Manuscript # acp-2017-455

Reply to Referee #2

We are very grateful to all important and helpful comments from the referee. The followings are our responses to each comment in detail.

1. In this manuscript author reported the observation phenomena describing the tight relationship between PM and PBL in two type haze events occurred in Beijing. Facts are always important for our better understanding of the severe haze events. Authors suggest possible feedbacks among PM, PBL, and/or humidity, whereas the PBL play dominant roles. However, in the present version of the manuscript, authors just demonstrate their co-changes by correlations. The physical explanation why/how the PBL changes need careful and substantial analysis/evidence.

Reply 1:

Thanks for the suggestion. We added more explanations and discussions relevant to the PBL changes and PM concentration in conclusions and discussions section of the revised manuscript, as "The new finding in this paper has important implications in explaining the frequent long–lasting polluted events in the study region. Generally, a typical pollution event is usually formed under a stable and shallow temperature–inversion condition at low atmospheric layers, and would disappear or obviously decrease when the daytime solar radiation increases. However, in the study region, we found that many severe haze and fog–haze mixed events lasted for several days even for several weeks. Most previous publications attributed the reason as the persistent abnormal weather system or high emissions. However, this study shows that except for the influence of meteorological condition and high emission, the interactions and feedbacks between PBL and aerosol loading linked by radiation process are crucial in enhancing and maintaining these polluted events. These feedbacks could cause an important variation of dynamical/thermal processes in lower troposphere. The formation of double inversion layer and their subsequent change is closely associated with persistent meteorological condition, high aerosol loading and associated radiation process. Due to the complex interactions and feedbacks, a deeper and more stable atmospheric low–level inversion layer is formed and it is hard to break up by daytime solar radiation heating process until the strong wind occurs and removes the high aerosol loading."

2. Page 3, line 3, '…inside of the surface', misleading.

Reply 2:

Thanks for the comment. It has been changed in the revised manuscript, as "The aerosols directly emitted from polluted source and those secondly formed might be concentrated in the PBL, resulting in high concentrations near the surface."

3. Page 4, line 26, 'NCEPT', typo

Reply 3:

It has been revised as "NCEP".

4. Sections 3.1 and 3.2, as authors indicated the humidity is a very important factor modulating both the PM concentration and visibility, the relationship obtained in Section 3.1 and 3.2 would be biased by humidity. Particularly, to what extent the humidity 'contaminate' the $PM_{2.5}$-PBL and $PM_{2.5}$-visibility relationship should be clarified. It seems reasonable to perform additional analysis using data under similar humidity conditions. Otherwise the explanation would be vague.

Reply 4:

Thanks for the suggestion. We have performed additional analysis using data under similar humidity condition. The relationship between visibility and $PM_{2.5}$ mass concentrations and that between $PM_{2.5}$ mass concentration and PBL height under different RH conditions for both long–lasting haze and fog–haze mixed events are shown in Fig. A and Fig. B. The results show that the variation of RH has some influences on the relationship between $PM_{2.5}$–PBL and $PM_{2.5}$–visibility. In general, the high RH could decrease the visibility and PBL height quicker than the low RH. However, the tendency and basic conclusion are not obviously changed.

