SC1:

The manuscript is meaningful for the prevention and control of regional pollution in north China. It is absolutely worth of publishing as the study itself is extremely interesting. However, some improvements are suggested.

Authors' reply: It is our honor to receive the valuable comments from Dr. Tang. We have revised the manuscript carefully according to these comments. Please see below for our point-to-point responses.

In the manuscript, the authors found the southwest-northeast transport pathway. Actually, it is the most important pathway in North China Plain, especially during the heavy polluted episodes. Tang et al. (2015) and Zhu et al. (2016) found aerosols transported from the southwest between 500-1200 m (in the upper boundary layer) using ceilometer observations, which were the same with your simulations. However, the transport just emerged during the initial periods of the heavy pollution episodes. With the in crease of the aerosols, the PBL decreases (below 500m) and the transport effects weaken during the heavy polluted periods. Could you please quantify the transport in different pollution degrees?

Authors' reply: The reviewer raised a very useful question. The transport fluxes vary with different meteorology conditions in different days. Following this suggestion, we calculated the flux for individual days in January and July, and sorted the data into groups based on different pollution levels (see Fig. R3). Taking Beijing as an example, in January, the simulated concentration ranges from 11 $\mu g/m^3$ to 271 $\mu g/m^3$, while in July, the range is from 6 $\mu g/m^3$ to 94 $\mu g/m^3$. We set 6 groups for January and 5 groups for July. The separating points are chosen to be near the 30, 55, 75, 85 and 95 percentiles in January, and the 30, 60, 80, 90 percentiles in July. The groups are denser at higher concentrations to better reveal the details before and after heavy pollution periods.

In January, the transport becomes stronger when the concentration is higher, but the transport flux decreases in turn when the concentration is the highest. The inflow from Baoding and outflow to Chengde, which are the indicator of the Southwest-Northeast pathway, also experience a gradual rise followed by a sudden decline. In July, the situation is similar, though the decrease is less significant. Such result is consistent with Tang et al. (2015) and Zhu et al. (2016) that the Southwest-Northeast transport pathway is more significant during the rising phase of a heavy pollution period, but fades when the pollution reaches the peak.

Inspired by these results, we also conducted a day-to-day analysis on the two heavy pollution episodes described in Section 3.3, which occur in January and July, respectively (Fig. R4). We find the "flowing in and accumulating" phenomenon for both episodes. For the episode in January, the inflow (especially from southwest) is strong in January 18th, while the inflow declines rapidly in January 19th, the day with the highest concentration. The phenomenon is more significant during the episode in July. In July 18th and 19th, the inflow flux is very strong, while in July 20th which has the highest concentration, the flux decreases for more than one order of magnitude. This finding emphasizes the importance of early temporary control before heavy pollution occurs. We have revised our manuscript to include the above results and discussions. (Page 11-12, Line 294-306)

