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 24; Page 5 Lines 111-113). 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 conducive PBL conditions are affected by AFI with high aerosol loading in Fog1, and then PBL promotes AFI in Fog2, resulting in 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 20-24).
- "The two fog scenarios provide an excellent opportunity to analyse AFI under polluted conditions as a chain, i.e., how high aerosol loading affects properties in the first fog scenario, how the properties in the first polluted fog scenario affect radiation and the PBL structure, and then how radiation and the PBL affect properties and AFI in the second fog scenario under polluted conditions" (Page 5, Lines 101-105).
- "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 115-116).
- "Furthermore, compared with the difference of 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" (Pages 11-12, Lines 266-269).

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

(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–fog interaction (AFI), we meant that it is not clear how AFI and planetary boundary layer (PBL) interacts with each other and the evolution of AFI in successive fog scenarios remains unknown. To make the description clearer, we pointed out the questions directly (Page 4, Lines 95-99): "What are the physical mechanisms behind the property changes during the two successive fog events? Furthermore, which fog scenario has fog macro- and microphysical properties more sensitive to aerosol, i.e., experiencing stronger AFIs? Are the mechanisms related to the interaction between AFI and PBL?"

(b) We have added the sentences to show that an event may be influenced by a previous event (Pages 4, Lines 92-95): "Previous studies typically focused on an individual fog event or analysed multiple fog events statistically, however, there were still several studies mentioning that LWC, N_f and liquid water path (LWP) in the latter fog scenario were larger than those in the preceding one (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 scenario 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 (Pages 4, Lines 93-94): “liquid water content, droplet number concentration and liquid water path in the latter fog scenario were larger than those in the preceding one”.

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

(3) The reason to analyze the evolution of AFI in two fog scenarios is that stronger AFI 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 AFI and study how the interaction between AFI and PBL make fog properties change in the two successive fog events. We have revised the manuscript accordingly:

- However, it is not clear how AFI in the first fog (Fog1) affects PBL and then AFI in the second fog (Fog2), which is important to understand the interaction between AFI and PBL as well as their effects on fog properties (Page 1, Lines 16-18).
- Our simulations indicate that conducive PBL conditions are affected by AFI with high aerosol loading in Fog1, and then PBL promotes AFI in Fog2, resulting in 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 20-24).

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 (HSS) score. 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 198-200).

Table 3. The 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 can be generalized due to the following reasons. First, the simulation design is reasonable. Similar to many previous studies, polluted and clean conditions are simulated through 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, the fog events are typical and have large coverage. Therefore, the findings in this study can be generalized, at least in polluted fog events during winter." The above discussions are added (Page 19, Lines 444-450).

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

- "Larger TOD, particularly larger FOD, leads to lower SW, T_{2m}, and PBLH" (Page 12, Lines 277-278).
- "Larger FOD and delaying dissipation result in lower temperature, higher relative humidity, and higher stability by affecting solar radiation during the daytime" (Page 13, Lines 293-294).
- "The cold centre is related to lower temperature under polluted conditions due to

larger FOD and longer duration in Fog1" (Page 13, Lines 298-300).

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

Response: Thank you for your comment. Hope this manuscript has been improved after a linguistic revision.

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–fog interaction (AFI) 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–fog interaction (AFI) 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 AFI in the first fog affects PBL and then AFI in the second fog. This is the knowledge gap.

We have revised the abstract accordingly (Page 1, Lines 16-18).

(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 20-24): “Our simulations indicate that conducive PBL conditions are affected by AFI with high aerosol loading in Fog1, and then PBL promotes AFI in Fog2, resulting in 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 40-41): “This leads to 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 41-46): “There exist uncertainties in fog forecasting (Zhou and Du, 2010; Zhou et al., 2011). An important reason is that the physical processes of fog remain unclear, because many processes (aerosol activation, condensation, radiation as well as turbulence) not only occur simultaneously but also interact with each other nonlinearly (Haeffelin et al., 2010), which affects fog properties (Mazoyer et al., 2022) and impedes the 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 52-53): "Since fog is a special type of cloud (Guo et al., 2021; Kim and Yum, 2010, 2013; Wang et al., 2023), AFI is expected to share similarities with aerosol–cloud interaction".

(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 60).

(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 the polluted conditions than in the clean one. Examples above are both continental radiation fog.

