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 #3

General comments:

The manuscript presents the interaction of absorbing and scattering aerosol with PBL under different synoptic patterns based on the observation and WRF-Chem model simulations. It's an interesting study that help understand how such aerosol-PBL interactions affect the PBL thermodynamics and air quality (PM2.5). This paper also discussed potential impact of synoptic weather conditions on the PBL thermodynamics. Overall, the paper is written well. But, there are some confusions or missing parts that need be clarified.

Response:

Dear Reviewer,

Many thanks for your positive comments and valuable suggestions. 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.

Specific comments:

Comment NO.1:

1. The paper was lack of describing how aerosols optical parameters (absorption and scattering coefficient) are obtained and constrained in the WRF-Chem model in order to estimate aerosol-radiative-effect (ARE). For instance, how large are those aerosol absorption coefficients for black carbon (BC) and single scattering albedo (SSA) used?

Response: Thank you for your valuable comments and insightful suggestions. In the revision, we have added a detailed description of the approach for obtaining and constraining aerosol optical parameters.

Changes in Manuscript:

[Pages 6-7 Lines 168-173 (in the "Track Changes" version)]

"The extinction, single-scattering albedo, and asymmetry factor of aerosols were computed as a function of wavelength and three-dimensional positions. Each chemical constituent of the aerosol was linked to complex indices of refraction. The refractive indices of the aerosols were calculated using volume averaging for each size bin, and the Mie theory was used to derive the extinction efficiency, the scattering efficiency, and the intermediate asymmetry factor. Aerosol optical properties were then determined by summarizing all size bins (Fast et al. 2006). The refractive indices of various aerosol components were reported in Barnard et al. (2010)."

References

Barnard, J. C., Fast, J. D., Paredes-Miranda, G., Arnott, W. P., and Laskin, A.: Technical Note: Evaluation of the WRF-Chem "Aerosol Chemical to Aerosol Optical Properties" Module using data from the MILAGRO campaign, Atmos. Chem. Phys., 10, 7325-7340, 10.5194/acp-10-7325-2010, 2010.

Fast, J. D., Gustafson Jr., W. I., Easter, R. C., Zaveri, R. A., Barnard, J. C., Chapman, E. G., Grell, G. A., and Peckham, S. E.: Evolution of ozone, particulates, and aerosol direct radiative forcing in the vicinity of Houston using a fully coupled meteorology-chemistry-aerosol model, Journal of Geophysical Research: Atmospheres, 111, https://doi.org/10.1029/2005JD006721, 2006.

Comment NO.2:

2. The paper did not clearly show the PBL-height until they were given in Fig.10 in Page-19. Please describe how the PBL-height is calculated or obtained? Is it based on the Richardson number or potential temperature gradient method, or else? It might be better to display the PBLH in Fig.7 or earlier.

Response: Thank you for your constructive comments. PBLH in the YSU scheme is determined from the Richardson bulk number method, which has been described in the revision. As you suggested, the PBLH has been moved forward and displayed in Fig. 4.

Changes in Manuscript:

[Page 7 Lines 165-166 (in the "Track Changes" version)]

"PBLH in the YSU scheme is determined from the Richardson bulk number method."

