Responses to comments of "Interaction between aerosol and thermodynamic stability within the PBL during the wintertime over the North China Plain: Aircraft observation and WRF-Chem simulation [Preprint acp-2021-769]" to *Atmospheric Chemistry and Physics*.

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We would like to thank the editor Dr. Li, Z. and the reviewers for giving constructive criticisms and comments, which are very helpful in improving the quality of the manuscript. We have made the point-by-point response to the comments below and revised the manuscript accordingly. We hope that the revised version can meet the favorable approval and journal requirements. The referee's comments are reproduced (*black, italic*) along with our replies (blue) and changes made to the text (red) in the revised manuscript. All the authors have read the revised manuscript and agreed with the submission in its revised form. Please check them.

Responses to Reviewers

Anonymous Referee #1

The study tries to distinguish the aerosol-PBL interaction of absorbing and scattering aerosols under contrasting synoptic patterns and aerosol vertical distributions. They use aircraft measurements model simulations to estimate the aerosol radiative effects over the North China Plain. In general, this manuscript investigated an interesting topic with ample analyses. A concept scheme is further summarized to describe their findings. However, the significance and representative of this study should be carefully discussed. This manuscript must address several major issues, before the potential publication.

Response:

Dear Reviewer,

We would like to thank you for your time in reviewing this manuscript. Many thanks for your meticulous judgments and suggestions, which are very helpful in improving our manuscript. We have made the point-by-point response to the comments below and revised the manuscript according to your substantive comments, which helps improve the quality of this paper. The revision mainly includes long-term modeling for a more robust and representative conclusion.

Major Comments:

Comment NO.1&2:

1. Based on the model and aircraft data, this manuscript presents a case study for two days. It is questionable whether the conclusions from the case study are *representative. The authors even draw a concept scheme from the case analyses. I believe the robustness of the conclusions needs to be carefully discussed.*

2. Only two cases of aerosol vertical distribution are discussed. However, the aerosol vertical distribution varies greatly case by case. It may not be feasible to discuss the impacts of synoptic conditions on the aerosol vertical distribution. It may not be valid to draw a meaningful conclusion about aerosol stratifications and absorptions based on the two cases.

Response: Thank you for your critical comments and insightful suggestions. Your first two remarks are both on the robustness of the conclusions based on the two cases, so we here reply to them together. In the revision, we have added the statistical analysis of a long-term simulation in Baoding city for nearly one month from January 3 to 30, 2020. The long-term simulation results give a more robust and representative conclusion, which can compensate for the two-day case investigation. Please see the revision below for the details.

Changes in Manuscript:

[Pages 24-29 Lines 394-469 (in the "Track Changes" version)]

3.3.3 Statistical properties of the PBL and AREs under different synoptic conditions

It is noticeable that different aerosol vertical distributions between the two days contribute to distinct AREs due to the synoptic condition and PBL thermal stability differences from the measurements and simulations. In particular, the absorptive BC aerosols have both stove and dome effects, which affect the PBL thermal structure. Here, we further analyze the modeling results for nearly one month from January 3 to 30, 2020 in Baoding city to give a more significant and representative conclusion.

Fig. 11 shows the correlations between the daily average 10 m meridional wind speed, lapse rate within 1.5 km, and PBLH. The negative correlation between the 10 m meridional wind speed and the lapse rate within 1.5 km (Fig. 11a) suggests that the increased south wind stabilizes the PBL, whereas the strong north wind destabilizes the PBL. The variation in lapse rate has a direct impact on the development of the PBL, as evidenced by the PBLH modification shown in Fig. 11b. Fig. 12 compares the distinct vertical distributions of aerosols caused by north and south winds. Samples with a daily average wind speed within $\pm$ 0.05 m s^{-1} are discarded to avoid the north-south reverse of wind direction in a day. Eventually, 16 days with the prevailing north wind and 8 days with the prevailing south wind are used. The result indicates that the synoptic condition influences the PBL thermal structure, thereby affecting the vertical dispersion of aerosols. The warm and polluted air is carried to the NCP by the south winds, which stabilize the PBL, exacerbating the surface air pollution. The cold and clean air is carried to the NCP by the north winds, forming an unstable stratification and transporting pollutants to the upper layer.

