Response to comments by referee 2

We would like to thank you for your comments and helpful suggestions. We revised our manuscript according to these comments and suggestions.

Specific comments:

This study reveals the spatial variation of mixing layer height (MLH) over northern China plain (NCP) based on a two-year measurement at four primary cities with different geographic allocation across NCP. The authors attribute the different spatial pattern of MLH between southern Hebei and northern NCP to the distinct wind shear features between the two interested regions. The analysis on the long-term measurement of MLH in this study provides a meaningfully insight on the climatological features of boundary layer condition during the haze episodes over NCP. Also, the discussions about the associations of MLH and other meteorological factors with the near-ground particle pollution are sufficiently presented in this work. However, the following concerns should be addressed before publication.

Comment 1:

Considering the possible strong aerosol-radiation interaction because of the heavily pollution, the surface net radiation is supposed to be lower over the regions with more heavily pollution because of the strong scattering and/or absorbing of solar radiation by aerosols. However, in this study, though the near-ground $PM_{2.5}$ concentration over southern Hebei is 1.3 times higher than that of north China plain (NCP), there is no significant difference in the net radiation at Shijiazhuang (SJZ) located southern Hebei from at Beijing (BJ) located over NCP. One probable reason is because the aerosol optical depth (AOD) over the two sites was comparable, leading to comparable capacity reducing solar radiation. The authors may check the AOD data to obtain a convinced explanation for why the net radiation is spatial consistent, given the presence of aerosol-radiation interaction.

Response 1:

Thank you for your helpful suggestion. We have checked the AOD distribution in NCP as you suggested. The AOD data were retrieved with the dark target algorithm from the Moderate Resolution Imaging Spectra-radiometer (MODIS) aerosol products on board the NASA EOS (Earth observing system) Terra satellite. As shown in Fig. 1 below, the AOD in Shijiazhuang (SJZ) was 1.1and 1.0 times higher than that at the Beijing (BJ) and Tianjin (TJ) stations, respectively. Given the presence of aerosol-radiation interaction, the comparative amount of AOD could be one probable reason to explain the nearly consistent net radiation between the SJZ and BJ stations. In our revised manuscript, the net radiation analysis was replaced by gradient Richardson number (*Ri*) studies, and *Ri* is a better index which can evaluate the turbulent stability from both of the perspective of thermal and mechanism forces. Then the low mixing layer height (MLH) in winter in southern Hebei was mainly resulted from the stable turbulent stratification (Fig.1). Relevant contents were modified in section 4.1 in the revised manuscript. Besides, we also discovered some new findings when the analysis of AOD was added in the discussion. Please refer to comment 2.