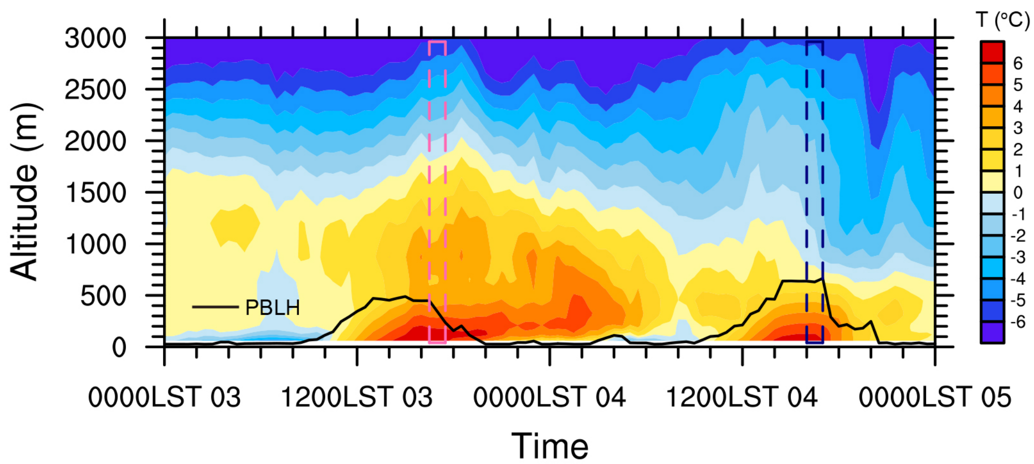

Figure 4: Temporal evolution of the EXP_Ctrl simulated temperature profile over the Baoding City. The pink and blue dashed boxes correspond to the aircraft observation periods on 3 and 4 January, respectively. The black line indicates the planetary boundary layer height (PBLH).

Comment NO.3:

3. The lapse rate is used for many times in the paper. What range of the altitude is it calculated or referred? In Line 376-377, it is referred the range between 1000 mbar and 850-mbar, but in Line 355it is referred below 1.5 km altitude.

Response: Thank you for your careful comments. Due to the difference in height coordinates of the measurement and reanalysis data, in this study, the lapse rate is calculated below 1.5 km altitude by the aircraft measurement, and the lapse rate is calculated between 1000 hPa and 850 hPa by the ERA5 reanalysis data when analyzing the long-term trend. The height between 1000 hPa and 850 hPa is approximately equivalent to the height below 1.5 km. We have illustrated it in the revision.

Changes in Manuscript:

[Page 6 Lines 138-139 (in the "Track Changes" version)]

"The height between 1000 hPa and 850 hPa is approximately equivalent to the height below 1.5 km."

Comment NO.4:

4. Fig. 2 (d)-(e), why are there no temperature and wind data below 750-m from the aircraft observation which are critical to assess the PBL height and thermal stability? Fig. 2 (e), why do the observed wind speeds show so large fluctuations and many stratified structures below 3 –km?

Response: Thank you for your careful comments. The aircraft observed data in Baoding city is from 650 m to 3000 m, which has been shown in Fig. 1(c)-(d). Therefore, the validations of temperature and wind are above 650 m. We regret that the aircraft observed data of temperature and wind speed were not accessible below 650 m, but the vertical profile of temperature and wind speed below 650 m can be judged through the validated simulation profile. The large fluctuations and stratified structures may be due to the influence of the aircraft itself on wind speed measurement during the circling flight. Nevertheless, the observed wind speed profile shows a consistent trend with the simulation.

Comment NO.5:

5. Fig.4, it might be better to give the horizontal wind speed, wind direction and vertical wind velocity on Jan.3 and 4 as shown for the temperature.

Response: Thank you for your comment. The detailed horizontal wind speed, wind direction and vertical wind velocity have already shown in Fig. 5.

Comment NO.6:

6. Fig.6 (a)-(c), what are those the horizontal dash lines? Fig.6, the observed aerosol number density profiles on Jan.3 and Jan.4 show very similar stratification structures below 1 km altitude except higher concentration on Jan.3. Was the aloft aerosol layer at 1.0-1.7 km altitude on Jan.4 related to the PBL vertical mixing transport?

Response: Thank you for your constructive comments. The horizontal dash lines are the reference altitude of 650 m, which have been illustrated in the revision. In addition, we agree with your comment that the aloft aerosol layer between 1.0 km and 1.7 km altitude on 4 January is related to the PBL vertical mixing transport, which has been incorporated into the revision.

Changes in Manuscript:

[Page 16 Lines 295-298 (in the "Track Changes" version)]

“Figure 6: Aircraft observations of aerosol vertical distributions in the afternoon during the flight. (a) the aerosol number concentrations on 3 and 4 January, the dashed and solid lines denote the observations over Beijing and Baoding, respectively; (b-c) the aerosol size distributions on 3 and 4 January, respectively. The shaded areas in (a) indicate the error bars (standard deviation). The horizontal black dashed lines are the reference altitude of 650 m.”

[Page 16 Lines 289-290 (in the “Track Changes” version)]

“The aloft aerosol layer between 1.0 km and 1.7 km altitude on 4 January is related to the PBL vertical mixing transport. The great difference in lapse rate shown in Fig. 4 leads to the disparity in atmospheric stability and aerosol dispersion ability.”

Comment NO.7:

7. Fig.8, How do the results show strong heating effects from BC and aerosol cooling effects in the night of Jan 3 and early morning of Jan 4 when there were lack of solar radiance?