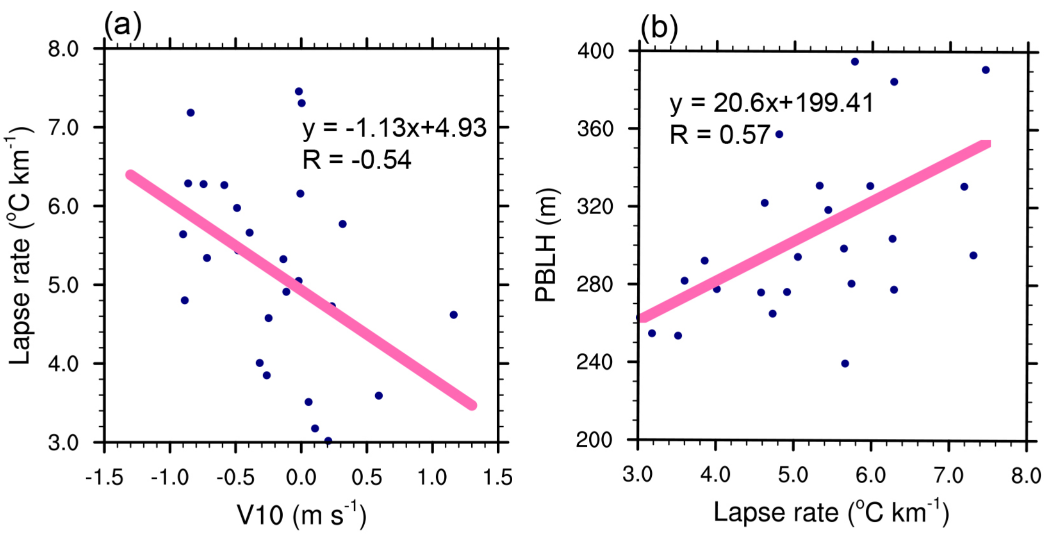

Figure 11: Scatter plots of the correlations between (a) 10 m meridional wind speed (positive: south wind; negative: north wind) and lapse rate within 1.5 km and (b) lapse rate within 1.5 km and PBLH. The data are daily averages from January 3 to 30, 2020.

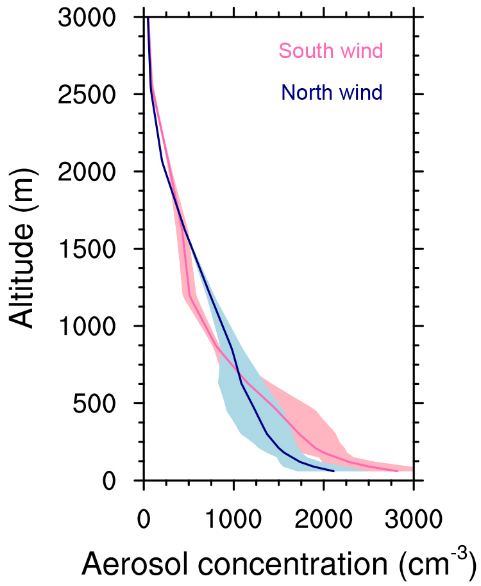

Figure 12: Vertical distributions of the aerosol number concentrations (particle diameter: 0.15-2.5 μm) under the prevailing south wind and north wind, respectively. The shaded areas indicate the error bars (standard deviation).

When evaluating the AREs of light-absorbing and light-scattering aerosols, the temperature profile variations show various patterns due to differences in aerosol concentration and vertical distribution caused by synoptic conditions, particularly the wind direction. Fig. 13 demonstrates that light-absorbing aerosols heat the atmosphere while light-scattering aerosols contribute to a cooling effect. Aerosols are constrained to the low layer under south wind conditions, and the BC aerosols result in a warming effect below 1 km (stove effect), while the scattering aerosols cool the layer below 0.6 km (umbrella effect). In contrast, the PBLs exhibit strong turbulence mixing when influenced by the north winds, and the aerosols are carried to the aloft layer. The aloft scattering particles prevent incident solar radiation from reaching the low layer, resulting in cooling effects below 1 km (umbrella effect), whereas the aloft absorbing aerosols heat the upper layer between 0.5 and 1.5 km (dome effect). The remarkable aerosol effects under south winds attribute to the accumulation of aerosols under adverse weather conditions. The contrasting aerosol vertical distributions caused by the varying synoptic conditions lead to different AREs, which is consistent with the results obtained on January 3 and 4, 2020.