We have revised the sentences as follow (Page 3, Lines 57-63): “Different 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). In those polluted fog observations, for instance, Quan et al. (2011) found that the fog droplet number concentration (N_f) was higher than 1,000 cm^{-3} and effective radius (R_e) was approximately 7 μm in the North China Plain. In those clean fog observations, for example, Wang et al. (2021) showed that N_f 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 77-79): “Early studies showed that radiative cooling was an important factor for temperature inversion, providing 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 AFI 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 92-99): “Previous studies typically focused on an individual fog event or analysed multiple fog events statistically, however, there were still several studies mentioning that LWC, N_f, and liquid water path

(LWP) in the latter fog scenario were larger than those in the preceding one (Quan et al., 2011; Wærsted et al., 2017). What are the physical mechanisms behind the property changes during the two successive fog events? Furthermore, which fog scenario has fog macro- and microphysical properties more sensitive to aerosol, i.e., experiencing stronger AFI? Are the mechanisms related to the interaction between AFI 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 105-108): "Additionally, because fog is a special cloud near ground, the evolution of AFI is also helpful to study the evolution of aerosol–cloud interaction, which is critical to 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: "Stronger AFIs" are 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, AFI is stronger. The reason to compare AFI strength in two fog scenarios is that stronger AFI can promote fog development, for example, increasing droplet number concentration more significantly. Furthermore, we would like to examine the mechanisms responsible for the evolution of AFI and study how the interaction between AFI and PBL make fog properties change in the two successive fog events. We have revised the manuscript accordingly (Page 4, Lines 96-98, Page 5, Lines 101-105).

(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 (Pages 5, Lines 116-118): "The $PM_{2.5}$ mass concentration was over 100 μg m^{-3} before fog events in the YRD 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 the polluted conditions with emission intensity directly from the MEIC database. The sensitive experiment is tested for the 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 (Pages 7, Lines 156-160).

(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 (Figure 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 184-187): "Qualitatively, the simulated fog spatial distributions and magnitude are generally consistent with satellite and ground-based observations. Similarly, Lee et al. (2016) evaluated fog distribution simulation against cloud optical depth from satellite; they also concluded that the distributions of simulation and observation were generally comparable with each other".

Besides the qualitative evaluation, we also use HSS to quantitatively evaluate the simulations. Please see the response to the next comment.

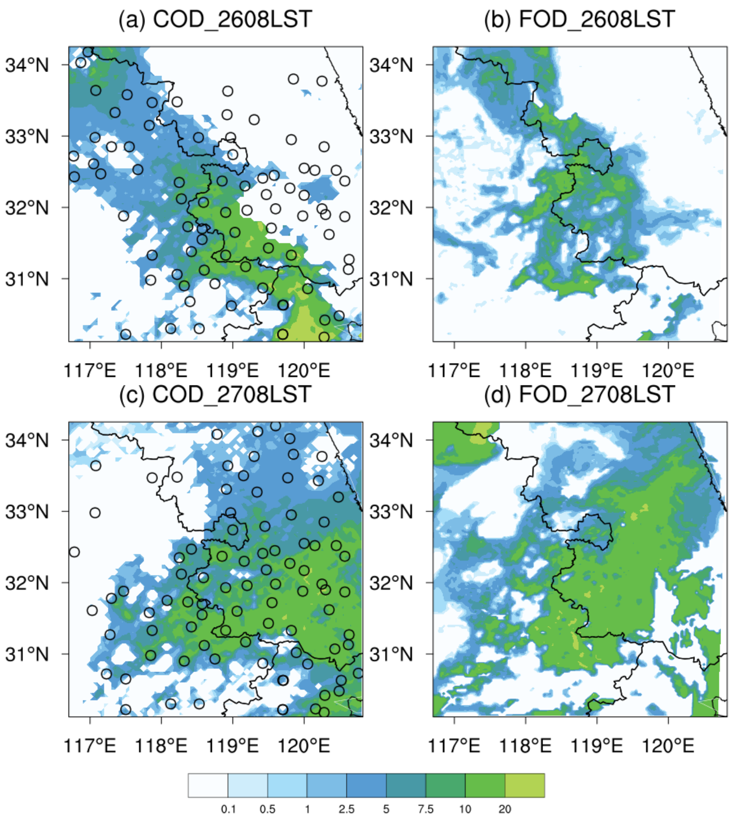

Figure 4. (a, c) Distributions of ground-based fog observations (the circular points) and cloud optical depth from Himawari-8 products at 08:00 LST on 26-27 November 2018. (b, d) Simulated fog optical depth (FOD) distributions in the domain 03 at the corresponding time of observations. Time '2608LST' 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 (Pages 8-9, Lines 191-197): "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 recognized based on three criteria (Jia et al., 2019; Zhao et al., 2013): fog water mixing ratio over 0.01 g kg^{-1}, N_f

greater than 1 cm^{-3}, and the fog base touching the ground. The elements *a*–*d* are calculated based on fog occurrence at the observation stations and the closest model grids".

