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Interactive comment on "Mixing layer transport flux of particulate matter in Beijing, China" *by* Yusi Liu et al.

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Received and published: 10 June 2019

We would like to thank you for your comments and helpful suggestions. We revised our manuscript accordingly. General Comments: The current study explores the seasonal source of PM2.5 pollution in Beijing by quantifying the transport flux based on measurements of mixing layer height and wind profile. In particular, this study raises two questions that are rarely addressed in previous studies: (1) effects of ventilation coefficient on PM2.5, and (2) observational quantification of transport fluxes. This topic is of broad interest to both the scientific community and policy-makers. The datasets analyzed in the study is valuable. However, the current analyses do not clearly address the questions raised in the beginning. In addition, the data and method section require some clarification. Therefore, I recommend major revision. Specific Comments: Comment 1:

I suggest changing the second question to emphasize its scientific merit. By quantifying transport fluxes from observation, what scientific question do you want to address? Response 1: Thank you for your helpful suggestion. We have emphasized the scientific merit of the second question and added it to the introduction, as follows: Although the problem of heavy pollution in northern China has improved in recent years, regional pollution problems remain, especially in the Beijing-Tianjin-Hebei region (Shen et al. 2019). To solve the regional pollution problem, joint prevention and control have been recommended for a long time. Many studies on regional transport have been carried out, but most observational studies cannot easily quantify the transport flux due to the lack of particle and wind vertical profiles, and it is still unclear when we need to control the emission sources and in which areas. In this study, we used the backscattering coefficient measured by a ceilometer and wind profile to quantify the transport fluxes to solve the problems mentioned above. Comment 2: Section 2.2 describe the method to determine MLH. Although details are provided in earlier papers, necessary steps should be clearly mentioned in the current paper, e.g. line 113-115 averaging the profile over time? If so, over what time window, daily, hourly? Response 2: Thank you for your helpful suggestion. The text has been revised to "the MLH was calculated by the improved gradient method after smoothly averaging the profile data". More details are as follows: Because the lifetime of the particles can be several days or even weeks, the distribution of the particle concentration in the MLH is more uniform than that of the gaseous pollution. However, the particle concentration in the mixing layer and that in the free atmosphere are significantly different. In the attenuated backscatter coefficient profile, the position at which a sudden change occurs in the profile indicates the top of the atmospheric mixing layer. In this study, we used the Vaisala software product BL-VIEW to determine the MLH. The time averaging is dependent on the current signal noise. Height averaging intervals range from 80 m at ground level to 360 m at a 1600 m height and beyond. Additional features of this algorithm, which is used in the Vaisala software product BL-VIEW, include cloud and precipitation filtering and outlier removal. Because the aerosol concentrations are particularly low above the BLH and the BLH

in the Beijing area is usually lower than 4 km, we halved the detection range to 7.7 km to reinforce the echo signals and reduce the detection noise. Comment 3: Section 2.4 cited a previous study to support the assumption that backscattering coefficient is relatively uniform in the mixing layer. I think your ceilometer observations include backscatter profile. Does your data quantitatively support this assumption? Response 3: Thank you for your helpful suggestion. Although previous studies have shown that the concentration of particulate matter in the mixing layer is basically uniform, there are still large differences in some time periods, especially in the time periods with transport effects. Based on your suggestions and those of Reviewer 2, we find it inappropriate to so rashly use the near-surface PM2.5 concentration as the concentration in the mixing layer. Because the ceilometer can measure the atmospheric backscattering coefficient, it is possible to obtain the vertical profile of the particles. Therefore, in the revised draft, we analyzed the relationship between the backscattering coefficient at 100 m measured by ceilometer and the near-surface PM2.5 concentration, discussed their correlations in different seasons, and obtained the fitting curves of different seasons. Using these four equations, we obtained the PM2.5 concentration at different heights in different seasons. According to this result, we have recalculated the TF in the revised draft. Comment 4: On line 156-158 and following statements, what is the number behind the ï'C's sign? Response 4: Thank you for your helpful suggestion. I guess you mean "$\pm$". The number after the "$\pm$" represents the standard deviation, a measure of the dispersion of the data. An explanation has been added where the notation first appeared. Comment 5: I suggest using the same color scheme for each season in Fig. 2 and Fig. 3. Response 5: Thank you for your helpful suggestion. The color scheme has been unified. Comment 6: Why didn't you show diurnal variations and growth rates of PM2.5 in Fig. 2? It seems directly relevant to the first scientific question. Response 6: Thank you for your helpful suggestion. The diurnal variations of the PM2.5 and the corresponding analysis have been added. More details are as follows: Notable differences are present when we compare the dilution-related parameters to PM2.5. The daily maximum PM2.5 concentrations in the spring, summer, autumn and