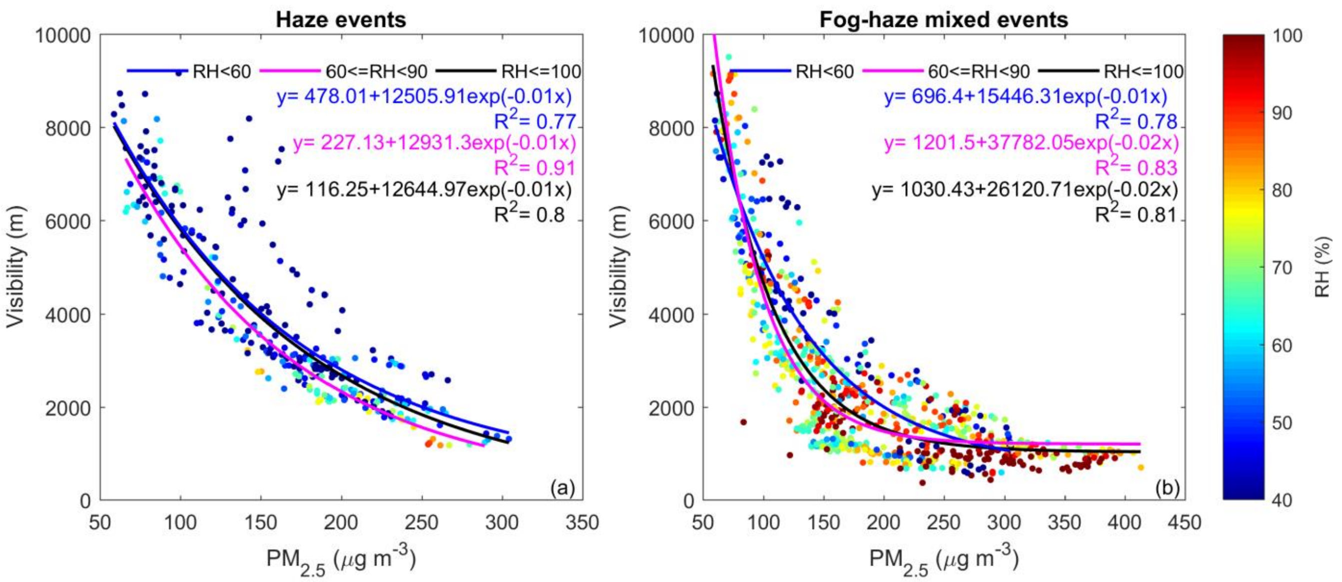

Figure A: Relationship between the measured visibility and $PM_{2.5}$ mass concentration under different RH conditions for (a) haze and (b) fog–haze mixed events from January 2014 to March 2015 in Beijing city. The exponential curves present the fits of the circles according RH.