Table 3. The 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 206-208). Figure 3 is added in the supplement.

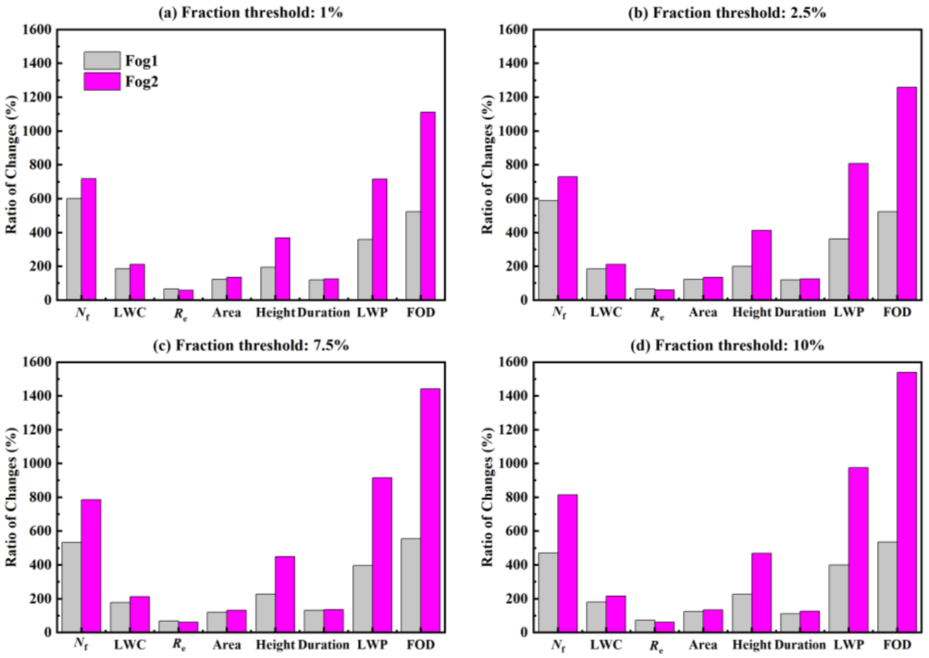

Figure S3. Aerosol effect on relative changes in macro- and microphysical properties during the first fog (Fog1) and the second fog (Fog2). Figure S3 a-d are the results with fog fraction area thresholds 1%, 2.5%, 7.5%, and 10% respectively. N_f, LWC, R_e, Area, Height, Duration, LWP, and FOD indicate 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.

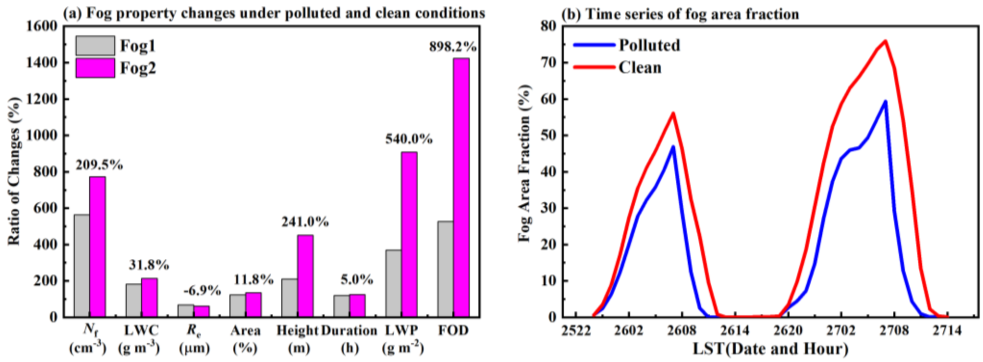

Figure 5. (a) Aerosol-induced changes in macro- and microphysical properties during the first fog (Fog1) and the second fog (Fog2) under polluted and clean conditions. (b) Temporal evolution of fog area fraction under clean and polluted conditions. N_f, LWC, R_e, Area, Height, Duration, LWP, and FOD 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 with PBL conditions which can be affected by AFI. The reasoning is that AFI postpones the dissipation of Fog1 due to feedbacks in fog and generates more conducive PBL meteorological conditions before Fog2 than before Fog1; these more conducive conditions promote the earlier formation of Fog2. We have revised the whole manuscript (e.g., Page 11, Lines 246-247; Page 2, Lines 33-36).

(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 302): "Therefore, lower temperature, higher relative humidity, and higher stability result from AFI in Fog1, contributing to the earlier formation of Fog2".

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