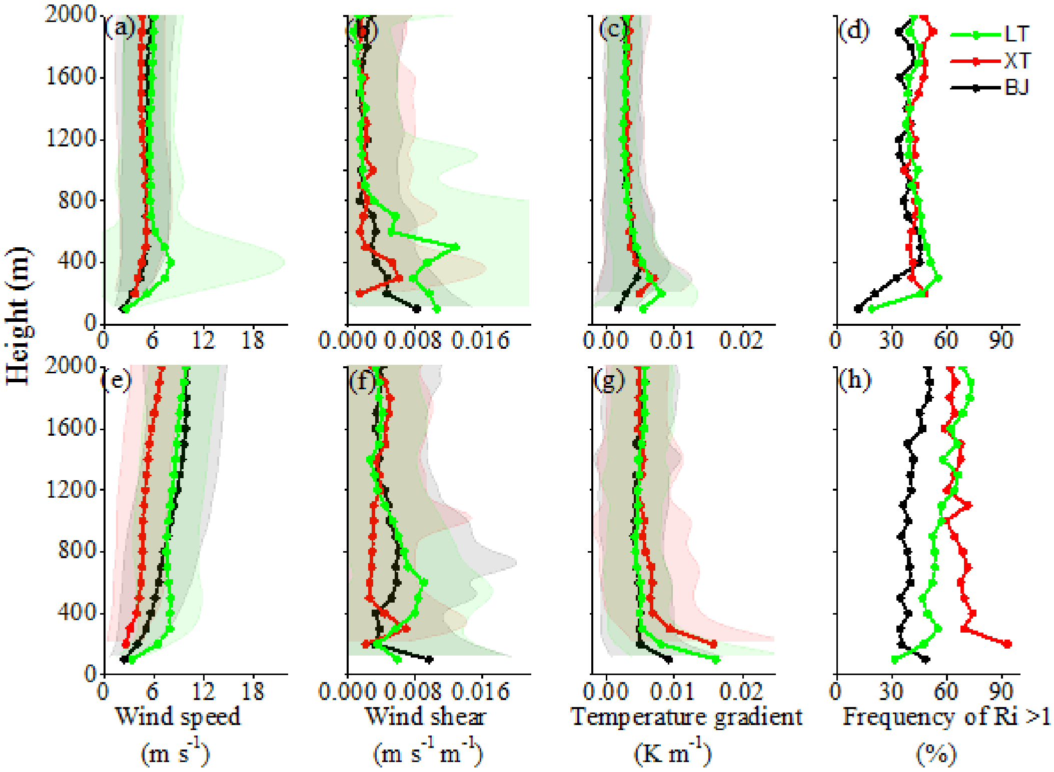

Fig.1Vertical profiles of (a, e) horizontal WS, (b, f) wind shear, (c, g) virtual potential temperature gradient and (d, h) percentage of *Ri*>1 at the BJ, XT and LT stations in summer (upper panel) and winter (lower panel).

Comment 2:

In addition to the difference in mixing layer height (MLH), how likely does the spatial variation in pollutant emissions contribute to the difference in the near-ground PM pollution between SJZ and BJ?

Response 2:

Thank you for your suggestion. Since the particle has direct emission sources and secondary sources, and the distribution of direct emissions cannot represent the total contribution of emissions to the particle concentration. The near-ground $PM_{2.5}$ concentration could represent the particle concentrations at the ground, but considering that the lifetime of particle is much longer than that of trace gases, the concentrations of particles are nearly uniform in the mixing layer because of the strong vertical mixing. Therefore, near-ground $PM_{2.5}$ concentrations cannot be used to evaluate the emissions influences between different regions if the mixing layer heights are different. AOD, which represent the aerosol column concentration, is a much better indicator for the emissions difference. As shown in Fig. 2, the major sites in southern Hebei (the SJZ, Handan (HD) and Xingtai (XT) stations) and northern NCP (the BJ, and TJ stations) were circled with white rectangles. The averaged AOD value at the southern Hebei stations was 1.2 times higher than the AOD at the northern NCP regions, while the near-ground $PM_{2.5}$ concentration in southern Hebei was 1.5 times higher than that in the northern NCP. If the difference of AOD represents the emission discrepancy, the remaining differences of $PM_{2.5}$ concentration may be induced by the meteorology. In other words, except for the emission effect, the meteorological conditions also play an important role in pollutant contrast between these two areas. Relevant contents were also modified in section 4.2 in our revised manuscript.