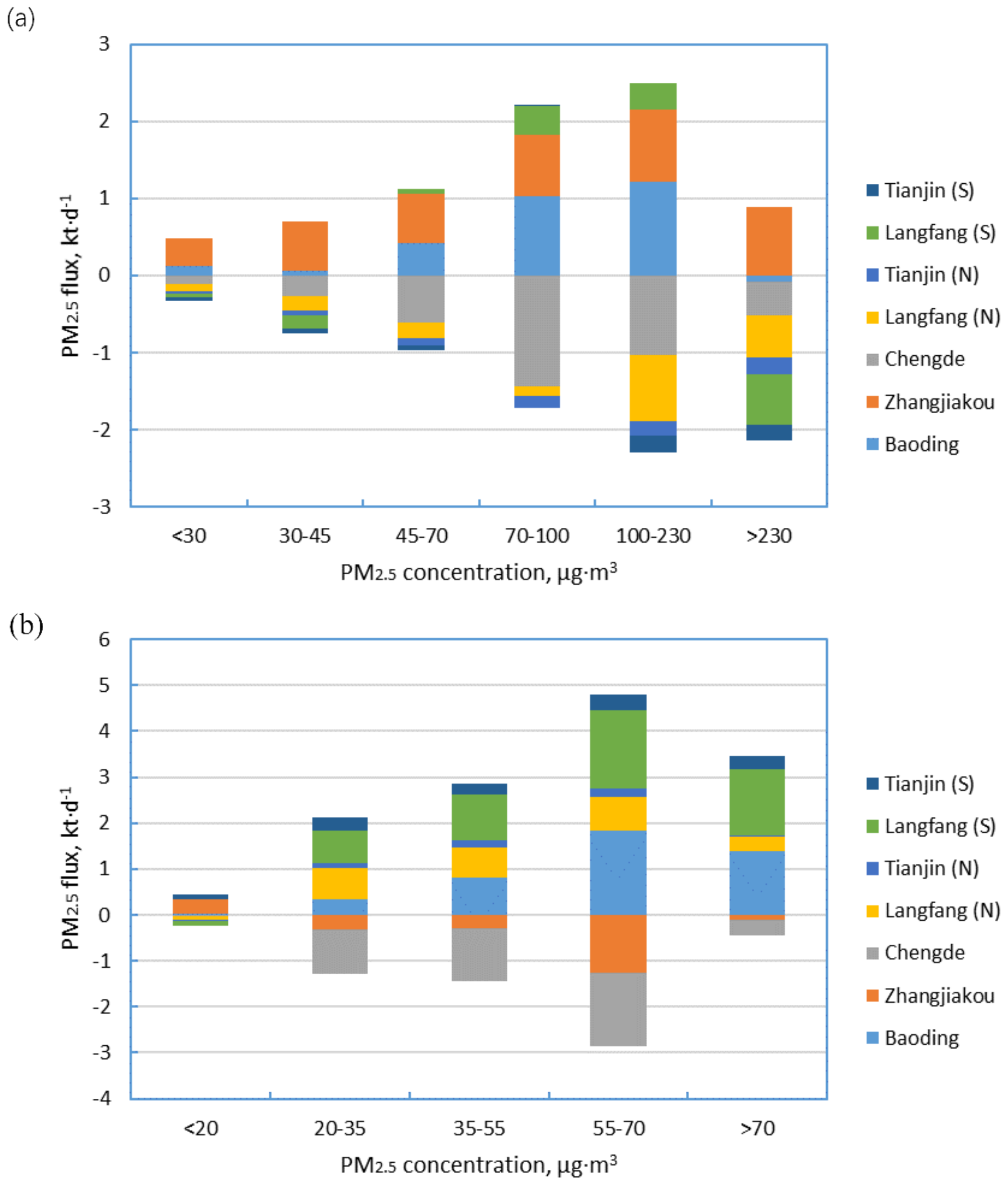

Figure R3 $PM_{2.5}$ average flux between Beijing and its neighboring cities in different pollution degrees in (a) January and (b) July.