Response: Thank you for your insightful comment. Figure 8 shows the temperature difference caused by the aerosol radiation effect. The heat absorbed by BC during the daytime is stored in the atmosphere, making the temperature higher at night than there is no BC radiation effect. The cooling effect of scattering aerosol during the daytime reduces the longwave radiation of the surface at night, resulting in the decrease of air temperature.

Comment NO.8:

8. Line 157, Which metric or parameter is used to quantify PBL thermodynamic stability?

Response: Thank you for your critical comment. The lapse rate below 1.5 km was used to quantify the PBL thermodynamic stability. We have revised it.

Changes in Manuscript:

[Page 7 Lines 175-176 (in the "Track Changes" version)]

"The lapse rate below 1.5 km was used to quantify the PBL thermodynamic stability."

Comment NO.9:

9. Line 265-275, authors pointed out that the PBL thermal stability potentially related to the simulated aerosol vertical distribution in Fig.7, but there are no potential temperature and winds displayed. Please give them for better understanding the discussions in Line 265-275 if possible.

Response: Thank you for your valuable comment. The temperature and wind profiles have already shown in Fig. 4 and Fig. 5, which are the important factors for the discussion of Fig. 7 as you mentioned. The detailed information is on Pages 14-15 Lines 257-281 in the "Track Changes" version.

Comment NO.10:

10. Fig.13, how to calculate the standardized anomaly of the wintertime boundary layer lapse rate?

Response: Thank you for your constructive comment. Standardized anomaly is calculated by dividing anomalies by the climatological standard deviation. We have described it in the revision.

Changes in Manuscript:

[Page 30 Lines 491-495 (in the "Track Changes" version)]

"Figure 15: (a) Time series of the standardized anomaly of the wintertime boundary layer lapse rate (LR) in domain d03 between 1000 hPa and 850 hPa, the index of Siberian High (SH), and the index of East Asian Winter Mooson (EAWM) from 1980 to 2020. The scatter plots of the correlations between (b) the standardized anomaly of the ESWM and LR, as well as between (c) the standardized anomaly of the SH and LR. Standardized anomaly is calculated by dividing anomalies by the climatological standard deviation."

Comment NO.11:

11.Line 289, how do you judge "stronger vertical mixing" on Jan.4 than those on Jan.3?

Response: Thank you for your helpful comment. The stronger vertical mixing on 4 January is demonstrated from the temperature profile in Fig. 4, and it has been specifically revised.

Changes in Manuscript:

[Page 19 Lines 334-335 (in the "Track Changes" version)]

"On 4 January, due to the strong turbulence mixing (as demonstrated from the temperature profile in Fig. 4), aerosols are carried to the aloft layer."

Comment NO.12:

12. Line 351, "….which are sensitive to the PBL thermal structure." The phrase "are sensitive to" might be replaced with "affect".

Response: Thank you. We have corrected it.

Changes in Manuscript:

[Page 24 Lines 396-397 (in the "Track Changes" version)]

"In particular, the absorptive BC aerosols have both stove and dome effects, which affect the PBL thermal structure."

Comment NO.13:

13. Line 389, please take out the word "systematically". This study only shows the analysis for the two-day data.

Response: Thank you. We have corrected it.

Changes in Manuscript:

[Page 31 Lines 497-499 (in the "Track Changes" version)]

"In this study, the complex relationships among the large-scale synoptic patterns, local PBL thermal structures, aerosol vertical distributions, and AREs of different aerosol types are investigated by combining aircraft observations, surface measurements, reanalysis data, and WRF-Chem simulations."

Comment NO.14:

14. The paper only considers the PBL thermodynamics and turbulent mixing related to the lapse rate and temperature variation, but ignores temperature-RH related secondary aerosols formation (SOA) on Jan.3 and 4 such as nitrate and sulfate SOA.

Response: Thank you for your insightful comment. In this study, our primary interest is to distinguish the aerosol-PBL interaction of absorbing and scattering aerosols under contrasting synoptic patterns and aerosol vertical distributions. We mainly focus on the absorbing/scattering aerosol vertical distribution and their contrasting radiation effect.

The temperature-RH related secondary aerosol formation is a rather important issue that needs to be investigated. In the WRF-Chem simulation, the secondary aerosol formation has been included.

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