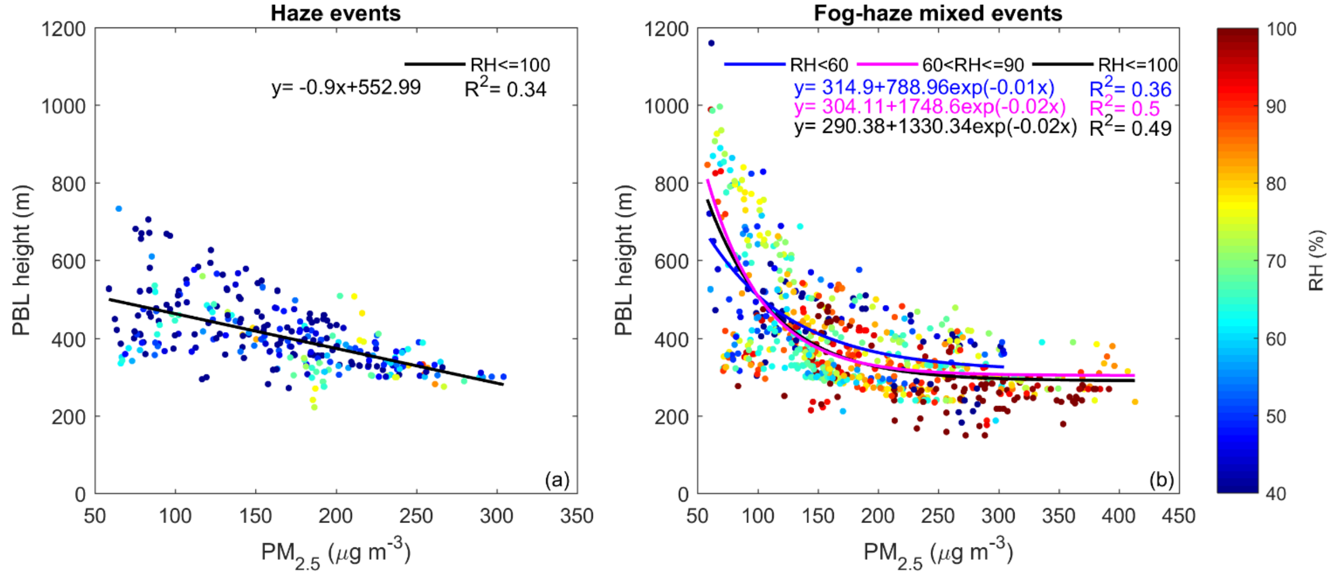

Figure B: Relationship between PBL height and $PM_{2.5}$ mass concentration under different RH conditions for (a) haze and (b) fog–haze mixed events from January 2014 to March 2015 in Beijing city. The curves present the fits of the circles according RH.

5. Page 9, line 14, 'col', typo

Reply 5:

The col pressure filed presents the pressure field of the saddle type. We rewrote the sentence in the revised manuscript as "The synoptic situation during the haze event characterized as a saddle field. Beijing was located in a saddle between two pairs of high and low pressure center."

6. Page 9, line 23, As you demonstrated, the temperature advection is important, but why the aerosol transport from the south is weak?

Reply 6:

Thanks for the comment. The sentence in the manuscript was revised as "The wind speed varied from 0 m s^{-1} to 3.9 m s^{-1}, with an average of 0.8 m s^{-1}, suggesting that the horizontal diffusion of aerosols was very weak."

7. On the PBL changes, what's the role played by the background synoptic processes? Is there any non-aerosol related dynamical/thermal causes in lower troposphere?

Reply 7:

Thank you for your comment. The background synoptic processes played an important role in the PBL changes in the cases we investigated. The upper inversion layer was formed by the persistent warm and humid airflow from south, and the PBL change was directly related to the descending process of the upper inversion layer. In the daytime, due to the existence of the upper inversion layer, the PBL tends to become stable and aerosol loading increases. As long as the aerosol loading reach certain high value such as that larger than 150–200 μg m^{-3}, the solar radiation will be strongly blocked, and then the strong surface cooling occurs, which cause the descending of the upper layer inversion. Since the upper inversion layer contains warmer and humid air, the descending process would cause the whole PBL to be suppressed and well-mixed. These processes will finally form a deeper and more stable PBL, so the daytime radiation heating cannot break up the stable layer and cause a long–lasting pollution event until strong wind comes. We can see that the interaction and feedback between PBL and aerosol loading is linked by radiation process. We cannot find additional influence from synoptic process such as downdraft etc. Moreover, the descending process of upper inversion layer also bring more water vapour to the lower layer, high content moisture might also play an important role in blocking solar radiation except for the aerosol loading.

8. Page 12, line 1, inconvincing. It seems actually the whole layer get warmer on 13-14 April. This might help set a higher PBL.

Reply 8:

Thanks for the comment. In general, when temperature within PBL becomes higher, the PBL height should increase. However, this study shows that due to the strong cooling at the surface, the whole PBL descending and the warm PBL is caused by the descending upper warm and humid air, which is favourable to the mixing process within the PBL, but cannot force the PBL to extend upward due to the influence of strong surface cooling process caused by the rapidly increased aerosol loading. The surface cooling is higher in 14 than in 13 April, 2014. For example, the inversion layer from 150 m to 550 m with the lapse rate of air temperature is –0.38 ℃ $(100\ m)^{-1}$ at 8:00 on 13 April, while the lapse rate of the same layer is –0.75 ℃ $(100\ m)^{-1}$ at the same time on 14 April. From the direct radiation and scattering radiation parameters in Table 3, we can also see the surface cooling effect is strengthened (the direct radiation is reduced and the scattering radiation is increased from 13 to 14 April).

9. Section 3.4.2, The PBL feedback is much stronger in fog-haze events than in haze event. This conclusion cannot be obtained, until you have ruled out the influence of synoptic processes on the PBL in these analyzed events.