winter were 73 μg m-3 (11:00 LT), 56 μg m-3 (09:00 LT), 78 μg m-3 (23:00 LT) and 101 μg m-3 (01:00 LT), respectively. The differences between the maximum and minimum were 14 μg m-3, 10 μg m-3, 20 μg m-3 and 38 μg m-3, respectively. Thus, the diurnal variation of PM2.5 can be divided into two categories: (1) the highest value occurs in the midday in the spring and summer and the overall change is small and (2) the highest value occurs during the night in the autumn and winter and differs greatly from the lowest value (Fig. 1). The main causes of air pollution are local emissions and regional transport. Thus, these results indicate that there is a greater local contribution in the autumn and winter and higher regional transport in the spring and summer. Comment 7: In Fig.3, it is worth discussing higher frequency of high VC (> 103 m2 s-1) in winter, is it due to high wind speed associated with frontal passage? Response 7: Thank you for your helpful suggestion. We agree with you. In winter, when the Siberian High transits, strong northwest winds prevail in the Beijing area (Fig. 2), resulting the higher frequency of the VC in the range of 1000-2000 m2 s-1. We explained this point in section 3.1.1 of the revised draft. Comment 8: In Fig.4, it seems to me that the dominant southerly wind partly explains the positive correlation between wind speed and PM2.5 in summer. Response 8: Thank you for your helpful suggestion. The southern wind generally appeared at 12:00-2:00 LT, and the high PM2.5 concentration generally appeared at 6:00-13:00 LT; therefore, there was no significant relationship between the two. In addition, due to the improper discussion of this section in the original text, we have deleted this section to avoid confusion. Comment 9: I don't think the conclusion on lines 289-294 that southerly wind is "dirtier" directly comes from Figure 5 and 6 Flux variation comes from PM2.5 and wind speed, it could be that southerly wind are generally stronger. In order to demonstrate this point, it will help to add PM2.5 fields in Figure 5 and Figure 6. Another way to demonstrate this conclusion is to show wind rose and flux rose, and PM2.5 composite in different wind directions. Response 9: Thank you for your helpful suggestion. According your suggestion, the diurnal variation of the PM2.5 concentration and the wind radar were added, and we found that the level of the TF is determined by two factors, the WS and PM2.5 concentration. In the spring, summer
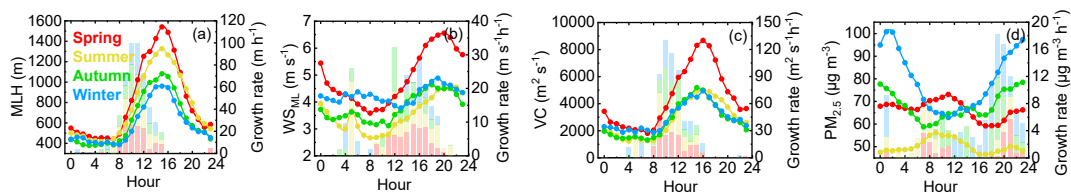
and autumn, the strong south wind prevails in the afternoon. As the south wind is often accompanied by a high PM2.5 concentration (Fig. 3), the TF is high. In the winter, the whole day is dominated by westerly and northerly winds. Although the northerly winds are strong, the TF is not high due to the low PM2.5 concentration. Generally, a high WS means fast mixing, and the corresponding MLH is also high. At this time, the TF is mainly controlled by the WS. When the WS is low, the mixing speed is slow, and the MLH is low. At this time, the TF is mainly controlled by the PM2.5 concentration. From the above analysis, it can be inferred that if the MLH and WS gradually decrease with the worsening of the pollution, the mixing layer TF is controlled by the WS first and then by the PM2.5 concentration, and the maximum TF may occur at a critical moment. This moment is neither the moment of the maximum WS nor the moment of the maximum PM2.5 concentration but should be somewhere in between. References: Shen, Y., L. Zhang, X. Fang, H. Ji, X. Li, and Z. Zhao: Spatiotemporal patterns of recent PM2.5 concentrations over typical urban agglomerations in China, Sci Total Environ, 655, 13-26, https://doi.org/10.1016/j.scitotenv.2018.11.105, 2019.
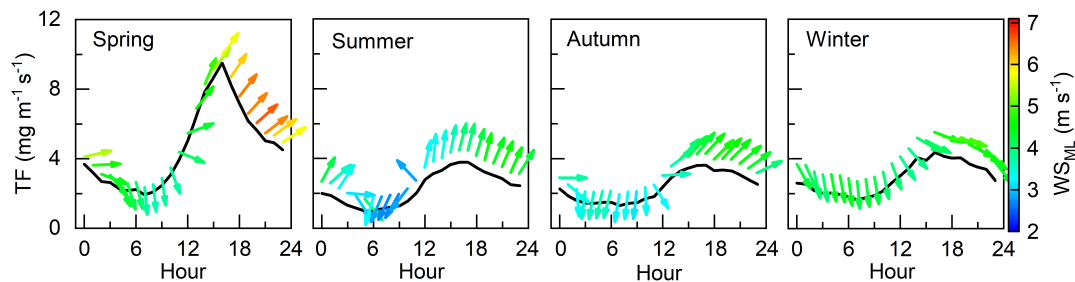
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Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-141, 2019.

Fig. 1. Diurnal variations and growth rates of the MLH (a), WSML (b), VC (c) and PM2.5 (d) in the spring, summer, autumn and winter in Beijing. Diurnal variations are represented by lines and scatters.
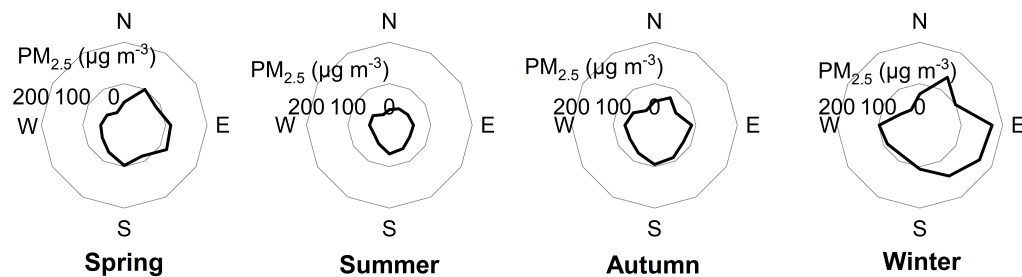
Fig. 2. Diurnal variations in the mixing layer transport flux of PM2.5 and transport direction during different seasons in Beijing.

Fig. 3. The wind radar in different seasons in Beijing.