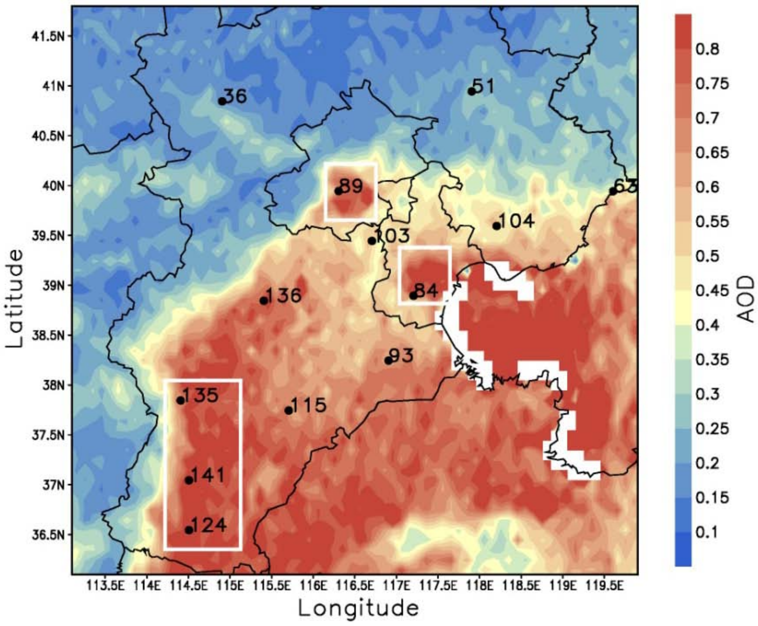

Fig. 2 Distribution of AOD from December 2013 to November 2014 in the NCP. The $PM_{2.5}$ concentrations of the 13 observation sites were also marked beside each station. Major sites in the Northern NCP (BJ and TJ) and the Southern Hebei (SJZ, XT and HD) were circled by white rectangles.

Comment 3:

The authors attribute the spatial difference in wind shear over NCP during winter to the influence of front passing associated with the Siberian High (lines 403-405). Is the front also the dominant control of the relative humidity over NCP during winter? Is there any other reason leading to the discrepancy in relative humidity between the two regions in question?

Response 3:

The spatial difference in wind shear over the NCP in spring, autumn and winter was probably resulted from the more frequent weak cold air impact on the northern NCP region. When the cold air was brought by a high-pressure system, the cold front formed and enhanced the wind shear in BJ. But in summer, due to the northward lift and westward intrusion of the subtropical high on the NCP, the lessened effect of the weak cold air on northern NCP accompanied with strong solar radiation and turbulent activities will lead to less wind shear contrast in the vertical direction between southern Hebei and the northern NCP. Certainly, the front is also the dominant control of the RH over NCP. And higher RH in southern Hebei might be resulted from the frequent passage of Siberian high in the north NCP, especially in spring and winter. In spring, when frequent sand storm happens, it brings dry air mass to the northern NCP, thus the RH in northern NCP was far less than that in southern Hebei (Fig. 3a). Meanwhile, under the impact of Siberian High, frequent weak northwest flow from the Inner Mongolia will bring cold and dry air to the northern NCP in winter and autumn, and such north flow was too weak to reach southern Hebei, which will lead to lower RH in the northern NCP (Fig. 3c and 3d). Besides, the higher RH in the southern Hebei could also be affected by the subtropical high (wet southeast flow from the yellow sea).