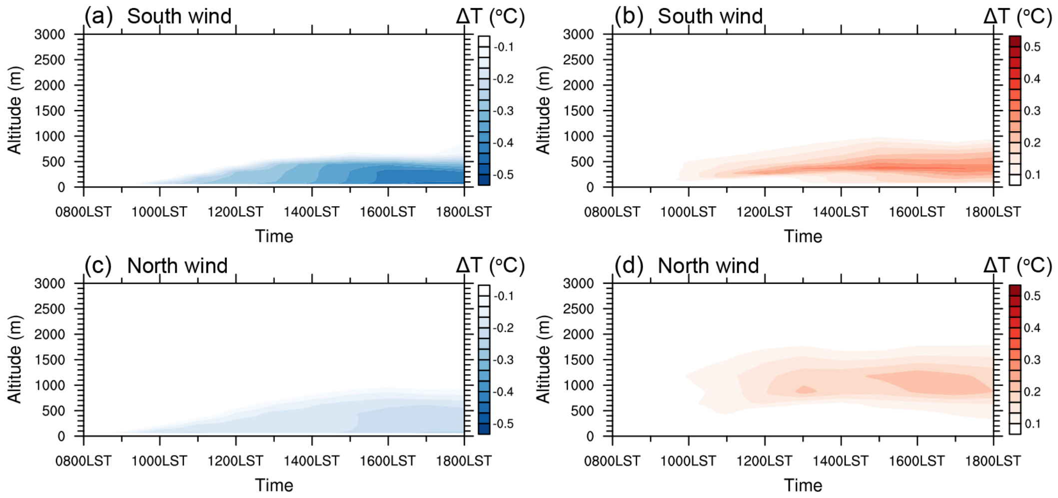

Figure 13: Temporal evolution of the temperature profile variation influenced by aerosol radiative effect (ARE). (a) ARE by other aerosols (EXP_WFexBC – EXP_WoF) and (b) ARE by BC (EXP_Ctrl – EXP_WFexBC) under the prevailing south wind; (c) ARE by other aerosols and (d) ARE by BC under the prevailing North wind.

Furthermore, based on the nearly one-month simulations, we quantify the variations in lapse rate within 1.5 km and PBLH under different synoptic conditions, respectively, caused by absorptive BC aerosols and other light-scattering aerosols. The results in Fig. 14 reveal that the BC stove effect induces a 0.04 ℃ km^{-1} increase in lapse rate within 1.5 km and a 3 m increase in PBLH under the stable stratifications with the prevailing south winds. However, the BC dome effect causes a 0.085 °C km^{-1} decrease in lapse rate within 1.5 km and a 3 m decrease in PBLH under the unstable stratifications with the prevailing north winds. The umbrella effect of scattering aerosols in both stable and unstable conditions reduces the lapse rate by about 0.15 °C km^{-1} and reduces the PBLH by about 3.5–4 m. The vertical distribution of absorbing aerosols has a significant impact on their aerosol-PBL feedback. The absorbing aerosols concentrated in the low layer have a strong radiative heating effect on the atmosphere develop the PBL in the case of stable weather patterns under the influence of the south wind. The absorbing aerosols in the upper layer heat the atmosphere and inhibit the development of the PBL in the case of unstable weather patterns under the influence of the north wind. The inhibition effect of scattering aerosols on the PBL, on the other hand, is independent of the aerosol height distributions and is solely dependent on the aerosol concentrations.