Reply 9:

Thanks for the comment. This study shows that the PBL feedback is much stronger in fog–haze mixed events than in haze event. This is because that the fog–haze events include many fog droplets, which can substantially block the solar radiation comparing with aerosol loading in haze events in the daytime and cause stronger surface cooling. The stronger surface cooling would cause stronger descending of the upper inversion layer and then form a highly suppressed and more stable PBL. So the PBL feedback is much stronger in fog–haze event. As seen in Table 5 in the manuscript, the radiation reduction imposed by aerosol particles is particularly stronger during the fog–haze mixed event than the haze event. The $PM_{2.5}$

concentration is higher and the PBL heights are lower in the fog–haze mixed event. We propose that The PBL feedback is much stronger in fog–haze mixed events than in haze event. We have added these descriptions in section 3.4.2 of the revised manuscript.

10. Page 32, The RH in Figure 10 seems not consistent with Fig.7. For example, high RH above 500m are event from 12 April to 14 April in Figure 7. But in Figure 10 (b,d) this feature cannot be found, instead, much drier conditions on 13 April and 14 April. Why?

Reply 10:

Thanks for the comment. This is primarily caused by different measuring system. Comparing with data from two methods, The RH derived from PMWR has larger uncertainties and the sounding data are more reliable. Since Fig.7 in the previous manuscript (Fig.6 in the revised manuscript) is from PMWR (Profiling microwave radiometer), which uses passive remote sensing way to obtain profiles of temperature and water vapor based on neural network algorithm with the input of past sounding data and bright temperature. So the RH values of PMWR are derived from the PMWR–retrieved temperature and water vapor density. The vertical resolution of PMWR is only 100m for the height between 500 and 2000 m, which is not enough to obtain the fine structure of the upper boundary layer. However, the RH from PMWR has higher temporal resolution, it is still very useful compared with conventional radiosonde observation, which only has observation twice a day. In the study of (Xu et al., 2015), atmospheric profiles of RH retrieved from PMWR measurements are compared with radiosonde soundings. The correlation coefficients of RH for clear and cloudy skies are less than 0.8 and decrease monotonically with height. The biases increase from ~3 % at the surface to ~15–20 % at 4–5 km. It is well known that radiosonde humidity has systematic dry bias relative to the Cryogenic Frostpoint Hygrometer (Vomel et al., 2007; Bian et al., 2011).

11. Page 34, Figure 12(e), PMcorse should be PMcoarse. And how did you define PMcoarse? Should be indicated, and the relevant analysis for PMcoarse also missed in Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-455,2017.

Reply 11:

Thanks for the careful review. In the section 2.1, PMcoarse is defined as that the particulate matter with aerodynamic diameter is >2.5 μm and <=10 μm. Since the averaged $PM_{2.5}/PM_{10}$ in the haze event and fog–haze mixed event was 0.82 and 0.94, respectively. So the primary pollutant was $PM_{2.5}$ in the study region. In general, the variation trend of PMcoarse was consistent with that of $PM_{2.5}$ in both two cases. According to the above reasons, we have deleted the lines of PMcoarse in Figure 5 (e) and Figure 10 (e) in the revised manuscript.

References

Bian, J., Chen, H., Voemel, H., Duan, Y., Xuan, Y., and Lue, D.: Intercomparison of Humidity and Temperature Sensors: GTS1, Vaisala RS80, and CFH, Adv. Atmos. Sci. , 28, 139-146, 10.1007/s00376-010-9170-8, 2011.

Vomel, H., Selkirk, H., Miloshevich, L., Valverde-Canossa, J., Valdes, J., Kyro, E., Kivi, R., Stolz, W., Peng, G., and Diaz, J. A.: Radiation dry bias of the vaisala RS92 humidity sensor, J. Atmos. Ocean. Tech., 24, 953-963, 10.1175/jtech2019.1, 2007.

Xu, G. R., Xi, B. K., Zhang, W. G., Cui, C. G., Dong, X. Q., Liu, Y. Y., and Yan, G. P.: Comparison of atmospheric profiles between microwave radiometer retrievals and radiosonde soundings, Journal of Geophysical Research-Atmospheres, 120, 10313-10323, 10.1002/2015jd023438, 2015.