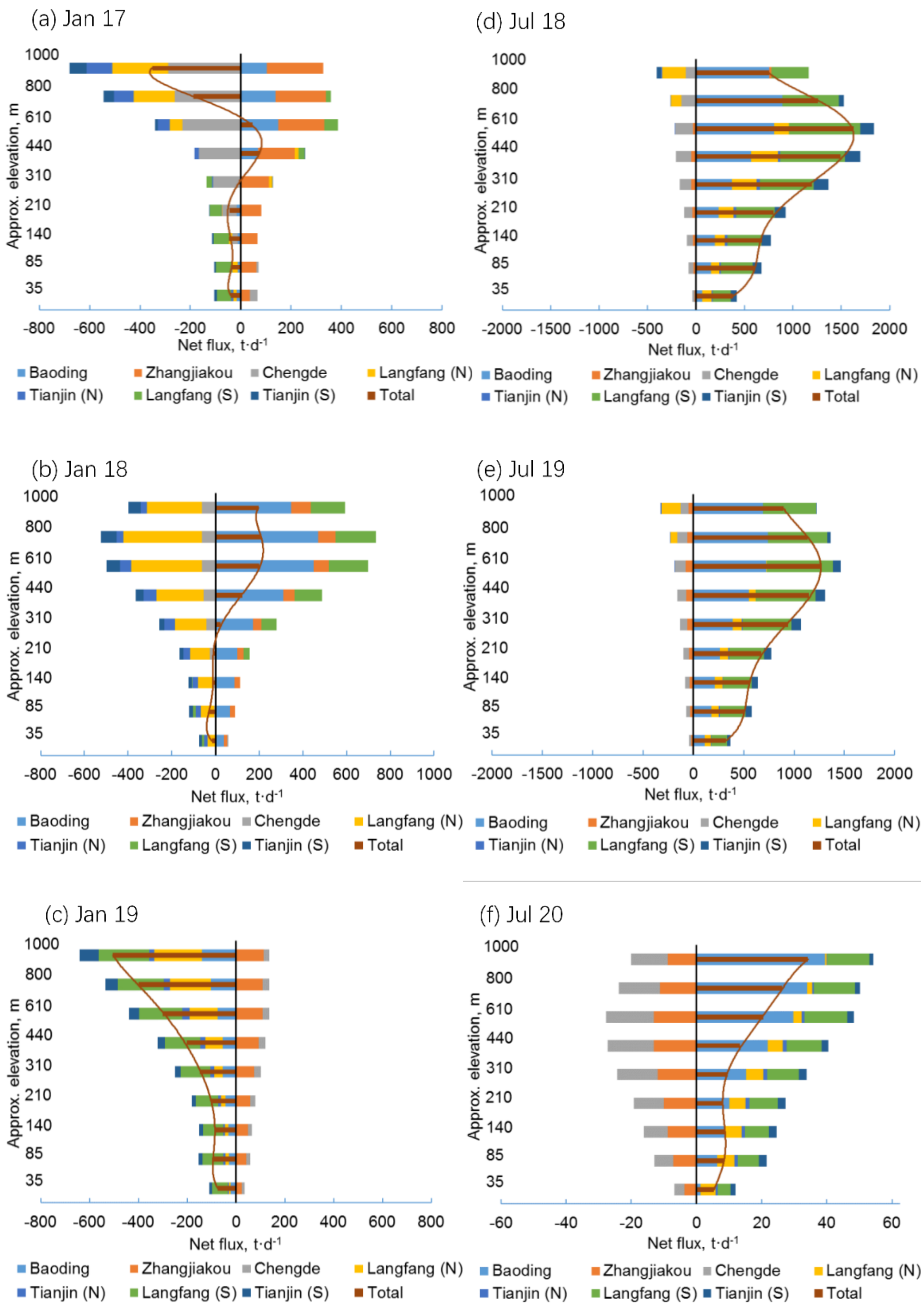

Figure R4 $PM_{2.5}$ fluxes during heavy-pollution days in Beijing in January and July: (a) January 17th, (b) January 18th, (c) January 19th, (d) July 18th, (e) July 19th and (f) July 20th.

In addition, some precursors were also transported in the initial periods. Afterwards, the precursors will react and form particles. Could you please quantify the contributions of the particles and the precursors' transport?

Authors' reply: The transport of precursors that may transform into particles is indeed an important factor. However, only if the precursors are tracked in all the physical and chemical reactions can we quantify the contribution of the precursor's transport to the $PM_{2.5}$. The flux approach is not able to account for this issue, which is one of the main shortages. Nevertheless, the flux approach can capture the transport features of all primary and most of the secondary $PM_{2.5}$. We have some discussion on this shortage in our manuscript, and we hope that future study can combine the tracer model with the flux approach to overcome this shortage.

