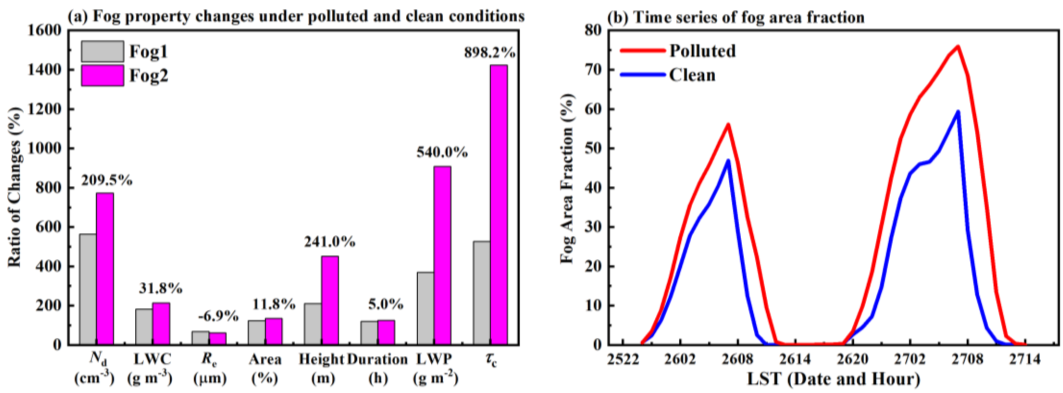

Figure 5. (a) Aerosol-induced changes in macro- and microphysical properties during the first fog (Fog1) and the second fog (Fog2) events under polluted and clean conditions. (b) Temporal evolution of fog area fraction under clean and polluted conditions. N_d, LWC, R_e, Area, Height, Duration, LWP, and τ_c indicate fog droplet number concentration, liquid water content, effective radius, fog area fraction, fog-top height, liquid water path, and fog optical depth, respectively. The ratios of changes are calculated by Polluted/Clean in Fig. 5a which reveal the aerosol-induced changes. The numbers above the bars in Fig. 5a represent the difference in those ratios of changes between Fog1 and Fog2 (calculated by Fog2–Fog1). Time '2522' in Fig. 5b indicates

22:00 local standard time (LST) (LST = Universal Time Coordinated + 8 h) on 25 November 2018. The other time expressions follow the same logic.

(24) 185ff: Here, and in several other places, you assume that AFI lead to changes in fog2. In section 5 you state that fog2 is different because boundary-layer conditions are different after a previous fog event, and not specifically because of the aerosol. Please make sure your reasoning is consistent.

Reply: Sorry for the confusion. Fog2 formation is related to the PBL conditions which are affected by ACI. The reasoning is that ACI under polluted conditions postpones the dissipation of Fog1 owing to these two feedbacks and generates PBL meteorological conditions that are more conducive to the formation of Fog2 than those prior to Fog1. These conditions promote the earlier formation of Fog2, further enhancing the two feedbacks and strengthening the ACI in Fog2. We have revised the whole manuscript (e.g., Page 11, Lines 252-253; Page 2, Lines 34-37).

(25) 241: higher stability

Reply: Stronger stability has been replaced by higher stability, according to your advice.

We have revised the sentence (Page 13, Line 299): "Therefore, lower temperature, higher relative humidity, and higher stability result from ACI in Fog1 under polluted conditions, contributing to the earlier formation of Fog2."

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