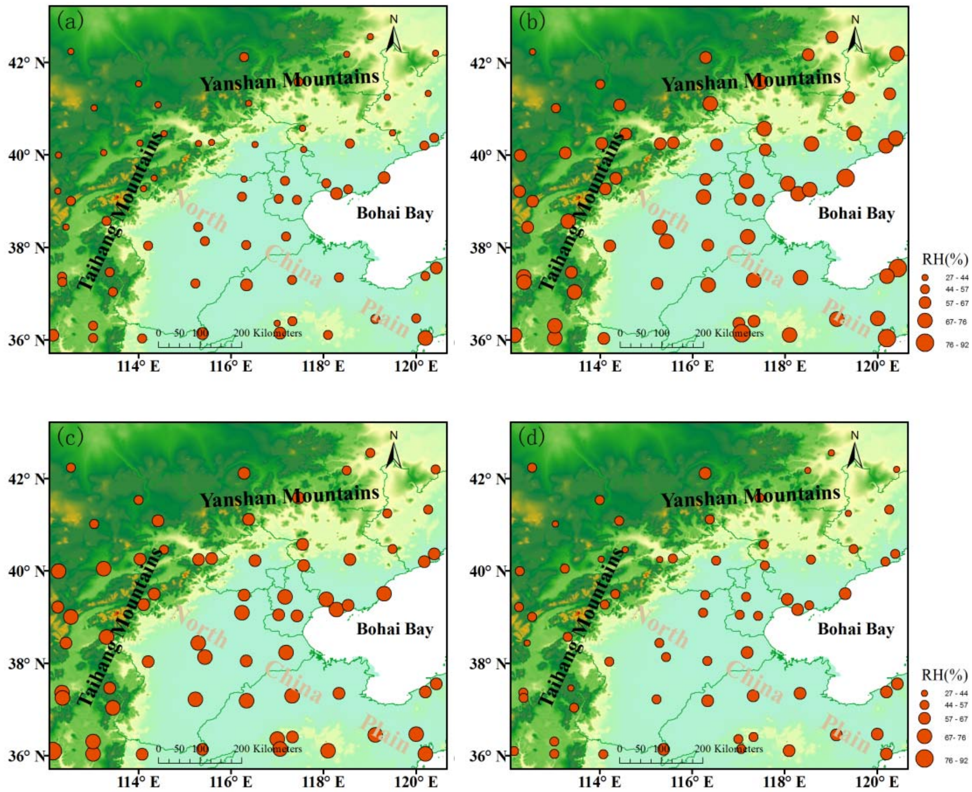

Fig. 3 Distributions of seasonal averaged RH in the NCP from December 2013 to November 2014: (a) spring, (b) summer, (c) autumn and (d) winter.

Comment 4:

Given that both Tianjin (TJ) and Qinhuangdao (QHD) are located at coastal region and suffering highly frequent sea breezes during summer (Fig. 5), why the MLH of TJ is much higher than the case in QHD, since the relatively low MLH in QHD is attributed by the authors to the intensive occurrence of sea breeze during summer (lines 265-266)?

Response 4:

Thank you for your suggestion and we are sorry for our unclear description. Actually, the MLH at the coastal region was affected by the thermal internal boundary layer (TIBL), not the sea breeze. When the cold air mass came with sea breeze and the top of the mixing layer was higher than the top of the air mass, the TIBL will form within the original mixing layer, interrupt the original mixing layer development and decrease the MLH. With distance inland, the top of the sea air mass will enhance and exceed the local MLH, if so, the TIBL will not form. Therefore, although the sea breeze impact will extend further inland, the TIBL impact will only matters within a distance of about 10 km out to the sea (Stull, 1988). Since the QHD station was only 2 km away from the coastline and the distance of TJ station was about 50 km out to sea, the TIBL will not form in the TJ station. The MLH for TJ was as high as those inland sites (BJ and SJZ). The relevant contents were modified in section 3.2.2 in our revised manuscript

Technical comments:

Comment 1:

Fig. 7: the unit for the wind shear should be m s-1 km-1.

Response 1:

Since the $\text{wind shear} = \sqrt{\left(\frac{\Delta \bar{u}}{\Delta z}\right)^2 + \left(\frac{\Delta \bar{v}}{\Delta z}\right)^2}$ and the unit of wind speed and Δz was m s^{-1} and m, respectively, the unit of wind shear was m $s^{-1}m^{-1}$.

Comment 2:

The descriptions on Figs. 5c and 5d in lines 320-322 seems not consistent with what was shown in figure. For example, the prevailed wind direction during spring and summer for TJ is southerly as shown in Fig. 5c, which is not the case stated by the text in lines 320-322, i.e. easterly wind is prevailed in TJ.

Response 2:

Thank you for your suggestion and we have already modified the relevant descriptions in section 3.2.2 in the revised manuscript.

References:

Stull, R.B.: An Introduction to Boundary Layer Meteorology, Kluwer AcademicPublishers, Dordrecht, 1988.