What's more, without the passage of large- or medium-scale meteorological system, the local mountain-plain winds emerges in North China Plain (Tang et al., 2016, Fig. 10). The alternation between the mountainous (northeast) winds that begin at 03:00 LT at night and the plain (southwest) winds that begin at 12:00 LT in the afternoon occurs. Therefore, air pollutants will transport to the northeast direction in the afternoon and then transport back during latter of half of the night. Could you please clarify the transport circulations combined with the influences of the mountain-plain winds?

Authors' reply: We thank the reviewer very much for this useful comment. In our original study, we calculated daily $PM_{2.5}$ fluxes, so that the mountain-plain winds (which is a diurnal variation feature) is not taken the into consideration. Following the reviewer's comment, we tried to probe into the diurnal wind and flux pattern in Beijing.
The simulated average diurnal wind patterns at 100 m height in January and July in Beijing are shown in Fig. R5(b). We also put the observation results from Tang et al., (2016) in Fig R5(a) as a reference. We find that the simulated wind pattern is consistent with the observation. In January, the mountain-plain winds are presented as the change in wind speed, but the wind direction does not change significantly during the whole day. In July, there is a significant wind direction shift, similar to the description of the reviewer. The mountainous wind (northeast) begins at 2:00 LT, and is taken over by the plain wind (southeast) at about 10:00 LT, and the mountainous wind is much weaker than the plain wind. A circulation of mountain-plain wind may have influence on the transport of $PM_{2.5}$ in July.
Considering that the mountain-plain wind circulation mainly happens at the foot of the mountains, we calculated the fluxes through the boundaries between Beijing and its three neighboring cities on the south/southeast (Baoding, Langfang and Tianjin) during mountainous wind hours and the plain wind hours in July separately (Fig. R6). During the plain wind hours, all the boundaries on the southwest and southeast of Beijing have positive net fluxes, which is due to the relatively strong southerly plain winds. During the mountainous wind hours, however, there is no significant direction

change of the fluxes except for the boundary of Baoding and Southern Langfang at levels below 200 m. The sign of fluxes mostly remaines unchanged because the mountain-plain wind circulation is weaker at higher levels, and the wind speed of the mountainous wind is even weaker at the southernly boundaries which has limited effect to alter the sign of the flux. Nevertheless, the magnitude of fluxes is significantly smaller than the plain wind hours, which is partly attributed to the mountain-plain wind circulation. Therefore, the summertime mountain-plain wind circulation in Beijing does not significantly alter the sign of inter-city $PM_{2.5}$ fluxes but does have considerable impact on their magnitude.

We have included the discussion on the mountain-plain wind in our revised manuscripts (Page 14, Line 365-369 in the main text, and Page 12-13, Line 102-131 in SI).