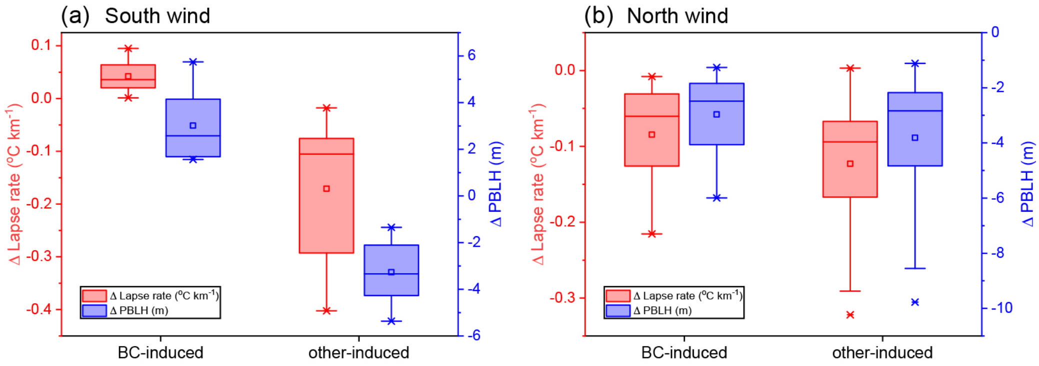

Figure 14: Box plots of the variations in lapse rate within 1.5 km and PBLH influenced by the BC and other aerosols under (a) the prevailing south wind and (b) the prevailing north wind, respectively. The squares represent the mean values, the horizontal lines inside the boxes are the medians, and the bottom and top sides of the boxes represent the first and third quartiles. The whiskers are the minimum (maximum) values within 1.5 interquartile ranges of the lower (upper) quartile. The asterisks indicate the minimum (maximum) values.

Comment NO.3:

3. There are large diurnal variations in PBL. However, figure 6 only mentions the date. How about the specific time? As aerosol vertical distribution in figure 6 may not represent the daily condition, the authors need to address the diurnal changes in PBL and aerosol vertical distribution.

Response: Thank you for your valuable comments. The specific time has been added in the revision, which is in the afternoon during the flight on 3 and 4 January. Table 1 also gives the specific take-off and landing time. Due to the aircraft measurement cannot characterize the diurnal variations in PBL and aerosol vertical distribution, we address the diurnal variations based on simulation results, which are shown in Fig. 7 and Fig. 10.

Changes in Manuscript:

[Page 15 Lines 283-284 (in the "Track Changes" version)]

"As demonstrated in Fig. 6, contrasting aerosol vertical distributions are observed with aircraft during the afternoon of January 3 and 4, 2020, and the specific times are shown in Table 1."

Comment NO.4:

4. After the case study, the manuscript presents the long-term variation in PBL thermodynamic stability. However, I feel this part is disconnected from the main analyses. The long-term changes in PBL are affected by numerous factors. I did not find any useful conclusion from the analyses. The analyses also cannot conclude that "the inter-annual variability of the EAWM and SH can influence aerosol vertical distribution and ARE", which is cited from Section 3.4.

Response: Thank you for your critical comments. We agree with you that the PBL is affected by numerous factors, but we mainly address the relation between PBL and meridional wind intensity in this study. Despite the two-day case study, substantial one-month simulation results in the revision indicate that the PBL stability is closely related to the synoptic pattern, especially the meridional wind direction. These results are attained from the synoptic-scale condition. Furthermore, section 3.4 aims to determine whether the same conclusion can be reached from a climatological standpoint. EAWM and SH are the two indicators of meridional wind intensity over the NCP, so it is valuable to analyze the relations between EAWM, SH and PBL stability from long-term datasets. In the revision, we have added the linkage between the discussions of long-term variations in PBL and the results of two-day measurements and one-month simulations, due to the contextual disconnects in the previous manuscript. In addition, the sentence “the inter-annual variability of the EAWM and SH can influence the aerosol vertical distribution and ARE” has been rewritten.

Changes in Manuscript:

[Page 29 Lines 471-474 (in the “Track Changes” version)]

“On a synoptic scale, the PBL stability is influenced by the meridional wind direction to a certain extent, which has been evidenced by the two-day detailed aircraft measurements and one-month model simulations. Furthermore, the linkage between synoptic pattern (meridional wind intensity) and PBL thermal structure is analyzed from a climatological view, which is critical for the examination of aerosol vertical distribution and ARE.”