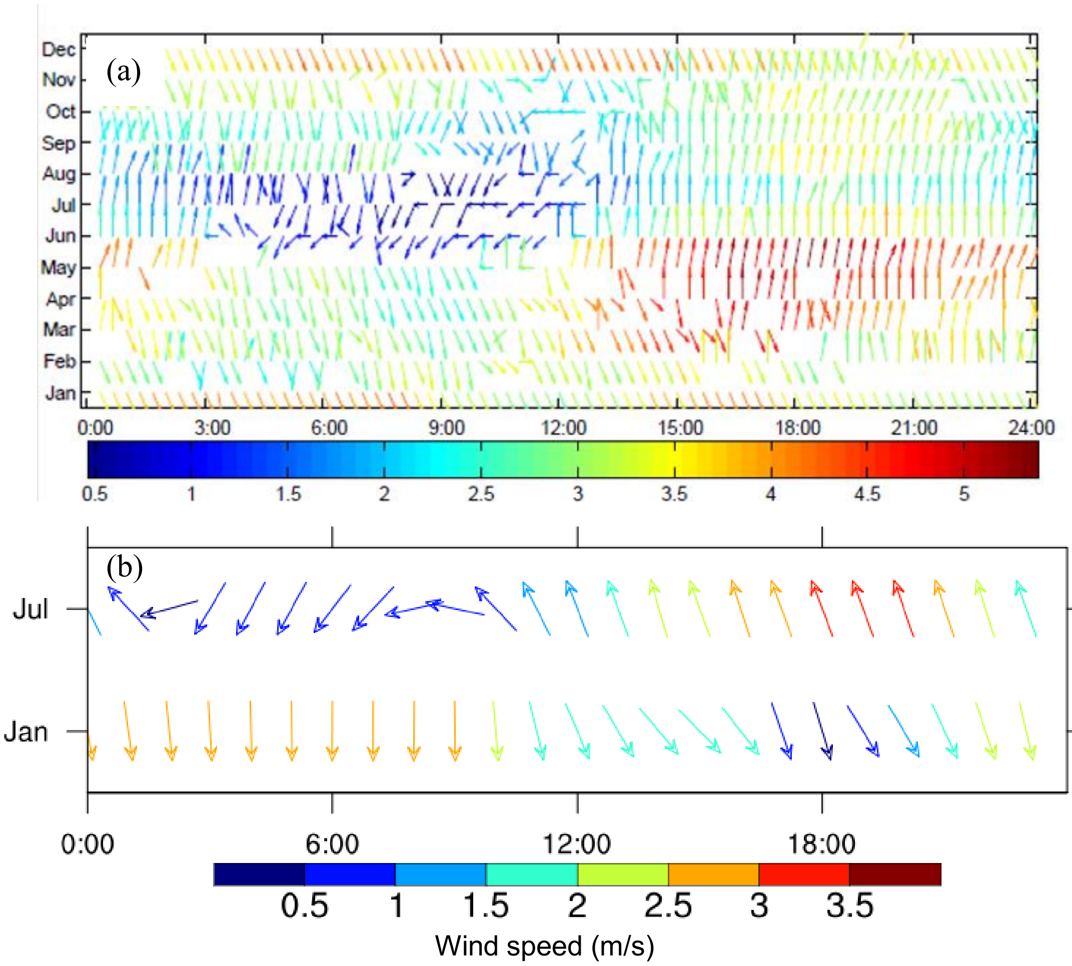

Figure R5 The observed and simulated monthly average diurnal variation of winds in Beijing in July. (a) The observation results from Tang et al. (2016). (b) The simulation results in this study.

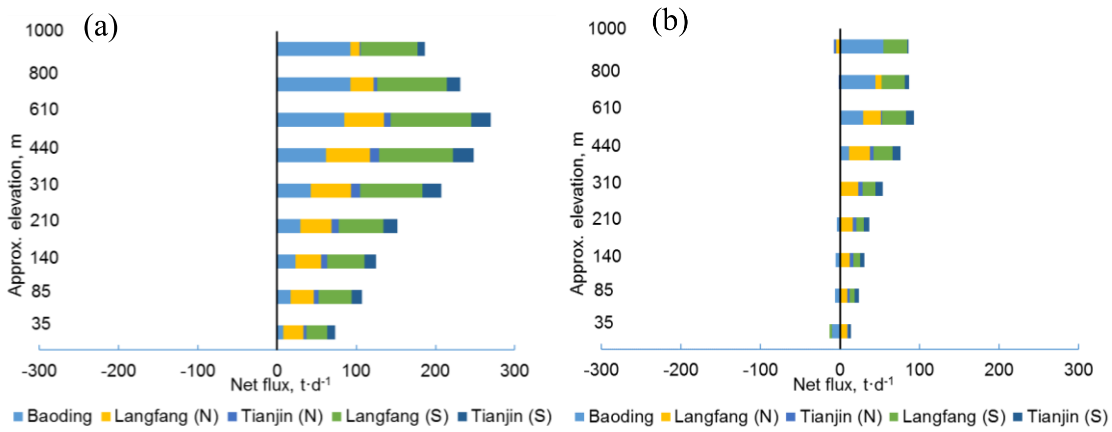

Figure R6 The transport fluxes in July between Beijing and its neighboring cities during (a) plain wind hours (11:00 – 1:00 (+1 day) LT) and (b) mountainous wind hours (2:00 – 10:00 LT)

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