[Pages 29-30 Lines 483-488 (in the “Track Changes” version)]

“The results indicate that the inter-annual variabilities of the EAWM and SH, which are indicators of the meridional wind intensity, are closely related to the PBL thermodynamic stability over the NCP region. According to the previous synoptic analysis, it is concluded that the changes in PBL properties will further affect the surface air quality, aerosol vertical distribution, and ARE.”

Comment NO.5:

5. Figure 14 seems to describe common sense. It is well-known that synoptic patterns, PBL thermodynamics, and aerosol vertical distribution can affect each other. What is the significance of Figure 14?

Response: Thank you for your constructive criticisms. As you suggested, Fig. 14 has been removed from the revised version since it cannot contribute any further information.

Comment NO.6:

6. Figure 15 tries to summarize the impacts of aerosol on PBL under different synoptic patterns. However, the "cold/warm advection" is only one factor and cannot fully represent the synoptic conditions. Four different scenarios are discussed but do not well support by their analyses.

Response: Thank you for your valuable comments. We agree with your concerns about the disconnection between the concept scheme and the analyses. In the revision, a long-term simulation result gives a robust conclusion shown in Fig. 13, which deepens the connection between the concept scheme and the analyses. Fig. 13 demonstrates that light-absorbing and light-scattering aerosols contribute to distinct AREs under different synoptic patterns, where the synoptic pattern is categorized by the cold/warm advection. Therefore, the "cold/warm advection" represents the synoptic condition in the concept scheme, and we agree with you that the advection is not the only factor. Four different scenarios summarized in Fig.16 (Fig. 15 in the original version) can well correspond to the four subgraphs in Fig. 13.

Changes in Manuscript:

[Page 32 Lines 528-530 (in the "Track Changes" version)]

"In summary, the umbrella, stove and dome effects of the scattering and absorbing aerosols under different synoptic patterns are illustrated with four scenarios in Fig. 16, which corresponds to the conclusion indicated in the four subgraphs of Fig. 13."

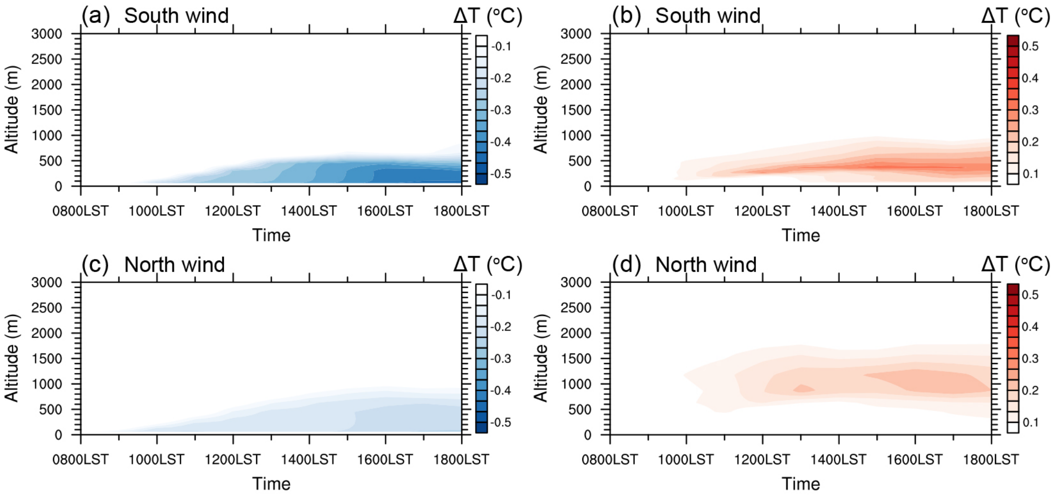

Figure 13: Temporal evolution of the temperature profile variation influenced by aerosol radiative effect (ARE). (a) ARE by other aerosols (EXP_WFexBC – EXP_WoF) and (b) ARE by BC (EXP_Ctrl – EXP_WFexBC) under the prevailing south wind; (c) ARE by other aerosols and (d) ARE by BC under the prevailing North wind.

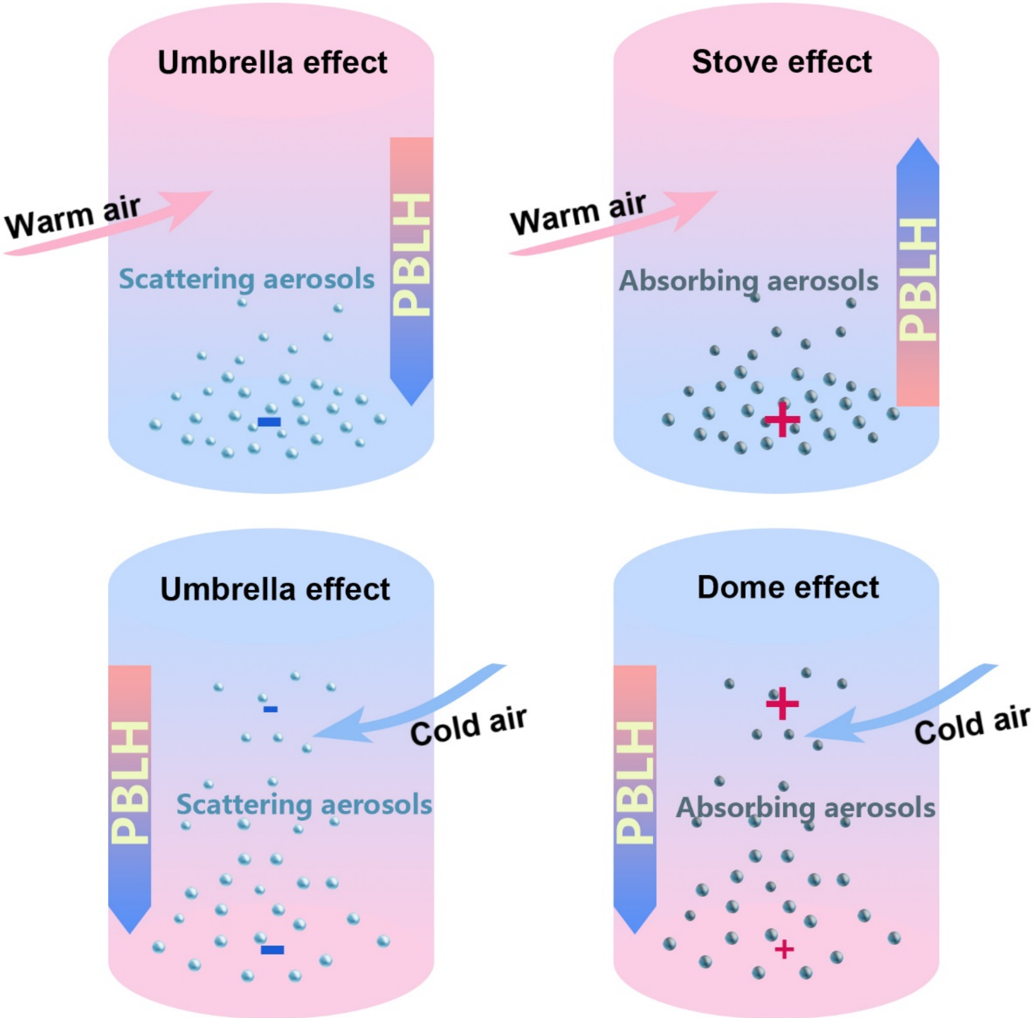

Figure 16: The illustration of the umbrella, stove, and dome effects of the scattering and absorbing aerosols under different synoptic patterns. The red plus and blue minus signs indicate the aerosol heating and dimming effect, respectively. The upward and downward arrows denote the increase and decrease in PBLH caused by ARE, respectively.

Again, we would like to thank you for taking your time to review this manuscript and providing insightful comments and advice. we believe that this work has been much improved with your constructive and informative remarks.

Dr. Yong Han

On behalf of all the authors